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Acoustic Studies on the North East Sakhalin Shelf
Volume 2: Equipment, Calibration and Methodology
7 July to 7 October, 2005
Sakhalin, Russian Federation

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Prepared for

Exxon Neftegas Limited
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Yuzhno-Sakhalinsk, Sakhalin,
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March 2006

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Executive Summary

Acoustic studies in support of the Korean-Okhotsk (western) gray whale monitoring program are designed to monitor acoustic changes due to oil and gas developments near the NE Sakhalin feeding areas of the western gray whale population (*Eschrichtius robustus*). This acoustic program monitors the ambient sound levels across the NE Sakhalin shelf and the temporal variation in anthropogenic sound levels due to oil and gas development activities. Transmission loss studies are also conducted to better understand acoustic propagation from current and proposed Exxon Neftegas Limited (ENL) and Sakhalin Energy Investment Company (SEIC) facilities and pipelines to the Piltun and offshore feeding areas.

The acoustic measurements were conducted using 14 digital Autonomous Underwater Acoustic Recorders (AUARs) developed at The Pacific Oceanological Institute (POI). Compared to sonobuoys these AUARs make high fidelity acoustic measurements with an improved dynamic range, increased bandwidth (1 Hz - 15 kHz) and extended recording time (16 days continuous recording), allowing acoustic measurements to be conducted over most of the NE Sakhalin shelf rather than a small range around a base camp or vessel. Four of these AUARs were Transmit-AUARs (T-AUARs), equipped with a radio channel and capable of simultaneously recording data on the AUAR hard drive and transmitting data (bandwidth 10 Hz to 5 kHz) to a receiving radio station. An additional two mini-AUARs were constructed for the 2005 field season; these were smaller, with a reduced (72 hours) record time and were used for Transmission Loss and source level measurements. Individually deployed acoustic sonobuoys also developed at POI (2 digital and 4 analog) were used to measure acoustic signals and to transmit them to a receiving station. Analog sonobuoys recorded frequencies from 10 Hz to 10 kHz and digital sonobuoys from 1 Hz to 2.6 kHz. When used together an analog and digital sonobuoy pair can record acoustic data from 1 Hz to 10 kHz. The radio signals from the analog and digital sonobuoys and the T-AUARs were received at a radio station at Piltun lighthouse and one on the vessel *Academik Lavrent'ev*.

In addition to the acoustic studies, a comprehensive sampling program for bathymetry and hydrology was initiated in 2004 and continued in 2005. The goal of this program was to better understand the temporal and spatial variations in the hydrologic parameters on the NE Sakhalin shelf.

1 Introduction

The acoustic program conducted on the NE shelf of Sakhalin Island in 2005 extends the long-term acoustic monitoring program initiated in 2003. The monitoring program was designed to study temporal and spatial variations in the amplitude and frequency characteristics of ambient and anthropogenic sound at the edge of the Piltun and offshore gray whale feeding areas. In addition to monitoring the background acoustic environment, detailed Transmission Loss (TL) studies were conducted along proposed ENL and SEIC pipeline routes and from current or proposed facilities. In order to estimate the sound transmission from project activities it is necessary to understand the characteristics of sound propagation from the proposed production facilities to the limits of the known gray whale feeding areas. These are the areas where the gray whales are concentrated, predominantly feeding in water depths of 5-20 m in the Piltun feeding area and 30-65 m in the offshore feeding area. Mother-calf pairs have mainly been observed in the Piltun feeding area in water depths less than 10 m. These acoustic studies, in conjunction with the amplitude and spectral content of the background acoustic environment, will be used to assess any potential impacts from the construction and to design more effective mitigation measures.

During the 2005 field season (7 July to 7 October), acoustic equipment was deployed from the research vessels *Academik Lavrent'ev and Academik Oparin* which also accommodated the biology teams (Benthic, Marine Mammal Observers (MMO) and Photo-ID). Synchronous acoustic measurements were made at stations ranging from north of the Odoptu license area to the southern edge of the offshore feeding area (Figure 1.1). This area extends a distance of 180 km from its northern to southern borders.

The acoustic measurements were conducted using 14 digital Autonomous Underwater Acoustic Recorders (AUARs) developed at POI FEB RAS[1] (POI). Four of these AUARs were Transmit-AUARs (T-AUARs)[2]. An additional two mini-AUARs were constructed for the 2005 field season; these were smaller with a reduced (72 hours) record time and were used for TL and source level measurements.

[1] POI FEB RAS - The Pacific Oceanological Institute, Far East Branch of the Russian Academy of Sciences.
[2] The T-AUARs were equipped with a radio channel and were capable of simultaneously recording data on the AUAR hard drive and transmitting data (bandwidth 10 Hz to 5 kHz) to a receiving radio station. The transmission can be continuous or on a pre-programmed schedule.

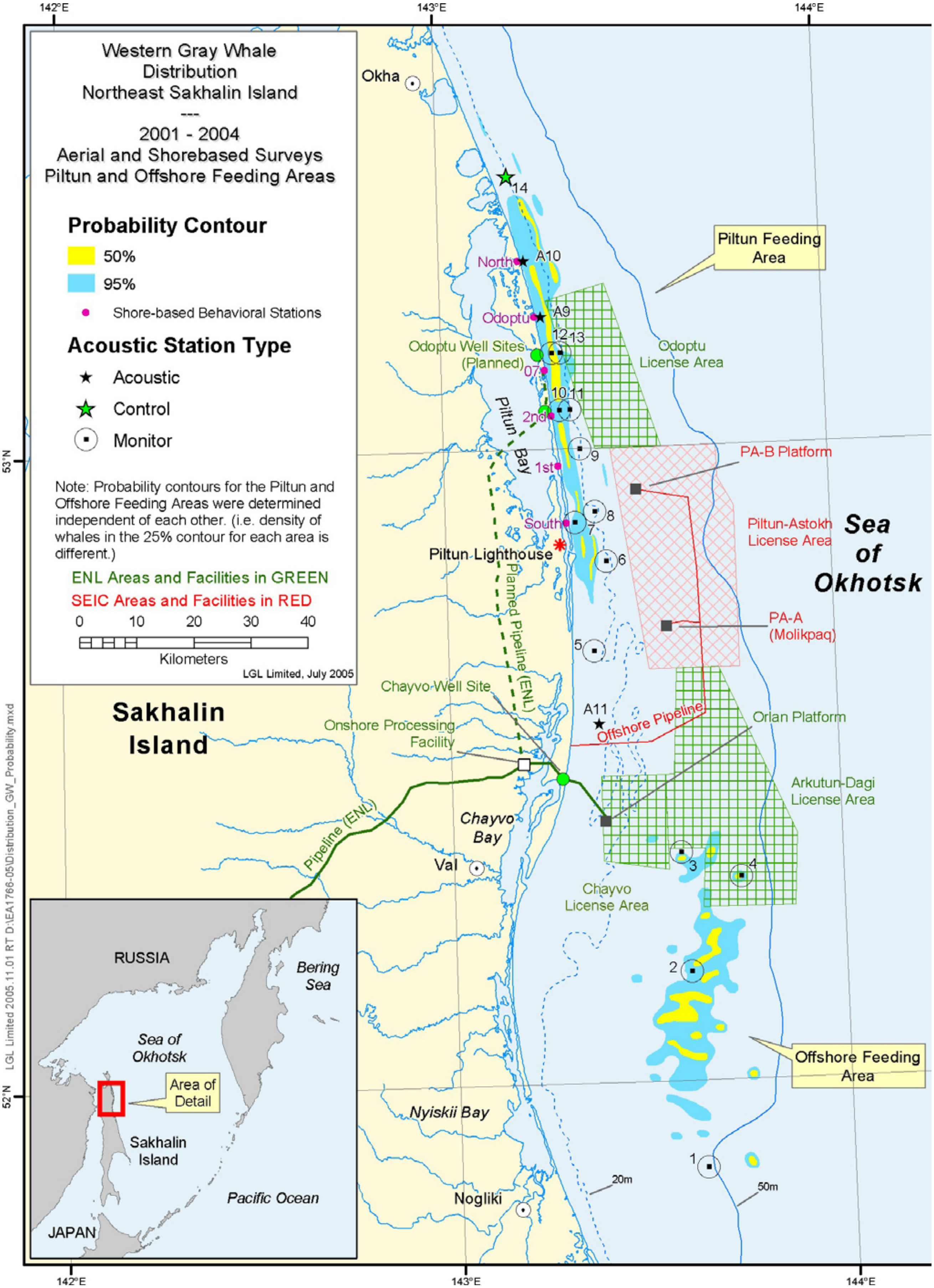

Figure 1.1 - Map of the NE Sakhalin Shelf showing the locations of the PA-B and Orlan platforms as well as the AUAR deployment locations.

The AUARs were designed to accurately record frequencies between 1-15,000 Hz and enable accurate, autonomous, synchronous acoustic measurements over a broad range of frequencies (including infrasounds[3]). Individually deployed acoustic sonobuoys also developed at POI[4] were used to measure acoustic signals and to transmit them to a receiving station. Analog sonobuoys recorded frequencies from 10 Hz to 10 kHz and digital sonobuoys from 1 Hz to 2.6 kHz. When used together an analog and digital sonobuoy pair can record acoustic data from 1 Hz to 10 kHz. A detailed description of this equipment is given in sections 2 and 3 of this report.

The radio signals from the analog and digital sonobuoys and the T-AUARs were received at one recording station at Piltun lighthouse and another on the vessel *Academik Lavrent'ev* (Lunskoye). The range of the digital radio channel was over 8 km when received by the non-directional antenna on the *Academik Lavrent'ev* (25 m) and is expected to be over 10 km when received by a directional antenna at Piltun lighthouse (35 m). The range of the analog radio channel depended on the type of radio receiver used and the elevation of the receiver. Broadband (10-10,000 Hz) signals could be transmitted up to 12 km; narrowband (10-5000 Hz) signals could be transmitted more than 20 km if received by the station at Piltun lighthouse.

Previous work had shown that the results from acoustic modeling are very sensitive to the hydrologic, bathymetric and sea bottom parameters along the profile of interest. A comprehensive suite of bathymetric and hydrologic measurements was therefore acquired using the vessel's sonar and a hydrologic sonde.

The results of the 2005 acoustic program are presented in three separate volumes. The first volume describes the objectives of the 2005 program. The volume contains DVDs with sonograms in 24-hour segments for all the data recorded in 2005; and the bathymetric and hydrologic data acquired during the 2004 and 2005 field seasons. The second volume describes the equipment used, its testing and calibration as well as the operational strategy

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[3] Infrasounds are sounds with a frequency of less than 20 Hz.
[4] The 2 digital sonobuoys have a 16-bit digitization and digital radio-telemetry channel and the 4 analog sonobuoys have a VHF FM analog telemetry channel.

and methodology for the 2005 field program. The third volume is dedicated to analysis of the data, conclusions and recommendations for future work[5].

1.1 Terminology and algorithms used in the report

Ambient and anthropogenic acoustic data recorded by the AUARs was written to the AUAR disc in a raw format and converted to microPascals (µPa)[6] after downloading to the computer on the *Academik Lavrent'ev or Academik Oparin* (or during analysis). Acoustic spectra in decibels will be used to describe the variation in acoustic power as a function of frequency. In this report sound pressure power density spectra *G(f)* ($\mu Pa^2/Hz$)[7] will be used when spectral data are plotted. The sonograms *G(f,t)* are plots of power spectral density vs. frequency and time and also include the variation in sound pressure level (μPa^2) with time over the annotated bandwidth $D(\Delta f,t)$[8]. The power spectral density scales generally run from ~37 to ~120 dB re 1 $\mu Pa^2/Hz$.

The ***Spectral level*** of an acoustic signal relates to the level of acoustic power in a 1 Hz band. This term is only applied to sounds with continuous frequency spectra[9]. These spectra are often averaged over a number of one-second windows[10] to improve the statistical stability of the ambient noise data[11]; the number of one-second windows used in the averaging is given at the top of each plot (if the data is averaged over multiple windows).

A detailed description of the methodology used for normalizing and calculating both the amplitude and spectral data is given in Appendix D.

1.2 Units

During the course of this report a number of different unit notations have been used. This is due to differences in standard notation between different disciplines and nationalities.

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[5] This analysis includes both the joint ENL/SEIC long-term western gray whale research program and the joint construction acoustic monitoring program.
[6] The data was scaled (after incorporating hydrophone sensitivity, system instrument response and system gain), to convert the data to standard units of pressure (measured through an omni-directional hydrophone).
[7] Energy and power spectra are scaled to 1 Hz whatever the analysis length.
[8] Sound pressure level is the integral of the acoustic energy over the specified frequency band.
[9] A continuous frequency spectrum is a spectrum with signal present at all sampled frequencies.
[10] Average of X 1-second spectral estimates.
[11] Spectral averaging is used to obtain a lower variance spectral estimate.

The following are equivalent units using the different standard nomenclatures:
1 mkPa = 1 μPa and 1 mkV = 1 μV.

For spectral density plots: Although the units for power spectral density are $\mu Pa^2/(s\ Hz)$, $\mu Pa^2/s/Hz$ or μPa^2, the units for power spectral density are sometimes defined as $\mu Pa^2/Hz$ or $\mu Pa/\sqrt{Hz}$.

2 Autonomous Underwater Acoustic Recorder (AUAR)

This section describes the Autonomous Underwater Acoustic Recorders (AUAR) developed by POI and used to record acoustic data during the 2005 field program, its instrument testing, calibration and operational deployment.

2.1 Description of the AUAR

In 2005, POI used the five AUARs designed and constructed in 2003, eight AUARs built in 2004[12], one newly fabricated AUAR, and two new mini-AUARs. In 2005, four existing AUARs were equipped with surface radio transmission capability and are called Transmit-AUARs (T-AUARs). These individually deployed AUARs were used to record acoustic measurements in the frequency band from 1 Hz to 15 kHz. Figure 2.1 shows the major components of an AUAR and how the AUAR and hydrophone are anchored when deployed. Figures 2.2 to 2.7 illustrate various aspects of AUAR operation and design.

The external shell of the 2003 AUAR is a cylinder 0.8 m long and 0.38 m in diameter constructed from welded titanium alloy; its weight in air is approximately 105 kg. To facilitate the deployment and retrieval of the AUARs from the work boat of the *Academik Oparin,* the diameter was decreased to 0.32 m and the length increased to 1.2 m in the 2004 design. This increased the strength of the 2004 design, the weight in air remaining at 105 kg. The 2003 design was used for the AUAR constructed in 2005 because the operational time is longer with this design and alternative methods of recovery have been developed for this AUAR design. The titanium alloy case of both types of AUAR can be opened at one end and has been strengthened for deployment in depths of up to 100 m. The open end is used to gain access to the unit and is sealed with an o-ring. The lid contains two waterproof connectors that allow external sensors (hydrophones, accelerometers or hydrologic measuring equipment) to be input to the AUAR electronics. This connector can also be used to connect a radio-channel cable to the AUAR electronics. Inside the AUAR there are batteries secured in a titanium frame and a tray containing the AUAR electronics and power handling circuitry (amplifiers, anti-alias filters, voltage

[12] The eight new AUARs were designed to improve the operational handling of the units following the experiences of the 2003 field program.

converter, computer, flask disk and hard drive). The number of batteries depends on the AUAR design.

The 2003/2005 AUARs have two sealed batteries that provide continuous operation of the AUAR for over 18 days, and the 2004 AUARs have three sealed batteries providing continuous operation of the AUAR for 16 days[13].

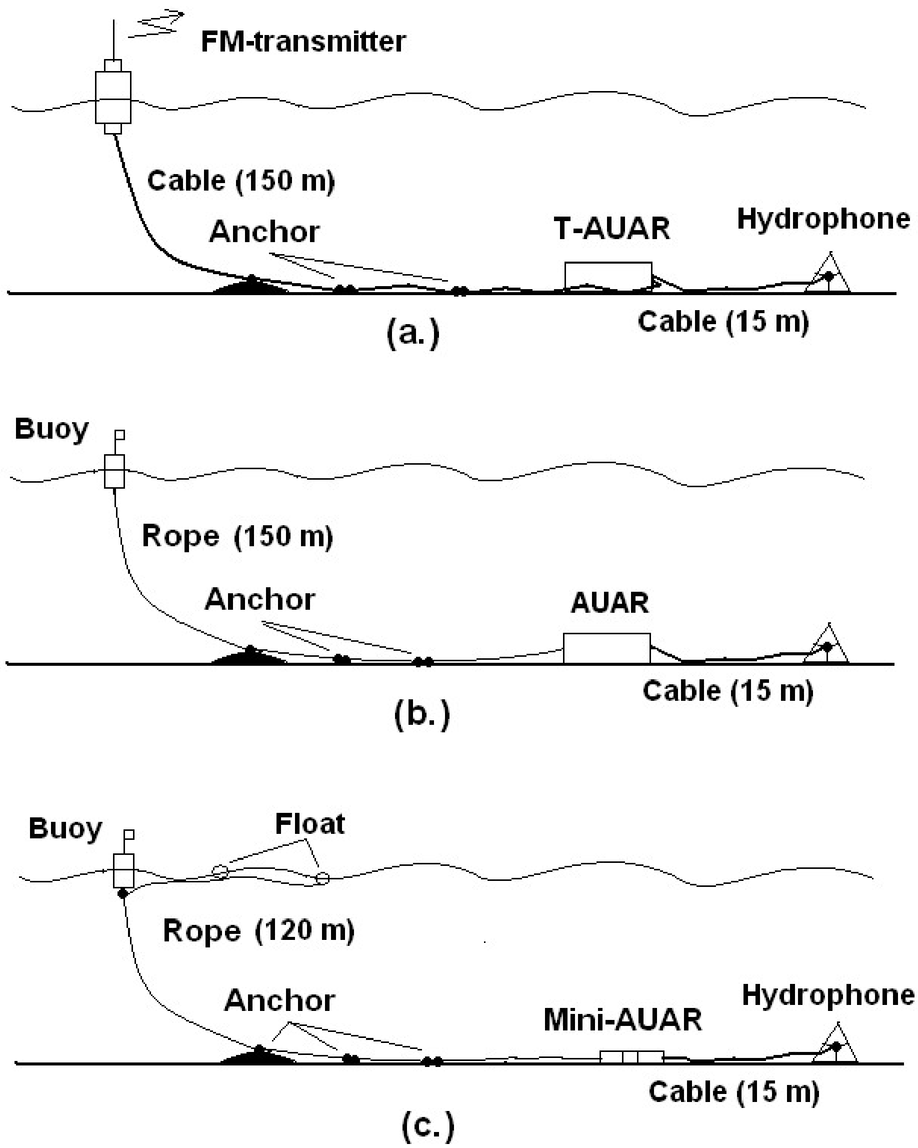

Figure 2.1 – Deployment schematics for (a) T- AUAR; (b) AUAR; and (c) Mini-AUAR.

[13] The two sealed batteries (2003/2005) have a capacity of 115 Ampere-hours each. The three sealed batteries (2004) have a capacity of 65 Ampere-hours each.

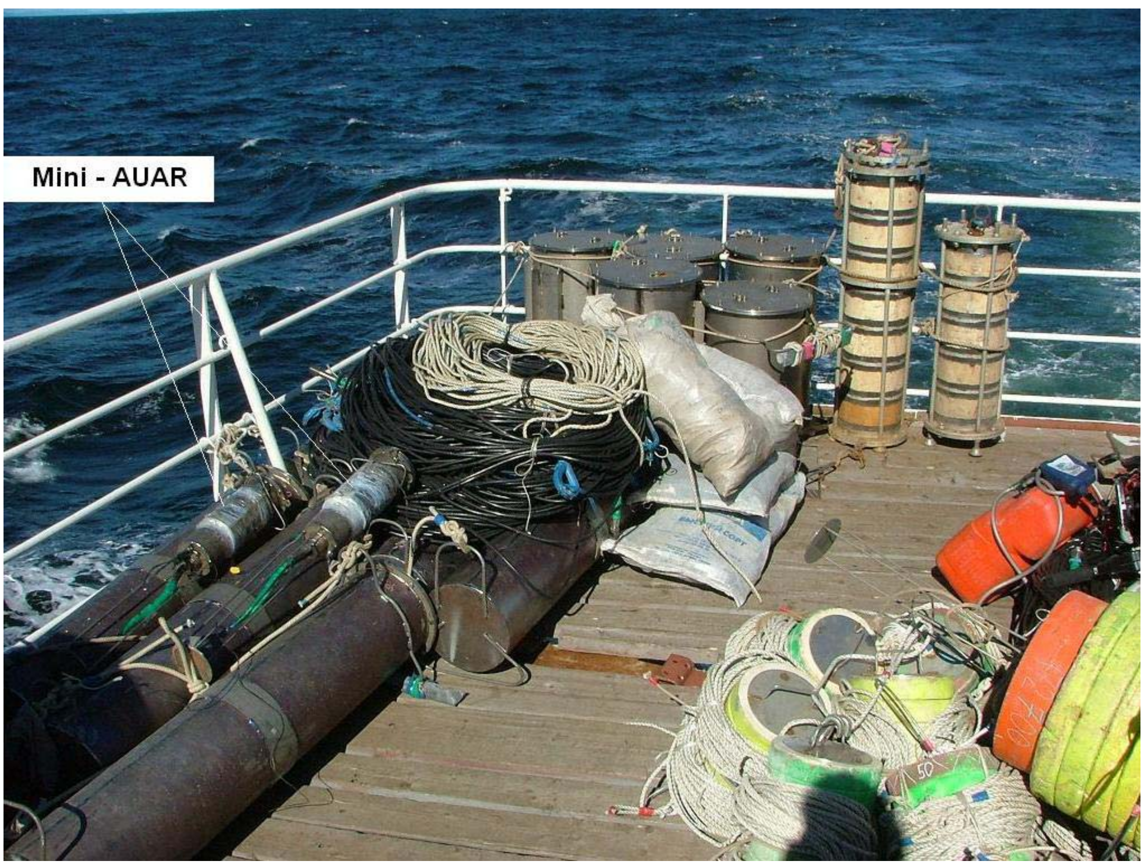

Figure 2.2 – Top: AUARs being prepared for cross-calibration prior to the 2005 field season; Bottom: different generations of AUARs on the *Academik Lavrent'ev.*

Figure 2.3 - Top: Components of an AUAR; Bottom: Deploying an AUAR from the *Academik Oparin*.

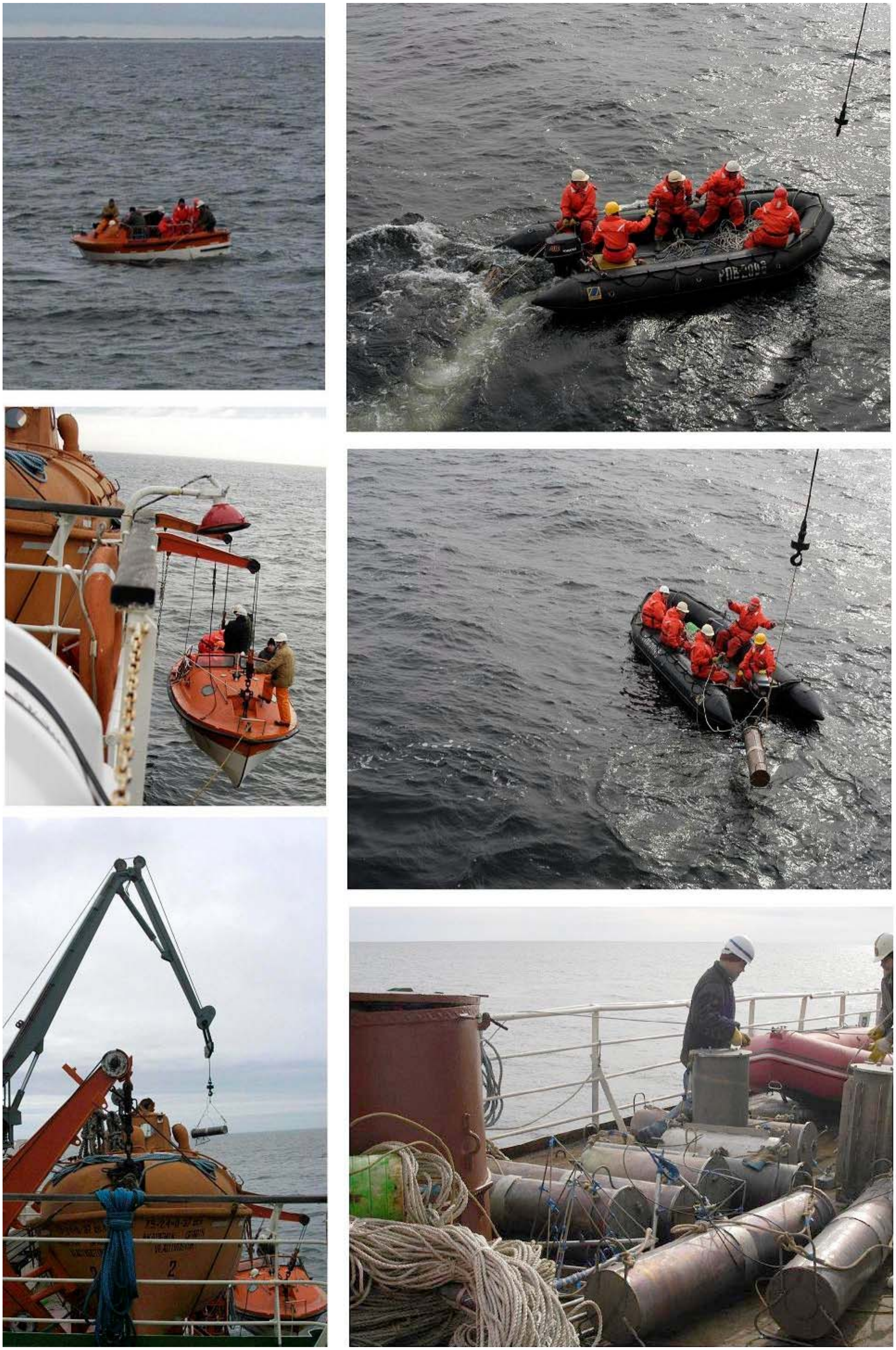

Figure 2.4 - Retrieval of an AUAR by a boat, zodiac and the *Academik Oparin.*

Figure 2.5 - (a) AUARs designed in 2003 and 2004, (b) spherical (left) and cylindrical (right) hydrophones with pre-amplifiers.

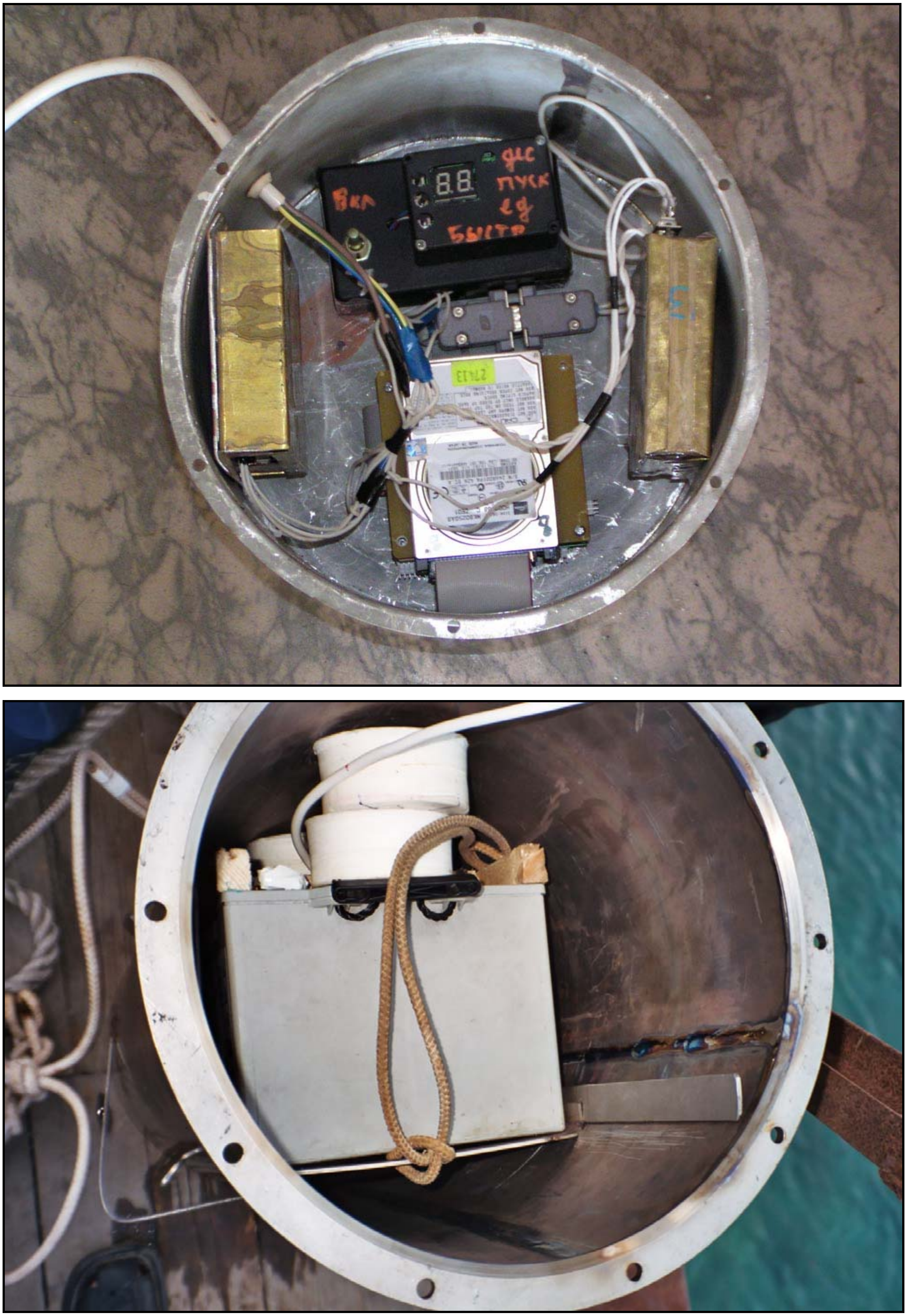

Figure 2.6 - Top: AUAR electronics tray showing power supply, disk and electronics. Bottom: Inside the titanium AUAR container showing frame holding the batteries.

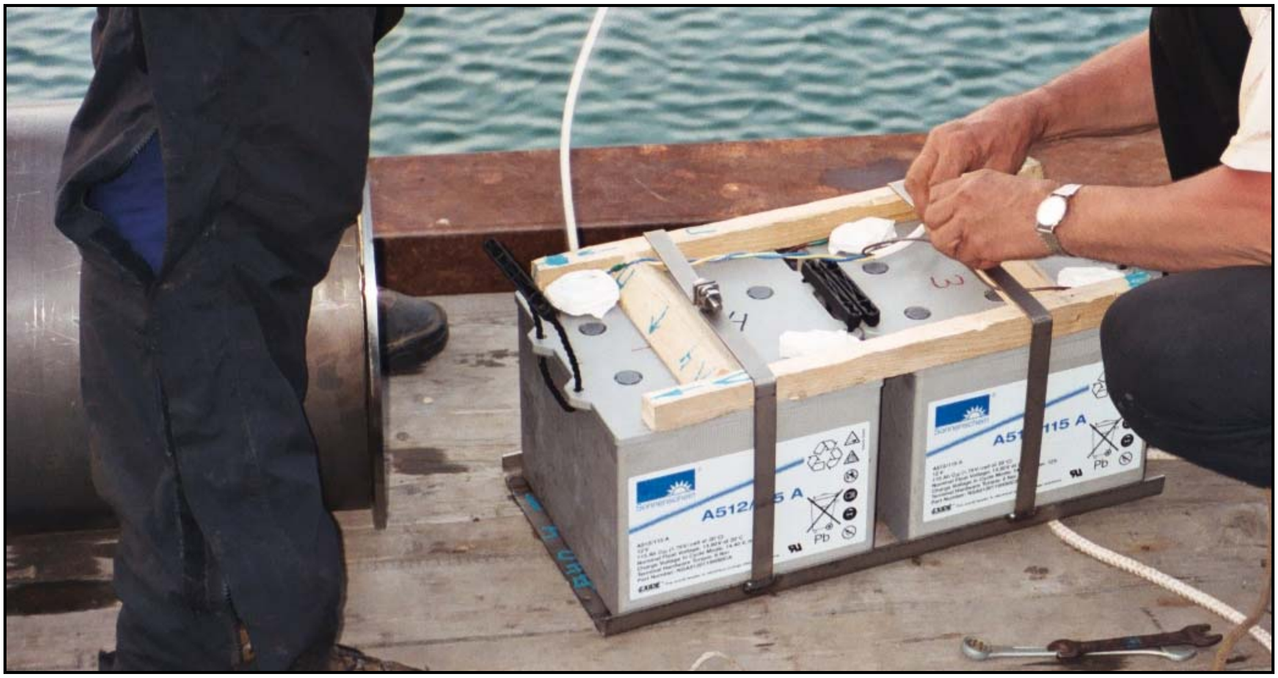

Figure 2.7 - Preparing the batteries in the battery frame prior to loading into AUAR.

In 2005, four AUARs were outfitted with surface floats containing VHF FM radio transmitters[14] (Figure 2.8). This radio-link[15] allowed real-time radio transmission of acoustic data in the frequency band from 10-5000 Hz for distances up to 20 km. The acoustic data is also concurrently written to the AUARs internal hard drive. The radio-transmitter is controlled by the AUAR computer and is turned on and off on a pre-programmed schedule.

The mini-AUARs utilize the titanium housing and the disposable power sources used for the sonobuoys. The systems are described in more detail in section 2.1.1[16].

Figure 2.1 shows the layout of the AUARs in the ocean. A surface float connected with a 40-70 m[17] rope to a 24 kg anchor marks the location of the AUAR on deployment. This anchor is linked to the AUAR by a 100-150 m long rope weighted down with lead weights. The GPS coordinates of both the anchor and the AUAR are logged during deployment and if necessary the vessel can grapple for the rope between them. The AUAR can therefore

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[14] The AUARs 2003 design specifically allowed this real-time monitoring capability to be added when required.
[15] The radio transmission channel is based on the analog sonobuoy electronics described in chapter 3.
[16] The mini-AUARs were designed for short term (up to 3 days) monitoring of anthropogenic sound sources (e.g. monitoring the near field of a transducer during TL experiments). The units had lower sensitivity to allow them to perform this specialized task.
[17] Length is dependent on water depth.

still be recovered in the event that the surface buoy is lost. One AUAR was recovered in this manner during the 2003 field season.

Figure 2.8 – T-AUAR being prepared for deployment (note the radio transmission unit connected to the AUAR container).

Practical experience has shown that at shallow deployment depths (10-30 m), movement of the surface buoy due to wave action can be mechanically conducted down the rope to the hydrophone. This mechanical movement can be recorded as acoustic noise, distorting the ambient acoustic measurements. Interaction of the surface float with waves can also generate noise that acoustically propagates to the hydrophone. The AUAR is deployed so as to reduce this noise by isolating the hydrophone from the surface buoy with an anchor, thus reducing the mechanical coupling between the surface buoy and the hydrophone. The hydrophone is also deployed 15 m from the AUAR to prevent scattering or masking by the AUAR container from distorting the acoustic field at high frequencies. The hydrophone is deployed inside a pyramid shaped steel frame and attached by rubber bands to the frame, to decouple it to the best extent possible from the sea floor (Figure 2.9).

