TRANSNAV
http://www.transnav.eu

the International Journal
on Marine Navigation
and Safety of Sea Transportation

Volume 15
Number 4
December 2021

DOI: 10.12716/1001.15.04.01

The Russian ALFA System in the Context of the Development of Radionavigation in the 21st Century

A. Felski
Polish Naval Academy, Gdynia, Poland

ABSTRACT. For nearly the entire post-World War II period, naval and air navigation relied primarily on ground-based radionavigation systems. However, the spontaneous development of satellite systems gradually led to their disappearance. They are currently used partly in air operations and marginally in maritime navigation in some areas around Asia, in Russia and in the Middle East.
However, at the beginning of the 21st century, the threat of effective interference with satellite systems began to be raised, which led to an increased interest in restoring or upgrading ground-based systems as backup systems in the Western world. In this context, the approach of Russia is interesting, as it is associated with the vast majority of deliberate GPS interference. There are reports in the world literature that various ground-based radionavigation systems operating in Russia are still observed. The article analyses, on the basis of the few available sources, information on the ALFA system, about which the least is known, and there are many indications that it is ready for use.

1 INTRODUCTION

In the second half of the twentieth century, both in maritime and air navigation, ground-based radionavigation systems were widely used, most often based on the measurement of the phase difference of signals received simultaneously from different transmitters, and thus classified as hyperbolic systems. The popularity of the phase difference technique, especially in the first half of the 20th century, can be explained by the imperfections of the time patterns, which could not ensure sufficiently accurate synchronization of independent radio wave sources at broadcasting stations, sometimes even hundreds of kilometres away. Therefore, the solution was to adopt the principle that one of the system transmitting stations is the master station, controlling the emission of signals from subordinate (slave) stations. In simple terms, it can be assumed that in fact the transmitters of the subordinate stations retransmitted the signal of the main station.

This variant of the radionavigation system has been reproduced in different variants differing in the frequencies used, the power of the transmitters and, certainly, some details with respect to the method of forming the signals. Therefore, in different areas there were different systems with a larger or smaller operating range, differing in accuracy and, above all, requiring different receiving devices from the user. The Loran C and DECCA systems were the most widely used, but there were many systems of local interest and scope. It is significant that these systems occurred mainly in the northern hemisphere, in the southern hemisphere only elements of the DECCA system were distributed in small numbers (on the southern tip of Africa and in a few places in Australia).

Against this background, a special place is occupied by the Omega system which, with a small number of transmitters, thanks to the use of very long waves (30000m, i.e. about 10kHz) ensured global coverage. Work on the system was started by the US Navy in the late 1950s [8], but it was not until 1971 that the system became operational. In the meantime, the US Navy lost interest in the system, because the first TRANSIT satellite system, which was also created at that time, turned out to be much more perfect, so the Coast Guard was made responsible for OMEGA [5]. However, the turbulently developing satellite systems of the time gave it too much competition, especially in terms of accuracy. TRANSIT provided an accuracy of 150m while OMEGA position accuracy ranged from 2 to 4 Mm, obviously due to the difficulty of taking into account the phase variation of very long waves on the propagation route. This eventually led to the abandonment of OMEGA and the shutdown at the end of September 1997.

The development of satellite systems also led to a gradual reduction in the use of other systems using ground-based transmitters in favour of satellite techniques, and in fact by the end of the 20th century almost all these systems had been withdrawn from use. Only a few elements of the Loran C system remained on the Asian coast of the Pacific Ocean and in Saudi Arabia and its Russian counterpart (copy) - Chaika [2], [7].

However, the monopoly of satellite navigation systems came into question at the beginning of the 21st century in the face of abundant evidence of effective jamming and spoofing of GPS receivers. Similar risks for other GNSS systems are currently not reported, but this may be due to the incomparably smaller number of users of these systems compared to GPS. In this situation, discussions have resumed on the need to ensure the availability of other sources of navigational information so as to ensure that navigation is also possible when GNSS is not available. The solution may be a radionavigation system based on radio signals with completely different characteristics. However, conditions in space limit the use of other radio wave bands, so there has been a resurgence of interest in ground-based systems.

