JOINT SOVIET/AMERICAN LORAN OPERATIONS, THE BERING SEA CHAIN

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Abstract

On 28 April 1988, the U.S. Coast Guard negotiated a proposal with the Soviet Union for the implementation of a mixed Loran-C/Chayka chain in the North Pacific. This agreement was signed at the May, 1988, Summit. This paper will discuss the similarities and differences of the U.S. Loran-C and USSR Chayka systems, and present the agreed upon design for a Bering Sea Chain. This proposed chain would provide marine and aviation coverage over the five-hundred-mile-wide coverage gap that exists in the North Pacific between the North Pacific Chain, and the Northwest Pacific and Soviet Eastern USSR chains.

II. TECHNICAL DIFFERENCES BETWEEN CHAYKA AND LORAN-C

Standardization of the two systems has resulted in essentially identical signal format with respect to phase code, group format, and Group Repetition Interval (GRI). Historical differences in Chayka and Loran-C transmitter development, however, have resulted in differences in pulse shape between the two systems.

Chayka transmitters are of two types, tube and Thyratron. The envelope of the signals formed by tube transmitters is approximated by the second-order exponential power function:

\[ U(t) = U_m \left( \frac{t}{t_m} \right)^{2} e^{-t/t_m} \]

where \( U_m \) is pulse amplitude, and \( t_m \) is the time to peak of pulse.

Thyratron transmitters generate a signal by impact excitation of a two or three-pole output circuit. The envelope is approximated by an exponential-sinusoidal function:

\[ U(t) = U_m ( \sin bt/b + e^{-at})^n \]

where \( a \) and \( b \) are chosen to determine steepness of growth and speed of attenuation of the generated pulses, and \( n = 1 \) for two-pole output networks, and \( n = 2 \) for three-pole networks.

Loran-C pulse envelopes are approximated by:

\[ U(t) = U_m t^2 e^{-2t/t_m} \]

The issue of pulse shape is critical for reliable signal acquisition. The receiver chooses the correct carrier cycle zero-crossing for tracking by determination of a well-defined slope on the pulse envelope. Error or distortion in pulse shape from that defined, or expected by the receiver, can cause the receiver to lock onto the wrong cycle zero-crossing. This cycle selection error causes errors in increments of 10 microseconds. The shape of the leading edge of pulses transmitted from an individual station must be stable, and also must be identical to within a few per cent of RMS distortion, to the pulses from
other transmitters. A stable pulse shape that provides for consistent acquisition of a particular cycle zero-crossing is required, to this end, modern receiver design can customize signal acquisition firmware to allow for differences in stable Chayka and Loran-C pulse shapes. A receiver test performed and reported on by Soviet engineers sheds light on the ability of Loran-C receivers to use Chayka signals.

Receiver Testing by the Soviet Union

In Leningrad, V. Bikov, of the Soviet Ministry of Marine Fleet, reported on tests he conducted on the ability of commercial Loran-C receivers to receive Chayka signals. Summarized from his informal report:

Several tests were carried out on the operation of Loran-C receivers with Chayka signals using the LR-770 receiver (produced by Furuno, Japan) and LC-70, LC-80, LC-90, and LC-1000 receivers (produced by Furuno, Japan).

The receivers were designed for operation with Loran-C signals. Geographic locations for the Chayka stations of chains 8000 and 7950 were entered into the LC-90 and LP-1000 receivers by Furuno at the request of the Soviet engineers to provide coordinate conversion.

The purpose of the tests was to estimate Loran-C receivers' characteristics operating with Chayka signals, and to compare the results with those from the reception of Loran-C signals.

The most comprehensive tests were carried out with the LC-90 and LP-1000 receivers during 20 March-20 April 1988, using the 7950 Eastern USSR Chayka Chain.

Tests were carried out to determine:
- the probabilities of correct cycle selection,
- groundwave receiving range, and
- autoacquisition time under various reception conditions.

The tests demonstrated:
- The probability of correct cycle selection was up to 97% at a range of 900 nautical miles in the main coverage area.
- Groundwave signals from Chayka stations were received by the LC-90 and LP-1000 receivers at ranges up to 1000-1170 nm with a probability of 93%.
- At ranges of 1000-1170 nm, average autoacquisition time for stations in the tests was 3.5 minutes, probability of correct cycle selection was 83%.