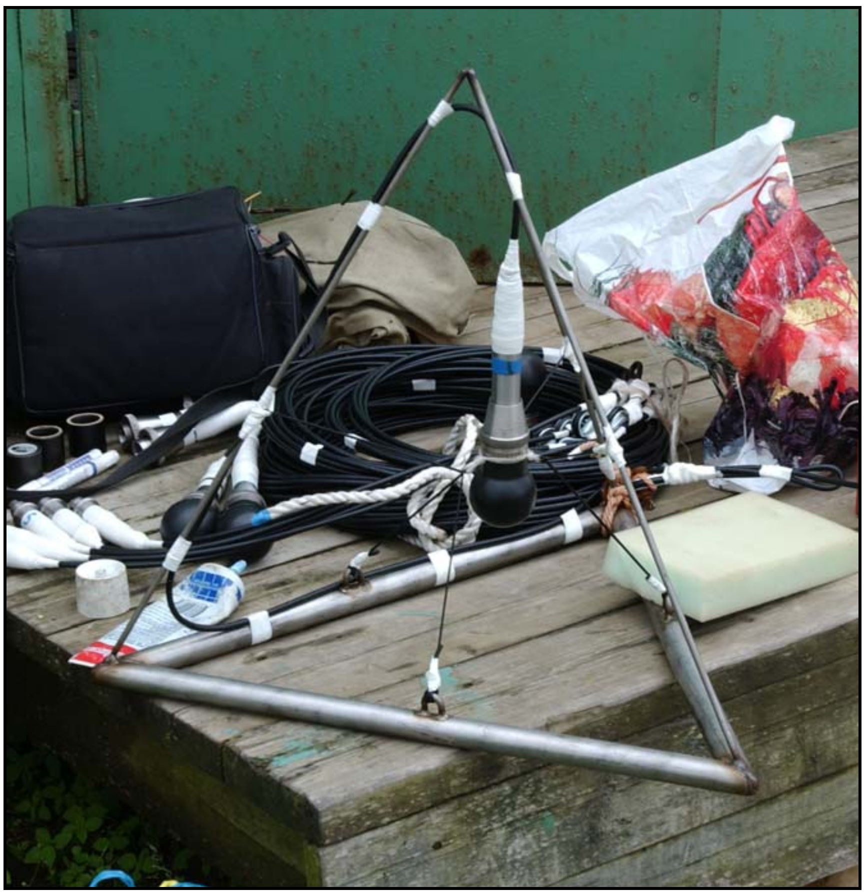

Figure 2.9 - Hydrophone deployment frame with spherical hydrophone.

Cylindrical hydrophones (model # GI-50 (ГИ-50)) and spherical hydrophones of type G33 (Г33), both with integrated pre-amplifiers designed specifically for the hydrophones, were used for the AUARs; Figure 2.5(c) shows the hydrophones. Cylindrical hydrophones were used for the first time in 2004. The pre-amplifier amplifies the signal prior to transmission along the 15 m connector to the AUAR[18]. The hydrophones were calibrated over the frequency band 1 Hz to 15 kHz[19]. AUARs were deployed at a low speed (3-4 knots) using an A-frame at the stern of the *Academik Lavrent'ev* and a crane at the stern of the *Academik Oparin* and were retrieved using a zodiac or fiberglass boat as discussed earlier.

Figures 2.10 and 2.11 give block diagrams for the AUAR and T-AUAR electronics. The output from the hydrophone and pre-amplifier is transmitted along the 15 m cable to the AUAR input connector. The AUAR houses the amplifier, filters and the Analog to Digital Converter (ADC).

In order to optimize the dynamic range of the 16 bit ADC[20] the signal amplitudes should be approximately equal across the entire frequency range. However, ambient noise generally has an amplitude maximum at low frequencies and drops off with higher frequencies. The ADC does not therefore have the instantaneous dynamic range required to record frequencies from 1 Hz to 15 kHz. The analog channel of AUARs that use G-33 hydrophones (with high sensitivity at low frequencies) have a low-frequency gain correction at frequencies below 100 Hz using a second-order RC circuit. For AUARs that use the GI-50 hydrophones, which were updated in 2005, low-frequency amplitude correction is effected in the hydrophone preamplifier. These amplitude corrections ensure a consistent signal level across the entire frequency band for the analog channel of the AUARs with these hydrophones. The reduction in gain is less than 3 dB at 1 Hz.[21]

[18] The purpose of the pre-amplifier is to amplify the signal as close as possible to the hydrophone. In this way the signal level relative to any noise picked up in the cable and AUAR will be maximized. The location of the pre-amplifier inside the hydrophone provides the maximum shielding against electromagnetic induction (electronic modules inside the AUAR container are more susceptible to induction).

[19] The calibration certificates are given in Appendix A.

[20] The ADC is on the Prometheus motherboard and has a maximum sample rate of 100 kHz.

[21] In previous years (2003 & 2004) the AUAR design had two analog channels, a Low Frequency (LF) channel with only a second order correction for frequencies below 50 Hz and a High Frequency (HF) channel that is processed to maximize the dynamic range. The HF channel has the low frequency component (<3 kHz) removed by a low cut filter, allowing the gain coefficient for frequencies above 1 kHz to be increased without overloading the ADC. Analysis of the data from these years indicated that the two channels were not required if the input data were gain balanced to equalize the input amplitudes across the frequency band.

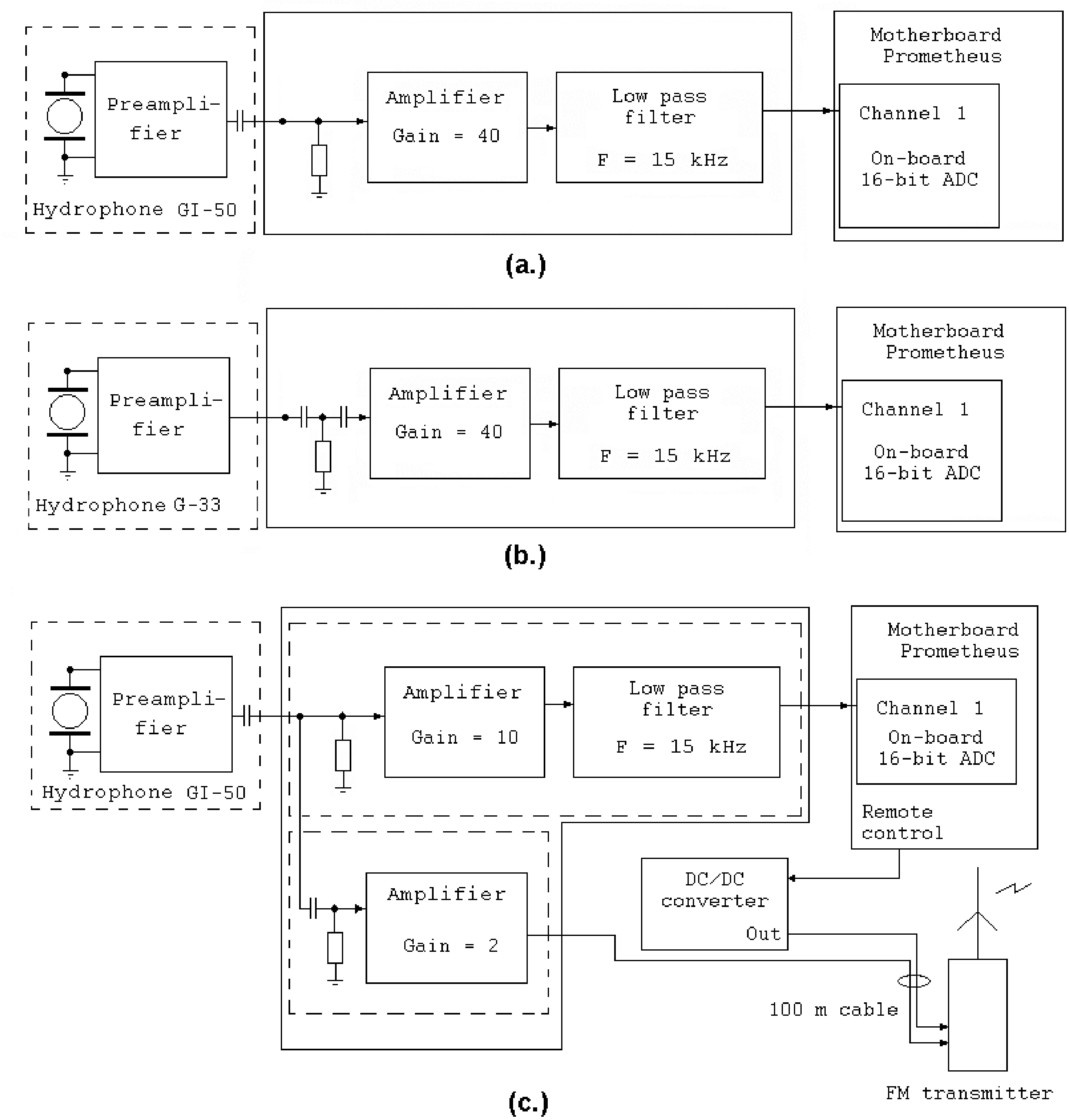

Figure 2.10 - Block diagram of the analog channel of the AUAR recording system. (a) AUARs with the GI-50 hydrophone, (b) AUARs with the GI-33 hydrophone, and (c) AUARs with the GI-50 hydrophone and radio-transmission data channel.

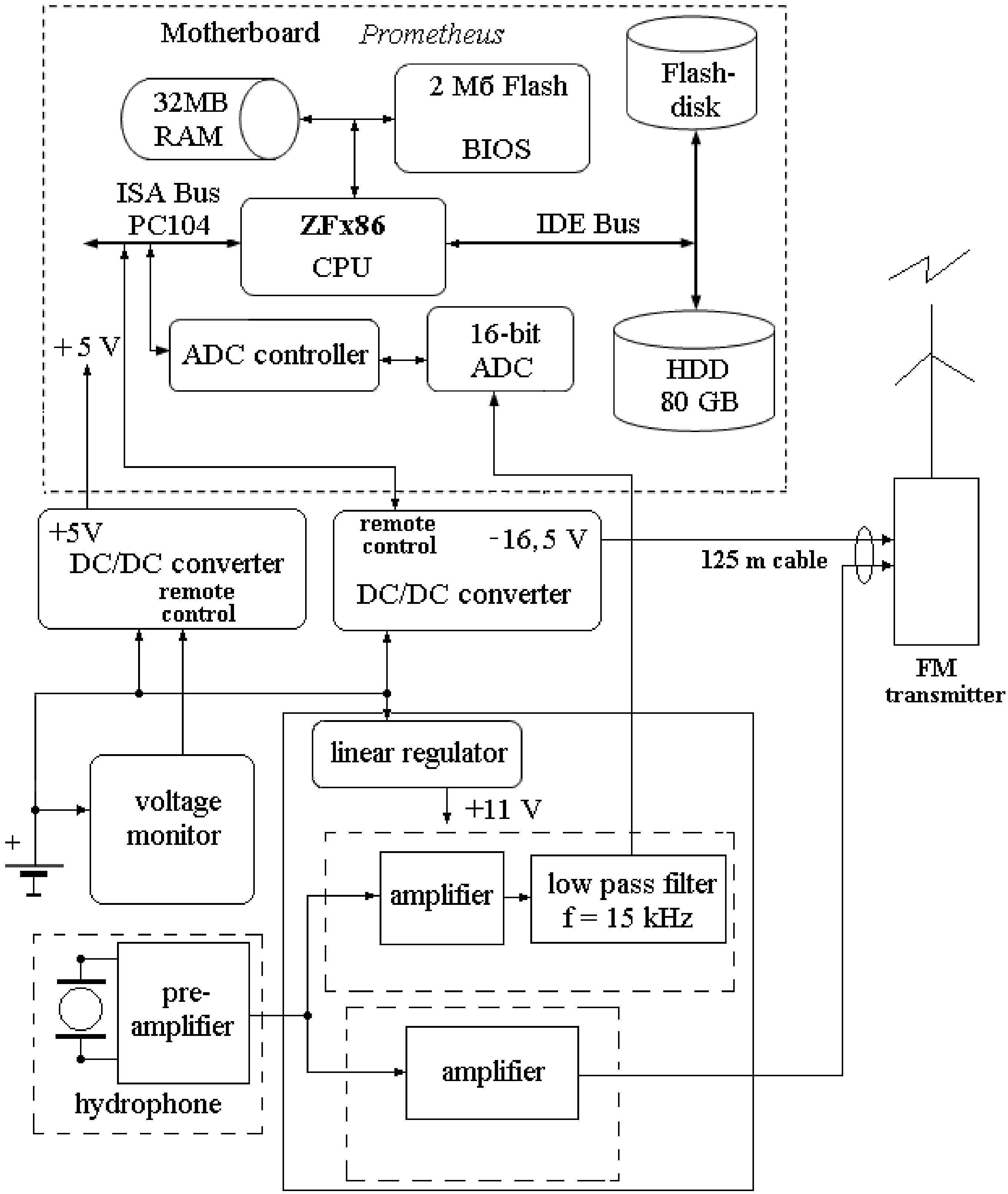

Figure 2.11 - Block diagram of the AUAR recording system.

The signal from the AUAR input connector is input to the scale amplifier of the analog channel, which has user selectable gain coefficients of 2, 10 or 40 (Figure 2.10). It is then passed into an 8th order elliptic low pass frequency filter with an anti-alias high cut frequency of 15 kHz and slope of 80 dB/Octave. For T-AUARs the input signal from the hydrophone preamplifier is also input to a first order RC filter at the input to the radio channel scale amplifier, which has user selectable gain coefficients of 0.5, 2 or 10.

Figure 2.12 - AUAR electronics (Prometheus board, flash memory and hard drive).

The AUARs digital recorder is based on the Prometheus single board computer (Figures 2.10 to 2.13)[22]. The 16 bit ADC is connected to the input controller by eight differential

[22]The computer, manufactured by Diamond Systems Corporation, consists of a 486-DX2-100 CPU, USB-port, 32 MB RAM, IDE-controller connected to the internal PCI bus, analog and digital input/output unit and 2 MB flash memory containing BIOS, OS and POI recording program.

inputs and a 48-sample FIFO (First In First Out) buffer. The primary AUAR data storage is a compact laptop 80 GB hard drive[23].

[23] Although significantly smaller in capacity than the largest desktop hard drive, the laptop hard drive has better power management and uses dramatically less power.

To optimize power management and prevent electromagnetic and acoustic noise generated by the rotating hard drive from contaminating the data a 1 GB flash memory drive is used as a buffer. While data is being recorded on the flash drive the hard drive is in standby mode with its motor off. A voltage converter takes the initial unstable battery voltage (18-72 V) to a stabilized 5 V required to power the computer[24]. The electronic components of the analog devices are powered with an independent linear stabilizer and housed in a shielded container. All units comply with the PC104 specification, having dimensions of 9.1 x 9.7 cm and can work in temperatures from -40 to +85 °C. If the voltage drops to 27.5 V, the power controller switches off the computer and the analog units to protect the batteries against over discharging, as this can cause a failure of the batteries.

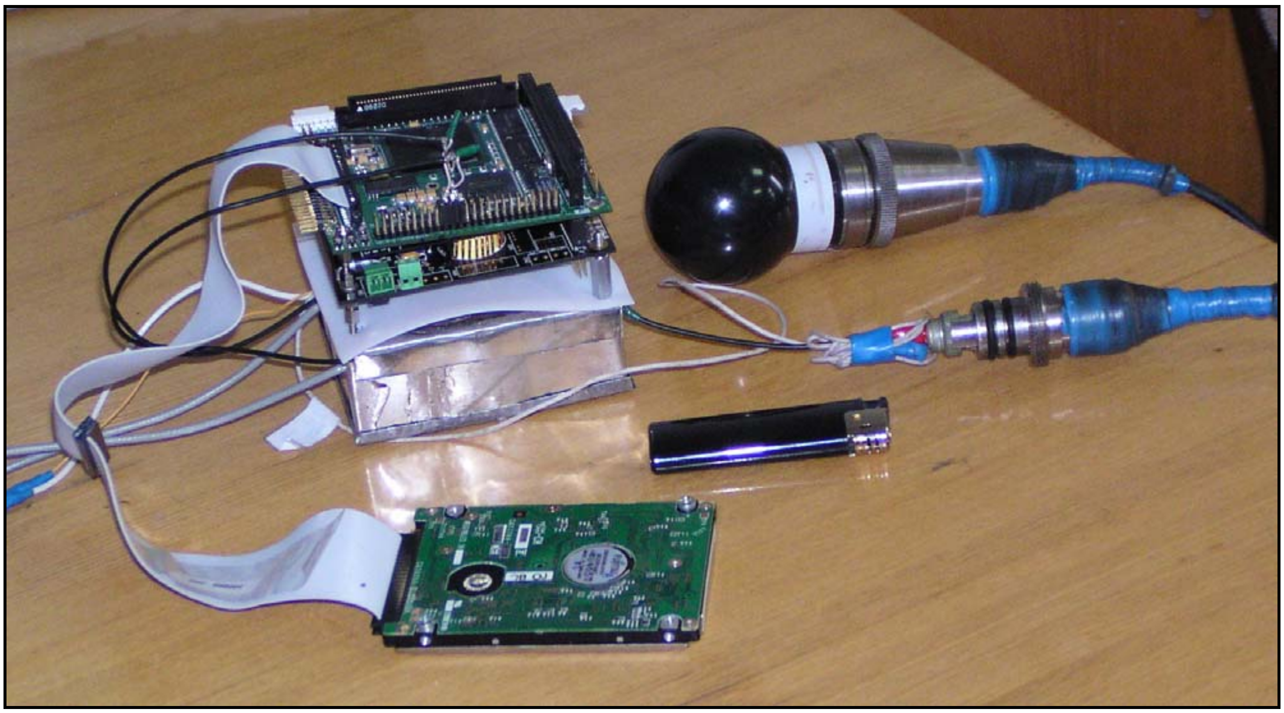

Figure 2.13 - AUAR electronics (Prometheus board, flash memory and hard drive).

The recording and data storage control program was developed at POI and fully tested between November 2004 and July 2005. The AUAR can be pre-programmed to fulfill a preset recording schedule. This can include a delayed start or an intermittent recording schedule[25]. Before the AUAR is deployed the user can select a number of program

[24] VE104 - input voltage: 8-40 V (2003/2005 AUARs); HE104 - input voltage: 8-40 V (2004 AUARs).
[25] A programmable timer and program executive controls the delayed start or power switching of the AUAR electronics when deployed, the unit is based on the AT90S1200 microcontroller. The delay timer is programmed just before deployment; it can delay recording from 10 minutes to 30 hours.

parameters including the duration of the recording cycles, the number of cycles, the ADC sampling rate and additional functions. A data file is created on the buffer flash disk during the execution of one operating cycle and is moved to the hard disk at the end of the cycle.

The following parameter settings were used as the primary AUAR operating mode:

- Continuous (24 hour) operation;
- ADC sampling rate of 30 kHz; and
- The data recording time in an operating cycle is approximately 4 hours 18 minutes (the time for writing stored data to the hard disk is about 22 minutes).

These parameters support at least 16 days of operations, based on the specifications of the hardware selected. Parameters can also be set for a second operating mode, where the AUARs power down for a set time. In this way upon completion of each cycle of data storage to the hard disk, a ‘power off’ control signal is transmitted to the AUAR power management unit. The AUAR down time is selected by setting a timer that controls the power unit. After the power is switched on, the system reboots and the operating cycle is repeated.

The program that controls the radio transmission cycle was developed at POI and again was fully tested between November 2004 and July 2005. The program transmits ‘on/off’ control signals to the power management unit of the transmitter according to a predefined operating schedule. For the 2005 monitoring operations a cycle of 1 hour on, 2 hours off was used[26].

The two programs run under the QNX operating system[27], which controls AUAR data storage. The data logger stores raw data on the AUAR hard disk in separate files; the filename includes the file creation date and time, accurate to the minute. In addition, a program activity log is kept, in which the start time for writing data to the file, accurate to the second, is recorded. The AUAR recording system operates in a cyclic mode. Each cycle is a sequence of data blocks streaming from the analog channel ADC (30 kHz sample rate) into the flash memory for storage. When the flash memory drive is full, the recording cycle is halted, and the data is transferred from the flash memory drive to the hard drive. The

[26] The AUAR computer clock controls the cycle.

number of records in the file is dependent on the size of the flash memory drive, since the recording cycle is interrupted when the flash disk is full and cannot be restarted until the flash memory drive is clear - the data contains controlled gaps. The size of these gaps depends on the capacity of the flash memory[28]. When AUARs with a radio channel are used, there are no interruptions in data transmission via the radio channel when the AUAR is writing data from the flash memory to the disk.

Acoustic data is copied from the AUAR hard drive to POI removable hard drives on the *Academik Lavrent'ev and Academik Oparin* which are used as the main data storage units. The acoustic data on the AUAR hard drive was copied to a removable hard drive as transient storage. Periodically data from this transient storage was backed up to DVDs, which are the primary archival media for field acoustic data. The raw data is therefore stored in the form of copies of the original files on DVDs and hard disks. A description of the autonomous station deployment, the logger activity log, and text files giving the amplitude vs. frequency response of the AUAR electronics, hydrophone and radio transmission channel that will be required for any future data processing and analysis, are stored along with the data.

2.1.1 Mini-AUARs for operational measurements

The mini-AUAR shown in Figure 2.14 was designed for short-term (up to 3 days) autonomous acoustic measurements at depths of up to 100 m. The reduced size and weight of the unit makes it possible to deploy and retrieve the mini-AUAR from a *Zodiac*. This flexibility allows acoustic measurements to be performed in shallow water and near facilities that cannot safely be approached by the *Akademik Oparin*. The unit can also be quickly deployed and retrieved during TL measurements if near-field measurements are required[29].

The assembled mini-AUAR container, including the power supply, has a length of 105 cm, a diameter of 16 cm, and its weight in air is less than 18 kg. Modified titanium sonobuoy housings are used as the containers (without the antenna connectors).

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[27] Version 4.25.
[28] For a 1 GB flash drive the gap was 22 minutes.
[29] The gain on the AUARs used for ambient noise measurements is often too high for acoustic measurements at close range to the transducer. A lower gain mini-AUAR can be deployed for this task and quickly retrieved.

A single marine connector is used to connect the external sensors to the mini-AUAR electronics, and to secure the 15-meter cable connecting the housing and the pyramidal hydrophone frame. The mini-AUAR power supply is based on the power supply for the sonobuoy radios, uses alkaline D-cells, and is capable of 75 hours of continuous operation.

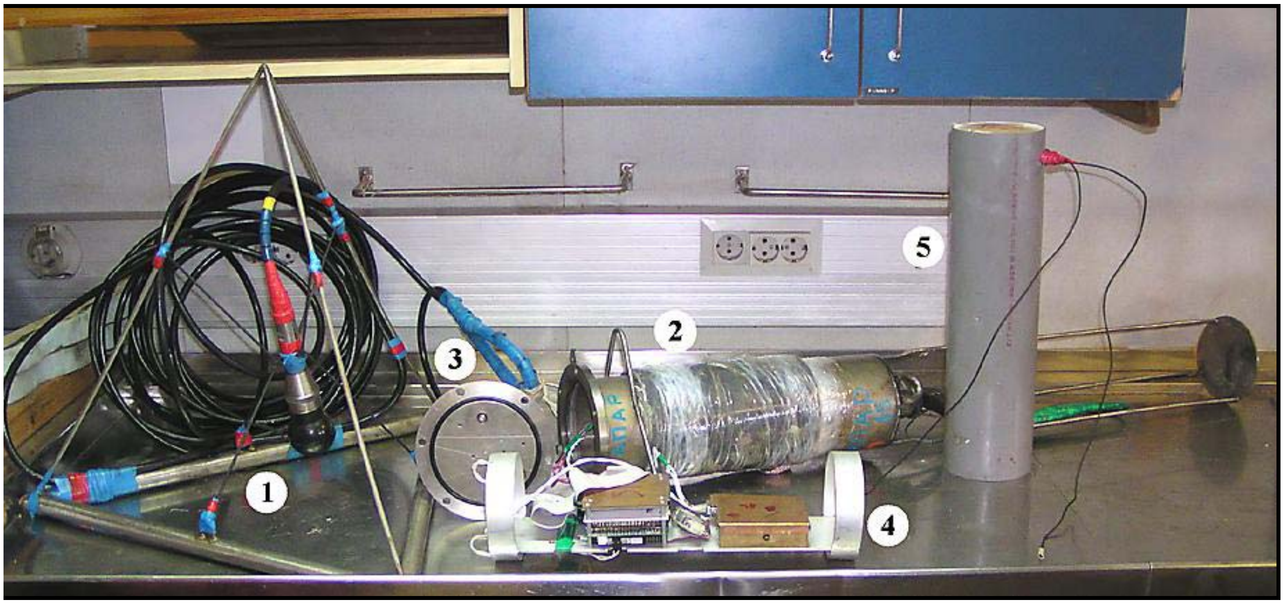

Figure 2.14 – Major components of the mini-AUAR.

Figure 2.14 displays the major components of the mini-AUAR: (1) Spherical hydrophone deployment frame and connecting cable; (2) AUAR container and keel to attach the power supply; (3) Sealed container cover with marine connector for cable; (4) Internal frame with digital recorder and analog unit; and (5) Sealed battery power supply.

2.2 AUAR instrument test analysis

In order to ensure that all of the AUARs adhered to the design specifications, and that the AUARs recorded accurate absolute acoustic measurements, a series of instrument tests was created (this test procedure is described in Appendix B). These tests had two goals: to ensure that the AUAR was operating within specifications and to generate an instrument response filter for the analog component of each AUAR. This estimate of the AUAR analog instrument response, measured in the laboratory prior to the field season $K(f)$ and the hydrophone sensitivity $M(f)$ was used to generate an inverse filter; this filter was subsequently applied to the analog voltage measurements to back out the system instrument response and generate absolute acoustic measurements. These frequency dependent responses correct the acoustic data over the range from 1 Hz - 15 kHz.

2.2.1 System internal noise test

Two dummy hydrophones were constructed in 2005, one each for the GI-50 (Figure 2.15(b)) and GI-33 hydrophones. The preamplifier electronics in a shielded housing of the dummy hydrophones are identical to those of the corresponding hydrophones except that piezoceramic capacitors with the same capacitance as the hydrophone piezoceramics are connected to their inputs. To perform the internal noise measurements, a dummy hydrophone (Figure 2.15(a)) was connected to the input of the AUAR analog channel via a 15 m cable. The output of the analog channel is connected to the input of the ADC for an AUAR digital recorder with a 30 kHz sample rate. The internal electrical noise of the entire analog channel including the dummy hydrophone is thus recorded.

Data was recorded to flash memory for one writing cycle (60 minutes) and from there to the hard drive. Figure 2.15(c) displays a spectral analysis of the results[30], showing the internal noise of the AUAR analog channels with GI-50 and G-33 hydrophones in the frequency bands from 0-15 kHz (top) and 0-500 Hz (bottom). Figure 2.15(c) shows that the internal noise level of the AUAR in the frequency range 1.5-15 kHz is approximately 27 dB re 1 $\mu Pa^2/Hz$[31]. The internal noise level of AUARs with a G-33 dummy hydrophone is 3 to 5 dB higher than that with the dummy GI-50 hydrophone in the frequency band from 10-80 Hz.

2.2.2 System dynamic range determination

Figure 2.16(a) gives a block diagram showing the experimental schematic for determining the dynamic range of the AUAR recording channel. A sine wave generator model # G3-118 (Г3-118) was used to generate signals at 10 Hz, 20 Hz, 40 Hz, 60 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz and 4 kHz into the hydrophone; a dummy hydrophone was connected parallel to the hydrophone sensor. The input data should be a smooth sine wave, not clipped or distorted at the peaks. The sine wave amplitude was therefore attenuated to ensure that any non-linear distortion at output was more than 60 dB below the input level. Figure 2.16(b) displays spectra of the tonal signals recorded by the AUARs during these measurements after correction for the instrument response of the analog channel.

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[30] Corrected by the amplitude-frequency response of the analog channel.
[31] The up to 20 dB increase in noise at low frequencies could be a result of electromagnetic pick-up during the testing.

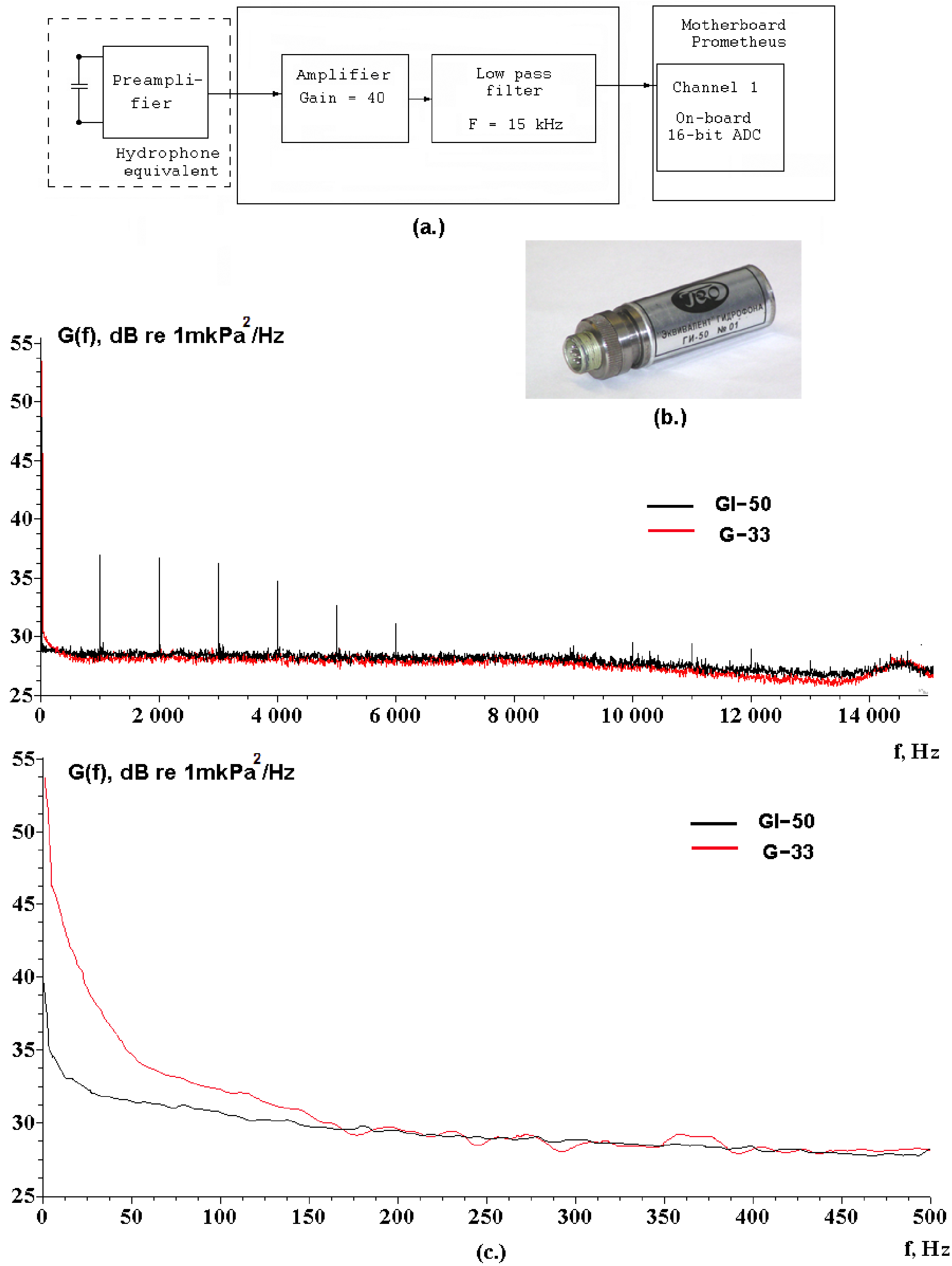

Figure 2.15 - (a) Block diagram showing the experimental schematic for the internal noise estimation test for the AUAR recording system; (b) GI-50 dummy hydrophone; (c) Spectra of the results for the frequency range 0-15 kHz and 0-500 Hz.

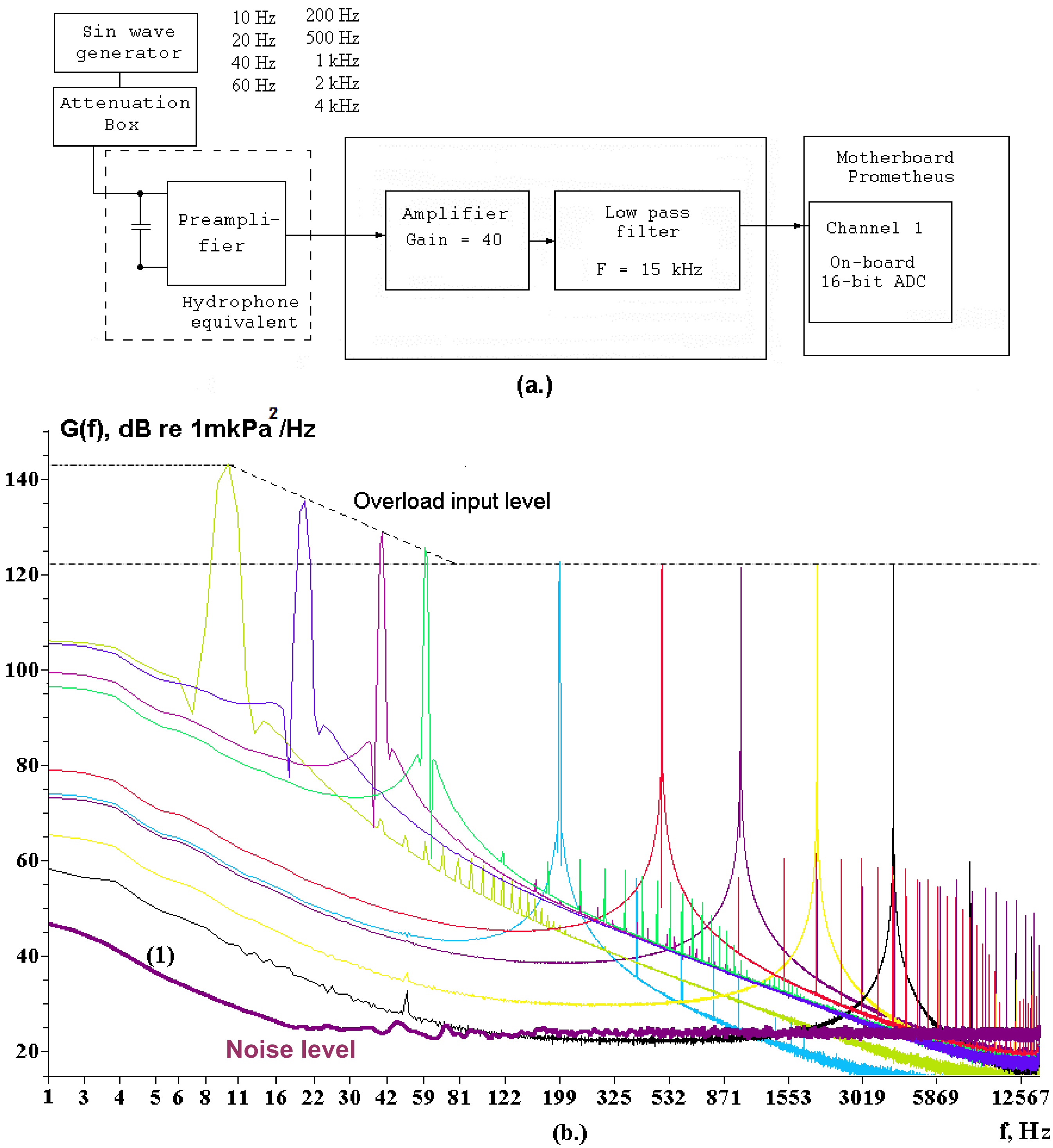

Figure 2.16 - (a) Block diagram showing the experimental schematic for system dynamic range estimation; (b) Spectra of the results for the frequency range 0-15 kHz (the purple curve is the internal noise level for an AUAR with a dummy GI-50 hydrophone).

This figure shows that, due to low-frequency amplitude correction of the system, the maximum input acoustic pressure level at which the non-linear distortion is 60 dB below the input level is a function of frequency, reaching 140 dB re 1 $\mu Pa^2/Hz$ at 10 Hz and 123 dB re 1 $\mu Pa^2/Hz$ at frequencies above 100 Hz. The purple curve (1) on Figure 2.16(b) shows that the internal instrument noise level of the AUAR recording channel with a dummy GI-50 is approximately 27 dB re 1 $\mu Pa^2/Hz$ in the frequency band from 100 Hz to 15 kHz, increasing to 35 dB re 1 $\mu Pa^2/Hz$ at a frequency of 10 Hz. Since the instrument noise is below the distortion for most of the recorded frequency range, distortion limits the dynamic range of the AUAR.

2.2.3 Analog channel system filter response

Figure 2.17 shows a block diagram giving the experimental schematic for determining the filter response of the AUAR analog channels, verifying the amplitude response of the system, and identifying aliasing. A white noise generator was attached to the input of the AUAR amplifier through an attenuator. A National Instruments 16 bit ADC card and 8-channel 8^{th} order elliptic filter[32] were used to record the data. Figure 2.18(a) shows the filter response (to a white noise input) of an AUAR analog channel with both a GI-50 hydrophone (C) and a G-33 hydrophone (CC) in the frequency band from 0 to 20 kHz. Figure 2.18(b) shows the same response over a more limited frequency band of 0 to 500 Hz.