Therefore, there was a growing interest in proposals to upgrade the existing infrastructure, especially the legacy of the Loran C system. In this respect, at the end of the 1990s, the idea of Eurofix emerged, which was implemented in Saudi Arabia at the beginning of the 21th century by upgrading the pre-existing Loran C infrastructure. A competing proposal has also emerged, known as e-Loran. The prevailing opinion was that the modernization of the remaining Loran C stations (especially the use of existing, huge antenna installations) gives the opportunity to create a system with completely different signal characteristics, of which the following are particularly valuable: low frequency of 100kHz in comparison to about 1.5 GHz of satellite systems, and large transmitter powers, measured in tens and sometimes hundreds of kW. It was assumed that these features greatly reduce the possibility of interference, although the limited range of such a system remains a disadvantage. However, the ranges of such a system can be estimated at 1,000 nautical miles, making it reasonable to assume that, apart from the open oceans, where deliberate GNSS interference seems unlikely, other areas can be protected from hostile activities. This issue is beyond the scope of this article, so we will limit ourselves to stating that this research is currently being tested in the USA, Great Britain and South Korea [6], [14]. Research is also underway, initiated by IALA, to modify DGPS and AIS systems so that additional signals synchronised to the world time scale (R-Mode variant) can be transmitted through them, providing the basis for their use for positioning purposes [15]. In this situation, the question arises about Russia's attitude in this context

2 RUSSIAN GROUND-BASED RADIONAVIGATION SYSTEMS

Russia, back in the days of the USSR, but also afterwards, was going in the same direction as the world, especially the USA. Shortly after the first satellite system (Transit) was launched in the USA, the Cicada system, a very similar satellite Doppler-type system. Only a few years behind GPS, the USSR started to implement the Glonass system, which is a very similar solution. It was similar before with regard to radionavigation systems deployed on Earth. The best known example of this is the Chaika system, which is so similar to the Loran C system that in the 1990s there was even an agreement to cooperate, resulting in the establishment of joint chains in northern Europe and the Far East [6]. This cooperation was abandoned after a few years with the decision to exclude the first American stations. However, while all USA-administered stations have not been operating since spring 2010, the Czajka system is still working.

Against this background, the Russian counterpart to the OMEGA system, which was abandoned in the US as recently as the 1990s, is intriguing, while there is evidence that its Russian counterpart, according to official documents, underwent an upgrade in 2000 and was operational at least as late as 2017 [9]. An explanation for this may be related to the fact that Russia is identified as one of the countries that is linked to a large proportion of cases of various GPS jamming [13]. A party which willingly and effectively uses methods to jam satellite navigation systems should expect similar capabilities from others, so it is worth protecting itself and maintaining backup systems.

Already in the fifties in the USSR, as well as in the USA, work began on a very long-range radionavigation system, which, according to many authors, was caused by the need to ensure navigation of nuclear submarines. However, there are also views expressed, for example [5], that it was more important on the American side to provide navigation for long-range bomber aircraft (B52). Information on such topics has always been scarcely available. Although in the 1990s the Russian side changed their approach and started to provide some information, especially on the Glonass system, and the closer cooperation then established in the context of Loran and Chayka also resulted in many details being provided on this system. However information on the Russian equivalent of OMEGA has always been extremely scarce.

Nevertheless, the website of the Russian Institute of Radionavigation and Time (RIRT) in Saint Petersburg was available on the Internet (recently archived), which provided some information that may be considered official [9], since they show, inter alia, that this institution was responsible for building this system. The system is also of interest to enthusiasts, among whom Trond Jacobsen has published particularly accurate information via the Internet [3]. Less detailed, but a valuable supplement to this information is provided by Alan Cordwell [7] and Jerry Proc [5]. Out of the book publications, the works [2] and [1] can be useful, in which basic technical information about the system is published. Information on the existence of the ALFA system was also confirmed by representatives of Russia at several international conferences.

This system is known in Western literature as ALFA (an early version of it also functions in literature as SIGMA), and in Russian publications it is code-named RSDN-20 (the abbreviation comes from the name Radionavigacionnaya Sistema Dalniej Navigacji, which can be translated as a long-range radio navigation system). It is clearly modelled on the OMEGA system, especially the frequencies emitted by the system are similar (very long waves of the 10-15 KHz range) and the sequential principle of signal emission. However, there are also significant differences from the American counterpart.