Engineer Bikov concludes:

"These tests of Loran-C receivers demonstrated that the Chayka system signals are received and processed by Loran-C receivers without degradation of specifications determined by Loran-C characteristics, namely, the operation of LC-90 and LP-1000 receivers by Chayka signals was similar to their operation with Loran-C signals."

From these analyses and Soviet testing, it appears that modern Loran-C receivers' ability to reliably lock onto signals of the proposed Chayka/Loran-C chain can be ensured by proper receiver design and prudent operational procedures.

Other, less critical but still noteworthy, technical differences exist between Chayka and Loran-C systems. Some Chayka chains periodically insert separate timing pulses. The ninth pulse in a Chayka master pulse train is positioned differently than in Loran-C. Standard phase sampling point and phase modulation tolerances need standardization.

Operational differences between the two systems are considerable. Out-of-tolerance situations are dealt with differently, and Chayka lacks an equivalent "blink" indication. A structure to provide notices to users/mariners/aviators as well as planned off-air notification and solicitation procedures must be developed and agreed upon. The joint command, control and communications structure, including a civil user interface, may be a considerable hurdle.

III. PROPOSED CONFIGURATION, BERING SEA (BERSEA) CHAIN

The published coverage of the Chayka Eastern Chain and the computed coverage for the Loran-C North Pacific chain (NORPAC, 9990) shows a gap in coverage about five hundred nautical miles wide to the south of the line between Petropavlovsk and Attu (figure 1). Without the Eastern USSR chain, there is a gap between the Coast Guard's Northwest Pacific Chain (NORWESTPAC, 9970) and NORPAC about 750 nautical miles wide. According to the computed coverage limits, NORPAC provides satisfactory marine coverage over essentially all the Bering Sea.

Table 1 lists the stations in the proposed Bering Sea Chain with station designations. The proposed functions were chosen to avoid confusion with the dual-rate designations. Since the baseline distances for the three baselines are about equal, minimum GRI should not be materially affected by the ordering of the secondaries. Power is peak-radiated-power (PRP).
For ease of computation, and considering that the noise values for range computations were taken from recently published information, the coverage for the existing Chayka stations and proposed joint chain is based on new computations using noise values transcribed from reference 2. The coverage shown for the existing Chayka Eastern USSR Chain (7950) is from reference 4 for Coast Guard stations and reference 2 for Soviet Chayka stations.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>POWER(KW)</th>
<th>DUAL RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master Petropavlovsk</td>
<td>700</td>
<td>7950(BM)</td>
</tr>
<tr>
<td>Xray/BM1 Kurilsk</td>
<td>300</td>
<td>7950(BM3)</td>
</tr>
<tr>
<td>Yankee/BM2 LORSTA</td>
<td>400</td>
<td>9990(x)</td>
</tr>
</tbody>
</table>

1. See reference 2
2. Assumes agreed upon equipment upgrades, present PRP is 6kW(2).
3. Assumes transmitters are replaced with 400 KW AN/FPN-44A's, present PRP is 325 kW(4).
4. See reference 4

IV. MONITOR AND CONTROL

Soviet and Coast Guard philosophies differ. The Coast Guard controls time-difference (TD) in the service area from a system area monitor (SAM); in the Chayka method, time differences are measured at each end of a baseline and communicated to the secondary station. These time differences are combined algebraically to extract coding delay (CD) and emission delay (ED). Control action is provided to keep emission delay constant (6). Desired emission delay is recomputed periodically, based on monitor data from the user area, to remove seasonal propagation effects.

In configuring a joint Loran-C/Chayka chain, the question arises of how to control the individual baselines of such a chain. In principle, the most acceptable solution is to control baselines of two Chayka stations (or two Loran-C stations) by the means of their respective systems, and control baselines of a Chayka master and a Loran-C secondary in the Coast Guard manner. In the Attu/Kamchatka case, especially considering the difficulties of communicating across the international date line, it seems easiest for both parties if the Coast Guard simply controls the time difference of the proposed secondary by tracking the Chayka master.