The analog channel system response of all 16 AUARs to a broadband white noise input signal was determined. Figure 2.19 shows the total system response (including hydrophones) of all 16 AUARs plotted in the frequency band from 0 to 15 kHz. The experimental schematic shown in Figure 2.17(b) was used to measure the response characteristics of the AUAR recording system with a radio channel (T-AUARs). The radio-telemetry signal from the AUAR surface float radio transmitter was received by an ICOM IC-R10 radio receiver. The output signal from the radio receiver was input to a recording system consisting of a National Instruments 16 bit ADC card and 8-channel 8^{th} order elliptic filter connected to a notebook computer. Figure 2.20 shows the system response characteristics of the T-AUAR recording system, including the radio channel, to a broadband white noise input.

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[32] National Instruments model # DAQCard-AL-16XE-50 and National Instruments model # SCXI-1142.

The broadband white noise test is the standard filter response test used for the AUARs; tonal signal tests are conducted once per AUAR to determine a system filter response. Figure 2.21 shows the shows the system response characteristics of the AUAR recording system to harmonic signals in the frequency band from 1.25 Hz to 20 kHz. The experimental schematic shown in Figure 2.17(a) was used for the analysis; the white noise generator being replaced by a sine wave signal generator. Figure 2.22 shows the peak-normalized response characteristics of the AUAR recording system with GI-50 (C) and G-33 (CC) hydrophones.

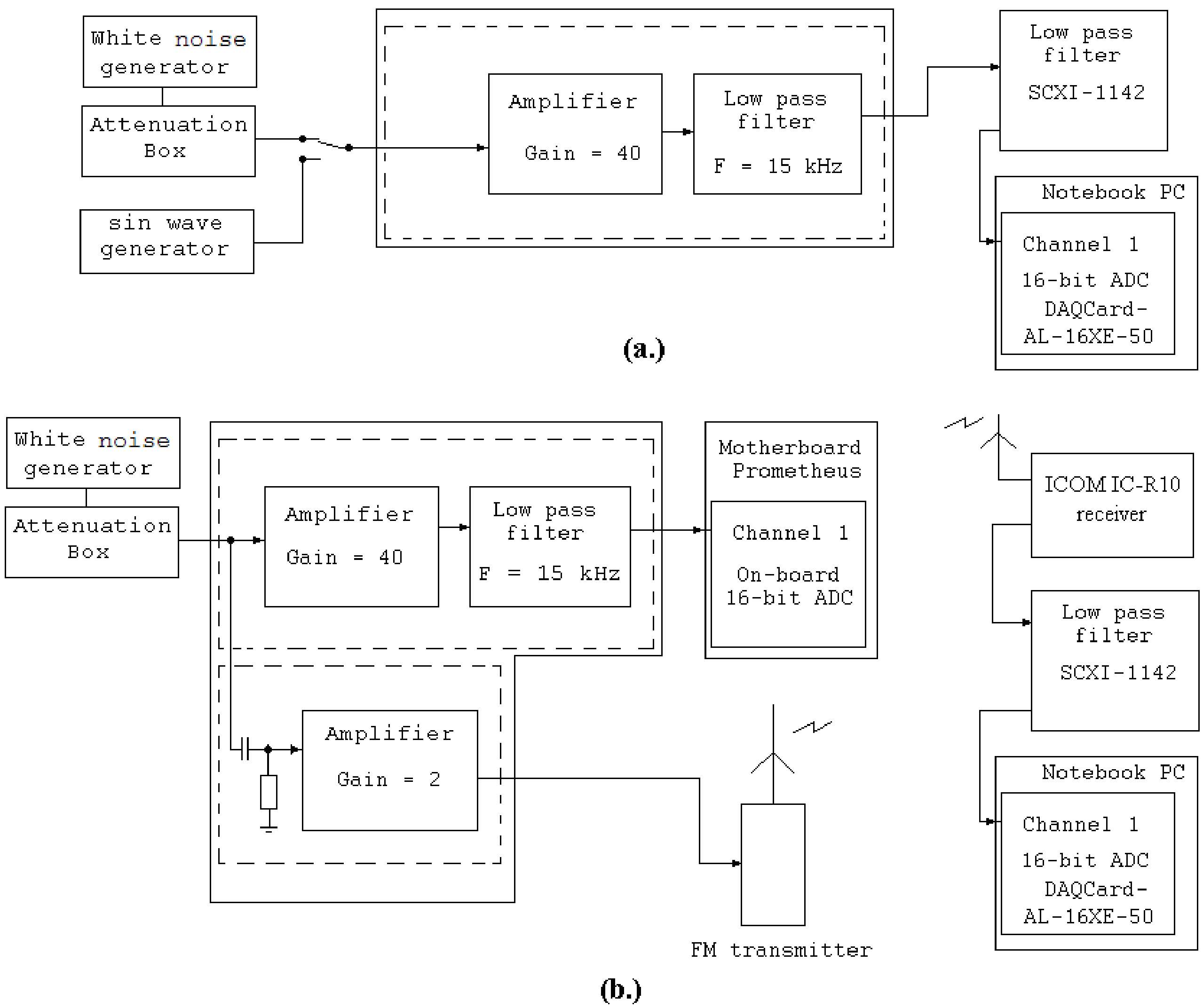


Figure 2.17 - Block diagram showing the experimental schematic for determining the analog channel amplitude frequency characteristics for the: (a) AUAR; (b) T-AUAR.

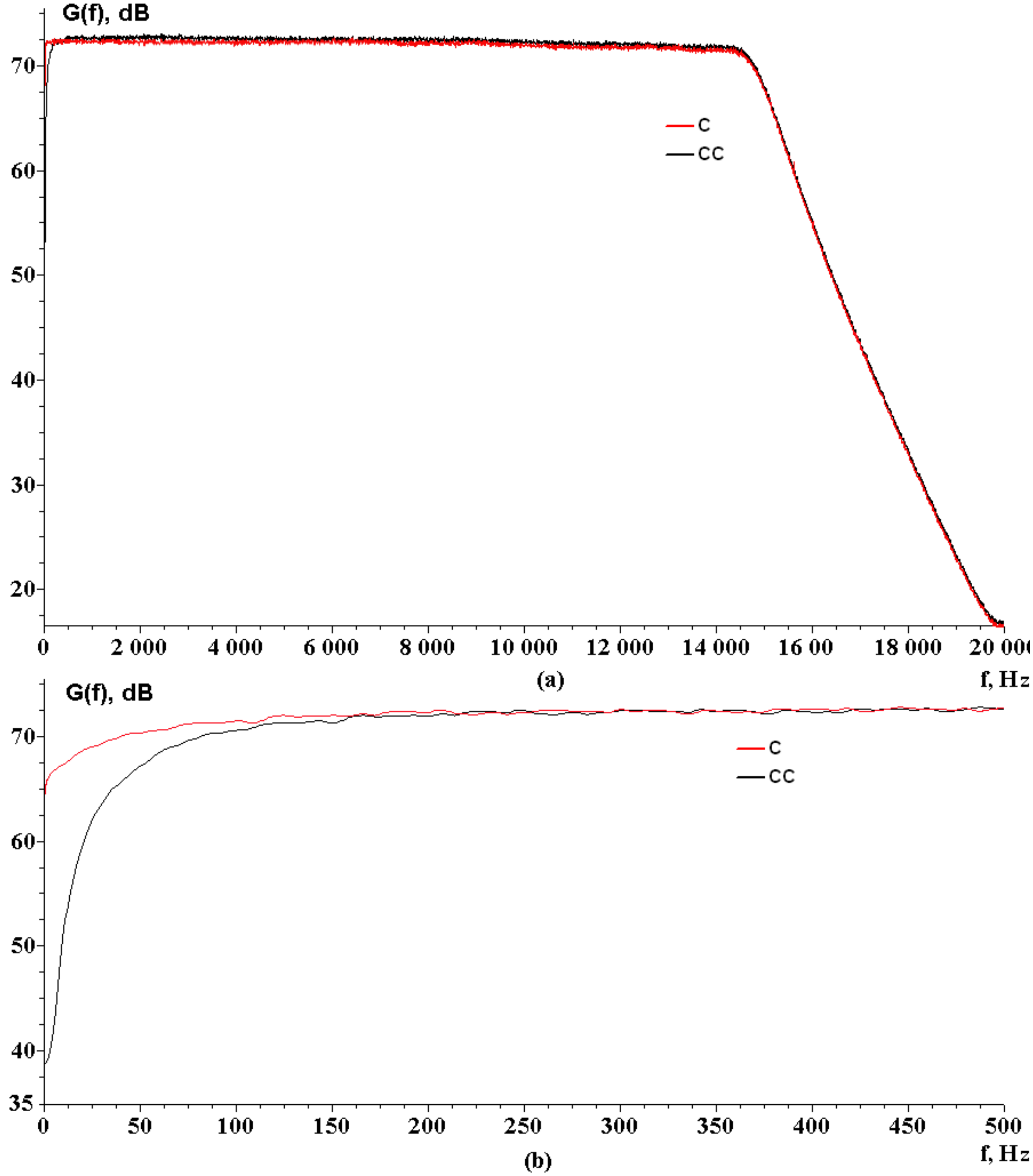


Figure 2.18 - Amplitude-frequency characteristics of an AUAR analog channel with both a GI-50 hydrophone (C) and a G-33 hydrophone (CC) measured with broadband white noise; (a) from 0 to 20 kHz; (b) from 0 to 500 Hz.

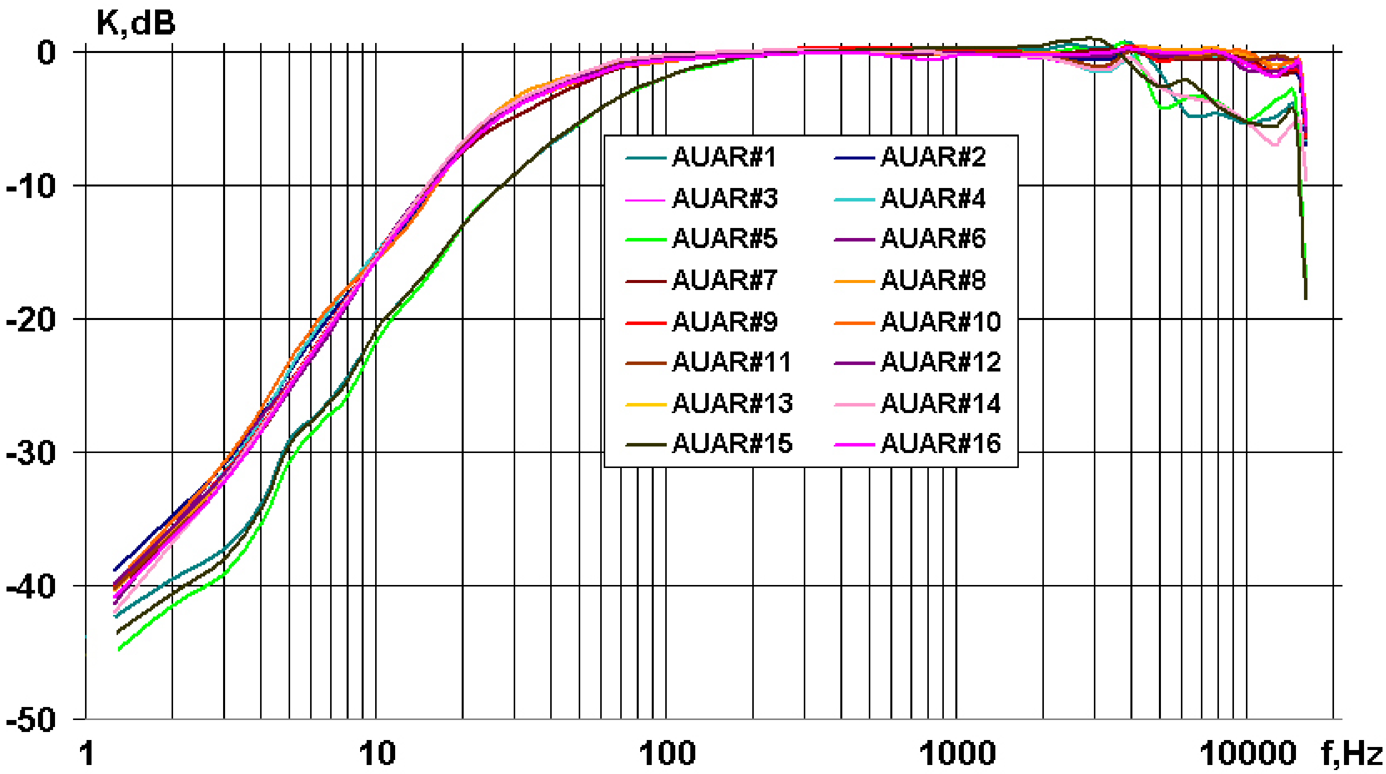


Figure 2.19 - Total system response (including hydrophones) of all 16 AUARs to a broadband white noise input signal. The five 2003 AUARs and one mini-AUAR have spherical hydrophones.

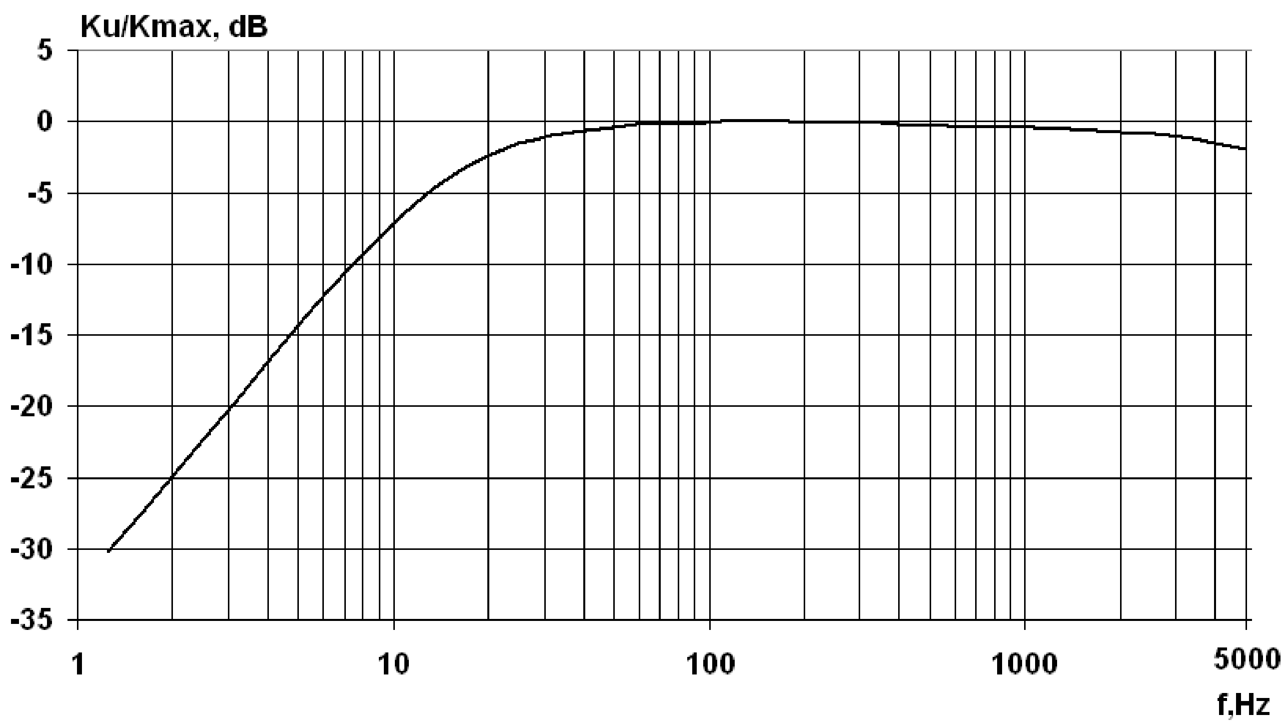


Figure 2.20 - Plot showing the system response characteristics of the T-AUAR recording system (including the radio channel) to a broadband white noise input.

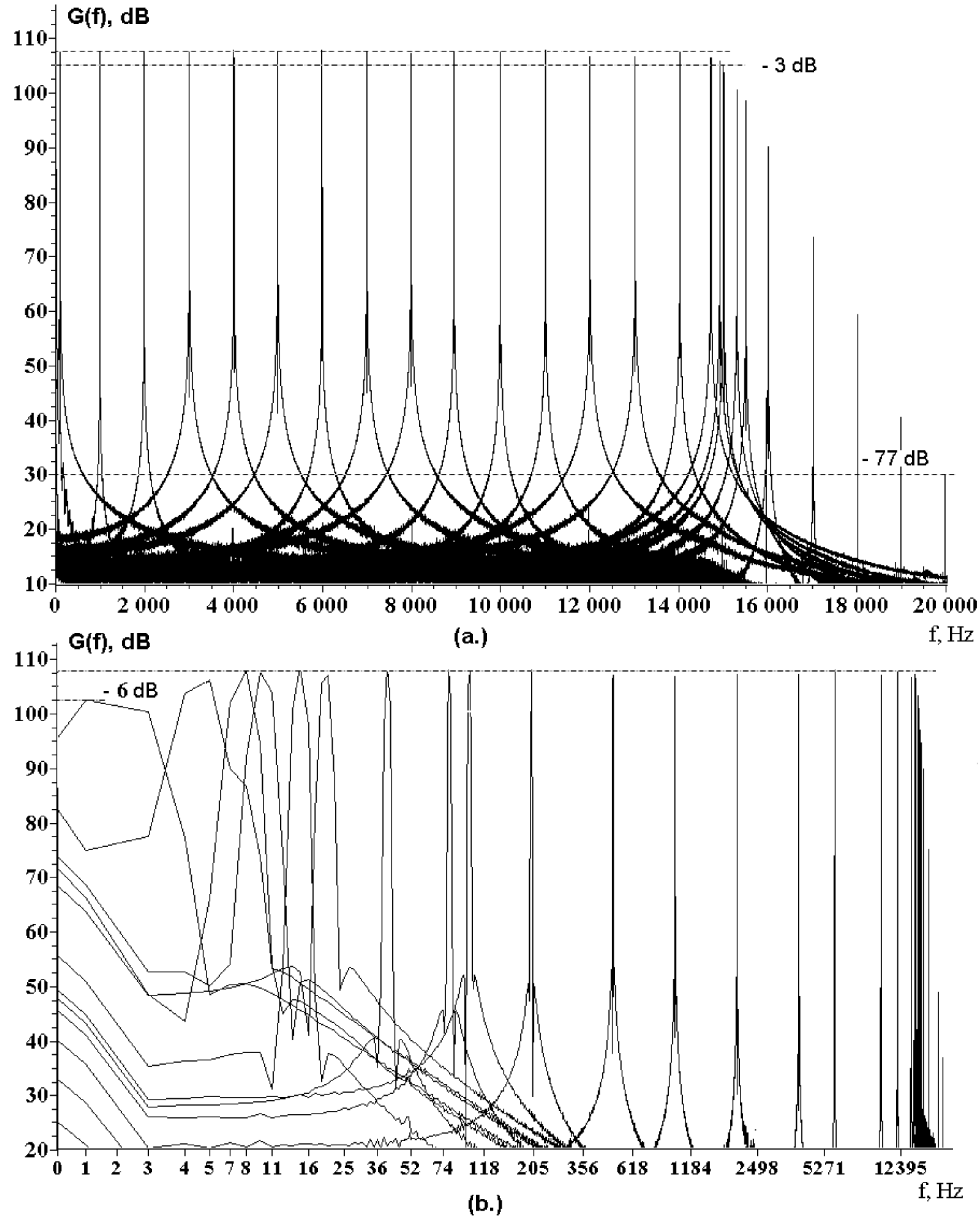


Figure 2.21 - System response characteristics of the AUAR recording system to harmonic signals in the frequency band from 1.25 Hz to 20 kHz: (a) linear frequency axis; (b) logarithmic frequency axis.

The combined results from the tonal signal test and broadband white noise test are used to estimate an analog instrument filter response for each AUAR. This filter response is used to correct the data as it is processed and to compensate for the decrease in amplitude response at frequencies lower than 100 Hz

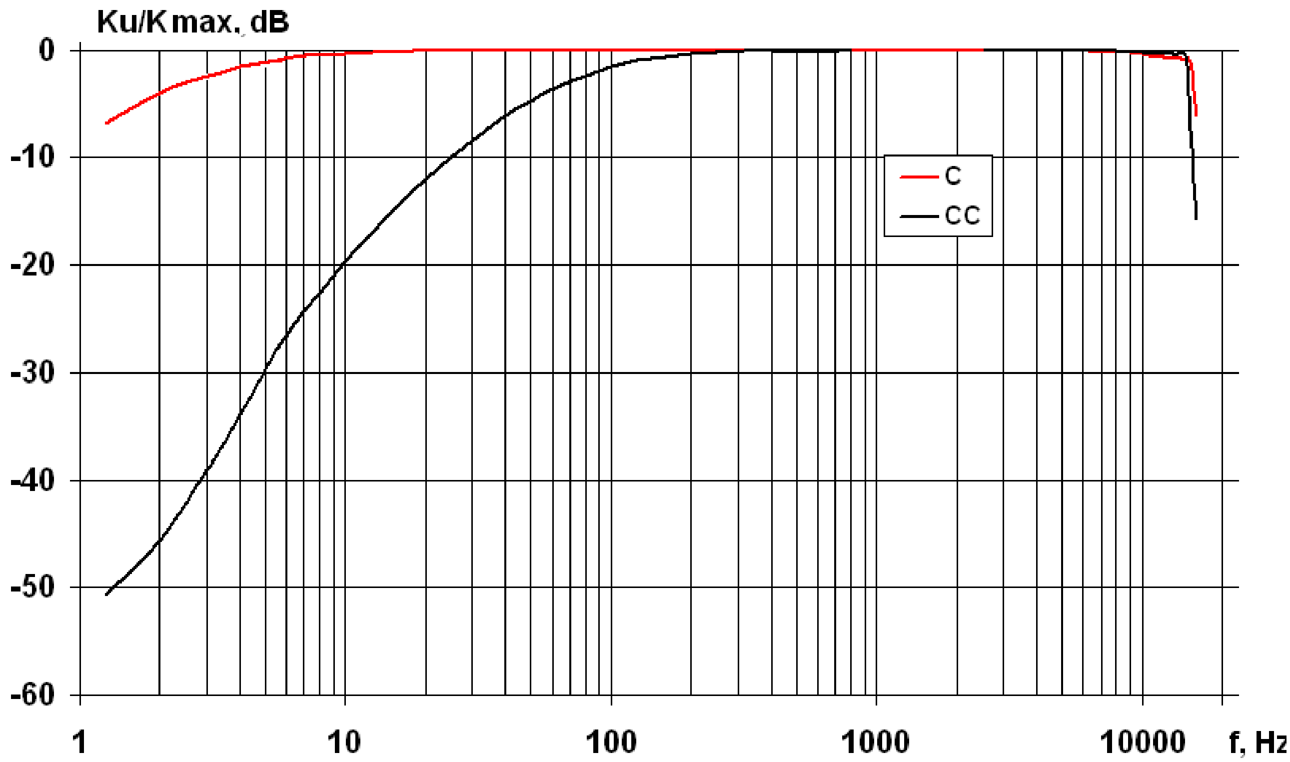
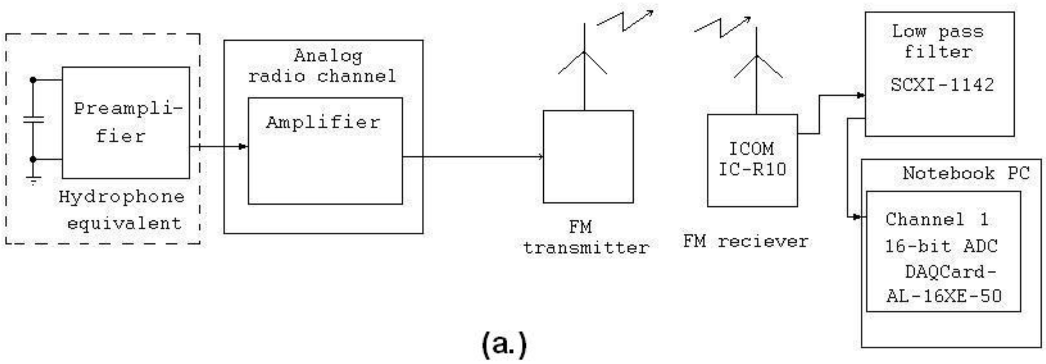


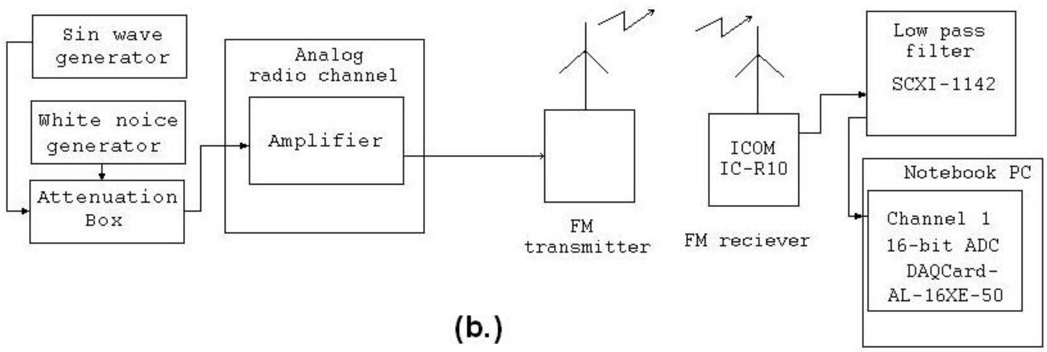
Figure 2.22 – Normalized system response characteristics of the AUAR recording system with GI-50 (C) and G-33 (CC) hydrophones derived from measurements using harmonic signals in the frequency band from 1.25 Hz to 20 kHz.

2.2.4 Instrument noise and dynamic range of T-AUAR telemetry channel

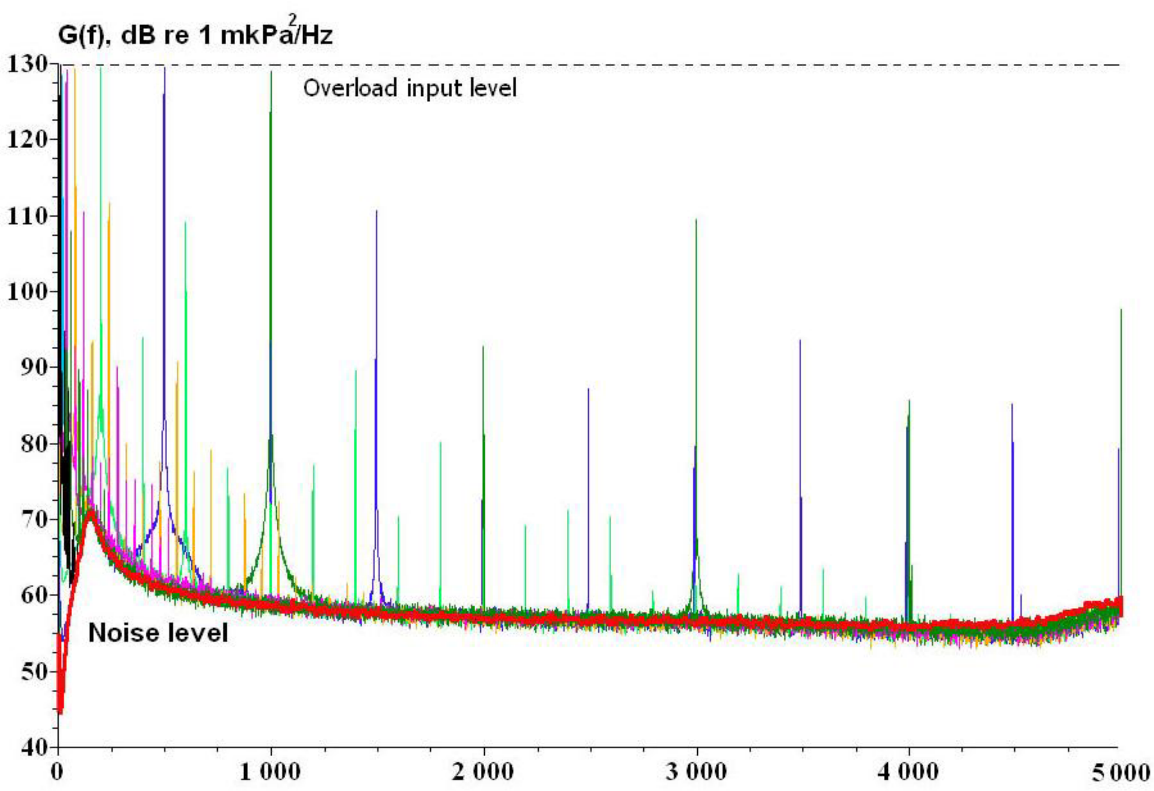
Measurement of the internal noise and dynamic range of the T-AUAR was conducted using the schematic shown in Figures 2.23(a) and 2.23(b); a dummy hydrophone was used for this test (Figure 2.23(a)). For dynamic range determination, a sine wave generator model # G3-118 (Г3-118) was used to generate signals that were input to the radio-telemetry channel of the T-AUAR (Figure 2.23(b)). As before the amplitude of the input signal was controlled by a step-attenuator. The radio (VHF FM) signals were received at a distance and were recorded using the same equipment used in 2005 to record the data at Piltun lighthouse. The output signal from the radio receiver was input to a recording system consisting of a National Instruments 16-bit ADC card and 8-channel 8th order elliptic filter connected to a notebook computer. The notebook computer controlled the recording parameters.



(a.)



(b.)



(c.)

Figure 2.23 – Block diagram showing the experimental schematics for the testing of the T-AUAR recording system: (a) internal noise estimation test; (b) Dynamic range estimation test; (c) Spectra showing the performance of the T-AUAR radio channel for the frequency range 0-5 kHz.

Figure 2.23(c) shows the performance of the T-AUAR radio channel. The red curve is the instrument noise recorded with a radio channel gain of 1 and a hydrophone sensitivity of 50 mV/Pa. Figure 2.23(c) shows that when the input signal level is set so that the non-linear distortion of the third harmonic is at least -20 dB, a tonal signal at 1 kHz is 70 dB higher than the instrument noise. The relatively broad peak at 100 Hz is a result of cross-talk within the receiver (ICR-10); this cross-talk is greater for AX-400 and AX-700 receivers. The increase in the level of instrument noise above 4.5 kHz is caused by the frequency response of the 8th order elliptic filter[33] used in the recording equipment. These instrument noise and dynamic range values are valid for stable radio channels with low radio noise.

2.2.5 Results of instrument tests

The unit to unit performance of all the AUARs was confirmed by regular testing. All the AUARs were subject to the tests listed in Appendix B; Table 2.1 gives the individual test results for all sixteen AUARs. All AUARs performed within specifications.

Table 2.1 - Performance of AUARs on the instrument tests.

AUAR serial number															
01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Internal noise (dB re 1 μPa²/Hz)															
(1-50 Hz)															
41.1	43.0	42.9	42.1	41.7	41.8	43.0	43.0	42.9	41.9	42.3	41.3	42.0	42.4	42.7	42.2
(50 Hz - 15 kHz)															
24.1	23.9	24.0	23.9	24.3	24.4	24.5	24.7	24.2	24.0	24.4	23.9	24.1	25.0	25.2	24.1
Dynamic range , dB															
98.1	98.2	98.0	98.4	98.7	98.6	98.6	98.3	98.7	98.5	98.6	98.3	98.1	98.0	97.9	98.1

2.3 Calibration of AUARs and cross-calibration error analysis

In order to compare the acoustic measurements made on the NE Sakhalin shelf to previous or future work, the data has to be calibrated to an absolute pressure standard. The hydrophones were manufactured with nominal sensitivities and the gains were set in the

[33] National Instruments SCXI-1142.

field. In order to confirm the calibration of the equipment a field cross-calibration was conducted.

The hydrophone calibrations were conducted over the frequency band 1 Hz to 15 kHz in compliance with state standard МИ 2098-90 at SMCHM[34] located at RSSRIPRTM[35] (Moscow). The sensitivities of the hydrophones were determined by comparative calibration against a reference hydrophone in acoustical calibration chambers[36] and have a relative error of less than 1.5 dB (95% probability)[37]. Figure 2.24 shows the frequency dependence of the hydrophone sensitivity over frequencies from 1 Hz-15 kHz. Calibration certificates for the hydrophones are shown in Appendix A.

At the start of the 2005 field season a cross-calibration of the 16 AUARs was conducted on the *Academik Lavrent'ev*. The AUARs were cross-calibrated by recording and comparing across all the AUARs acoustic signals generated by the *Academik Lavrent'ev* and tonal signals generated by the broadband sound transducer.

The field cross-calibration procedure is described in detail in Appendix C. The maximum absolute error from the mean for any AUAR was 2.9 dB in the frequency band from 10 to 100 Hz and less than 0.5 dB between 100 and 2500 Hz[38]. These values were within the expected relative error limits for the equipment and the absolute calibration of the data was therefore confirmed.

2.4 Acoustic data storage, processing and real-time analysis

The data recorded by the AUAR was stored in a raw format. When an AUAR was recovered the data from its hard drive was downloaded to a removable hard drive in a computer on the *Academik Lavrent'ev or Academik Oparin* and was archived to DVD. The batteries of the AUAR were recharged and the disk then wiped clean prior to redeployment. During the 2005 field season over 4.5 TB of data was accumulated.

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[34] SMCHM - State's Metrological Center of Hydro-acoustical Measurements.
[35] RSSRIPRTM - Russian State's Scientific Research Institute of Physical Radio Technical Measurements.
[36] A Model UVT 71-a-90 calibration chamber to 600 Hz and an anechoic chamber above 600 Hz.
[37] This error includes the approximately 1 dB error associated with estimation of absolute pressure for the calibration of the reference hydrophone.
[38] See Appendix C - Table C.1 for all the results. The highest errors were due to the low level of the calibration signal at low frequencies.

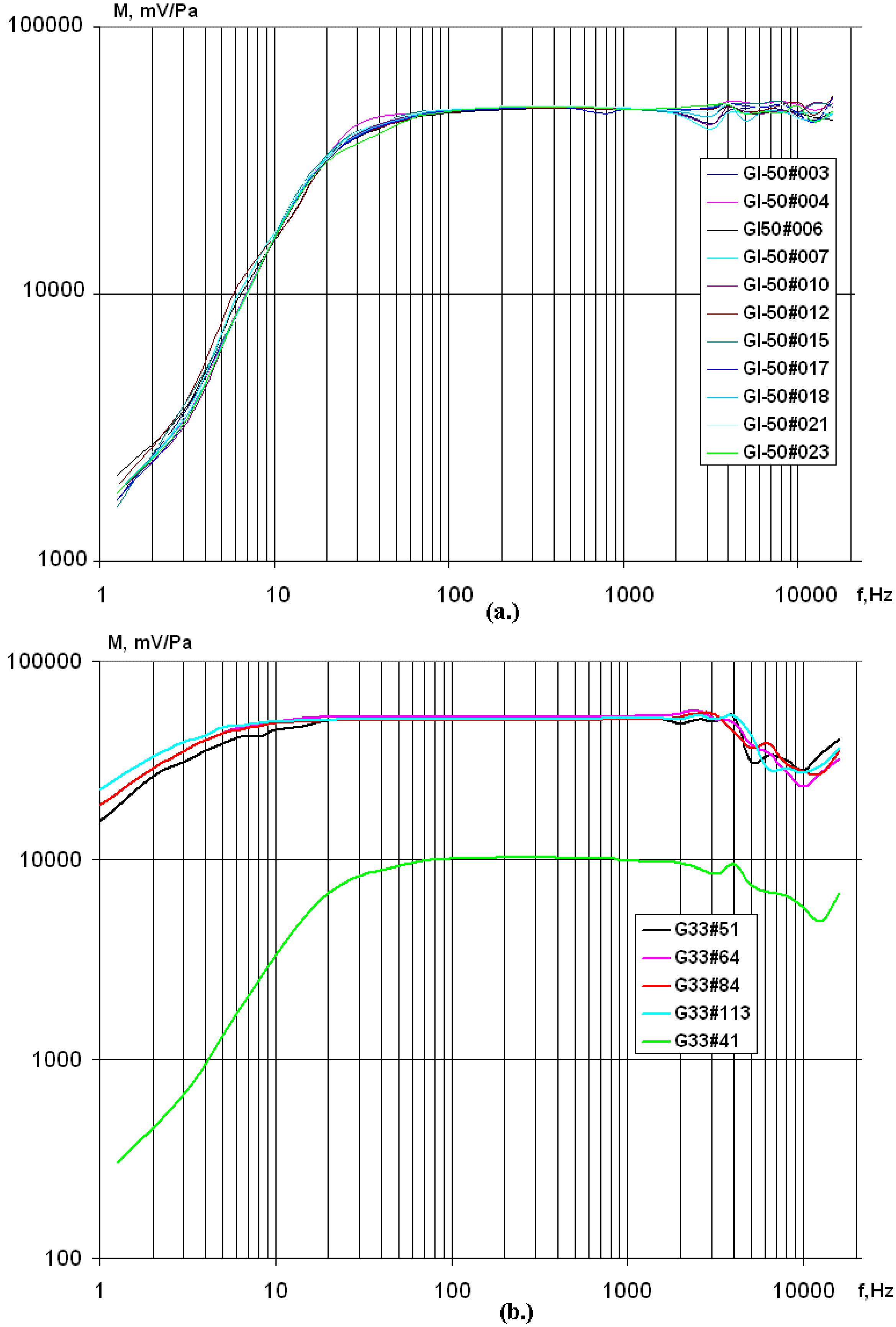

Figure 2.24 - Spectral characteristics of the cylindrical (GI-50) and spherical (G-33) hydrophones used by the AUARs, T-AUARs and Mini-AUARs.