According to the information available on the web portal (RIRT) [9], the system had been under development since the mid-1950s but was only put into operation in 1972 (an astonishing coincidence with the available knowledge of the American counterpart) although some Western sources cite 1968 as the year the system went into operation with a set of three stations: Novosibirsk, Khabarovsk and Krasnodar (SIGMA version). According to [2], in 1991 the configuration was supplemented with two additional stations: Seydi and Revda. In the same year (in August), such information was also presented by the chairman of the Soviet delegation at the meeting of the International Omega Association in Vancouver, General Anatoly Funtikov, who also informed that the new transmitters operate on a new, previously not used in the system, frequency 12.090773 kHz. Official statements justified this by making the system available to civilian users.

Table 1. Transmitters of ALFA system and theirs localisation.

Simbol	Name	Latitude	Longitude
NS	Nowosybirsk	55º45′22″N	084º26′52″E
KD	Krasnodar	45º24′18″N	038º09′29″E
CH	Chabarowsk	50º04′24″N	136º36′24″E
MR	Revda	68º02′08″N	034º41′00″E
SE	Seydi	39º28′16″N	062º43′07″E

Source: [3], [9].

The institute considered to be the creator of the system states that the accuracy of determining the position was then estimated at 2 to 7 km. There it is stated that the range of the system is 10,000 km from the main station, which is located near Novosibirsk. This value should be treated with scepticism, because in 2000 the aforementioned Jacobsen recorded the system signals [3] in Halden (approx. 90 km from the SE from Oslo) and clearly states that the signals from Seydi and Khabarovsk stations have not been registered. This second station in particular is relevant in this context, as several sources, including the manufacturer of the RIRT system state that this station was operating at the time, and is closer than 10 000km (approx. 7 000km) from Halden. Moreover, the same materials contain information that in 2000 the modernization of all five stations of the system was completed, providing a positioning accuracy of 1.2 to 1.5 km over more than 70% of the Earth surface! This seems unlikely, if only because the system's transmitters were deployed exclusively on the territory of the former USSR. At the same time, however, it is worth noting that the creators of the system declared the power of transmitters as high as 500kW (compared to 10kW in the OMEGA system).

At the turn of the 20th and 21st centuries, the system consisted of five stations, one of which served as the main station, and the others - as subordinate stations. This is an important difference to the OMEGA system, where all stations functioned independently and the user could freely compose pairs of stations to determine the distance difference. It is worth noting that the names used in the table are not unique. None of the stations are located in any of the above-mentioned towns, and the Khabarovsk station is also referred to in some sources as Komsomolsk-on-Amur. The point is that the emission of such strong signals at such low frequencies requires a large antenna field placed outside human settlements. In fact, Khabarovsk station is located 28 km from the village of Elban, which in turn is 60 km from Komsomolsk-on-Amur and 200 km from Khabarovsk. The city of Novosibirsk is located approximately 150 km from the antenna field associated with the station under this name, the Revda station is approximately 120 km from Murmansk, and the Krasnodar station is located 26 km from Poltavskaya and 70 km from Krasnodar. In turn, the Seydi station is about 140 km from Bukhara, so it is located outside of Russia, currently in Turkmenistan.

They all have a distinctive shape that can be identified in the images available on Google Earth because they are a set of seven masts arranged in a regular hexagon, at the tops of which stand the aforementioned masts, with the seventh placed in the centre of the area.

Figure 1. The antenna field of Novosibirsk. Source: Google Earth.

The very low frequencies used in the system would suggest that the transmitting antennas should be very high, but there is no official data on this. On the Internet, however, there is a photo of the antenna system near Novosibirsk, which shows 7 partially overlapping masts, giving an idea of their size. The area in the picture is partly covered with forest and gives an idea of the size of the antennas. Furthermore, since all the antenna fields are similar in shape and the antennas are about 600m apart, it can be inferred from the photograph that the antennas are at least 300m high. This is consistent with information on the OMEGA antenna system, which operated at similar frequencies [5] and had antenna masts over 300m high.

Figure 2. Novosibirsk antennas (foto: Dmitry Afonin © 28.06.2009) accessible at: [12]).