Where should a SAM receiver be placed for control of the Attu/Kamchatka baseline? An ideal geographic location for a primary monitor for the BERSEA Master-Yankee (MY) baseline is on the Komandorskie Ostrova (Commander Islands). These Islands are about twelve nautical miles north of the MY baseline on the baseline-perpendicular. However, communications and physical access problems appear to be considerable. These difficulties, plus the installation cost of a new monitor site at Komandorskie Ostrova, suggest the use of the existing NORPAC monitors at Adak and the addition of a near-field monitor on Attu Island itself.

Adak would be on the BERSEA (MY) baseline extension. Placement of a monitor on the baseline extension results, effectively, in control of coding delay rather than control of service area time difference. The Coast Guard generally tries to avoid this type of control from a primary monitor because changes in propagation in the path from the transmitting station to the monitor can cause translatational shifts over the entire hyperbolic time difference grid with the greater distortion in the service area. In contrast, a monitor in the service area close to the baseline-perpendicular would be expected not to translate the grid but only to stretch it a minimal amount with the least amount of distortion in the service area. Fortunately, the environmental effects that cause these changes are such phenomena as sudden ionospheric depressions (SID), and freezing or snow cover of a land path. SIDS are confined to lower latitudes, and there is little land from Petropavlovsk to Attu or Adak, where the waters are also ice-free.

Attu-Kamchatka Signal Study

To observe Chayka signal stability, an additional back-up control receiver was installed at the Lorain Station at Attu to receive the signal transmitted from Petropavlovsk and track it relative to the Loran-C time base at Attu. To do this, a local trigger signal at the Chayka Eastern Chain (7950) rate was provided by a rate generator tied to Attu's cesium frequency standard suite. This test configuration simulated the tracking of Petropavlovsk, as a master, by Attu, as a secondary. The receiver used, the Austron 2000C, is a manual lock-on, linear, time-of-arrival receiver.

The study showed that the Soviet signal from Petropavlovsk can be easily locked onto and tracked by the Coast Guard's standard back-up control receiver at the secondary end of the baseline. The study also showed that the Chayka signal timing is
Figure 1
Existing Loran-C/Chayka Coverage in the North Pacific

Figure 2
Proposed Bering Sea Chain
sufficiently synchronous to universal time (UTC) to provide for tractable control. In fact, Petropavlovsk drifted not much worse with respect to the NORPAC master at St. Paul (~540 ns/week) than Attu did with respect to St. Paul (~440 ns/week). This degree of synchronization is noteworthy in that Petropavlovsk was observed as the BM1 secondary of the Eastern USSR Chain. As a master station in the Bering Sea Chain, its synchronism with Soviet universal time, and thence to UTC, should become even closer.

A curious phenomenon occurred for the first fifteen days of the test (23 February-08 March 1988) and disappeared for the last twenty days for which data were available (09 March-28 March). The Petropavlovsk signal would shift every six hours by about 1 microsecond relative to the Attu time base. The shifts appeared as fairly smooth unimodal humps in the traces, positive or negative, before returning to center. Coast Guard experts reviewing the curves could not identify the cause of the phenomenon. Soviet experts were queried at the Leningrad meeting. They could not explain the shifts but took copies of the relevant plots and agreed to investigate. Since the effect did finally disappear, indications are the baseline can be controlled reliably, but knowing the cause would inspire more confidence.

V. CONCLUSIONS

The implementation of a usable Loran-C/Chayka radionavigation chain is technically feasible. The diplomatic overtures to implement such a chain have been carried out but many details remain. Technical differences appear slight and easily dealt with compared to operational considerations. Differing command and control doctrine and user interface philosophies, communications difficulties, and considerations of state add to the technical challenge of implementing a joint US/USSR Bering Sea Chain.

VI. REFERENCES


2. "CHAYKA, Pulse-Phase Radio Navigation System", Unofficial translation by the U.S. Department of State, LS #122564, held by U.S. Coast Guard, Washington D.C.


5. U.S. Coast Guard, "Aids To Navigation Manual, Radionavigation", COMDTINST M16500.13, Department of Transportation, Washington D.C.