Once the data was downloaded from the AUAR disk it was then converted to absolute amplitude (μPa) and written to a second removable hard drive. The data was corrected for the hydrophone sensitivity and gain at 1 kHz[39]. The program uses equation (D1) in Appendix D to convert the data; the inputs are the response of the analog channel of the AUAR (measured in the laboratory) K_u and the hydrophone sensitivity from calibrations made in Moscow (and confirmed by cross-calibration) S_H.

Software was specifically designed for the experimental data processing required for this work in order to more effectively evaluate the acoustic data. Sonograms and spectra were computed for the data. Additional programs were written for cross-calibration, calculating spectra and applying correction factors (from cross-calibrations). The instrument responses of the analog electronics of the AUARs were empirically determined and the response removed from the final data.

[39] Correction for the instrument response of the AUAR is made prior to spectral analysis. The correction is relative to the response at 1 kHz.

3 Acoustic sonobuoys

This section describes the four analog and two digital acoustic sonobuoys developed by POI in 2002 [Borisov et.al, 2003] and updated in 2005, their instrument testing, calibration and operational deployment. The sonobuoys were used to make real-time acoustic data measurements during the 2005 field program. The 2005 modifications improved the reliability and range of the radio telemetry channels while reducing the operational preparation time. The reliable reception range when received at Piltun lighthouse (elevation 35 m) was 23 km for an analog sonobuoy. The reliable reception range was 8 km for a digital sonobuoy when received on the *Academik Lavrent'ev.*

Analog and digital sonobuoys both have advantages and disadvantages. For the analog sonobuoys the advantages are greater bandwidth and longer range (>10 km for a bandwidth of 10 Hz to 10 kHz and >20 km for a bandwidth of 10 Hz to 5 kHz). However the dynamic range of an analog sonobuoy is much lower than that of a digital sonobuoy and is highly dependent on the quality of the radio channel. The digital sonobuoy has a significantly greater dynamic range than the analog sonobuoy, is not susceptible to radio noise and has stable performance characteristics. The digital sonobuoy can also measure frequencies as low as 1 Hz accurately. The disadvantages of a digital sonobuoy are narrower bandwidth and shorter range (≤ 8 km for a bandwidth of 1 Hz to 2.6 kHz).

3.1 Analog and digital sonobuoys

Individually deployed acoustic sonobuoys were used to measure acoustic signals at the edge of the Piltun feeding area and to transmit them to a shore station at Piltun lighthouse or a marine station on the *Academik Lavrent'ev* (Lunskoye). Analog sonobuoys were used to record frequencies from 10 Hz to 10 kHz and digital sonobuoys from 1 Hz to 2.6 kHz. When used together an analog and digital sonobuoy pair can record acoustic data from 1 Hz to 10 kHz. Figure 3.1 shows the major components of these sonobuoys and how the sonobuoy and hydrophone are anchored when deployed at sea.

Figure 3.2 shows the sonobuoys being prepared for cross-calibration. The flotation collar holds a steel (analog) or titanium (digital) canister containing the sonobuoy electronics. The sonobuoy is powered by an external battery pack that can be changed at sea. The sonobuoy antenna is kept upright by a keel to which the batteries are attached. The surface unit is connected by a cable to a spherical hydrophone of type G33 (Г33) with an integrated pre-amplifier designed specifically for the hydrophone. Figure 3.3 displays the frequency amplitude characteristics of the hydrophones[40]. The hydrophone is suspended in a pyramid shaped metal frame and attached by rubber bands as with the AUAR hydrophone. The hydrophone pre-amplifier amplifies the signal prior to transmission along the 150 m connector to the sonobuoy container[41].

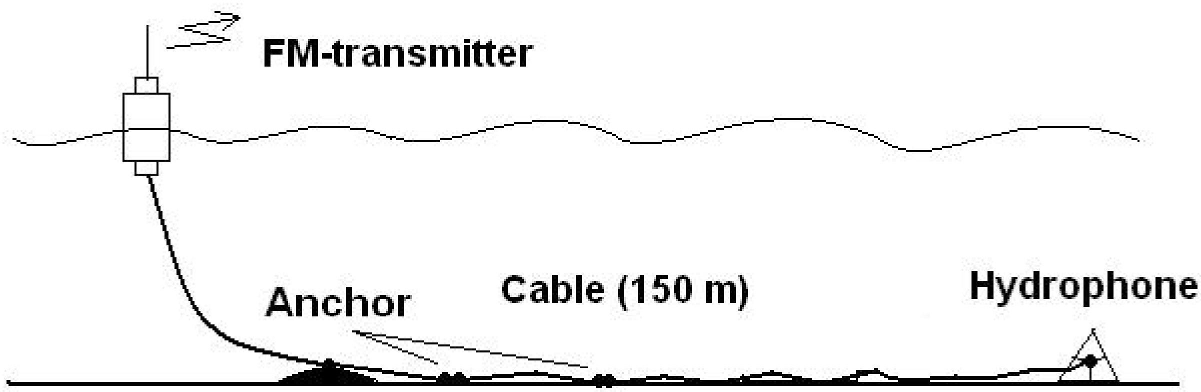

Figure 3.1 - Diagram showing the deployment of analog or digital sonobuoys.

In 2005, a number of design improvements were made to the sonobuoys. The strong signal from the hydrophone pre-amplifier allowed the bottom unit of the digital sonobuoy to be removed and a unified design was used for the surface units with the same connectors, cables and battery packs. Connectors were installed on the main cables to allow the hydrophone cable to be disconnected from the sonobuoy. A power connector was used to allow the sonobuoy to be turned on and off easily when not in use and Shakespeare 5241-R marine antennas (Figure 3.7) were installed. Switching voltage regulators were used to equalize the transmission power over the operational period of the sonobuoy.

[40] Calibration certificates for the spherical hydrophones are in Appendix A.
[41] As for the AUAR, the purpose of the amplifier is to amplify the signal as close as possible to the hydrophone. In this way the signal level relative to any noise picked up in the cable will be maximized

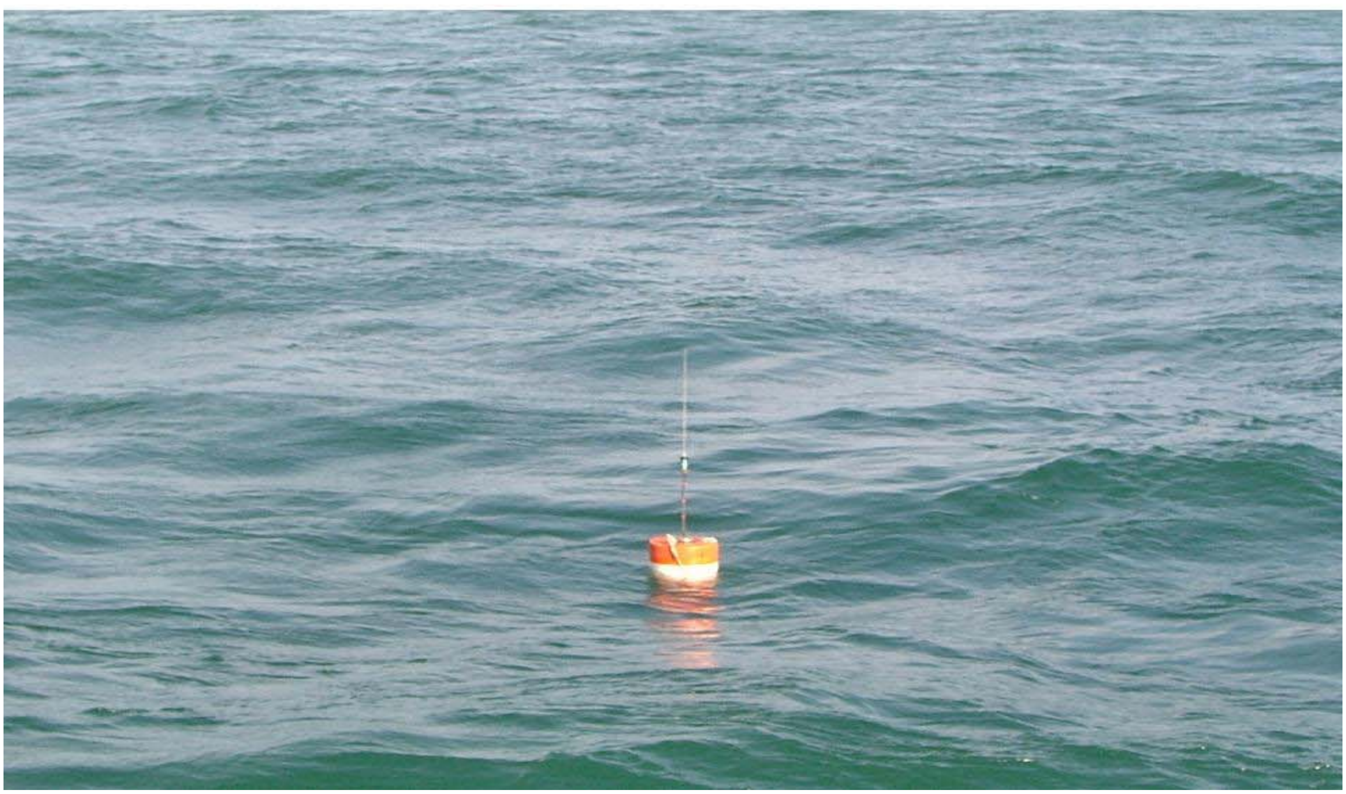

Figure 3.2 – Top: Analog and digital sonobuoys being prepared for cross-calibration; Bottom: Sonobuoy after deployment.

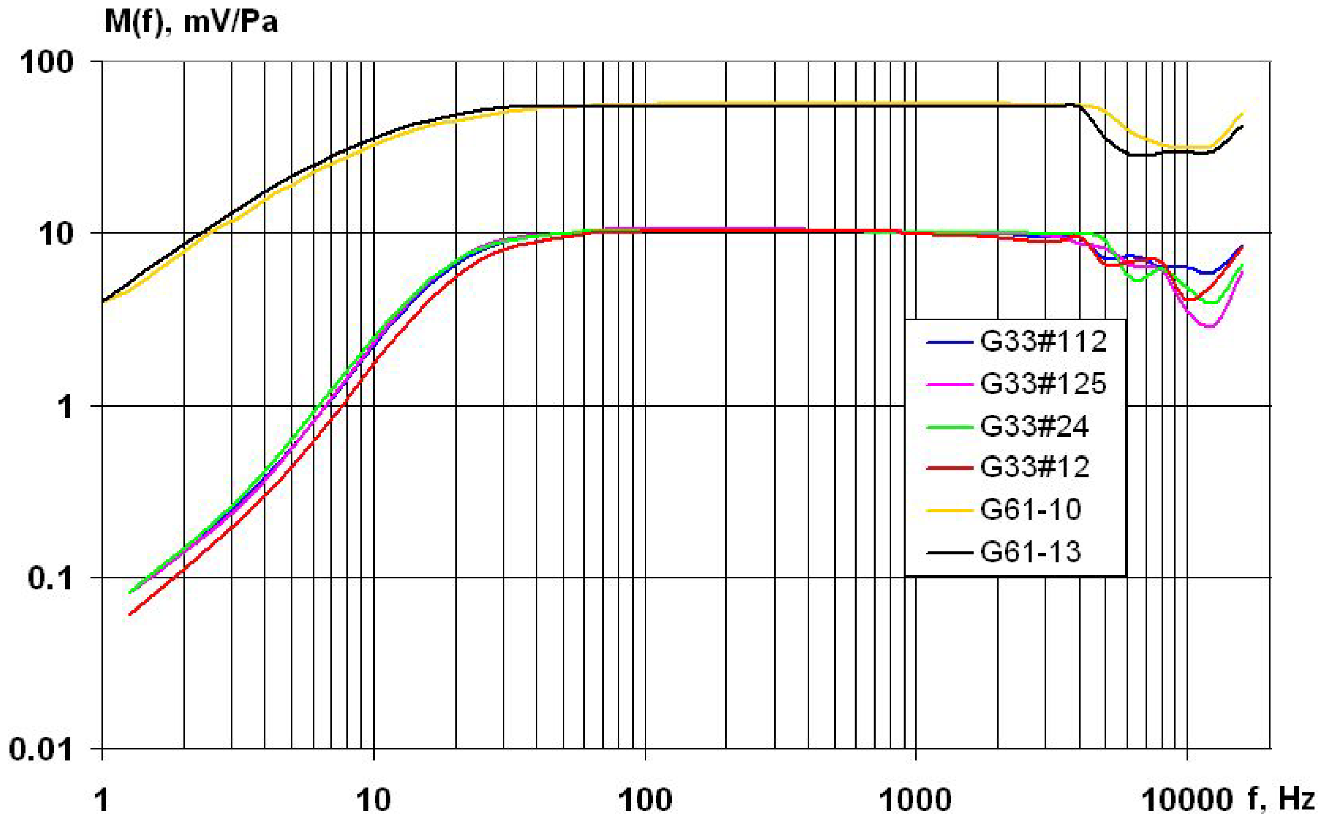

Figure 3.3 - Frequency-amplitude characteristics of the spherical hydrophones

3.1.1 Analog acoustic sonobuoy

Autonomous analog sonobuoys were used to make acoustic measurements in the frequency band from 10 Hz to 10 kHz. Figure 3.4 is a block diagram showing the analog sonobuoy components and the components of the recording system at Piltun lighthouse.

The low frequency response of the pre-amplifier reduces the low frequency components of the signal. This equalization of amplitudes across the frequency band optimizes the use of the dynamic range (approximately 43 dB) of the radio receivers and transmitters. The amplified acoustic signal is low pass filtered (cut-off frequency 10 kHz), converted into an Ultra High Frequency (VHF) band Frequency Modulated (FM) radio signal, and transmitted to the receiving station by an VHF FM transmitter. The modulators were calibrated to avoid cutoff of the carrier signal at the receiver due to a strong signal in the isolation amplifier.

This improved the reliability of the radio-telemetry channel and reduced power consumption, while preserving transmission power.

Radio receivers at Piltun lighthouse or on a vessel received the radio-telemetry signals transmitted by the analog sonobuoys. The analog output from these receivers was input to one channel of a National Instruments multi-channel amplifying, filtering and digitizing unit prior to storage and display on a computer. This is described in detail in section 3.2.

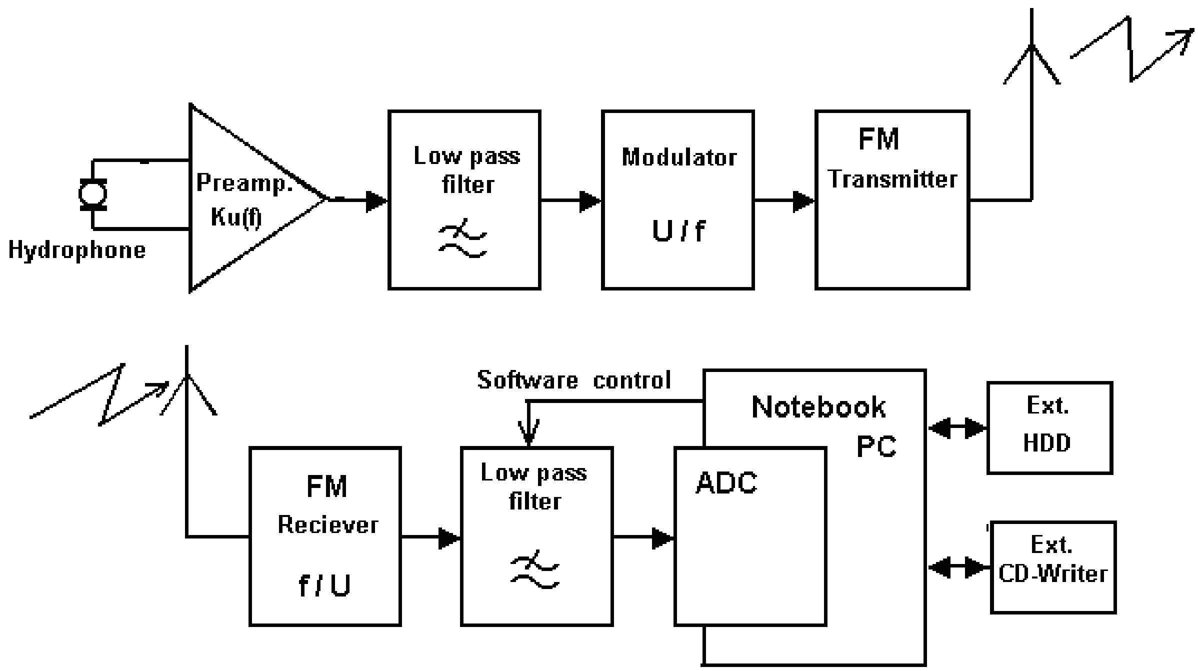

Figure 3.4 - Block diagram of the analog sonobuoy recording system.

3.1.2 Digital acoustic sonobuoy

Autonomous digital sonobuoys were used to make acoustic measurements in the frequency band from 1 Hz to 2.6 kHz. The output from the hydrophone and pre-amplifier is transmitted along a 100 m cable to the surface sonobuoy module[42]. The signal is then low pass filtered to 2.6 kHz prior to input to the 16 bit ADC[43], which has a 5.2 kHz sample rate. A controller with a quartz clock synchronizes the digitization process and determines the sample rate of the ADC. The digitized signal is then encoded and modulated prior to transmission by the

[42] The sonobuoy module houses the amplifier and filter (often referred to as the corrector) as well as the Analog to Digital Converter (ADC) and signal encoder/modulator.
[43] The Analog to Digital Converter is a 16 bit Analog Devices AD977.

VHF-FM radio transmitter[44], which transmits the signal to the receiving station (see Figure 3.5)[45]. Figures 3.6 and 3.7 show a digital sonobuoy.

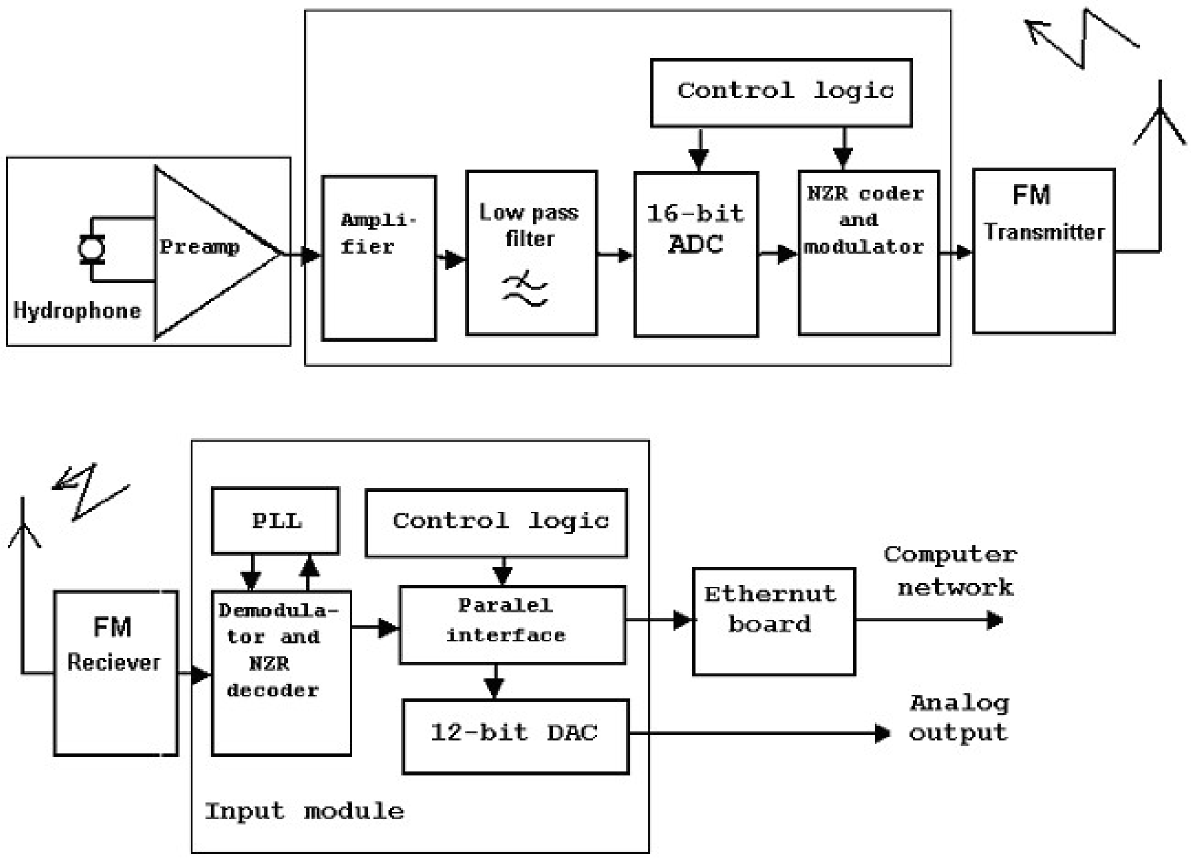

Figure 3.5 - Block diagram of the digital sonobuoy recording system.

Radio receivers at Piltun lighthouse or on a vessel received the radio-telemetry signals transmitted by the digital sonobuoys. The output from these receivers was input directly to an input module that can output digital data directly into a computer and analog data to the National Instruments recording system. This is described in detail in section 3.2.

[44] Standard HX 180V radio transmitter - output transmit power adjustable up to 5 W.
[45] In the 2002 design the filtering and analog to digital conversion was performed in a separate bottom module prior to transmission to the radio channel in the surface buoy. In 2005 the filtering and analog to digital conversion electronics were placed in the sonobuoy rather than in a separate module, allowing mechanical standardization of the analog and digital sonobuoys. This modification did not degrade the signal performance due to the superior characteristics of the hydrophone preamplifier.

Figure 3.6 - Digital sonobuoy showing the battery pack and Shakespeare antenna.

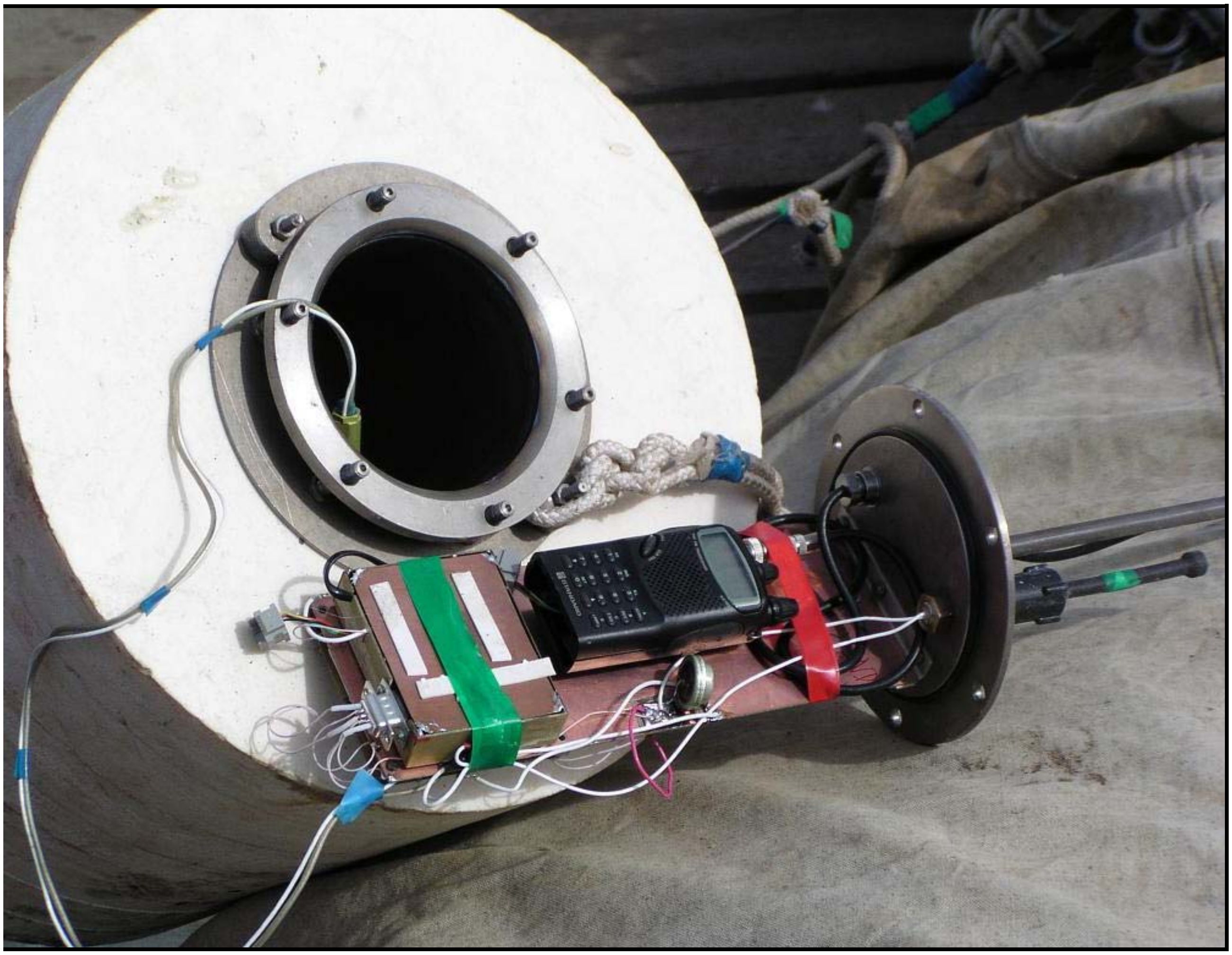

Figure 3.7 - Digital sonobuoy container and electronics.

3.2 Radio-telemetry data reception, processing and storage

Radio-telemetry data was received at radio stations on the *Academik Lavrent'ev* (Lunskoye program) (both analog and digital sonobuoys) and at Piltun lighthouse (analog sonobuoys). The following section describes the system used to store data received from the four analog and two digital sonobuoys and the four T-AUARs.

The output from each active digital sonobuoy radio receiver was input to an input module that has two outputs. The first connects through a digital decoder to an Ethernet card[46] and from there through an Ethernet HUB to a notebook computer. The Ethernet HUB allowed

[46] The (Ethernut) Ethernet card has an ATmega 103(128) RISC micro-controller and a Realtek 8019AS Ethernet controller. The card has 22 simultaneous digital inputs, an 8 channel 10 bit ADC and 32 kb SRAM.

two Ethernet cards to be input to the notebook computer simultaneously. The decoder outputs 16 data bits and one synchronization bit to the Ethernet card. The data are then stored in a 16 kbyte SRAM buffer. When this buffer is full the data are transferred as 512 byte segments to the notebook via the Ethernet network. The Ethernet cards have a 128 micro-controller with a 14 MHz bit rate and can transfer and store the data in real time without loss. The second output is sent to an analog interface after reception, where it is converted to an analog signal and input to the analog sonobuoy recording system. This duplication increased the reliability of the recording system and provided a synchronization of all channels (analog and digital sonobuoys).

A special recording unit was built for the storage and pre-processing of the analog acoustic data. This unit was based on National Instruments equipment, and was housed in a power chassis[47]. The output from each active radio receiver was connected to an eight channel terminal block[48] with BNC connectors and from there input to a low pass filter module[49] containing eight preamplifiers and elliptic filters with a user-selectable filter response. These filters were used to limit the frequency range of the input signal to within the Nyquist frequency for the sample rate of the Analog to Digital Converter (ADC). The data from all active receivers for the analog sonobuoys or the input module for digital sonobuoys was then simultaneously converted to digital data by a multi-channel gain ranging 16 bit ADC data acquisition card[50] housed in a notebook computer. This unit provides the filtering, digitization, storage and visualization, for up to eight separate channels. The main technical specifications for the National Instruments equipment are in Table 3.1. This data was then stored on the hard drive of the computer using software written by POI for this task. At the end of a recording period the data was copied to portable disks that were used as transient data storage. Periodically data from the portable disks were backed up to a central computer; data from this transient storage was also backed up to DVD's. During the 2005 field season over 1 TB of data was accumulated. The radio receivers, National Instruments chassis and computers were powered by vessel power (*Academik Lavrent'ev)* or four batteries (Piltun lighthouse).

[47] National Instruments SCXI-1000DC
[48] National Instruments SCXI-1305
[49] National Instruments SCXI--1142
[50] National instruments DAQCard-AL-16XE-50

Table 3.1 - Technical specifications National Instruments filtering and digitizing boards.

8 channel low pass Bessel filter module SCXI-1142	
Channel gains(software-selectable):	1, 2, 5, 10, 20, 50, 100
Input impedance (power on):	10 Gohm in parallel with 40 pf
DC gain error (after calibration):	± 0.02 %
Filter slope:	135 dB/octave
Stop band attenuation:	80 dB at 6 Fc
16-bit ADC DAQCard-AL-16-XE-50	
Number of the channels:	16 (8 differential, software selectable)
Type of ADC:	Successive approximation
Resolution:	16 bit (1 in 65536)
Maximum sample rate:	200 ksamples/s (single-channel), 20 ksamples/s Guaranteed
Board gain:	1, 2, 10, 100 (software selectable)

National Instruments software[51] was also bought with their hardware (Figure 3.8). This included a program for monitoring and controlling the equipment[52] and utility software for data acquisition which were used to configure the equipment described above. This program will configure the filter and gain parameters and the mode of work (parallel or multiplex); the equipment can be tested using this software.

Software written in Object Pascal 2 and Delphi 5 calculates the parameters for converting the input data to absolute amplitude (μPa) prior to data storage. The inputs to the program are the hydrophone sensitivity and gain for each channel. All the input data (including system parameters such as the station name, water depth, and coordinates of the sonobuoy location) are stored in tabular form in an initialization file. This file is read when the program loads. The program inputs data from the ADC into RAM, sorts the data into channels, converts the data to microPascals and writes the files to the hard drive (each channel having its own file).

[51] National Instruments - Component works starter kit software

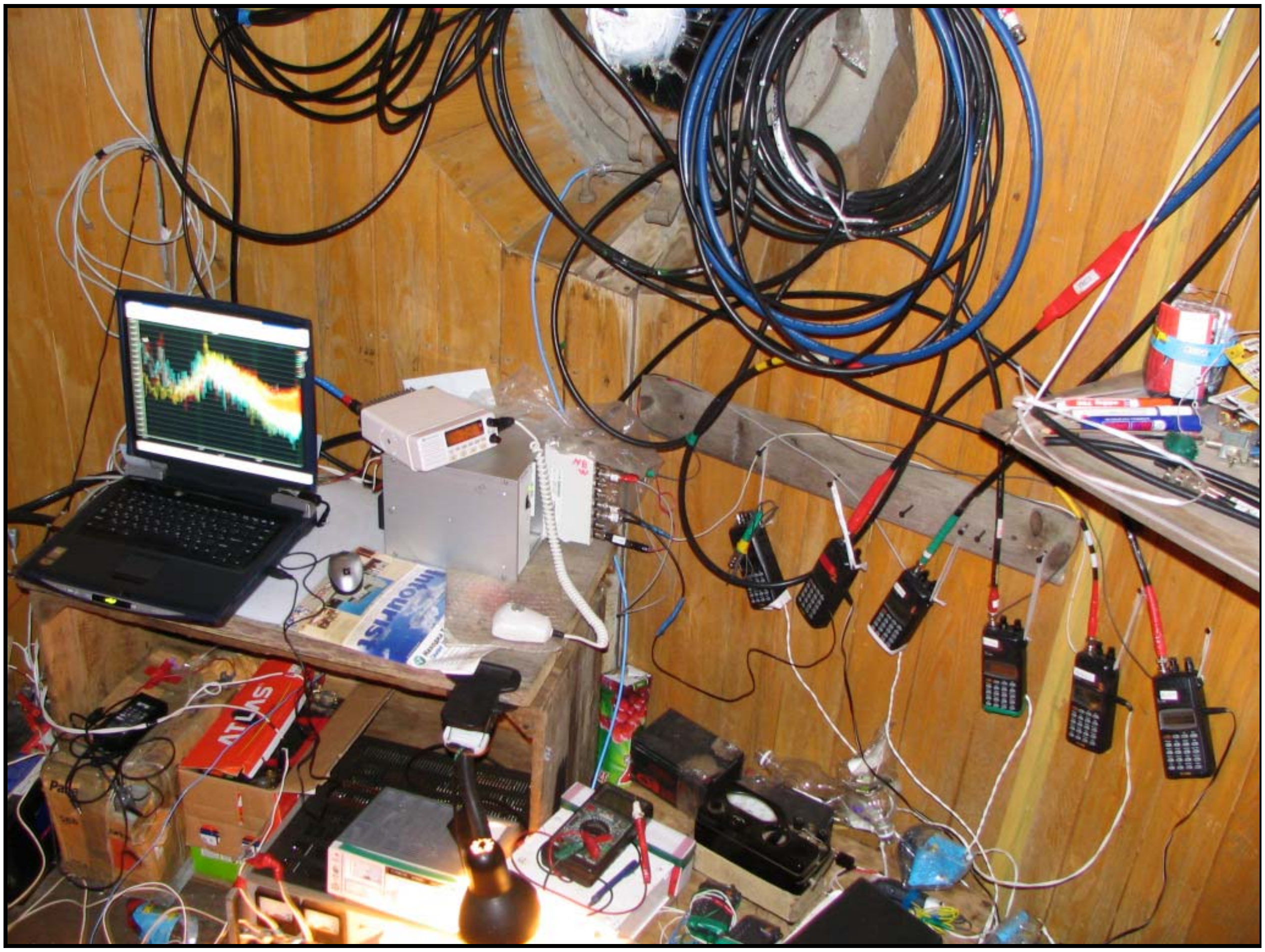

Figure 3.8 - Monitoring data recording at Piltun lighthouse.

3.2.1 Piltun lighthouse radio station

Figure 3.8 is a photograph showing the radio reception and recording station at Piltun lighthouse. Figure 3.9 is a block diagram showing the functional layout of the system designed for the pre-processing and recording of data received from the analog and digital sonobuoys as well as the T-AUARs, and housed in Piltun lighthouse (elevation 35 m). Six Yagi resonant directional antennas, aimed so as to receive radio-telemetry signals from specified sonobuoys, and two relatively broadband whip antennas were deployed on the outside catwalk of the lighthouse. The antennae are connected to radio receivers by coaxial cables. Power for the equipment used in the lighthouse was provided by batteries which were recharged using a gasoline generator. Figure 3.10 shows photographs of the separate functional components of the radio station described above. At the end of a

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[52] National Instruments - Measurement and automation software

recording period the data was copied via a LAN to a server in the laboratory, which processed and analyzed the data and archived it to DVD disks.

A program designed by POI was used for data storage and real-time visualization. Additionally this program computes the sound pressure level in specified bandwidths. This data is recorded to the hard drive of the computer for later analysis. This program is described in more detail in section 3.5.