The above-mentioned RIRT website [9] also states that the system was upgraded in 2000, but also states that the Seydi station was shut down in January 2010 without giving reasons. This may be justified by the fact that it is currently located on the territory of Turkmenistan, so unlike the others - outside the territory of Russia. Oddly enough, the same source also reports that the Revda (Murmansk) station has been switched off, which is more difficult to explain. This state of affairs is confirmed by Cordwell stating that in 2017 only Novosibirsk, Krasnodar and Khabarovsk stations were operational. The fact that the system was operational in October 2016 is also evidenced by the information available on the YouTube channel (https://www.youtube.com/watch?v=GnLLC0G_3Mo), video recording of the spectrum analyser with audio evidence of the reception of the three stations. If the system were to operate as a hyperbolic system in the configuration of Novosibirsk and two subordinate stations, one would expect a zone of operation similar in shape to the version shown in the Fig. 3.

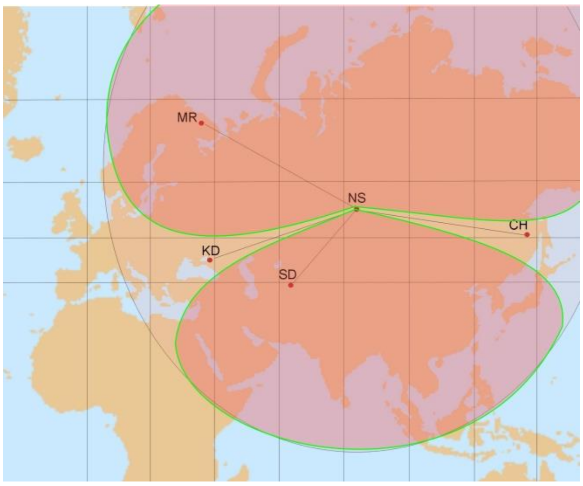

Figure 3. The probable operating-zone of the system in the configuration KD-NS-CH. Source:author.

It is likely that the reason for the abandonment of the Murmansk station was due to financial or geopolitical aspects (need for navigational services in other areas?). However, it is not impossible that in view of the development of atomic time standards (RIRT is the producer of time standards for the Glonass system), similar stable standards were implemented on the three transmitters of the old system and it was upgraded to the rang variant (R-mode). It is also possible that Revda station is treated as a backup for special situations, because its activity is still periodically monitored.

Analysis of the probable zones of the system operation suggests that originally the developers were interested in Arctic waters, there are suggestions that the zone of operation even includes Alaska. It can be seen, moreover, that this largely refers to the Pacific Ocean, including the seas surrounding the coasts of China, Korea and Japan (including their territories) and the Baltic Sea, which seems natural for Russia's armed forces. However, it may be surprising that the Black Sea was not within the operating zone of the system. Perhaps it was recognised that poor positional accuracy did not make the system attractive in this area . The analysis of the older version of the system also suggests that the station in Turkmenistan was probably set up in an earlier configuration to ensure the availability of the system in the eastern part of the Mediterranean Sea. In turn, the configuration noticed in 2016 and 2017 seems to suggest the intention to provide signals in the waters of the Indian Ocean and the Red Sea (which was probably not sufficiently guaranteed before), regardless of the range still maintained in the waters of the Far North and the seas surrounding the coasts of China, Korea and Japan.

3 SYSTEM ORGANIZATION

Jacobsen reports that the system started working in 1962, which was confirmed by Harvard researchers who registered such signals and reached operational status in 1968 in a constellation of three stations (SIGMA version). This configuration was finally returned in the 21st century, despite the modernization declared in 2000. In the same year 1968 these stations were reported to the International Frequency List declaring the following frequencies:

- F1 = 11,905 kHz;
- F2 = 12,500 kHz;
- F3 = 12.649 kHz;
- F4 = 13.281 kHz;
- F5 = 14.881 kHz;
- F6 = 15.625 kHz.

Originally, the system worked on the F1, F3 and F5 frequencies. Later, after launching two additional stations, the frequencies F2, F4 also became active, but additionally a previously undeclared frequency of 12.700kHz appeared. In this combination, the frequency F6 (15.625 kHz) seems to be of particular importance and is noticed extremely often by system observers, but it is not impossible that it is not part of the system but a transmission coming from the same source for other purposes. It is possible that these low frequencies are also used for communication, especially with submarines.

The organization of the system operation is very similar to that used in the OMEGA system (previously, a similar solution was proposed by DECCA in the DELRAC system, which was not finally implemented). Individual transmitters emit a sequence of signals consisting of six identical elements (slots) lasting 400ms each with 200ms intervals in a 3.6s cycle. It is a combination of signals from different stations on different frequencies. It is worth noting here that OMEGA worked with segments of various lengths, and the entire cycle lasted 10 seconds.

Recordings of these signals are available, inter alia, via the Internet [10] and [11]. Spectrogram of system signals received on May 14, 2000 in position 59o 08'12"N and 011o 23'55"E, at 0656UTC is shown in Fig. 4 [3].

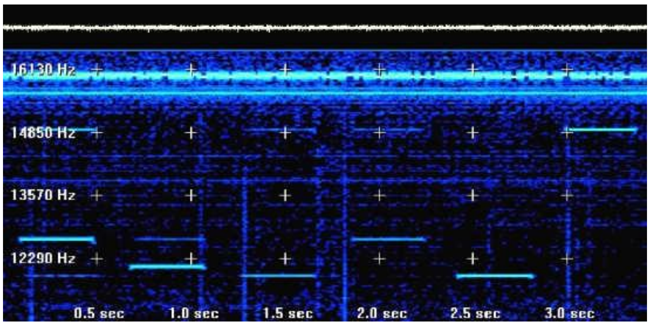

Figure 4. Spectrogram of system signals received in Norway on May 14, 2000. Source: [3].

On the above spectrogram, signals from the Novosibirsk, Krasnodar and Revda stations can be identified. There are also presented in Tab. 3. No signals are received from Khabarovsk, possibly because of the distance, but also no signals are received from Seydi, a station which is at a similar distance from southern Norway as Novosibirsk.

There have undoubtedly been changes in the organisation of the system and it is difficult to state clearly what the current state of affairs is. The registrations made by Jacobsen show that in 2000 the system operated on frequencies (in kHz) 11.905, 12.649 and 14.881 and these registrations show the activity of stations in Novosibirsk, Krasnoyarsk and Revda. Cordwell lists additional frequencies 12.045, 12.091. The latter referred to the shutdown stations Revda and Seydi.

The issue of organizing emissions into cycles is also not very clear. While in the Omega system the transmit cycle was 10 s the basic cycle in Alpha was assumed to be 3.6 s. However, it is known that in the OMEGA system the phase of the radio wave generated in each slot was constant and consistent with the start of the slot. It was observed in the Russian system that the phase of the individual pulses is not the same in each of the 3.6 second cycles and is repeated every 7 cycles (7 x 3.6 = 25.2 s). Moreover, the signals emitted by the transmitters are not ordinary continuous wave (CW), but the pulses also contain unknown modulation, which may mean conveying additional information, regardless of the likely use of the phase for navigation measurements. Information on signal modulation suggests that this is the effect of modernizations made at the turn of the century, and therefore would suggest some newer solutions. It is possible that these solutions are similar to what is implemented as part of the modernization of the Loran system to the e-Loran version. Modulation could, for example, be used to communicate corrections to users similar to that used in DGPS systems and thus guarantee better accuracy.

The OMEGA system used perfect atomic time standards at each of the eight stations, which did not require mutual synchronisation. In the ALFA system, regular phase jumps are observed at all stations. This takes place at 0000 Moscow time (2100UTC) with the same value and can be interpreted as a synchronization of all transmitters. This is also due to the fact that the individual emission cycles on the individual frequencies do not change by a full phase within 24 hours, so these jumps are also intended to reset the phase at the beginning of each day. These are 360o divided by 7 which meant jump of 51.4o for the frequency 11.905kHz, 2x360o/7 = 102.9o for 12.649 kHz and 3x360o/7 = 154.3o for the frequency of 14.881kHz. Jacobsen also points out that all the frequencies in the system are the result of duplicating the common base frequency Fo = 744.047619047619 Hz (744 and 1/21Hz). The exception is the frequency he calls F3p which differs from F3 = 14881.09127 by 5/36 Hz and is only transmitted from the main station.