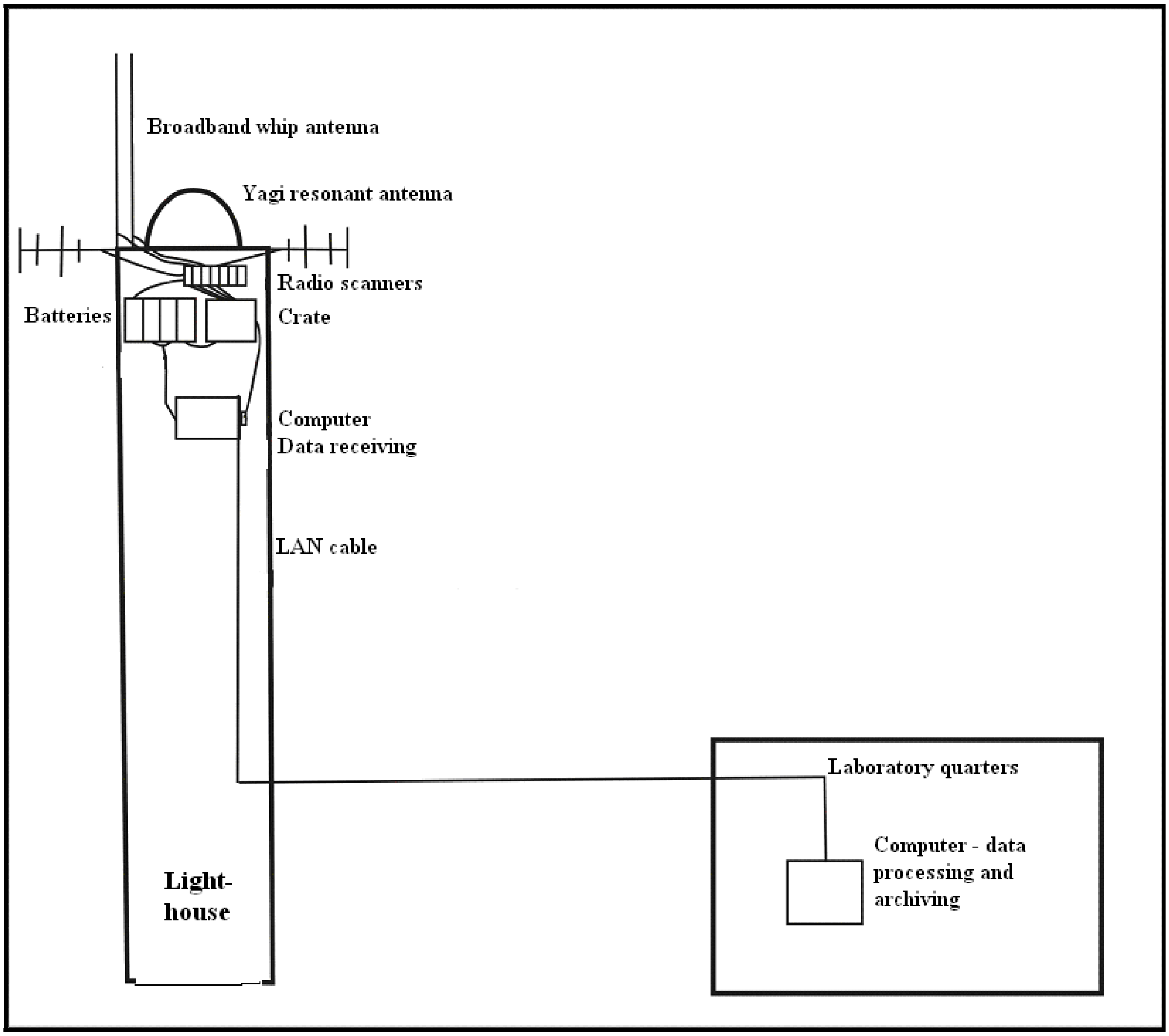


Figure 3.9 – Block diagram showing a functional schematic for the data reception station at Piltun lighthouse.

3.3 Acoustic data storage, processing and real-time analysis

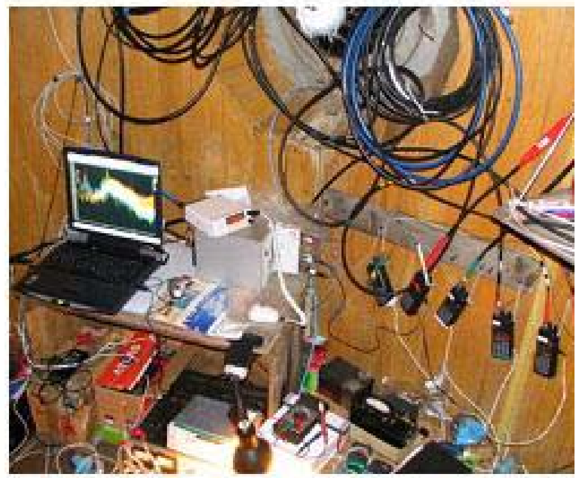
The raw data was corrected for the hydrophone sensitivity at 1 kHz and for gain[53]. The program uses equation (D1) in Appendix D to convert the data; the inputs are the response

[53] Correction for the instrument response of the sonobuoy is made prior to spectral analysis.


(a.)


(b.)


(c.)


(d.)


(e.)


(f.)

Figure 3.10 – Radio reception station at Piltun lighthouse: (a) and (b) Yagi antennas on the lighthouse catwalk; (c) General view of the lighthouse and laboratory quarters; (d) Radio receivers, NI chassis and computer in the upper indoor room of the lighthouse; (e) and (f) Laboratory.

of the analog channel of the AUAR (measured in the laboratory) K_u and the hydrophone sensitivity from calibrations made in Moscow (and confirmed by cross-calibration) S_H Software was specifically designed for the experimental data processing required for this work in order to more effectively analyze the real-time acoustic data. Sonograms, spectra and sound pressure levels were computed for the data. During the 2005 field season acoustic data was received at Piltun lighthouse from the four T-AUARs and three analog sonobuoys. A monitoring program controlled the recording of the acoustic data on the hard drive of a computer and visualized the data in near-real-time. The monitoring program computed spectra $G(f)$, sonograms $G(f,t)$, and the variation of sound pressure level with time and frequency band $D(\Delta f,t)$ for the synchronously received acoustic data concurrently with recording the data. The monitoring program thus estimated the variation in the received sound pressure level in near-real-time, allowing the sound levels from construction activities to be monitored and action taken to reduce the sound levels in the event acoustic threshold limits were exceeded[54]. Figure 3.11 shows a screen shot displaying the sonogram $G(f,t)$, and the variation of sound pressure level with time and frequency band $D(\Delta f,t)$ for synchronous signals being received from four T-AUARs. Figure 3.12 displays spectra $G(f)$ for the same data.

The program ***DispControl*** is used for near-real-time analysis of the variation in sound pressure level $D(\Delta f,t)$ over predetermined time windows, using 1-second SPL estimates. The program filters out random noise, evaluates the 3-minute average sound pressure levels, and computes the average sound pressure level for 1 hour for three frequency intervals[55]. Figure 3.13 is a screen grab and gives three plots showing the results of near-real-time processing of acoustic data recorded from 12:00 to 13:00 on 31 August 2005. The average sound pressure level for each hour was estimated and the daily results were collected in a Microsoft Excel® file that was sent daily by e-mail to the ENL and SEIC operations teams. Figure 3.14 shows one of these plots. The different colors show the hourly average sound pressure level estimates synchronously recorded at seven monitoring locations on 30 August 2005, by four T-AUARs and three analog sonobuoys.

[54] This mitigation procedure is discussed in greater detail in [Rutenko, 2006] and [SEIC, 2005][1] .
[55] The three frequency intervals (Δf) were 10-500 Hz, 10-800 Hz, and 10-2500 Hz.

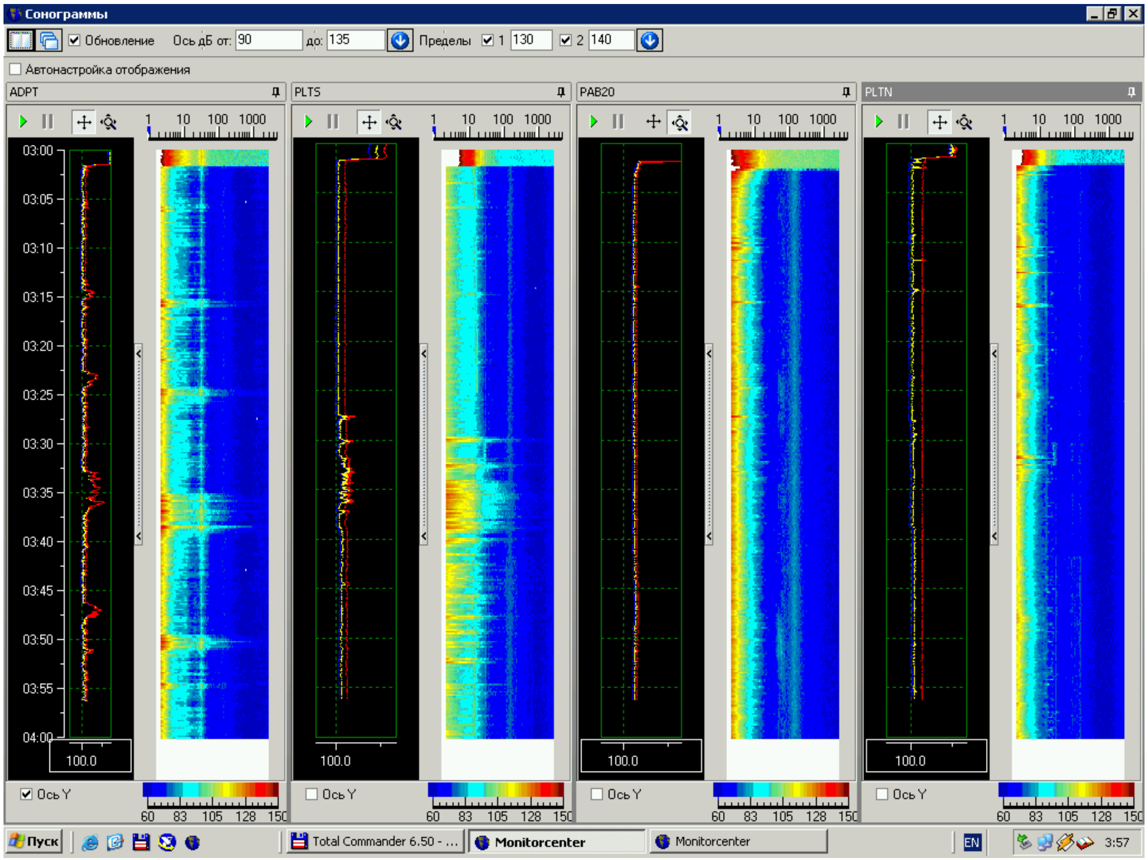


Figure 3.11 - Screen shot showing sonograms *G(f,t)* and plots of sound pressure level with time *D(∆f,t)* of data received from the four monitoring T-AUARs.

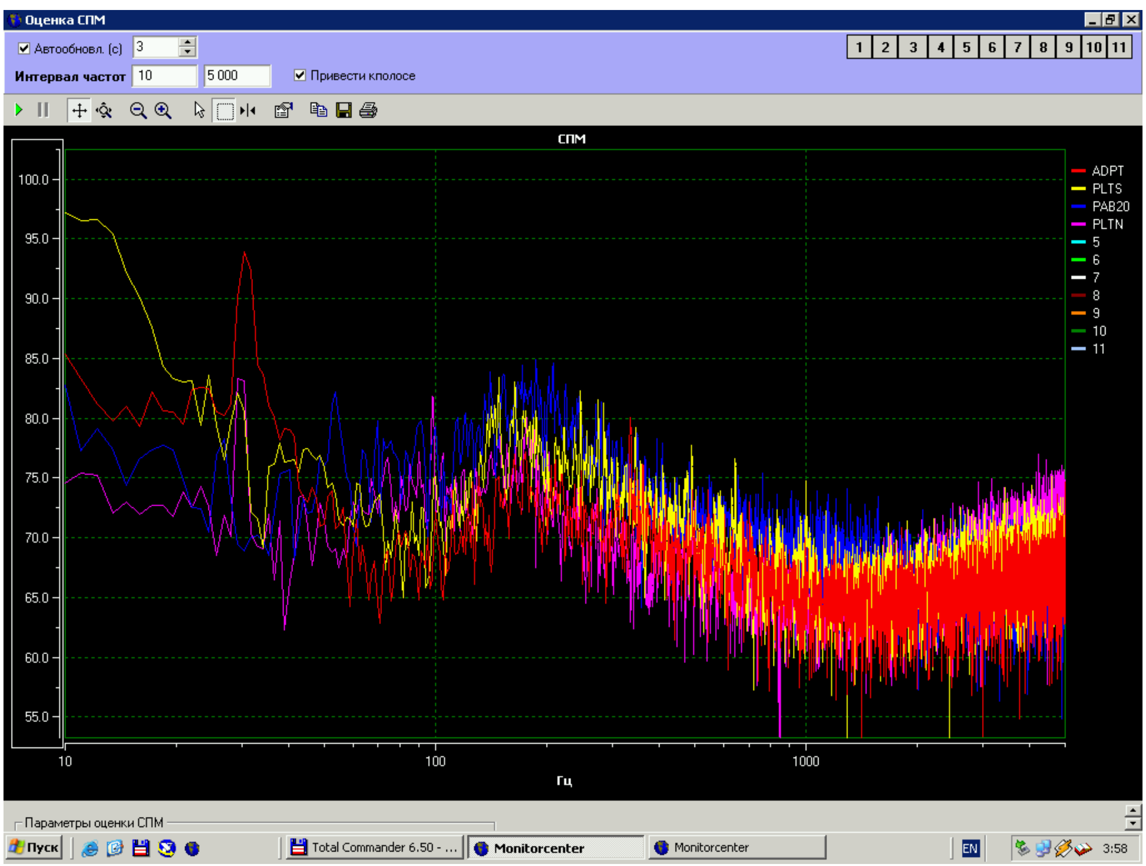


Figure 3.12 – Screen shot showing power spectral density *G(f)* plots of data received from the four monitoring T-AUARs.

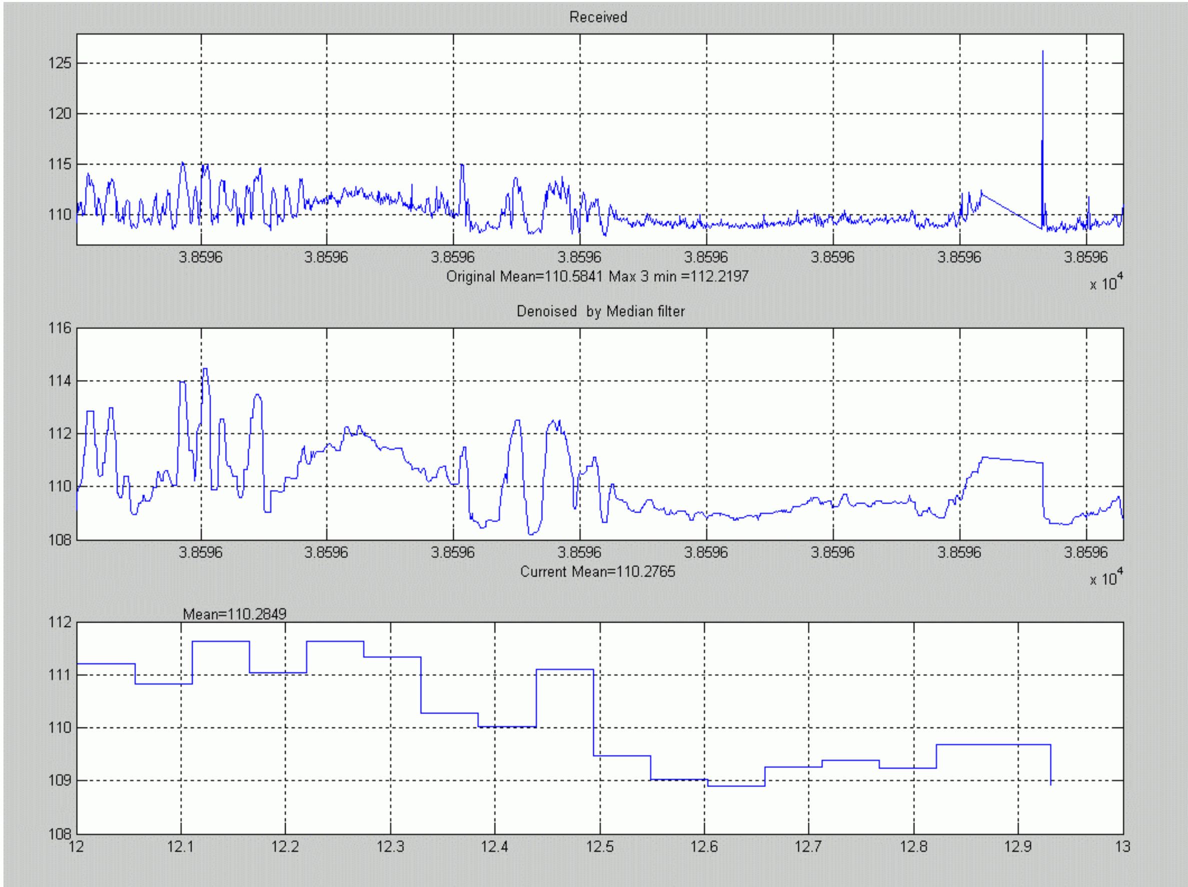


Figure 3.13 – Screen grab showing the analysis of data from 12:00 to 13:00 on 31 August.

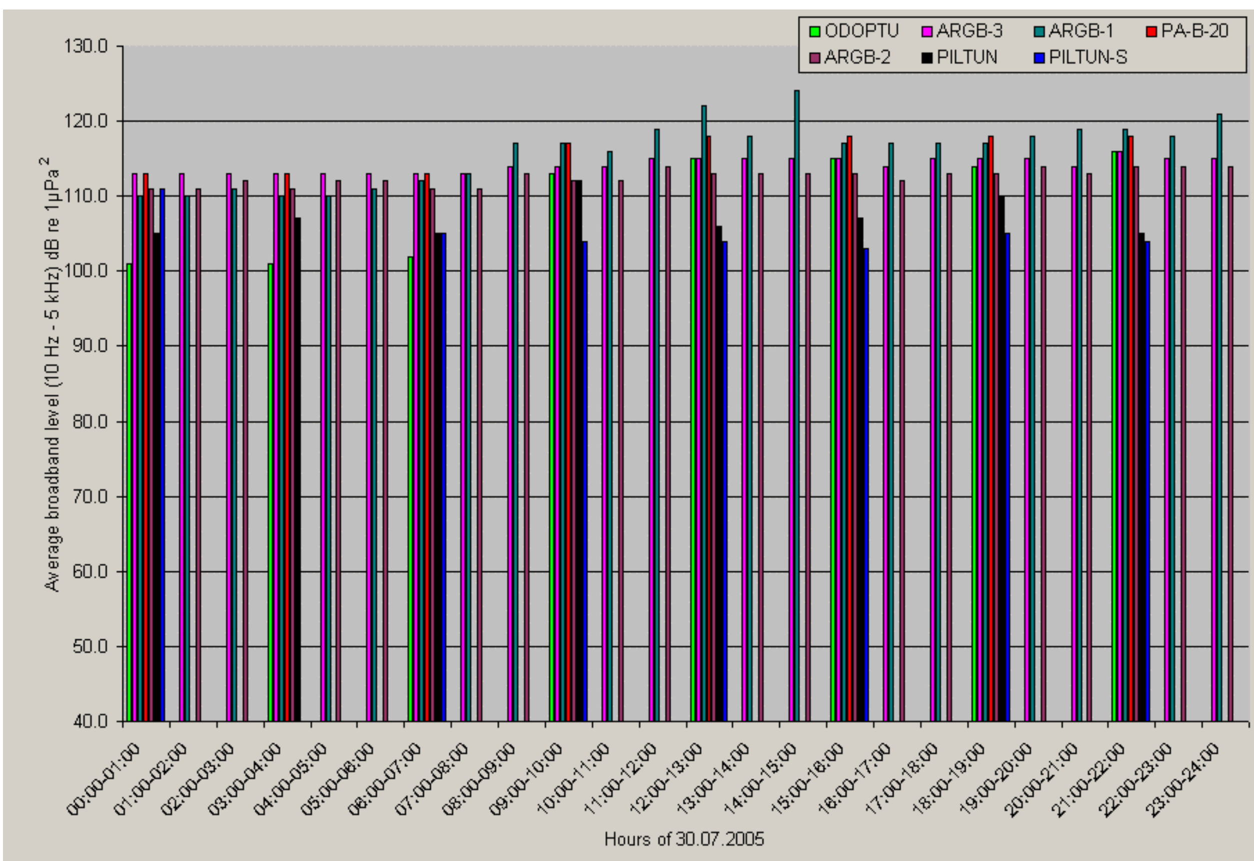


Figure 3.14 – Average hourly received sound pressure level for 7 stations, 30 August.

3.4 Analog and digital sonobuoy instrument tests

Four analog and two digital sonobuoys were used for the 2005 field season; they were upgraded from sonobuoys designed and manufactured by POI between 2002 and 2005. In order to ensure that all of the sonobuoys adhered to the design specifications, and that they recorded accurate absolute acoustic measurements, a series of instrument tests were created[56]. These tests had two goals: to ensure that the sonobuoy was operating within specifications and to generate an instrument response filter for the analog component of each sonobuoy. This estimate of the sonobuoy analog instrument response *K(f)*, measured in the laboratory prior to the field season, and the hydrophone sensitivity *M(f)* was used to generate an inverse filter; this filter was subsequently applied to the analog voltage measurements to back out the system instrument response and generate absolute acoustic measurements. These frequency dependent responses correct the acoustic data over the range from 1 Hz - 2.6 kHz (digital sonobuoys) and 10 Hz - 10 kHz (analog sonobuoys).

3.4.1 Methodology for testing the analog and digital sonobuoys

The procedure for testing sonobuoys was changed in 2005 to improve the efficiency and quality of the instrument tests. Testing was performed only in the narrow (FM) band of the radio receivers, up to 5 kHz for analog sonobuoys and up to 2.6 kHz for digital sonobuoys.

3.4.2 System response of the analog sonobuoys

Before determining the full system response, all the radio transmitters used in 2005 were calibrated while being received on an ICOM IC-R10 radio receiver. This receiver has very consistent operational characteristics, with less than 0.5 dB gain variation $K_u(f)$ between the units. All the analog radio circuits could be adjusted using a gain coefficient; this gain coefficient at 1 kHz ($K_u(1\ kHz)$) was 0.7. During the testing the transmitters were also found to have closely matched response characteristics, thus the transmitter in a sonobuoy could be quickly replaced if required. During cross-calibration, each sonobuoy was calibrated with its own receiver, an average gain factor was selected, and the system response was determined using this gain. If two different radio receivers were used with the same sonobuoy, the gain factor was selected for the ICOM IC-R10 radio receiver. The system response characteristics with a different radio receiver, such as the STANDARD AX700,

[56] The sonobuoy instrument tests are given in Appendix B.

was established using the gain factor selected for the ICOM IC-R10 radio receiver to reduce the potential for human error when using the system in the field.

Figure 3.15 shows a block diagram showing the experimental schematic used to measure the system response of the analog sonobuoys (without hydrophones) using tonal and white noise signals.

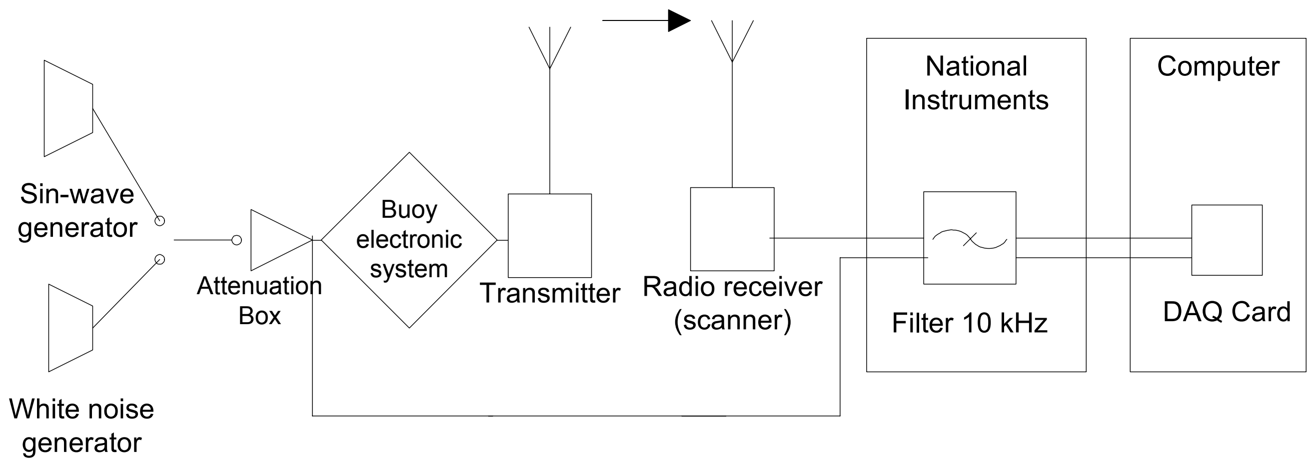


Figure 3.15 - Block diagram showing the experimental schematic for determining the system response of the analog sonobuoys.

3.4.3 System response of the digital sonobuoys

The response of the radio receivers only affects the system response of analog sonobuoys since the radio-telemetry channel of digital sonobuoys does not modify the transmitted data. For digital sonobuoys the data is already digitized prior to encoding and transmission and is completely reconstructed on reception. However, since the sonobuoys were tested as a group, the digital sonobuoy testing procedure does not differ from that of analog sonobuoys. In order to better synchronize the sonobuoys during testing or while recording acoustic information, data is input through the analog decoder output, in a similar fashion to signals from analog sonobuoys.

Figure 3.16 is a block diagram showing the experimental schematic used to measure the system response of the digital sonobuoys (without hydrophones) using tonal and white noise signals. This is identical to that used for analog sonobuoy cross-calibration, with the addition of a digital signal decoder. The gain coefficient for the digital circuit is always 0.5. This gain factor is multiplied by the gain factor of the filter-amplifier card (1, 2, 4 or 8), and the resulting scalar is used as the gain factor in the input program for the respective digital sonobuoy analog to digital converter channel.

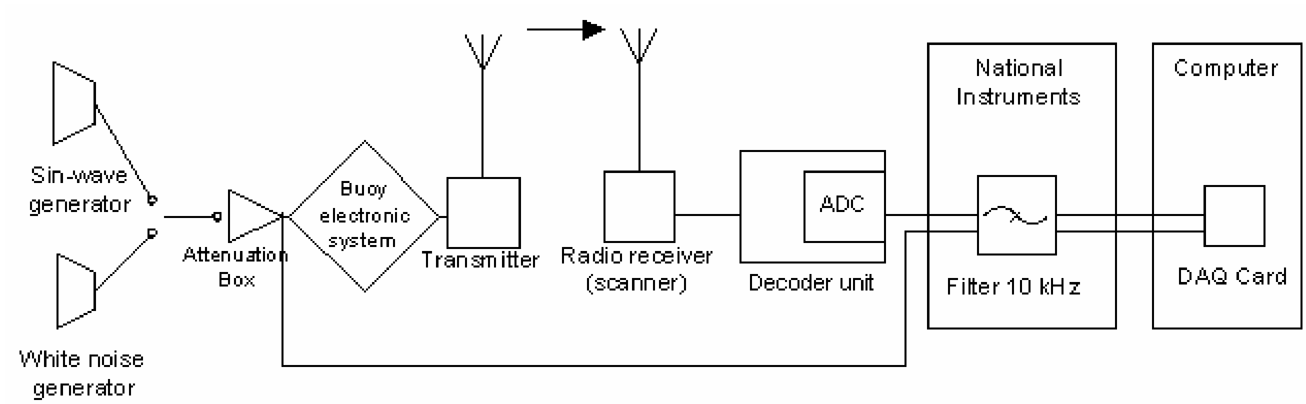


Figure 3.16 - Block diagram showing the experimental schematic for determining the system response of the digital sonobuoys.

3.4.4 Determining the operational characteristics of the analog and digital sonobuoy

3.4.4.1 Maximum input signal determination

The upper limit of the dynamic range of the radio-telemetry VHF-FM channel was determined and the absence of artifacts due to overdriving the radio receiver was confirmed. A sine wave generator model # G3-118 (Г3-118) was used to generate signals at 1 kHz which were input to the transmitter. The received signal was examined for clipping or distortion at the peaks. The input signal amplitude was then reduced until the level of the 2^{nd} and 3^{rd} harmonics in the received signal dropped to -20 dB below the fundamental. This input signal level was adopted as the maximum input signal level. The input signal level was further reduced until the harmonic distortion level at the output of the receiver was -30 dB. This input signal level was selected as the normal operating level.

3.4.4.2 System instrument response (including radio channel)

A white noise signal was input to the analog circuit of a sonobuoy. The average amplitude (0.15 V) of the input white noise signal exceeded the internal noise of the receiver (due to cross-talk with the radio receiver) by a sufficient amount to determine the system response[57]. This signal level was used for the following step in the system response determination:

A signal from the generator and a signal from the output of the radio transmission channel (compensating for the gain), were simultaneously input to a computer. The spectra of these signals were averaged over 2 minutes. The system response characteristics of a sonobuoy channel were determined using the peak-normalized, smoothed ratio of the output and input signal spectra. Each sonobuoy system response was obtained by multiplying the respective system response by the frequency response of the hydrophone *M(f)* as measured at RSSRIPRTM and given in Appendix A.

3.4.5 Instrument noise and dynamic range determination

3.4.5.1 Results of the analog sonobuoy instrument tests

Measurement of the internal noise and dynamic range of the analog sonobuoy was conducted using the schematic shown in Figures 3.17(a) and 3.17(b). For the instrument noise test a dummy hydrophone with the same response as the real hydrophone was used. For dynamic range determination, a sine wave generator model # G3-118 (Г3-118) was used to generate signals that were input to the analog channel of the sonobuoy. As before the amplitude of the input signal was controlled by a step-attenuator. The radio (VHF FM) signals were received at a distance and were recorded using the same equipment used in 2005 to record the data at Piltun lighthouse. The output signal from the radio receiver was input to a recording system consisting of a National Instruments 16-bit ADC card and 8-channel 8th order elliptic filter connected to a notebook computer. The notebook computer controlled the recording parameters.

Figure 3.17(c) shows the performance of the analog sonobuoy radio channel. The red curve is the instrument noise recorded with a radio channel gain of 0.35 and a hydrophone sensitivity of 50 mV/Pa. Figure 3.17(c) also shows that when the non-linear distortion level of the first harmonic is -20 dB a tonal signal at 1 kHz is 70 dB higher than the instrument noise. As with the T-AUAR radio channel the relatively broad peak at 100 Hz is a result of cross-talk within the receiver (ICR-10); this cross-talk is greater for AX-400 and AX-700 receivers.

[57] For example the maximum cross-talk level is in the 50-100 Hz band for AX-700 radio receivers.

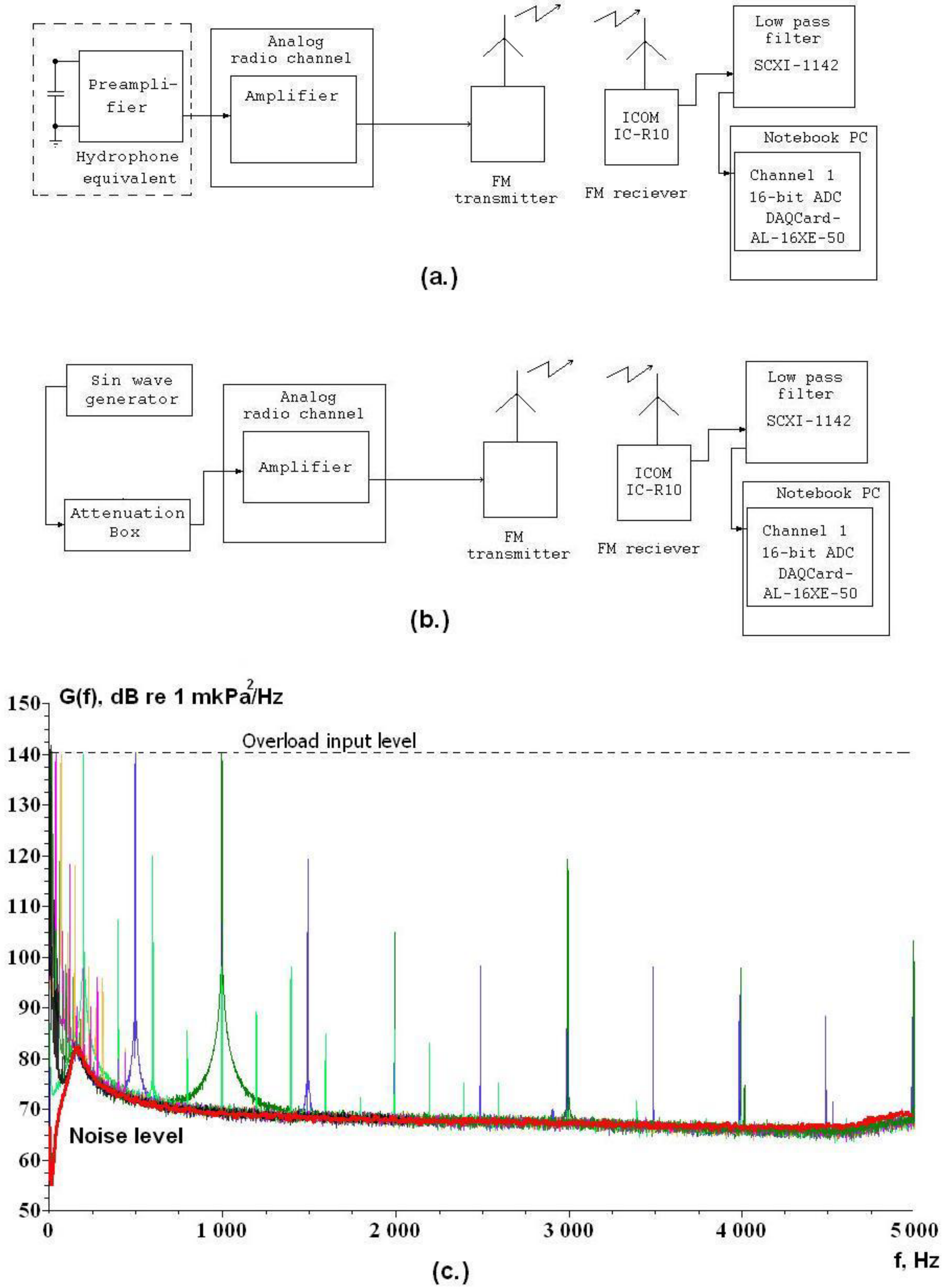


Figure 3.17 – Block diagram showing the experimental schematics for the testing of the analog sonobuoy: (a) internal noise estimation test; (b) Dynamic range determination test; (c) Spectra showing the performance of the analog sonobuoy for the frequency range 0-5 kHz (instrument noise with dummy hydrophone G-33 (Г-33, M=50 mV/Pa) is shown in red.

The increase in the level of instrument noise above 4.5 kHz is caused by the frequency response of the 8th order elliptic filter[58] used in the recording equipment. These instrument noise and dynamic range values are valid for stable radio channels with low radio noise.

3.4.5.2 Results of the digital sonobuoy instrument tests

Measurement of the internal noise and dynamic range of the digital sonobuoy was conducted using the schematic shown in Figures 3.18(a) and 3.18(b). For the instrument noise test, a dummy hydrophone with the same parameters was used (Figure 3.18(a)). For dynamic range determination, a sine wave generator model # G3-118 (Г3-118) was used to generate signals that were input to the analog channel of the digital sonobuoy. As before the amplitude of the input signal was controlled by a step-attenuator. The radio (VHF FM) signals were received at a distance and were recorded using the same equipment used in 2005 to record the data at Piltun lighthouse. In order to record synchronous records for both the analog and digital sonobuoys, data from the digital sonobuoys were also recorded on the same computer and used the same National Instruments recording system as the analog sonobuoys[59]. The output signal from the radio receiver was converted to an analog signal and input to the National Instruments 16-bit ADC card and 8-channel 8th order elliptic filter connected to a notebook computer on the *Academic Lavrent'ev* (Figure 3.19). The instrument noise and dynamic range tests were therefore conducted using this configuration (Figures 3.18(a) and 3.18(b)).

Figure 3.18(c) shows the performance of the digital sonobuoy radio channel. The red curve is the instrument noise recorded with a radio channel gain of 1 and a hydrophone sensitivity of 50 mV/Pa. Figure 3.18(c) also shows that when the non-linear distortion level of the 3rd harmonic is -60 dB a tonal signal at 800 Hz is 92 dB higher than the instrument noise. The increase in the level of instrument noise above 2.3 kHz is caused by the frequency response of the 8th order elliptic filter[60] used in the recording equipment. These instrument noise and dynamic range values show that unlike the analog sonobuoys the performance of the digital sonobuoys is not dependent on the range and radio noise.

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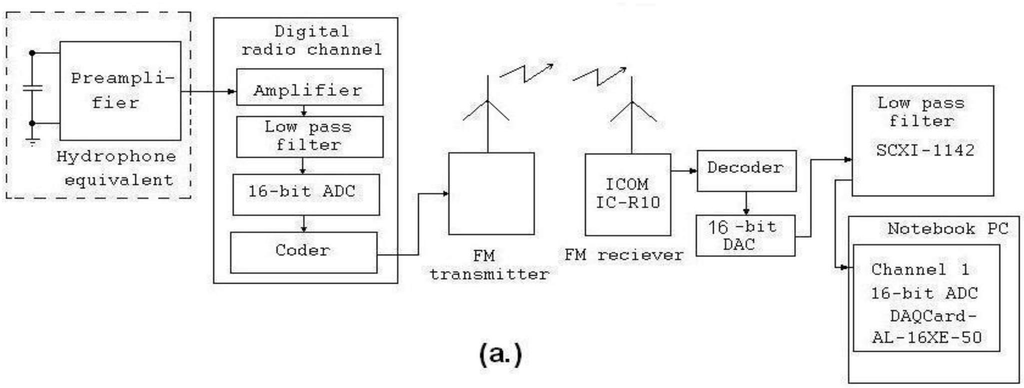
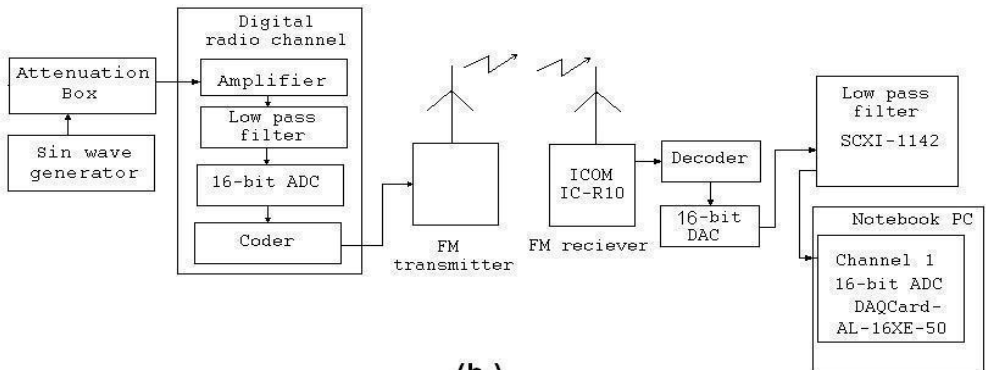
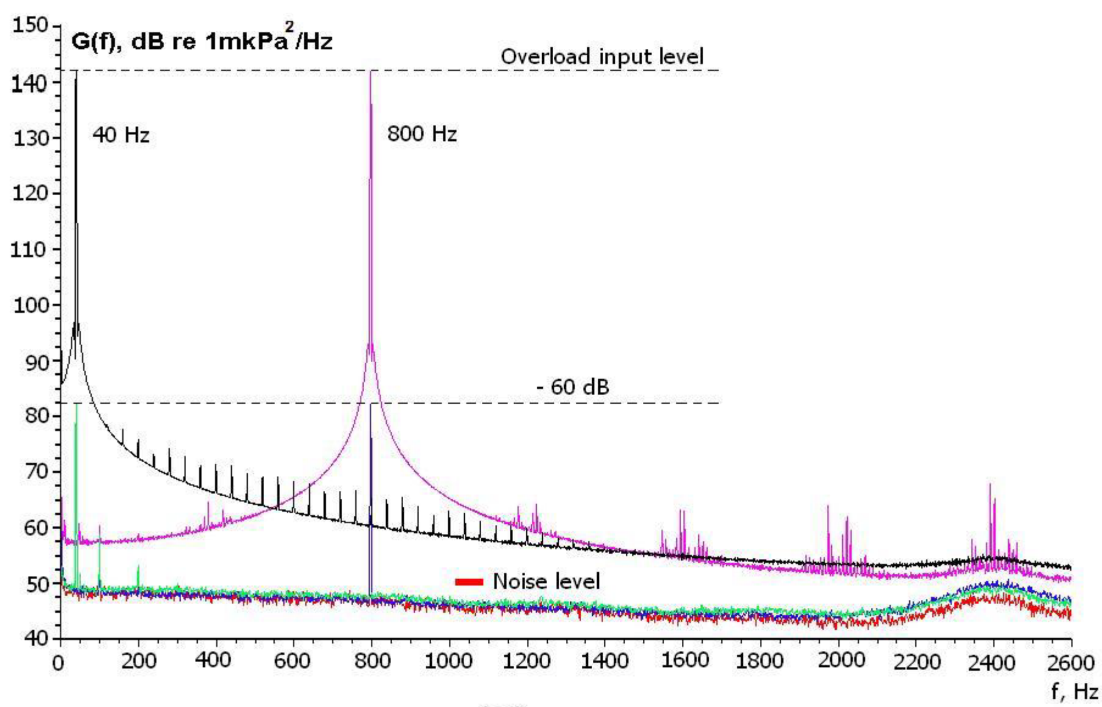
[58] National Instruments SCXI-1142.
[59] This system was used for the 2005 field season to record synchronous real-time data from four analog and two digital sonobuoys during the LUN-A CGBS installation.
[60] National Instruments SCXI-1142.



(a.)

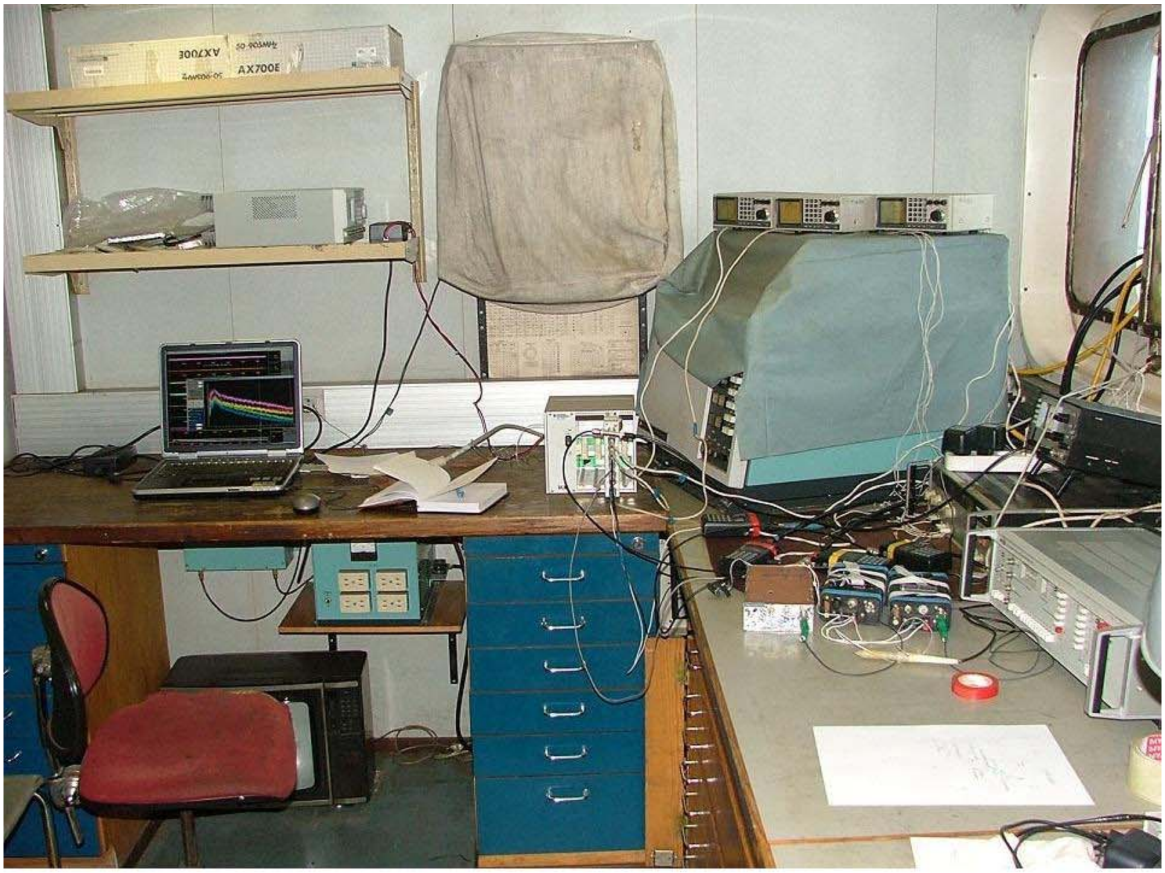


(b.)



(c.)

Figure 3.18 – Block diagram showing the experimental schematics for the testing of the digital sonobuoy: (a) internal noise estimation test; (b) Dynamic range determination test; (c) Spectra showing the performance of the analog sonobuoy for the frequency range 0-2.6 kHz (instrument noise with dummy hydrophone G-33 (Г-33, M=50 mV/Pa) is shown in red.



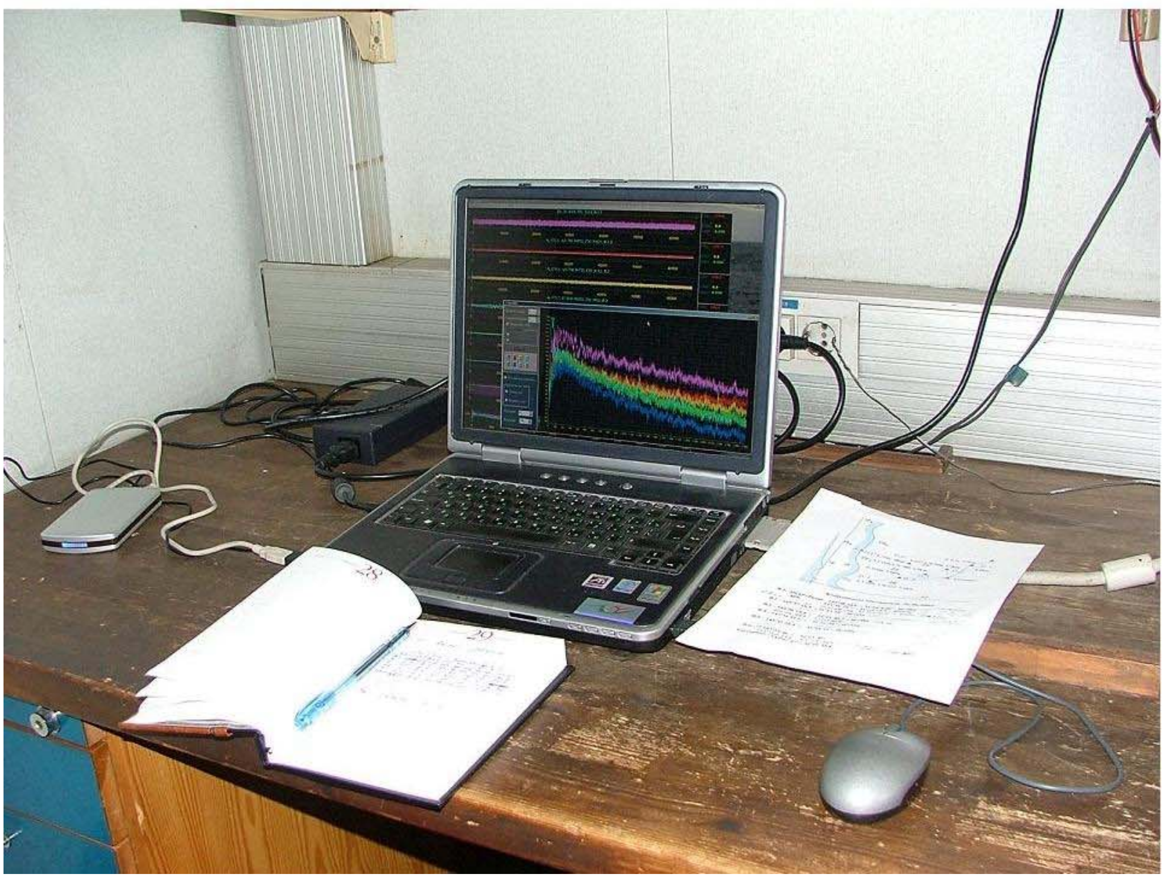


Figure 3.19 – Radio reception and recording station on the *Academik Lavrent'ev*.

3.4.5.3 Results of the sonobuoy instrument tests

The unit to unit performance of all the sonobuoys was confirmed by regular testing. All the sonobuoys were subject to the tests listed in Appendix B; Table 3.2 gives the individual test results for the four analog and two digital sonobuoys. All sonobuoys performed within specifications.

Table 3.2 - Performance of sonobuoys on the instrument tests.

	Internal noise (dB re 1 μPa²/Hz)				
Sonobuoy	**Frequency band, Hz**	**Noise level**	**Frequency band**	**Noise level**	**Dynamic range , dB**
DRB-1	1 – 20	55	20 - 2400	48	94.5
DRB-2	1 – 20	56	20 - 2400	48.2	95
ARB-1	10 - 500	82	500 - 5000	68	69.9
ARB-2	10 - 500	71	500 -5000	59.1	71
ARB-3	10 - 500	75	500 - 5000	63	70
ARB-4	10 - 500	73	500 - 5000	63	71

3.4.6. Calibration of digital and analog buoys and cross-calibration error analysis

As with the AUARs the data had to be calibrated to an absolute pressure standard so that the acoustic measurements made on the NE Sakhalin shelf could be compared to previous or future work. The hydrophones were manufactured with nominal sensitivities and the gains were set in the field. In order to confirm the calibration of the equipment a field cross-calibration was conducted.

The hydrophone calibrations were conducted at SMCHM located at RSSRIPRTM (Moscow). The sensitivities of the hydrophones were determined by comparative calibration against a reference hydrophone in an acoustical calibration chamber[61] and have a relative error of less than 1.5 dB (95% probability)[62]. Figure 3.3 shows the frequency dependence of the spherical hydrophone sensitivity over frequencies from 1 Hz-10 kHz. Calibration certificates for the hydrophones are shown in Appendix A.

The cross-calibration procedure was changed in 2005 to improve its effectiveness and performance. The cross-calibration was conducted using the narrow band mode of the radio receivers, giving an improved signal to noise ratio in the radio channel. Analog sonobuoys were cross-calibrated in the frequency range from 10 Hz to 5 kHz[63] and digital sonobuoys from 1 Hz to 2.5 kHz.

At the beginning of the 2005 field season a cross-calibration of the digital and analog sonobuoys was conducted on the *Academik Lavrent'ev*. All the sonobuoys were cross-calibrated by recording and comparing across all the sonobuoys acoustic signals generated by the *Academik Lavrent'ev*, as well as tonal signals generated by the broadband transducer. The field cross-calibration procedure is described in detail in Appendix C. The maximum absolute error from the mean for any digital sonobuoy was 0.76 dB, and for any analog sonobuoy was 1.62 dB[64]. These values were within the expected relative error limits for the equipment and the absolute calibration of the data was therefore confirmed.

[61] Model UVT 71-a-90
[62] This error includes the approximately 1 dB error associated with estimation of absolute pressure for the calibration of the reference hydrophone
[63] Real-time transmission of frequencies above 5 kHz was not required for the 2005 field program.
[64] See Appendix C - Tables C.2 to C.4 for all the results. The highest errors were due to the low level of the calibration signal at low frequencies.

4 Acoustic Transducers

This section describes the three types of acoustic transducers utilized for sound propagation studies and the monitoring of the acoustic field generated by the transducers. It also includes a description of the tools and methodology for estimating the reference amplitude at 1 m for each transducer, using a reference hydrophone.

4.1 High Frequency (HF) broadband piezoelectric transducer

Broadband noise, frequency modulated and tonal signals in the frequency band from 400-15000 Hz were used for high frequency propagation studies, TL measurements and cross-calibrations. Figure 4.1 shows the broadband piezoelectric (ceramic) transducer that generated these signals. The transducer is cylindrical[65] and consists of seven piezoelectric rings connected in parallel, coated with a composite material and sealed at the ends with a metal shield. A marine connector at one end connects the transducer to the power supply and control system. A 1500 Watt power amplifier drives the transducer[66].

Figure 4.2 is a block diagram giving a schematic of the control system for the transducer. Three signal generators produce tonal signals from 10 Hz - 20 kHz, broadband noise signals or linearly frequency modulated signals (with adjustable frequency range and frequency of modulation). A precise signal generator (Г3-122) was used as modulator and provides a stable sin wave with controllable amplitude at frequencies from 0.001 Hz to 3 MHz. This output was input to a frequency-modulating generator (GFG-8216A). The output of this generator was therefore a FM signal whose carrier signal was determined by the GFG-8216A and whose modulation was controlled by the Г3-122 signal generator. White noise from a white noise generator (RFT-1123) can also be input to the transducer instead of a FM signal. The manufacturers specifications indicate that the white noise signal had a signal variation of <0.1 dB in the band from 1 Hz to 200 kHz.

4.2 Low Frequency (LF) electromagnetic resonance transducer

A Low frequency resonance transducer was used for propagation studies, TL measurements and cross-calibrations. The LF transducer has a cylindrical container[67] filled

[65] Dimensions are diameter 28 cm, Height 136 cm; Weight ~ 60 kg in air, ~ 15 kg in water.
[66] Phonic MAX-2500 1500 Watt power amplifier.
[67] Dimensions are Diameter 58 cm, Height 15 cm; Weight 48 kg in air, ~ 6 kg in water.

Figure 4.1 - High frequency broadband piezoelectric transducer.

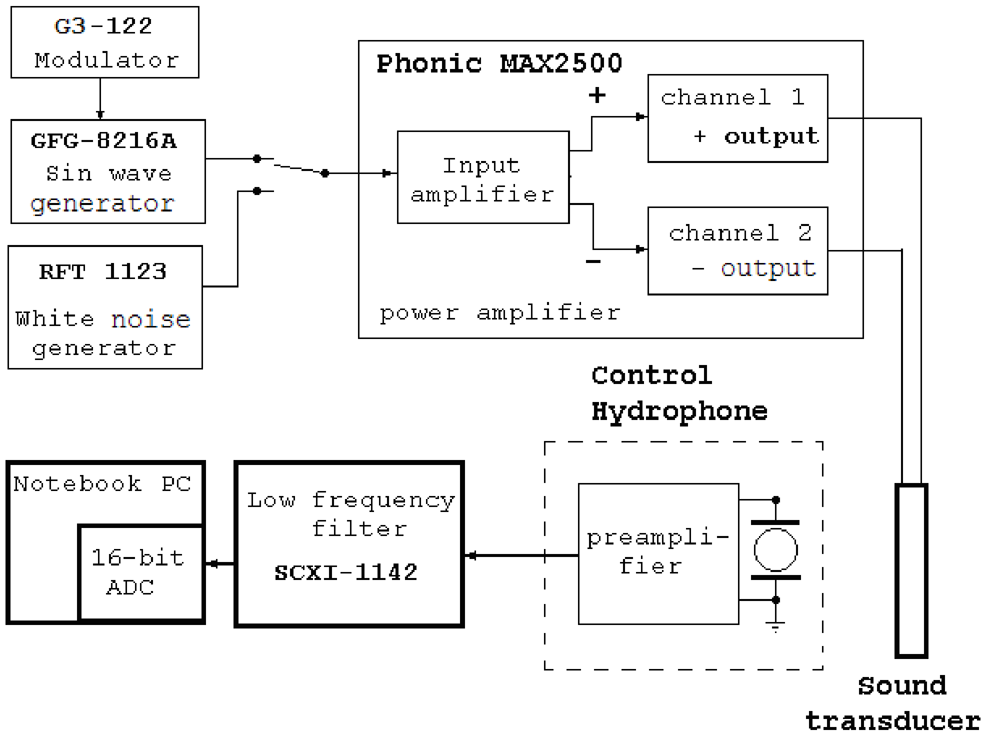
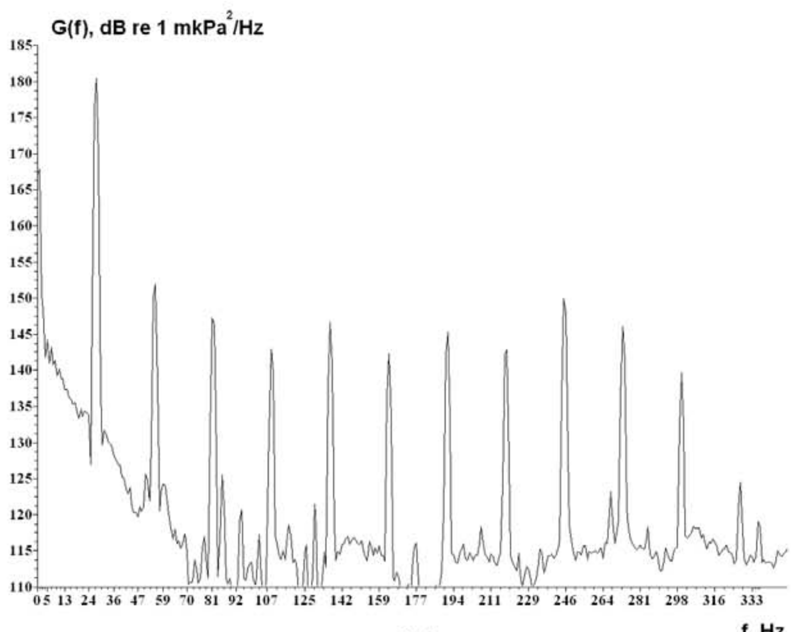


Figure 4.2 - High frequency broadband piezoelectric transducer control electronics.

with air, and a pair of identical closely spaced radiating pistons oscillating in opposite directions creating a volume displacement. An electromagnetic controller controls the motion of the pistons; the ends of the pistons are connected together by cylindrical springs and to the edge of the cylindrical container with rubber gaskets. A bridge thyristor inverter connected to the transducer by a 4-line 34 m long cable drives the transducer. Hydrostatic compensation is achieved using an air pump and control manometer connected to the transducer by a 27 m hose[68]. In order to achieve electric resonance, a battery of electric capacitors and solenoids located on board the *Academik Oparin* are connected sequentially with the solenoid of the transducer. Figure 4.3(a) shows the LF resonance transducer and reference hydrophone being deployed over the side of the *Academik Oparin.*

[68] During calibration tests in the Sea of Japan the amplitude of the piston motion at the resonance frequency was 3.3 mm. The amplitude of the volumetric oscillation was therefore 0.0012 cubic meters. The tests using calibrated accelerometers, and conducted at a depth of 2 m, indicated that when the maximum number of springs (30) are used, the resonance frequency of the transducer is 20.2 Hz with marginal frequencies of 15.2 and 30.6 Hz (-3 dB).

(a.)



(b.)

Figure 4.3 - (a) Low frequency resonance transducer and calibrated monitor hydrophone; (b) Power spectral levels of the acoustic field generated by the transducer recorded by a reference hydrophone at 1 m for a resonance frequency of ~27 Hz.

The LF resonance transducer was deployed at a depth of 8 m from the anchored *Academik Oparin*. Figure 4.3(b) displays the spectral levels, recorded by a control hydrophone at 1 m, of the acoustic field generated by the transducer at a resonance frequency of ~27 Hz and its harmonics. The ~27 Hz acoustic signal has a spectral level of ~180 dB re 1 $\mu Pa^2/Hz$ at 1 m from the transducer[69].

4.3 Autonomous electromagnetic resonance transducer

An autonomous electromagnetic resonace transducer was used during the 2005 field season. The advantage of an autonomous transducer is that it can be used to conduct propagation experiments on a pre-determined schedule even when the vessel is not present. The disadvantage is that the transducer remains at a single location. The transducer consists of a transmitter (with an electromagnetic converter), power amplifier and transformer; a stable harmonic generator based on a quartz crystal[70] and a battery. A voltage stabilizer is used to remove the variation in transmitted signal amplitude with the battery voltage (i.e. battery charge). The transmitter is housed in a sealed cylindrical container[71] with a transmitting diaphragm at one end and is depth rated to 100 m (Figure 4.4).

The transducer produces a continuous tonal signal with a power of 10 W at the center frequency; the acoustic pressure at 1 m from the transducer is 173 dB re 1 μPa-m. The center frequency can be adjusted in steps over the frequency band 290-392 Hz using heavy disks attached to the diaphragm. The transducer can transmit at a defined acoustic level for 72 hours with a battery capacity of 100 Ampere hours.

4.4 Reference amplitude

The acoustic pressure level generated by both the HF and LF transducers were monitored by a calibrated reference hydrophone located a fixed distance from the transducer[72]. The monitor data could be contaminated by flow noise, vibration from currents, surface waves, rocking of the vessel and noise from the *Academik Oparin*.

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[69] While the transducers were operating the acoustic signal levels were measured using a calibrated hydrophone located 1 - 2 m away from the transducer.
[70] This quartz generator is used to stabilize the signal from the power supply to the transducer (frequency).
[71] Dimensions are: Diameter 30 cm, Length 1 m; Weight 100 kg in air, ~40 kg in water.
[72] The calibration certificates for the reference hydrophones are given in Appendix A.

In order to reduce contamination of the reference signal by this noise, the reference hydrophone and preamplifier were located a distance of 2 m from the center of the broadband transducer and 1 m from the edge of the LF transducer. The reference hydrophone was isolated from mechanical noise using a rubber suspension system inside a weighted triangular frame. Data from the reference hydrophone was recorded on a laptop using a system based on National Instruments equipment. This system is described in greater detail in chapter 3. Figure 4.5 shows the laboratory on the *Academik Oparin* with the equipment used to control the transducers and record the reference signals.

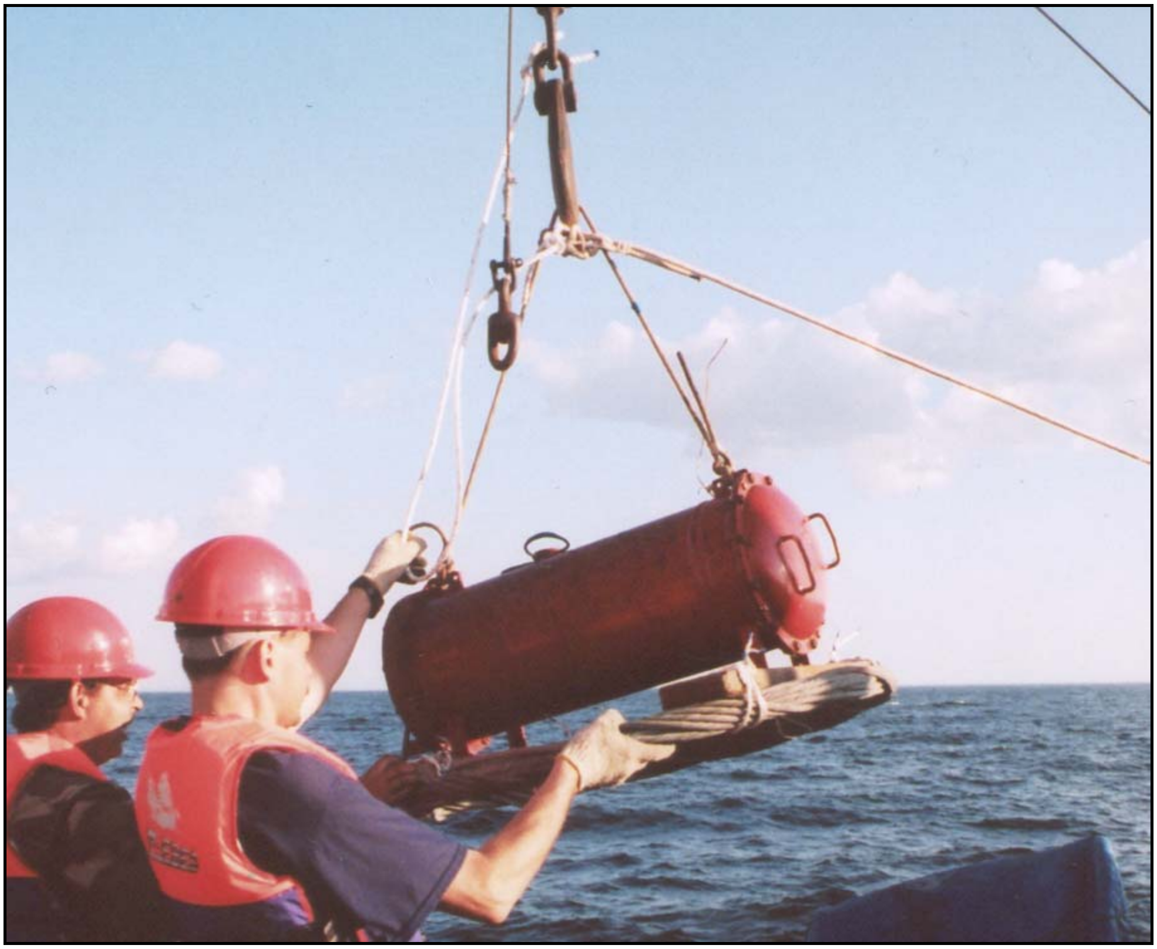

Figure 4.4 - Autonomous electromagnetic resonance transducer.

Figure 4.6 shows the spectra of signals produced by the HF transducer and monitored by the reference hydrophone located 2 m from the center of the transducer. Figure 4.6(a) shows the spectra *G(f)* when the transducer is driven by a white noise signal, the dotted line gives a measure of the noise from the *Academik Oparin* recorded between transmissions. Figure 4.6(b) gives the spectra when the transducer is driven by a FM signal. The 25 dB variation in the output spectrum is a function both of the output of the transducer and interference between the direct and reflected waves from the vessel and the sea floor. The signal was recorded by the 12 m deep reference hydrophone in 30 m water depth; the vessel hull was 4.5 m deep.

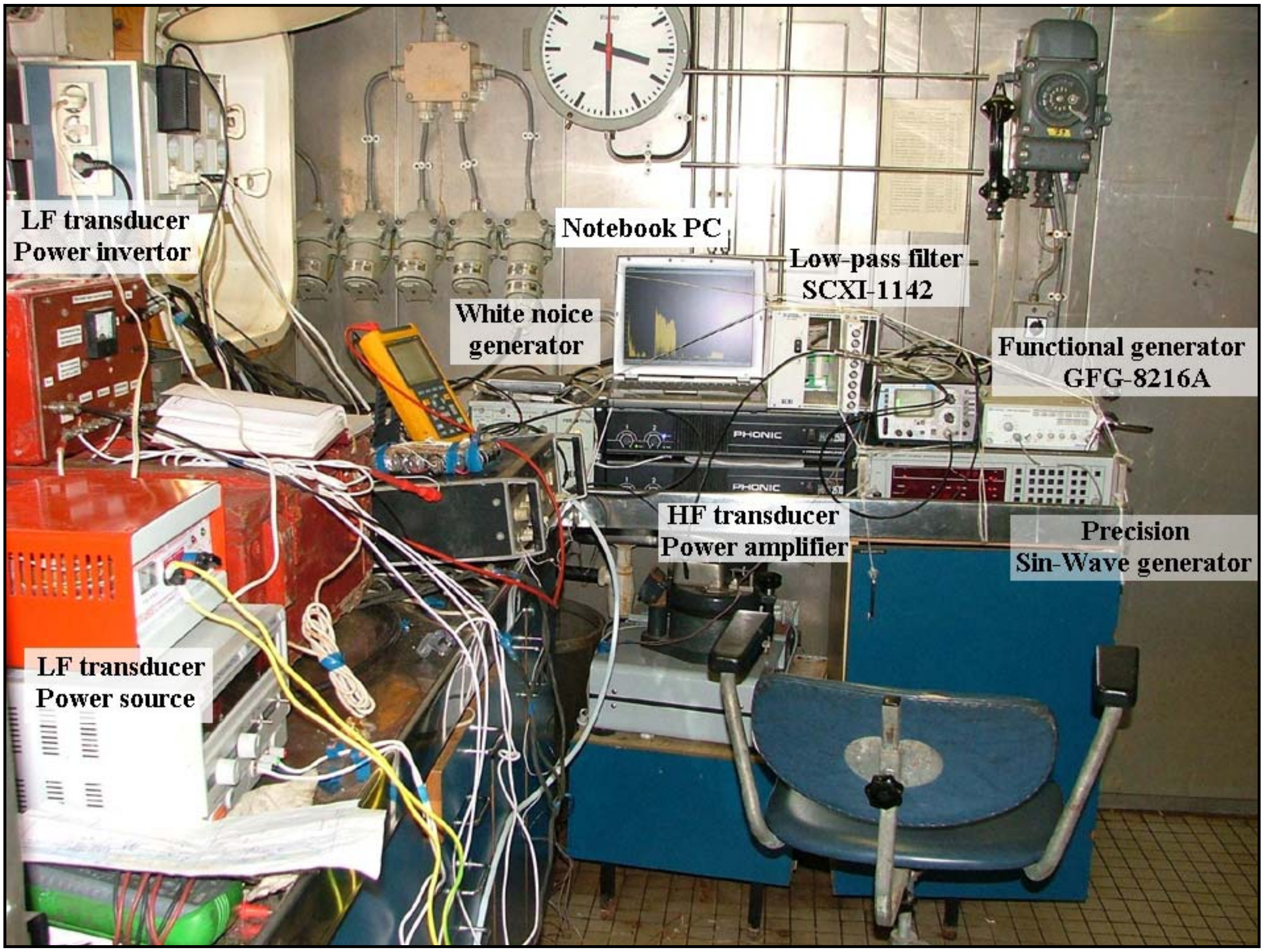

Figure 4.5 - Laboratory on the *Academik Oparin* showing the equipment for controlling the transducers and recording the reference signal.

4.4.1 Reference hydrophone

Ideally the reference hydrophone used to monitor the output of the transducer would in the far field of the transducer. However, on the NE Sakhalin shelf the water depths are too shallow to allow the reference hydrophone to be placed in the far field without propagation effects making the output of the transducer impossible to determine. The optimum location for the reference hydrophone in these TL experiments is therefore difficult to determine.

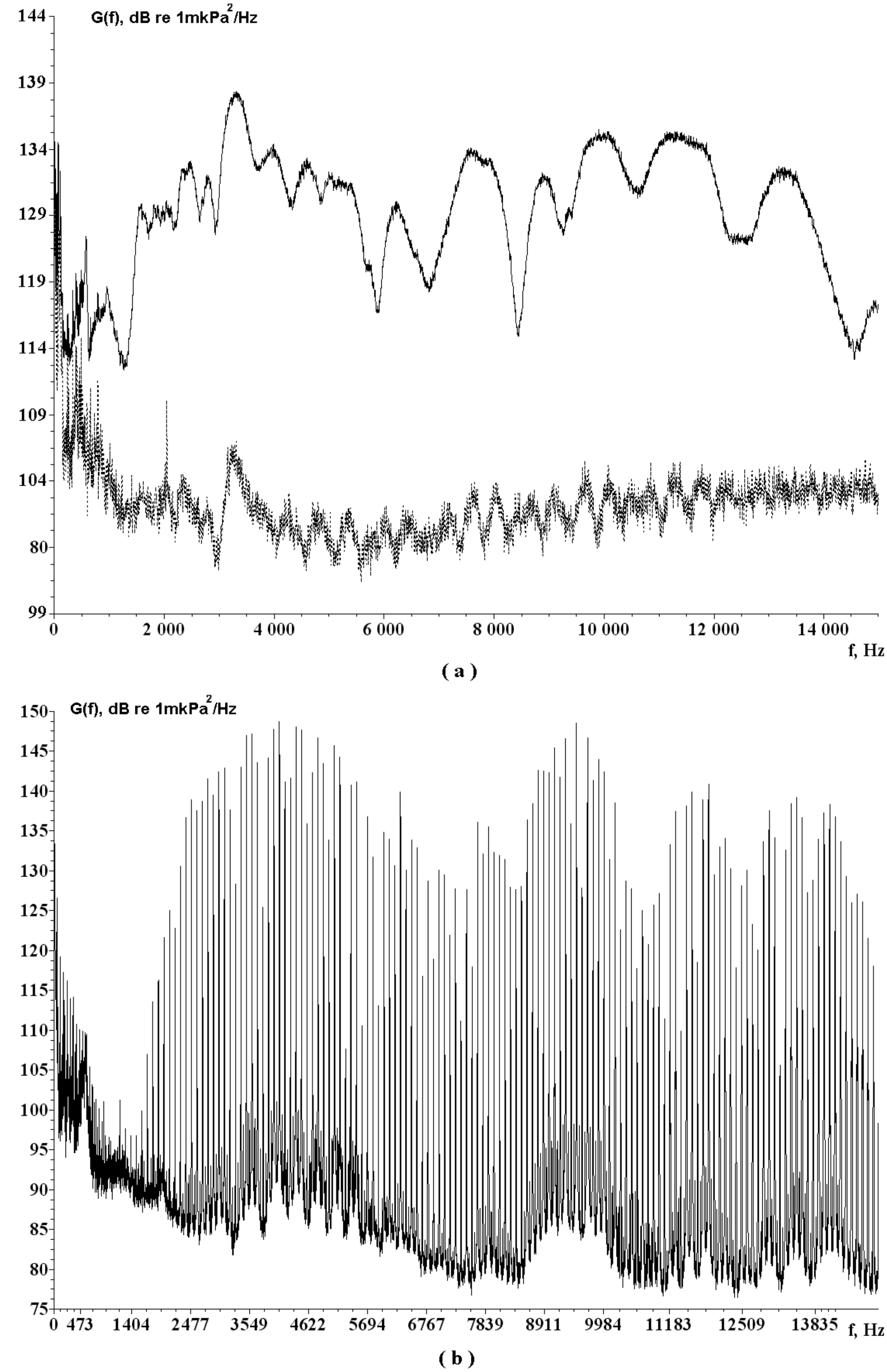

Figure 4.6 - Spectra G(f) of signals from the broadband transducer monitored by the reference hydrophone at 2 m; (a) White noise signal (solid line) and vessel noise from the *Academik Oparin* (dotted line); (b) FM signals.