Table 2. The cycle of the transmission by stations of ALPHA system after the modernization in 2000.

	1	2	3	4	5	6
Nowosybirsk	11,904761	12,648809	14,880952	14,881091		
Krasnodar	14,880952		11,904761	12,648809		
Chabarowsk		14,880952	12,648809	11,904761		
Revda	12,648809	12,090773		14,881091	11,904761	14,880952
Seydi		11,904761	12,044270	14,881091	14,880952	12,648809

Source: on basis of [3].

Table 3. The interpretation of recordings from the spectrogram (Fig. 4).

	1	2	3	4	5	6
14,881091				Novosibirsk		
14,880952	Krasnodar		Nowosibirsk			Revda
12,648809	Revda	Nowosibirsk		Krasnodar		
12,090773		Revda				
11,904761	Novosibirsk		Krasnodar		Revda	

Source: author.

The frequencies of the oldest stations in the system:

- F1 11904.76190 Hz = 16 x Fo
- F2 12648.80952 Hz = 17 x Fo
- F3 14880.95238 Hz = 20 x Fo

The frequencies of the additional (Revda i Seydi):

- F4 12090.77381 Hz = (260/16) x Fo
- F5 12044.27083 Hz = (259/16) x Fo

In addition, extremely rarely emitted signals are observed at other frequencies. This may mean that in the system, due to its military purpose, there is a backup variant of operation, sometimes activated to check its efficiency.

4 CONCLUSIONS

While the development of satellite navigation systems in the Western world has led to an almost complete abandonment of land-based systems, and only in the last decade have there been tendencies to restore the possibility of using ground-based systems as a backup, such solutions have never been completely abandoned in Russia. The incidental reports available from unclassified sources show that at least some of these systems are in a usable state, as evidenced by reports of receiving signals from these systems.

It is worth recalling that Russia inherited from the USSR the very long-range ALFA system, the long-range Chaika (Loran C) system and the closer range systems: BRAS and MARS. A few years ago, a message appeared on the Internet that the Mars system was observed in the Black Sea, the Chaika system is still functioning, while the ALFA system remains the most mysterious. According to the information discussed in this article, which is available through non-confidential written sources, both on paper and electronically, it can be concluded that even if this system is not used on a daily basis, it has undergone an upgrade in the 21st century and is most likely in a state of fitness for use as a backup navigation system, in case satellite systems, primarily the Glonass system, are blocked.

REFERENCES

[1] Forssell B. Radionavigation Systems. Artech House. Norwood 2008.

[2] Groves P.D. Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems. Artech House, Norwood 2008.

[3] Jacobsen T. The Russian VLF NAVAID System, ALPHA, RSDN-20. Dostępne na: trond.jacobsen@halden.net (02.11.2020)

[4] Loran-C User Handbook. Commandant Publication P16562.5. United States Coast Guard ran-C User Handbook 1980.

[5] Proc J. Omega. Dostępne na http://www.jproc.ca/hyperbolic/omega.html (10.11.2020).

[6] https://www.ndgps.go.kr/html/en/gnsys/gnsys_040101.html (11.11.2020).

[7] http://www.radionavigation.alancordwell.co.uk/systems.html (22.05.2020).

[8] https://www.skybrary.aero/index.php/Omega (11.11.2020).

[9] https://web.archive.org/web/20080613063718/http://www.rirt.ru/onas/rirt-e.htm (12.06.2020).

[10] https://www.youtube.com/watch?v=g0VbDIkX6gU (14.11.2020).

[11] https://www.youtube.com/watch?v=Ys9Qmm4-ws4 (14.11.2020).

[12] http://www.panoramio.com/photo/23892185 (08.11.2020).

[13] https://navcen.uscg.gov/?Do=GPSReportStatus# 26-07-2020

[14] Ward N., Hargreaves C., Williams P., Bransby M. Can eLoran Deliver Resilient PNT? Proceedings of The Institute of Navigation 2015 Pacific PNT Meeting, Honolulu, Hawaii, April 20–23, 2015, pp. 1051–1054

[15] Wirsing M., Dammann A., Raulefs R. Investigating R-Mode Signals for the VDE System. Oceans 2019 MTS/IEEE Seattle Conference doi: 10.23919/OCEANS40490.2019.8962635.