The frequency and range dependent TL is estimated by subtracting the power spectral density level (dB) of the acoustic signal at 1 m from the transducer from the power spectral density of the acoustic signal as recorded at the AUAR:

$$TL(f,r) = 10\log G_r(f) - 10\log G_{1m}(f) \tag{4.1}$$

Where:

TL(f,r) is the frequency and range dependent TL,

$G_r(f)$ is the power spectral density of the acoustic signal at range r from the transducer,

$G_{1m}(f)$ is the power spectral density of the acoustic signal at 1 m from the transducer.

4.4.2 Methodology used to monitor acoustic levels generated by the transducers

Ideally, in order to eliminate the near field phenomena described in the previous section the reference hydrophone used to monitor the output should be located several wavelengths from the transducer (in the far field). However, this is impractical since for the study area on the NE Sakhalin shelf the water depths are too shallow (10-40 m). The length of the *Academik Oparin* (75 m) limits the horizontal distance; additionally the stern area of the ship is noisier since it is near the engine compartment. Also, as the range increases, interference between the direct arrival and reflections from the sea floor, the sea surface and the hull of the *Academik Oparin* can complicate the interpretation of the results.

The reference hydrophone was located at a distance of 2 m from the center of the broadband transducer and at 1 m from the edge of LF transducer. The reference hydrophone was isolated from vibration using a rubber suspension system. The goal of the system was to minimize contamination of the data by flow noise, vibration from currents and surface waves, as well as noise from equipment on and the rocking of the *Academik Oparin*. The previous studies indicate that the source level of the transducers could be slightly lower than the reference level for the LF transducer (~4 dB) and slightly higher than the reference level for the HF transducer (~2 dB).

In summary it can be seen that a more extensive experiment to study the near field of the HF and LF transducers must be conducted. This experiment should be designed to extend the results of the 2004 and 2005 experiments and to study the attenuation in both the vertical and horizontal directions in one experiment.

5 Hydrologic Equipment and methodology

This section describes the equipment used for bathymetric and hydrologic studies, as well as the hydrologic sonde used to make water column measurements during these and other experiments. It also includes a description of the tools and methodology for correcting the bathymetric measurements (e.g. tidal corrections), analyzing the hydrology data and archiving the field data.

To estimate the cumulative effect of sound generated by developments on the NE Sakhalin shelf on the sound field it is necessary to understand the transmission characteristics between oil and gas facilities and operations and the gray whale feeding areas. Detailed bathymetric and hydrologic measurements are required to improve the accuracy of the acoustic models used for this task.

5.1 Hydrologic sonde

Empirical TL results are used to calibrate numerical modeling work. In order to more effectively characterize the variation in TL over time it is necessary to know the hydrologic properties of the water column (temperature and salinity) in addition to the acoustic properties and bathymetry. Acoustic TL studies are therefore accompanied by bathymetric and hydrologic profiling. A hydrologic sonde[73] was used to determine the hydrologic properties of the water layer. The *Academik Oparin* was upgraded with an electric winch in order to deploy the sonde (and transducers), and the *Academik Lavrent'ev* used a hydraulic winch; Figure 5.1 shows the sonde being deployed. The sonde can independently measure conductivity, sound velocity, temperature and pressure. The main characteristics of the sonde are given in Table 5.1; Appendix A has calibration certificates for the sonde sensors.

The sensors can be programmed with a sample rate of 1, 2, 4 or 8 Hz; all parameter values are measured synchronously and stored in the sonde's internal 8 MB flash memory. Once the measurements are complete the data can be transferred to a computer via a RS232 port[74]. The sonde is powered by a set of eight D-cells, providing approximately 180 hours of continuous operation.

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[73] Model SVXtra manufactured by Valeport Limited, England.
[74] The DataLog400 program included with the sonde is used to adjust measurement modes, to transfer data to a computer, for data visualization and relative density calculation from the other parameters.

Figure 5.1 - SVXtra Hydrologic sonde being deployed from the *Academik Oparin*.

Table 5.1 - Technical specifications - Valeport SVXtra sonde.

Parameter	Type	Range	Accuracy	Resolution	Response time
Conductivity	Pressure balanced inductive coils	0.1-60 mS/sm	±0.01 mS/sm	0.003 mS/sm	100 ms
Speed of sound	Time of flight	1400-1600 m/s	±0.05 m/s (±0,03 m/s rms)	0.001 m/s	Single pulse. Maximum time of flight 145 µs
Temperature	Fast response PRT	-5°C +35°C	± 0.01°C	0.002°C	100 ms
Pressure	Strain gauge pressure sensor	5000 dBar	± 0.1% FS	± 0.005% FS	20 ms

Figure 5.2 - SVXtra Hydrologic sonde.

5.2 Processing and storage of hydrologic data

To more effectively manage the quantity of hydrology and bathymetric data acquired during these expeditions, the acoustic team developed a database for the storage and analysis of hydrologic data. The database client software for hydrologic measurements was based on the 2004 software version [Borisov et.al., 2005], and was updated in the course of preparatory work for the 2005 expedition[75]. The main window of the database client module is shown on Figure 5.3.

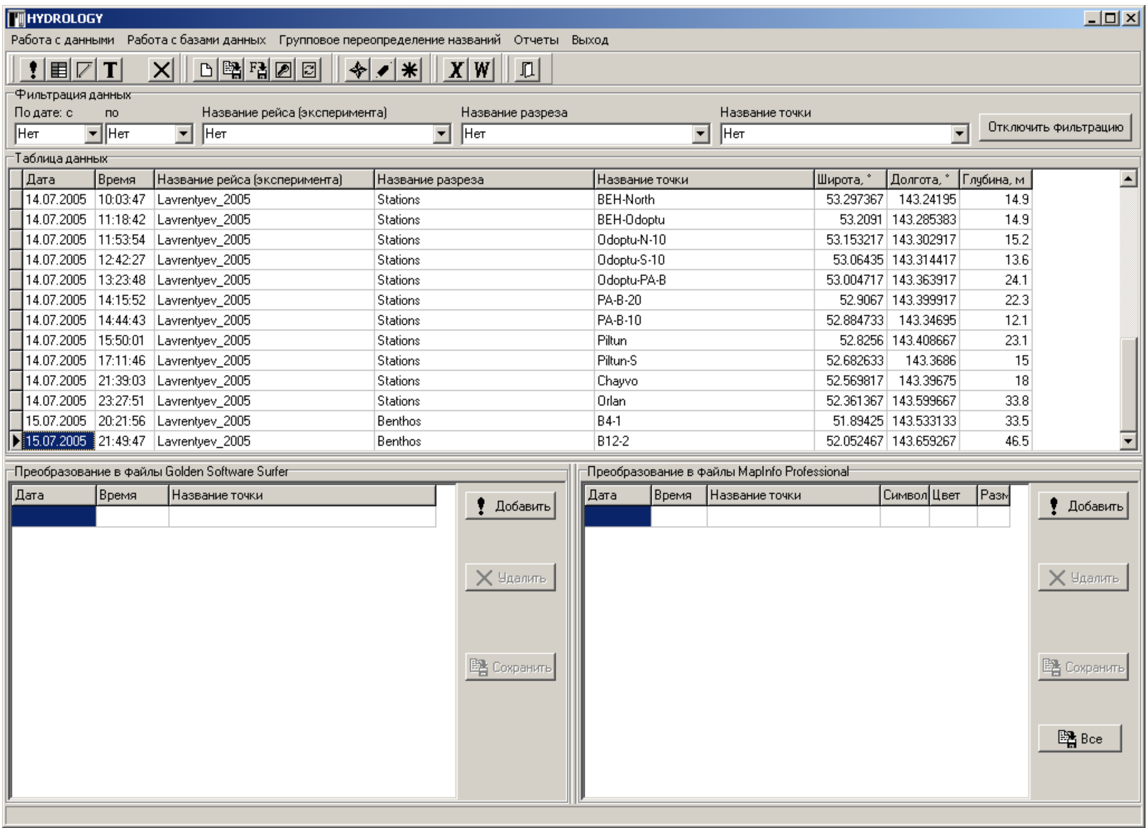

Figure 5.3 - Main window of the database client module for the storage and analysis of hydrologic data.

Data is read from the sonde using the DataLog400 program, converted into text and input into the database. Since the hydraulic winch of the research vessel *Academik Lavrent'ev* and the electric winch of the research vessel *Academik Oparin* deploy the sonde slowly and the sonde samples the hydrologic parameters eight times a second, a large number of depth samples are acquired during each vertical profile.

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[75] New functions were added to the program to facilitate data backup, creation of new databases, switching between databases, batch renaming of experiments, profiles and points, and exporting measurement data directly to MS Excel. In addition, the database itself now runs under MS Access, and there is no need to install additional database management software

Data is collected into depth bins (the depth horizons stored in the database are 2.5 cm thick) and averaged. Extra information is added (e.g. the experiment or profile name and coordinates). Every entry in the database contains the measurement date, experiment, profile and point name, as well as the coordinates and depth (max depth recorded by the sonde) of the point, the sensor readings and the number of depth bins measured.

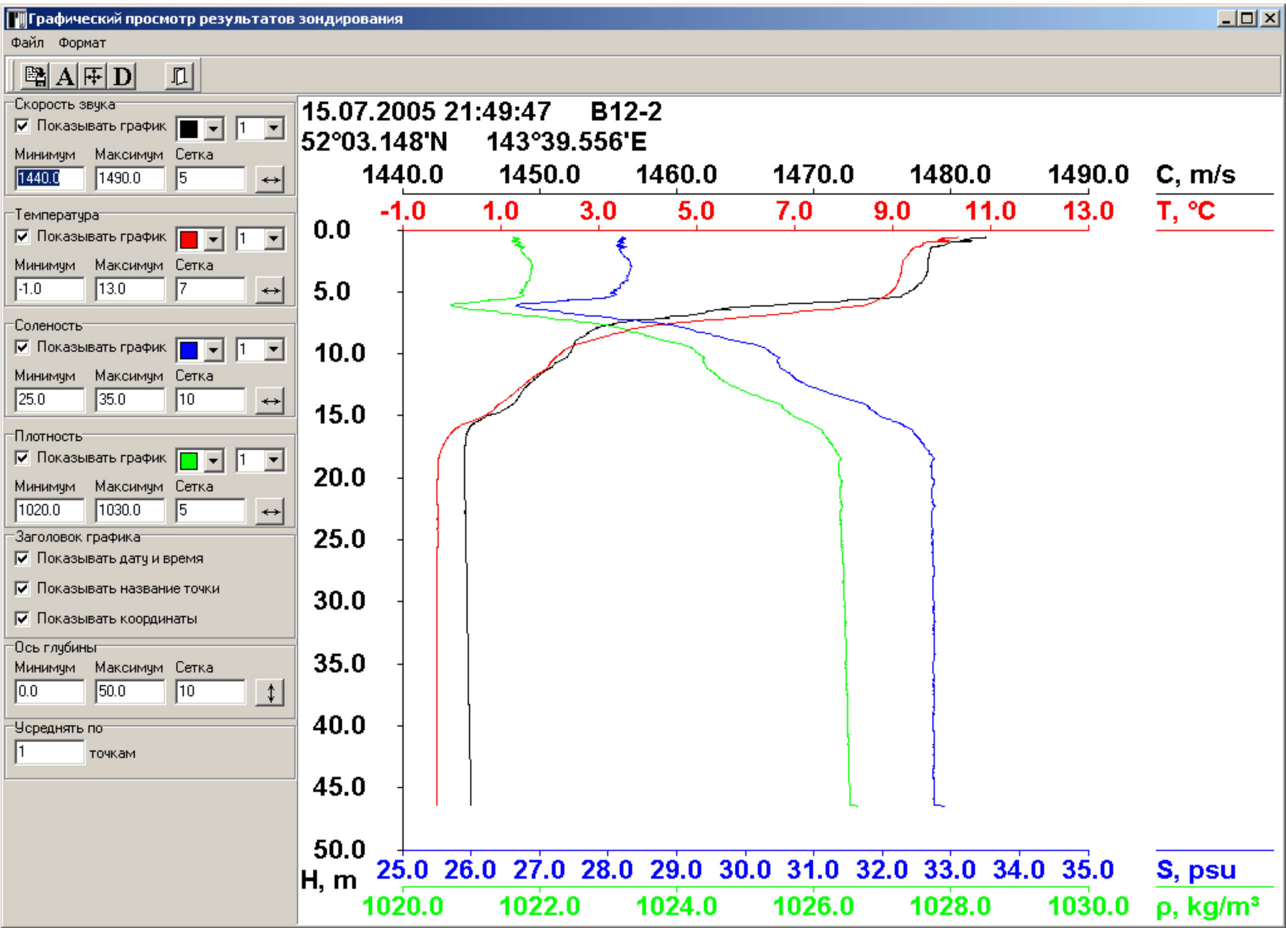

Figure 5.4 - Plot showing the results from a vertical hydrologic profile acquired from the *Academik Lavrent'ev*. Note that the density and salinity have been computed from other measurements.

The software can output data in tables or plots (Figure 5.4); it can sort the data by date, experiment, and profile or point name and can export data into MS Word and Excel. Additionally, data can be exported into Surfer[76] to better visualize the spatial variation of the acoustic velocity, temperature, salinity and density fields. Figure 5.5 shows an example of

[76] Golden Software.

sound velocity, temperature and salinity sections plotted in Surfer [Kruglov et. al., 2006]. The data can also be input into MapInfo to plot the experimental profiles on a map.

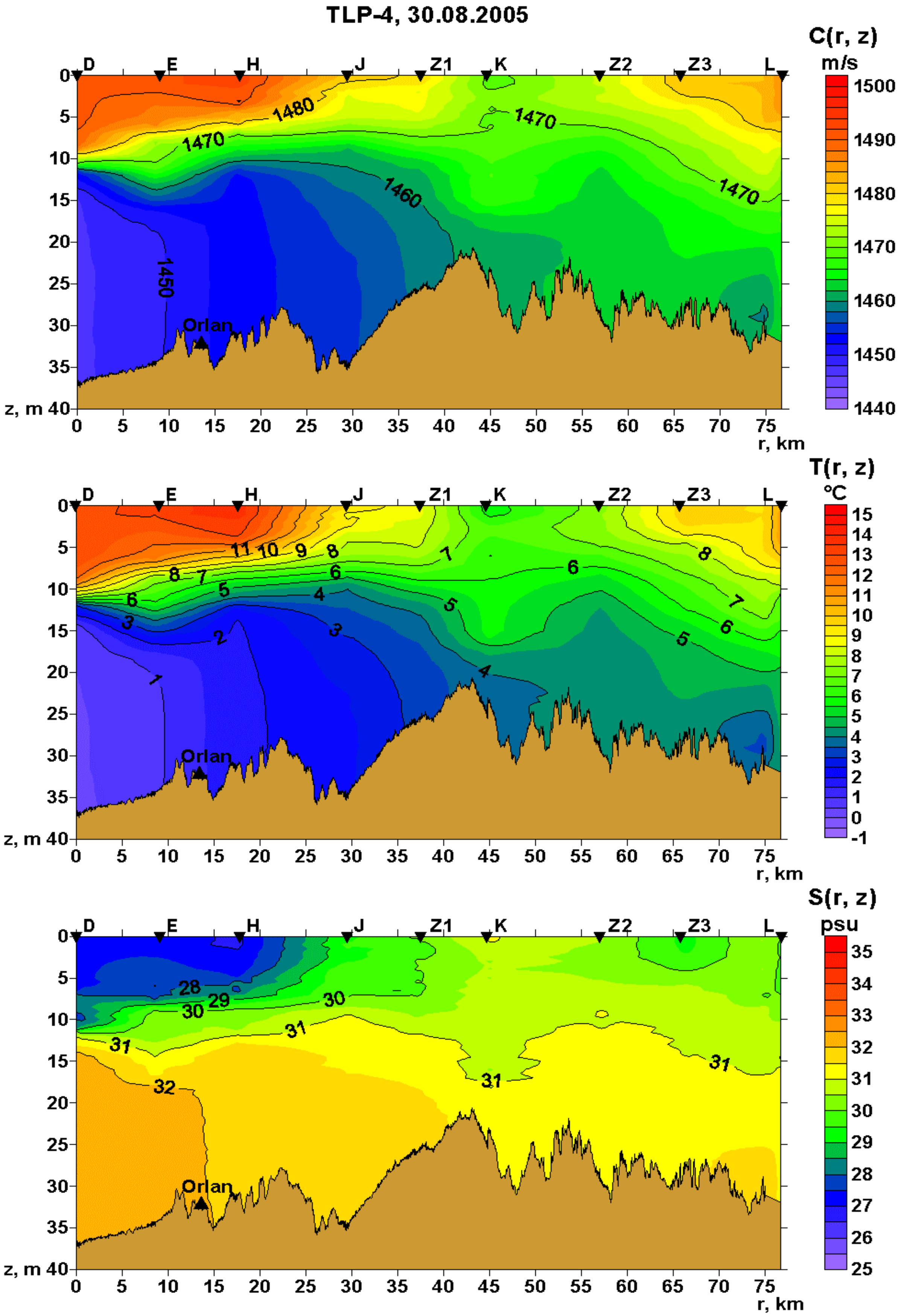

Figure 5.5 - Plots of sound velocity, temperature and salinity along a profile from the PA-B platform location to the Orlan (#3) and OFA (#2) AUAR locations.

5.3 Equipment and software for bathymetric profiling

The equipment available for bathymetric profiling on the two vessels (*Academik Lavrent'ev* and *Academik Oparin*) used for the survey operations in 2005 was not the same. Different equipment and survey methodologies were therefore used on the two vessels during the 2005 field program. This will have no effect on the final data as these differences were compensated for during processing.

5.3.1 Logging positional data on the Academik Lavrent'ev

Beginning on 17 July 2005, local time, survey coordinates, speed and heading was recorded aboard the *Academik Lavrent'ev*. The speed and heading were determined by the ship's Lawrance GPS receiver, Figure 5.6(a) is a schematic of the navigation recording system. The NMEA (National Marine Electronics Association) standard 0183 signal from the GPS receiver was passed to the computer's serial port. Data was recorded by an independent program developed for the purpose; Figure 5.6(b) is a view of the main window. The program stores the navigational data in text files. Visualization and processing of the stored data was performed using Surfer and MapInfo.

5.3.2 Logging positional and bathymetric data on the Academik Oparin

NMEA standard format signals from the depth profiler[77] and GPS receiver[78] on the *Academik Oparin* were input into an NMEA hub[79] attached to the serial port of a computer. The computer was running the dKart Navigator[80] that can process and store data in NMEA format, and computes and plots the vessel's course.

Figure 5.7(a) shows the equipment used for continuous bathymetric recording on the *Academik Oparin,* Figure 5.7(b) is a schematic of the bathymetric equipment. Navigation information (time, coordinates, depth, speed, and course (from compass)) was recorded every 10 seconds.

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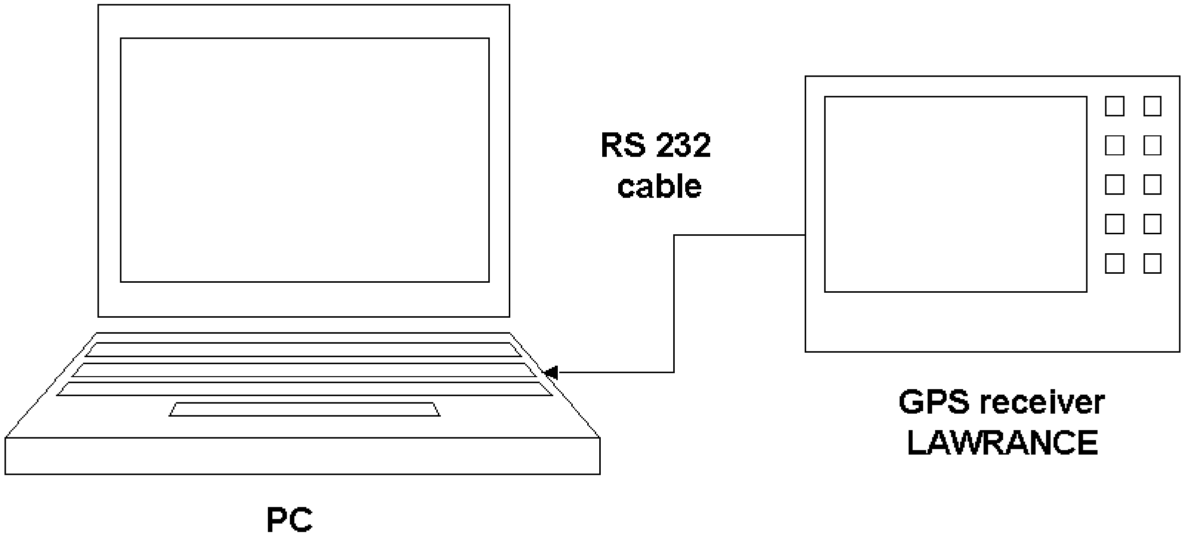
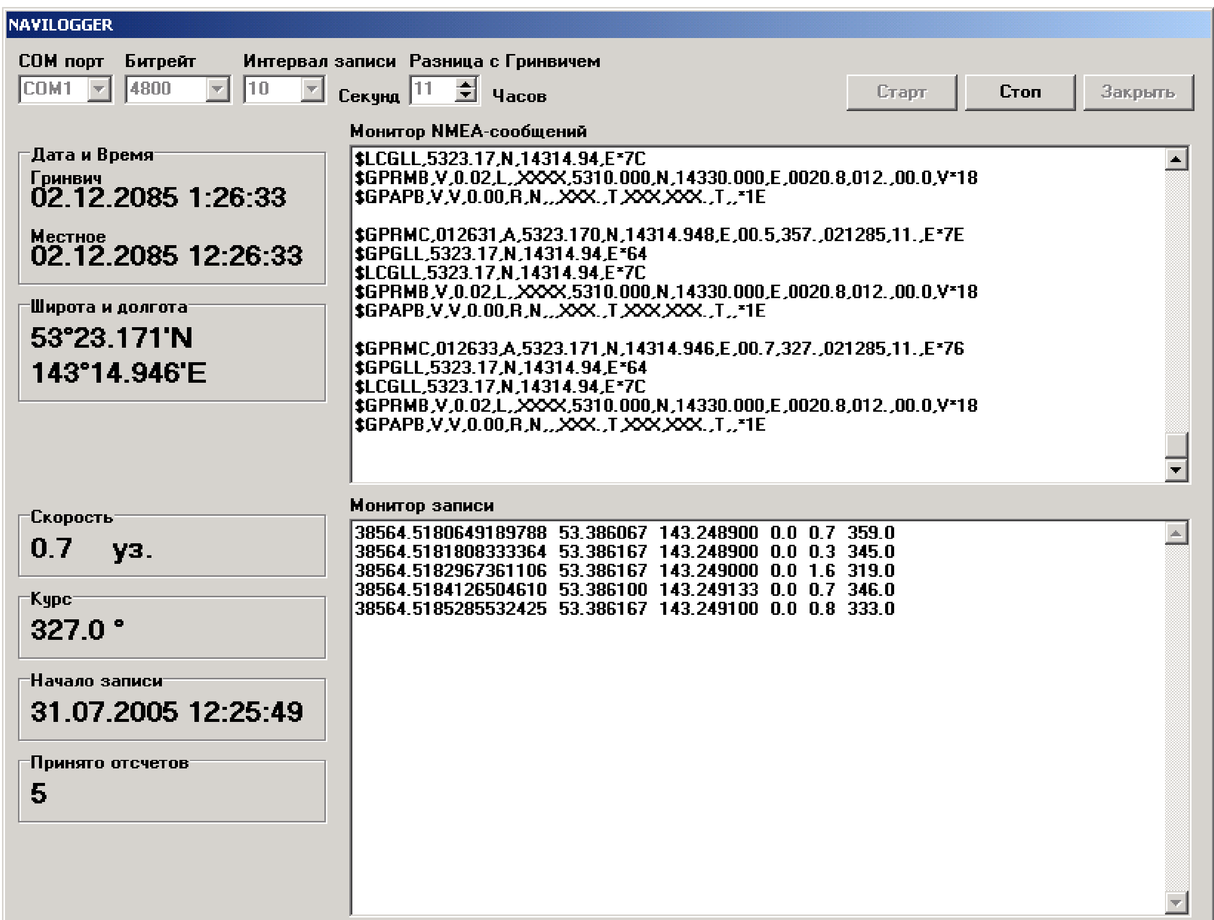
[77] Wesmar, operating frequency 20 kHz, beam width 7°.
[78] Furuno.
[79] HUB51MK.
[80] dKart Navigator (version 6.32) is a professional navigation solution for communication with navigation equipment such as GPS, sonar, AIS, radar, compass, log etc.

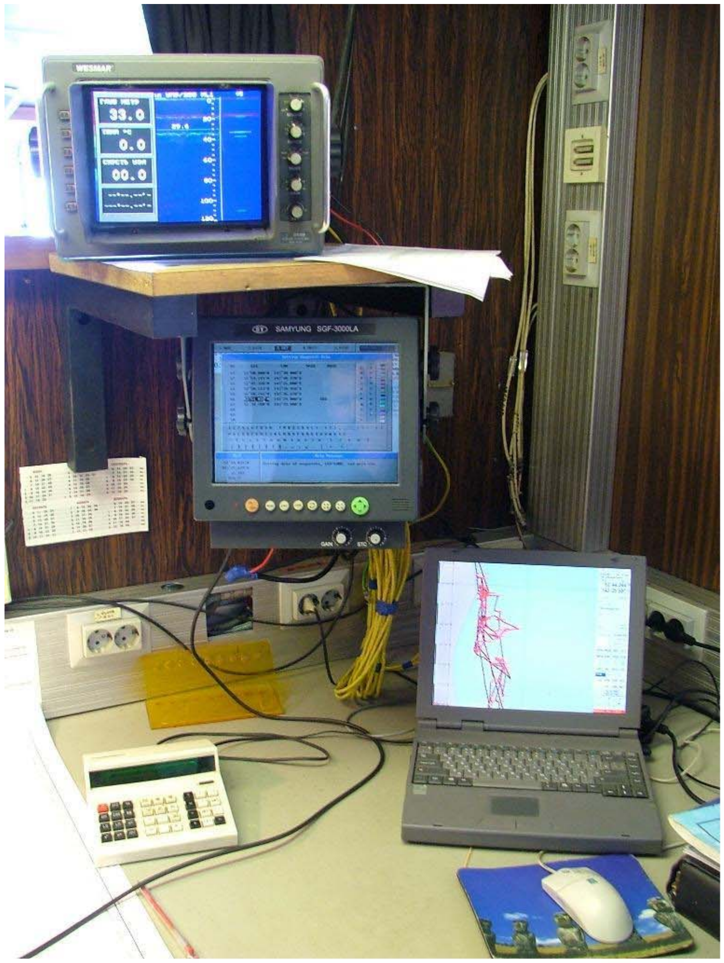


(a.)

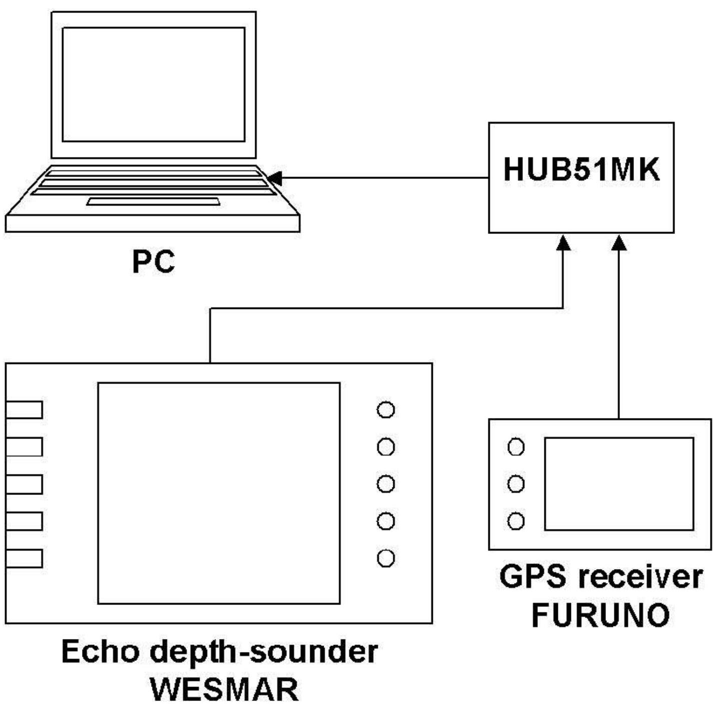


(b.)

Figure 5.6 - Equipment used for continuous recording of bathymetric and positioning data on the *Academik Lavrent'ev.*



(a.)



(b.)

Figure 5.7 - Equipment used for continuous recording of bathymetric and positioning data on the *Academik Oparin*.

5.4 Applying tidal corrections to bathymetry data

The top plot on Figure 5.8 demonstrates the tidal correction of hydrologic data acquired (using an echo sounder) on the NE Sakhalin shelf from 11:00 on 19 August 2005 to 11:00 on 20 August. The results are presented as graphs of depth vs. time $\eta(t)$. The tidal height was estimated from comprehensive observations in the area of Piltun Bay. This theoretical estimate was subtracted from the measured depth to give a tide-corrected depth. The bottom plot gives the theoretical value of tide height vs. time H(t).

The period plotted corresponds to the syzygial[81] tidal phase, where the greatest differences between the high and low tide levels are observed. The clear diurnal nature of the tides is characteristic of the area; semidiurnal components are exhibited only in the quadrature[82] phase.

In standard practice (for marine navigation), tides are calculated relative to the lowest low water low tide (chart datum), and chart depth is displayed relative to this datum. Common practice is to tide correct the depths by adding the tidal values (from tide tables) to the chart depths. Since the tidal corrections are identical to those from tide tables the correction procedure can be considered as the adjustment of the bathymetry data to the chart datum using generally accepted navigational practice. Theoretical tidal data for the period of August to September 2004 and 2005 yield the following statistical characteristics for the tides in the Piltun Bay area: mean 0.782 m; standard deviation 0.342 m. Thus the estimated measurement accuracy will be within 35 cm of mean sea level, and the rise of mean sea level will be approximately 80 cm above the lowest low water low tide datum.[83]

Figure 5.9 clearly shows the impact of tides on the bathymetry. During the period of these measurements the *Academik Oparin* was anchored at a single point. The results are given as plots of the uncorrected bathymetry, the tide-corrected bathymetry, and the chart datum level corrected by 21 m (the mean correction value).

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[81] The maximum tide level – the earth and moon are aligned with the sun.
[82] The minimum tide level – the earth and moon are 90° out of phase with each other and with the sun.
[83] The maximum tidal range in the area is ±1 m.

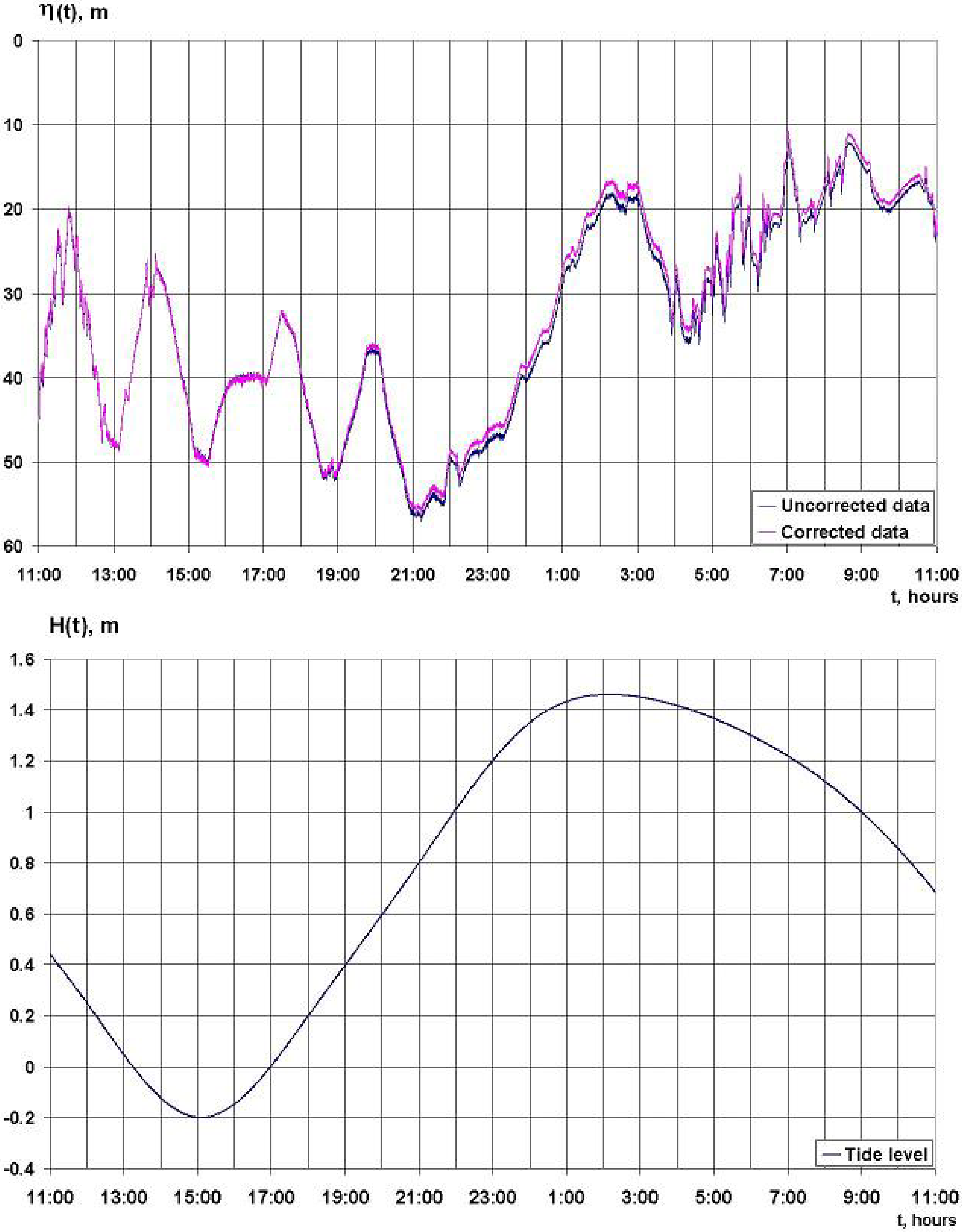

Figure 5.8 - Bottom: Tide level for bathymetric measurements made on 20 August 2005; Top: Corrected and uncorrected data from a bathymetric survey.

The figure shows that low frequency variations of the uncorrected depth match the theoretical tide level closely; the real tide level can therefore be predicted by theoretical calculations. The impacts of wind and changes in atmospheric pressure on sea level are significantly smaller than the magnitude of the tide and are therefore ignored.

It is therefore possible to tide-correct the bathymetric measurements by subtracting the theoretical tidal values from real measurements. This correction was applied to all bathymetry data acquired in 2004 and 2005.

Bathymetry data also has errors due to surface waves and other stochastic effects. The magnitude of surface waves can be comparable to those of tides, but surface waves fluctuate much more rapidly. This effect can therefore be compensated for by averaging inside a spatial grid (i.e. all the data is divided into spatial groups and averaged). This excludes the effects of surface waves from the data as every cell of the grid contains data from different times and also corrects the bathymetry data for the switching of currents. This procedure will be applied to bathymetric data acquired in the field. Further data processing and visualization will be performed using Surfer. If uncorrected bathymetry is required for a specified time a back correction can be applied (i.e. theoretical tidal value can be added to the corrected data).

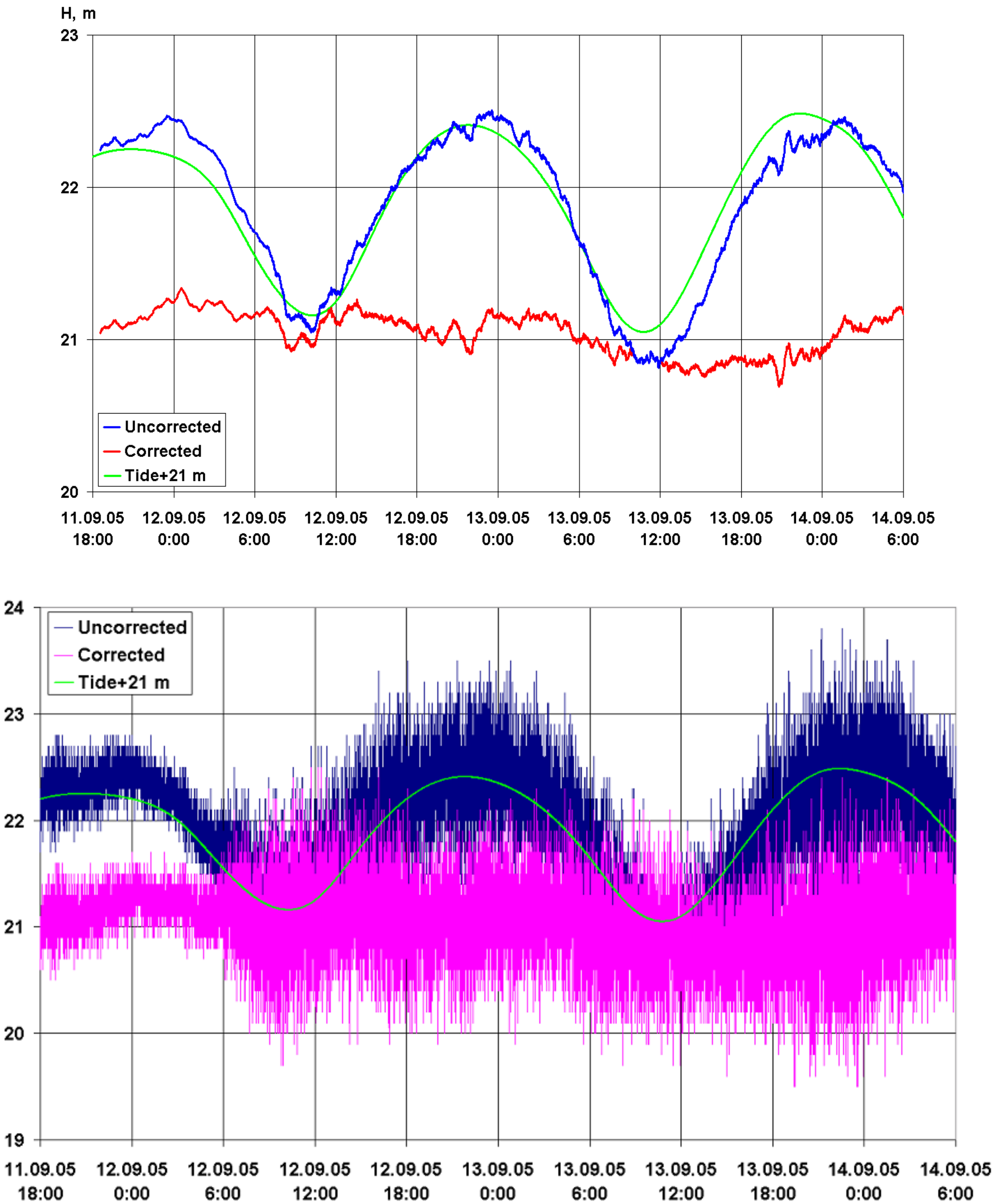

Figure 5.9 - Bathymetric measurements at a single point Top: corrected and uncorrected measurements and a theoretical estimate of the tide level; Bottom: corrected and uncorrected raw (unsmoothed) measurements and a theoretical estimate of the tide level.

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Appendix A - Calibration Certificates.

Hydrophones:

1. Certificate # 18-06-2003	Hydrophone # Г3304-0.1 №51	Type G33 (Г33)
2. Certificate # 19-06-2003	Hydrophone # Г3304-0.1 № 64	Type G33 (Г33)
3. Certificate # 21-06-2003	Hydrophone # Г3304-0.1 №84	Type G33 (Г33)
4. Certificate # 22-06-2003	Hydrophone # Г3304-0.1 №113	Type G33 (Г33)
5. Certificate # 5/24-002-05	Hydrophone # Г3304 № 112	Type G33 (Г33)
	Hydrophone # Г3304 № 125	Type G33 (Г33)
	Hydrophone # Г3304 № 24	Type G33 (Г33)
	Hydrophone # Г3304 № 41	Type G33 (Г33)
	Hydrophone # Г3304 № 28	Type G33 (Г33)
	Hydrophone # Г3304 № 12	Type G33 (Г33)
6. Certificate # 5/24-004-05	Hydrophone # ГИ-50 № 003	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 004	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 006	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 018	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 010	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 008	Type GI-50 (ГИ-50)
7. Certificate # 5/24-005-05	Hydrophone # GI-50 №015	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 007	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 023	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 012	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 021	Type GI-50 (ГИ-50)
	Hydrophone # ГИ-50 № 017	Type GI-50 (ГИ-50)
8. Certificate # 17-06-2004	Hydrophone # Г61 №10	Type G61 (Г61)
9. Certificate # 19-06-2004	Hydrophone # Г61 №13	Type G61 (Г61)

SVXtra hydrologic sonde:

1. Equipment Checklist
2. SVXtra Calibration and Instrument build record

3. Conductivity sensor Calibration record	SN #10905	Type 62R
4. Sound Velocity sensor Calibration record	SN #10903	Type 100 mm
5. Pressure sensor Calibration record	SN # 1599575	Type PDCR4000
6. Temperature sensor Calibration record	SN # 405	Type PRT

Государственное предприятие
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141570, Московская обл.,
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ГМЦГИ

СВИДЕТЕЛЬСТВО № 18-06-2003

о первичной (периодической) поверке
рабочего гидрофона

Рабочий гидрофон типа Г3304-0.1 заводской № 51, рассчитанный на диапазон частот 5 ÷ 16000 Гц,

разработанный и изготовленный ГП “ВНИИФТРИ”,

принадлежащий ГМЦГИ,

на основании результатов государственной периодической поверки, признан годным и допущен к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 5 ÷ 16000 Гц, в соответствии с государственной поверочной схемой по МИ 2098-90.

Приложение: Инструкция по эксплуатации. Гидрофоны типа Г33.

10 июня 2003 г.
Срок действия свидетельства до 10 июня 2004 г.

ГОССТАНДАРТ РОССИИ ГНМЦ ВНИИФТРИ

Ученый хранитель
УВТ 71-А-90 С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г3304-0.1 заводской № 51

Результаты измерения чувствительности Г3304-0.1 № 51.

F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па
5	38,6	63	50,9	1000	51,5	12500	34,0
6,3	41,7	80	50,9	1250	51,0	16000	40,5
8	42,0	100	50,9	1600	51,0	20000	—
10	45,0	125	51,0	2000	48,4	25000	—
12,5	46,7	160	51,2	2500	51,2	31500	—
16	48,2	200	51,2	3150	49,6	40000	—
20	50,6	315	51,2	4000	52,3	50000	—
25	50,7	400	51,4	5000	30,9	63000	—
31,5	50,8	500	51,4	6300	33,8	80000	—
40	50,8	630	51,4	8000	32,1	100000	—
50	50,8	800	51,5	10000	28,4		
1,0	12,2	2,0	23,0	4,0	36,4		
1,25	15,2	2,5	28,2				Исаенко А.И.П.
1,6	18,6	3,15	31,9				

Доверительная относительная погрешность поверки при доверительной вероятности P=0,95 не превышает 1,0 дБ в диапазоне 5 – 1000 Гц и 2,0 дБ в диапазоне 1250 – 10000 Гц.

Температура воды при измерениях находилась в пределах 15 ± 2,0 °С.

ПРИМЕЧАНИЯ 1 Рабочий гидрофона следует применять только на частотах треть октавного ряда в диапазоне частот, указанном в свидетельстве о поверке.

2 При измерениях гидрофон ориентировался риской на источник звука.

Поверитель Л.Ф. Кособродова

Государственное предприятие
"Всероссийский научно-исследовательский институт
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ГП "ВНИИФТРИ"
ГОСУДАРСТВЕННЫЙ МЕТРОЛОГИЧЕСКИЙ ЦЕНТР
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СВИДЕТЕЛЬСТВО № 19-06-2003

о первичной (периодической) поверке
рабочего гидрофона

Рабочий гидрофон типа Г3304-0.1 заводской № 64, рассчитанный на диапазон частот 5 ÷ 16000 Гц,

разработанный и изготовленный ГП "ВНИИФТРИ",

принадлежащий ГМЦГИ,

на основании результатов государственной периодической поверки, признан годным и допущен к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 5 ÷ 16000 Гц, в соответствии с государственной поверочной схемой по МИ 2098-90.

Приложение: Инструкция по эксплуатации. Гидрофоны типа Г33.

10 июня 2003 г.
Срок действия свидетельства до 10 июня 2004 г.

Ученый хранитель
УВТ 71-А-90 С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г3304-0.1 заводской № 64

Результаты измерения чувствительности Г3304-0.1 № 64.

F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па
5	43,6	63	52,2	1000	52,8	12500	27,7
6,3	46,7	80	52,5	1250	53,0	16000	32,4
8	48,3	100	52,5	1600	53,0	20000	—
10	50,0	125	52,5	2000	54,5	25000	—
12,5	51,2	160	52,5	2500	56,1	31500	—
16	52,0	200	52,5	3150	51,3	40000	—
20	52,2	315	52,6	4000	49,1	50000	—
25	52,2	400	52,6	5000	37,9	63000	—
31,5	52,2	500	52,6	6300	34,8	80000	—
40	52,2	630	52,8	8000	27,9	100000	—
50	52,2	800	52,8	10000	23,5		—
1,0	11,7	2,0	25,0	4.0	40,6		
1,25	15,5	2,5	29,8				Исаенков И.П.
1,6	19,4	3,15	34,5				

Доверительная относительная погрешность поверки при доверительной вероятности Р=0,95 не превышает 1,0 дБ в диапазоне 5 – 1000 Гц и 2,0 дБ в диапазоне 1250 – 10000 Гц.

Температура воды при измерениях находилась в пределах 15 ± 2,0 °С.

ПРИМЕЧАНИЯ 1 Рабочий гидрофона следует применять только на частотах треть октавного ряда в диапазоне частот, указанном в свидетельстве о поверке.

2 При измерениях гидрофон ориентировался риской на источник звука.

Поверитель Л.Ф. Кособродова

Государственное предприятие
“Всероссийский научно-исследовательский институт
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ГМЦГИ

СВИДЕТЕЛЬСТВО № 21-06-2003

о первичной (периодической) поверке
рабочего гидрофона

Рабочий гидрофон типа Г3304-0.1 заводской № 84, рассчитанный на диапазон частот 5 ÷ 16000 Гц,

разработанный и изготовленный ГП “ВНИИФТРИ”,

принадлежащий ГМЦГИ,

на основании результатов государственной периодической поверки, признан годным и допущен к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 5 ÷ 16000 Гц, в соответствии с государственной поверочной схемой по МИ 2098-90.

Приложение: Инструкция по эксплуатации. Гидрофоны типа Г33.

10 июня 2003 г.
Срок действия свидетельства до 10 июня 2004 г.

ГОССТАНДАРТ РОССИИ
ОТЗ
ГНМЦ
ВНИИФТРИ

Ученый хранитель
УВТ 71-А-90 С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г3304-0.1 заводской № 84

Результаты измерения чувствительности Г3304-0.1 № 84.

F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па
5	43,7	63	50,4	1000	50,8	12500	27,0
6,3	45,4	80	50,4	1250	51,2	16000	35,4
8	46,9	100	50,4	1600	51,2	20000	—
10	49,0	125	50,6	2000	52,3	25000	—
12,5	49,4	160	50,6	2500	54,4	31500	—
16	50,0	200	50,6	3150	54,2	40000	—
20	50,2	315	50,6	4000	43,9	50000	—
25	50,3	400	50,6	5000	36,5	63000	—
31,5	50,4	500	50,6	6300	38,3	80000	—
40	50,4	630	50,6	8000	30,5	100000	—
50	50,4	800	50,8	10000	27,8		—
1.0	12,6	2,0	26,1	4,0	41.2		
1,25	16,8	2,5	31,5				Исаенко И.Б.
1,6	21,0	3,15	35,3				

Доверительная относительная погрешность поверки при доверительной вероятности Р=0,95 не превышает 1,0 дБ в диапазоне 5 – 1000 Гц и 2,0 дБ в диапазоне 1250 – 10000 Гц.

Температура воды при измерениях находилась в пределах 15 ± 2,0 °С.

ПРИМЕЧАНИЯ 1 Рабочий гидрофона следует применять только на частотах треть октавного ряда в диапазоне частот, указанном в свидетельстве о поверке.

2 При измерениях гидрофон ориентировался риской на источник звука.

Поверитель Л.Ф. Кособродова

Государственное предприятие
“Всероссийский научно-исследовательский институт
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ГМЦГИ

СВИДЕТЕЛЬСТВО № 22-06-2003

о первичной (периодической) поверке
рабочего гидрофона

Рабочий гидрофон типа Г3304-0.1 заводской № 113, рассчитанный на диапазон частот 5 ÷ 16000 Гц,

разработанный и изготовленный ГП “ВНИИФТРИ”,

принадлежащий ГМЦГИ,

на основании результатов государственной периодической поверки, признан годным и допущен к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 5 ÷ 16000 Гц, в соответствии с государственной поверочной схемой по МИ 2098-90.

Приложение: Инструкция по эксплуатации. Гидрофоны типа Г33.

10 июня 2003 г.
Срок действия свидетельства до 10 июня 2004 г.

Ученый хранитель
УВТ 71-А-90 С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г3304-0.1 заводской № 113

Результаты измерения чувствительности Г3304-0.1 № 113.

F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па	F, Гц	М,мВ/Па
5	46,7	63	50,9	1000	51,6	12500	29,9
6,3	47,2	80	50,9	1250	51,6	16000	36,3
8	49,3	100	50,9	1600	51,6	20000	—
10	50,0	125	51,0	2000	50,9	25000	—
12,5	50,2	160	51,2	2500	52,9	31500	—
16	50,4	200	51,2	3150	51,2	40000	—
20	50,6	315	51,3	4000	53,3	50000	—
25	50,8	400	51,4	5000	42,1	63000	—
31,5	50,8	500	51,4	6300	28,7	80000	—
40	50,8	630	51,4	8000	29,2	100000	—
50	50,8	800	51,5	10000	27,6		—
1,0	15,6	2,0	30,7	4,0	43,7		
1,25	19,5	2,5	35,5				Исаенко И.Б.
1,6	25,1	3,15	40,2				

Доверительная относительная погрешность поверки при доверительной вероятности Р=0,95 не превышает 1,0 дБ в диапазоне 5 – 1000 Гц и 2,0 дБ в диапазоне 1250 – 10000 Гц.

Температура воды при измерениях находилась в пределах 15 ± 2,0 °С.

ПРИМЕЧАНИЯ 1 Рабочий гидрофона следует применять только на частотах треть октавного ряда в диапазоне частот, указанном в свидетельстве о поверке.

2 При измерениях гидрофон ориентировался риской на источник звука.

Поверитель Л.Ф. Кособродова

МИНИСТЕРСТВО
ПРОМЫШЛЕННОСТИ И ЭНЕРГЕТИКИ
РОССИЙСКОЙ ФЕДЕРАЦИИ

ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ
И МЕТРОЛОГИИ

ВНИИФТРИ

**ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ
УНИТАРНОЕ ПРЕДПРИЯТИЕ
ВСЕРОССИЙСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
ФИЗИКО-ТЕХНИЧЕСКИХ И РАДИОТЕХНИЧЕСКИХ ИЗМЕРЕНИЙ**

ФГУП ВНИИФТРИ

СВИДЕТЕЛЬСТВО

о поверке

№ 5/24-002-05

Действительно до

“ 05 “ апреля 2006 г.

Средство измерений рабочие измерительные гидрофоны типа Г3304;

заводские № № 112, 125, 24, 41, 28, 12;

Серия и номер клейма предыдущей поверки (если такие серия и номер имеются)

рассчитанные на диапазон частот 1,25 Гц ÷ 16,0 кГц;

принадлежащие ФГУП “ВНИИФТРИ”;

поверены и на основании результатов первичной (периодической) поверки признаны пригодными к применению.

Поверительное клеймо 0 С Т 5 ГУИП ВНИИФТРИ

Начальник лаборатории № 24 С.Ф. Некрич

Поверитель Л.Ф. Кособродова

Дата “05” апреля 2005 г.

0000561

ЗАО фирма"ЭПО", г.Москва, з.522, 2004 г., уровень"В".Тир.14400

Результаты поверки

рабочих измерительных гидрофонов типа Г3304.

Значения чувствительности Мгг рабочих измерительных гидрофонов приведены в таблице.

Тип	Г3304-10		Г3304-0,1			
№	112	125	24	41	28	12
Частота Гц	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па
1,25	0,08	0,08	0,08	0,06	0,07	0,06
3,15	0,26	0,25	0,28	0,22	0,24	0,21
6,3	0,87	0,87	0,98	0,76	0,84	0,66
12,5	3,3	3,4	3,6	3,0	3,3	2,6
20	6,6	6,9	6,9	6,2	6,4	5,6
31,5	9,1	9,2	9,1	8,8	8,9	8,2
63	10,3	10,3	10,2	10,1	10,0	10,0
80	10,4	10,4	10,3	10,2	10,2	10,1
125	10,4	10,4	10,3	10,3	10,3	10,3
250	10,4	10,4	10,3	10,3	10,3	10,3
315	10,4	10,4	10,3	10,3	10,3	10,3
500	10,3	10,3	10,2	10,2	10,2	10,2
800	10,3	10,2	10,1	10,2	10,2	10,2
1000	10,0	10,1	10,0	9,9	10,0	9,8
2000	9,8	9,8	10,0	9,7	9,9	9,5
3150	9,5	9,6	9,8	8,6	10,1	8,9
4000	9,4	8,6	9,9	9,5	9,8	9,5
5000	7,0	8,2	9,1	7,5	6,8	6,6
6300	7,3	6,5	5,3	6,9	8,0	6,9
8000	6,3	6,1	6,2	6,5	6,5	6,7
10000	6,3	3,5	4,8	5,6	6,4	4,1
12500	5,9	2,9	3,9	4,7	5,1	5,1
16000	8,5	5,9	6,6	6,3	7,8	8,4

Температура воды находилась в пределах от 15 до 19 С

Доверительная относительная погрешность поверки (градуировки) при доверительной вероятности Р=0,95 не превышала 1,5 дБ.

ПРИМЕЧАНИЕ. При измерениях гидрофон следует ориентировать риской на источник звука.

Измерения проводили

Поверитель В.А. Смелов

Поверитель Л.Ф. Кособродова

Дата

МИНИСТЕРСТВО
ПРОМЫШЛЕННОСТИ И ЭНЕРГЕТИКИ
РОССИЙСКОЙ ФЕДЕРАЦИИ

ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ
И МЕТРОЛОГИИ

ВНИИФТРИ

**ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ
УНИТАРНОЕ ПРЕДПРИЯТИЕ
ВСЕРОССИЙСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
ФИЗИКО-ТЕХНИЧЕСКИХ И РАДИОТЕХНИЧЕСКИХ ИЗМЕРЕНИЙ**

ФГУП ВНИИФТРИ

СВИДЕТЕЛЬСТВО

о поверке

№ 5/24-004-05

Действительно до
"05" апреля 2006 г.

Средство измерений рабочие измерительные гидрофоны типа ГИ50;
заводские № № 003, 004, 006, 018, 010, 008;

Серия и номер клейма предыдущей поверки (если такие серия и номер имеются)

рассчитанные на диапазон частот 1,25 Гц ÷ 16,0 кГц;
принадлежащие ФГУП "ВНИИФТРИ";
поверены и на основании результатов первичной (периодической) поверки признаны пригодными к применению.

Поверительное клеймо

Начальник лаборатории № 24 С.Ф. Некрич

Поверитель Л.Ф. Кособродова

Дата "05" апреля 2005 г.

0000563

ЗАО фирма "ЭПО", г. Москва, з.522, 2004 г., уровень "В". Тир.14400

Результаты поверки

рабочих измерительных гидрофонов типа ГИ50.

Значения чувствительности $M_{гг}$ рабочих измерительных гидрофонов приведены в таблице.

Тип	ГИ50					
№	003	004	006	018	010	008
Частота Гц	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па
1,25	0,24	0,24	0,25	0,24	0,24	0,028
3,15	1,24	1,23	1,18	1,20	1,18	0,06
6,3	5,2	5,3	4,6	5,2	5,0	0,17
12,5	19,4	19,7	16,7	19,7	19,2	0,57
20	36,7	37,4	33,3	37,6	37,1	1,09
31,5	46,3	47,4	44,5	47,3	47,3	1,45
63	48,8	50,0	48,1	49,7	50,1	1,56
80	49,3	50,1	48,5	49,8	50,3	1,56
125	50,0	50,0	49,0	50,0	50,3	1,56
250	50,0	50,2	49,5	50,1	50,3	1,57
315	50,0	50,3	49,8	50,1	50,3	1,57
500	50,0	50,1	49,8	50,0	50,1	1,58
800	49,5	50,0	49,3	50,0	50,0	1,56
1000	49,4	49,6	49,0	49,5	49,5	1,55
2000	47,7	48,8	48,1	48,0	48,3	1,54
3150	43,7	49,4	46,3	46,3	47,7	1,55
4000	48,8	52,6	50,5	51,1	50,8	1,62
5000	49,6	52,4	47,2	44,6	48,7	1,55
6300	50,0	51,9	47,9	48,3	47,8	1,59
8000	48,6	52,2	48,3	47,8	48,7	1,63
10000	45,9	50,1	46,9	44,9	47,4	1,53
12500	43,6	47,3	44,6	43,2	51,1	1,52
16000	46,7	49,2	43,5	44,6	48,3	1,63

Температура воды находилась в пределах от 15 до 19 С

Доверительная относительная погрешность поверки (градуировки) при доверительной вероятности P=0,95 не превышала 1,5 дБ.

ПРИМЕЧАНИЕ. При измерениях гидрофон следует ориентировать риской на источник звука.

Измерения проводили

Поверитель В.А. Смелов

Поверитель Л.Ф. Кособродова

Дата

МИНИСТЕРСТВО
ПРОМЫШЛЕННОСТИ И ЭНЕРГЕТИКИ
РОССИЙСКОЙ ФЕДЕРАЦИИ

ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ
И МЕТРОЛОГИИ

ВНИИФТРИ

**ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ
УНИТАРНОЕ ПРЕДПРИЯТИЕ
ВСЕРОССИЙСКИЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
ФИЗИКО-ТЕХНИЧЕСКИХ И РАДИОТЕХНИЧЕСКИХ ИЗМЕРЕНИЙ**

ФГУП ВНИИФТРИ

СВИДЕТЕЛЬСТВО

о поверке

№ 5/24-005-05

Действительно до

" 05 " апреля 2006 г.

Средство измерений рабочие измерительные гидрофоны типа ГИ50;

заводские № № 015, 007, 023, 012, 021, 017;

Серия и номер клейма предыдущей поверки (если такие серия и номер имеются)

рассчитанные на диапазон частот 1,25 Гц ÷ 16,0 кГц;

принадлежащие ФГУП "ВНИИФТРИ";

поверены и на основании результатов первичной (периодической) поверки признаны пригодными к применению.

Поверительное клеймо 05 ФГУП ВНИИФТРИ

Начальник лаборатории № 24 С.Ф. Некрич

Поверитель Л.Ф. Кособродова

Дата "05" апреля 2005 г.

0000564

Результаты поверки

рабочих измерительных гидрофонов типа ГИ50.

Значения чувствительности $М_{гг}$ рабочих измерительных гидрофонов приведены в таблице.

Тип	ГИ50					
№	015	07	023	012	021	017
Частота Гц	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па	Мгг мВ/Па
1,25	0,23	0,23	0,24	0,24	0,22	0,24
3,15	1,20	1,15	1,21	1,15	1,10	1,21
6,3	5,1	4,8	5,2	4,6	4,5	5,2
12,5	18,9	18,1	19,4	16,6	16,8	19,4
20	36,7	35,9	36,6	33,3	34,1	37,0
31,5	47,3	46,7	45,9	44,8	47,4	46,9
63	50,3	49,9	48,5	48,4	49,9	49,2
80	50,0	50,0	48,9	48,8	50,5	49,8
125	50,1	50,0	50,0	49,3	50,5	50,1
250	50,0	50,0	50,0	49,8	50,5	50,3
315	50,0	50,0	50,0	49,6	50,6	50,3
500	50,0	50,0	50,0	49,5	50,5	50,1
800	50,0	50,0	49,5	49,2	50,2	50,0
1000	49,7	49,5	49,2	49,0	50,0	49,4
2000	48,3	47,3	49,5	49,0	48,5	49,2
3150	50,2	41,5	51,2	48,9	48,2	50,1
4000	51,8	47,7	51,3	51,4	51,7	52,1
5000	51,9	47,9	47,1	48,4	48,4	51,0
6300	51,9	48,4	48,3	48,8	50,4	50,4
8000	51,8	47,8	47,1	50,7	51,0	51,0
10000	46,7	47,4	49,6	51,8	44,7	46,8
12500	49,7	46,7	42,9	45,8	45,1	42,8
16000	47,8	45,4	46,4	54,1	49,1	52,0

Температура воды находилась в пределах от 15 до 19 С

Доверительная относительная погрешность поверки (градуировки) при доверительной вероятности Р=0,95 не превышала 1,5 дБ.

ПРИМЕЧАНИЕ.   При измерениях гидрофон следует ориентировать риской на источник звука.

Измерения проводили

Поверитель В.А. Смелов

Поверитель Л.Ф. Кособродова

Дата

Федеральное государственное унитарное предприятие
“Всероссийский научно-исследовательский институт
физико-технических и радиотехнических измерений”
ФГУП “ВНИИФТРИ”
ГОСУДАРСТВЕННЫЙ МЕТРОЛОГИЧЕСКИЙ ЦЕНТР
ГИДРОАКУСТИЧЕСКИХ ИЗМЕРЕНИЙ
ГМЦГИ

141570, Московская обл.,
п/о Менделеево, ГП ВНИИФТРИ

СВИДЕТЕЛЬСТВО

О ПОВЕРКЕ

№ 17-06-2004

Действительно до
1 июня 2005 г.

Средство измерений, рабочий гидрофон типа Г61
заводской № 10,
принадлежащее ФГУП “ВНИИФТРИ”,
поверено с применением РЭ-2 «УГПА-100» №01,

на основании результатов периодической поверки, признано пригодным к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 1 Гц ÷ 20000 Гц .

1 июня 2004 г

Начальник лаборатории № 24
ГМЦГИ

ГОССТАНДАРТ РОССИИ
О Т 4
ГНМЦ
ВНИИФТРИ

С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г61 заводской № 10

Результаты измерения чувствительности М гидрофона типа Г61 заводской № 10 приведены в таблице 1.

Таблица 1

F, Гц	М, мВ/Па	дБ отн. 1 мкВ/Па	F, Гц	М, мВ/Па	дБ отн. 1 мкВ/Па
1	3,39	70,60	63	55,75	94,92
1,25	4,57	73,20	80	55,54	94,89
1,6	6,04	75,62	100	55,71	94,92
2	7,86	77,91	125	56,77	95,08
2,5	9,97	79,97	160	56,41	95,03
3,15	12,2	81,73	200	56,72	95,07
4	15,58	83,85	250	56,72	95,07
5	18,99	85,57	315	56,59	95,05
6,3	23,25	87,33	400	56,88	95,10
8	27,56	88,81	500	56,86	95,10
10	32,43	90,22	630	56,33	95,01
12,5	37,04	91,37	800	56,66	95,07
16	41,76	92,42	1000	57,05	95,13
20	45,21	93,10	1250		
25	47,85	93,60	1600		
31,5	50,94	94,14	2000		
40	52,85	94,46	2500		
50	53,52	94,57	3150		

Доверительная относительная погрешность поверки при доверительной вероятности P=0,95 не превышает 1,0 дБ.

Избыточное статическое давление 0,1 МПа.

Температура воды при измерениях находилась в пределах 15 ± 1,0 °С.

ПРИМЕЧАНИЕ Погрешность градуировки гарантируется только на частотах и давлениях, указанных в свидетельстве о поверке.

Измерения проводил

Поверитель Л.Ф. Кособродова

Результаты измерения чувствительности М
гидрофона типа Г61
заводской № 10

Продолжение таблицы 1.

F, кГц	М, мВ/Па	дБ отн. 1 мкВ/Па	F, кГц	М, мВ/Па	дБ отн. 1 мкВ/Па
1	57,1	95,1	5	51,3	94,2
1,25	56,6	95,0	6,3	38,1	91,6
1,6	57,1	95,1	8	33,0	90,4
2	56,8	95,0	10	31,7	90,0
2,5	56,0	94,9	12,5	33,0	90,4
3,15	55,6	94,9	16	50,0	93,9
4	55,7	94,9	20		

Федеральное государственное унитарное предприятие
“Всероссийский научно-исследовательский институт
физико-технических и радиотехнических измерений”
ФГУП “ВНИИФТРИ”
ГОСУДАРСТВЕННЫЙ МЕТРОЛОГИЧЕСКИЙ ЦЕНТР
ГИДРОАКУСТИЧЕСКИХ ИЗМЕРЕНИЙ
ГМЦГИ

141570, Московская обл.,
п/о Менделеево, ГП ВНИИФТРИ

СВИДЕТЕЛЬСТВО

О ПОВЕРКЕ

№ 19-06-2004

Действительно до
1 июня 2005 г.

Средство измерений, рабочий гидрофон типа Г61
заводской № 13,
принадлежащее ФГУП “ВНИИФТРИ”,
поверено с применением РЭ-2 «УГПА-100» №01,

на основании результатов периодической поверки, признано пригодным к применению в качестве рабочего гидрофона, предназначенного для измерения звукового давления в водной среде в диапазоне частот 1 Гц ÷ 20000 Гц .

1 июня 2004 г

Начальник лаборатории № 24
ГМЦГИ

ГОССТАНДАРТ РОССИИ
G
О Т 4
ГНМЦ
ВНИИФТРИ

С.Ф. Некрич

Результаты периодической поверки
гидрофона типа Г61 заводской № 13

Результаты измерения чувствительности М гидрофона типа Г61 заводской № 13 приведены в таблице 1.

Таблица 1

F, Гц	М, мВ/Па	дБ отн. 1 мкВ/Па	F, Гц	М, мВ/Па	дБ отн. 1 мкВ/Па
1	3,97	71,98	63	54,41	94,71
1,25	5,13	74,20	80	54,23	94,68
1,6	6,71	76,53	100	54,5	94,73
2	8,69	78,78	125	54,78	94,77
2,5	10,82	80,68	160	54,81	94,78
3,15	13,73	82,75	200	54,48	94,72
4	17,29	84,76	250	54,56	94,74
5	21,29	86,56	315	54,59	94,74
6,3	25,55	88,15	400	54,64	94,75
8	30,64	89,73	500	54,24	94,69
10	35,68	91,05	630	54,01	94,65
12,5	40,18	92,08	800	54,82	94,78
16	44,53	92,97	1000	54,13	94,67
20	48,59	93,73	1250		
25	51,77	94,28	1600		
31,5	54,55	94,74	2000		
40	54,66	94,75	2500		
50	54,22	94,68	3150		

Доверительная относительная погрешность поверки при доверительной вероятности Р=0,95 не превышает 1,0 дБ.

Избыточное статическое давление 0,1 МПа.

Температура воды при измерениях находилась в пределах 15 ± 1,0 °С.

ПРИМЕЧАНИЕ Погрешность градуировки гарантируется только на частотах и давлениях, указанных в свидетельстве о поверке.

Измерения проводил

Поверитель Л.Ф. Кособродова

Результаты измерения чувствительности М
гидрофона типа Г61
заводской № 13

Продолжение таблицы 1.

F, кГц	М, мВ/Па	дБ отн. 1 мкВ/Па	F, кГц	М, мВ/Па	дБ отн. 1 мкВ/Па
1	54,1	94,6	5	35,7	91,1
1,25	54,2	94,6	6,3	28,2	89
1,6	54,4	94,7	8	29,4	89,4
2	54,5	94,7	10	29,3	89,4
2,5	54,8	94,7	12,5	30,1	89,6
3,15	54,3	94,7	16	42,1	92,5
4	54,6	94,7	20		

7 EQUIPMENT CHECKLIST

Serial No. 21001.	Model No. SV Extra System
Customer: Technopole Company.	Con Number: 12992.
5-183 Entuziastov Street.	Customer Ref: 03/141.
Dubna, Moscow Region.	Del. Note: –
141980 Russia.	Calibration Cert.: C-14156.

ITEM	Quantity	Serial Number	Initials
Hardware			
Model SVXtra Sound Velocity Profiler	1	21001	
1.5v alkaline cells fitted	8		
Zinc anode fitted	1		
Stainless steel deployment frame	1		
3m Y Lead	1		
Switching Plug	1		
Tools and Accessories Kit	1		
Signal cable on hand reel (m)	–	–	–
Transit Case	1		
Software			
DataLog 400 CDROM	1	400-707 G8.	
Documentation			
Operating Manual	1		
Calibration Certificate Enclosed	1		

SIGNED ....

DATE 11th July 2003.....

Calibration and Instrument build record					Valeport Ltd. Dartmouth, Devon, UK
Calibration certificate number			14156		
Instrument type			SVExtra		
Serial number			21001		
Communications set up ex-factory			RS232		
Baud rate set ex factory			AUTO		
Main micro software version & Date			0400703V	15/05/2003	

PCBs	Part	Version	Ser No		
PSU 1	0400501	C	9660		
PSU 2	0400502	C	9768		
Micro	0400500	D	10474		
RAM	0400511	C	8460		
Flash Memory & Size	0400506	C	8646	8	Mbyte
Press/Temp	0400507	D	10053		
SVP	0650500	C	8610		
Conductivity	0400507	B	7619		
Conductivity	0400505	B	10107		
Redox	0400517	A	N/A		
Do	0400517	A	N/A		
Ph	0400517	A	N/A		
Turbidity	0400517	A	N/A		
FSK Line	0400521	B	N/A		
FSK Micro	0400520	B	N/A		Code

Calibrations for each sensor/PCB are on separate sheets, with filenames defined by the PCB serial number

Name	PJT
Date	10.07.03
Signed	

21001B400 Calibrated to Valeport's procedures using test equipment with calibrations traceable to NAMAS or national standards 11/07/2003 08:45

Sensor Calibration Record — CONDUCTIVITY — Valeport Ltd

No. of Conductivity PCBs	2		
400 PCB		400 PCB	
Serial no.	7619	Serial no.	10107
Part no.	0400507E	Part no.	0400505B
Firmware	0400702F		
Module address set	10		

Conductivity sensor	
Serial no.	10905
Type	62R

Calibration Equipment used

Instrument	Type	Serial No
Multimeter	HP34401	US36049071
Decade Box	Hatfield 2901	51262
Temp Bridge	ASL - F26	14-005
PRT	S17915/A T25/62	X1984A/ITE MA/93
Autosal	8400B	65741

Stage 1: Circuit Calibration with Resistance Loop

Decade box setting Ohms	Measured Resistance [Through coil] Ohms	Counts nnnn	1/R 1/Ohms	Polynomial fit for 1/R: Order >>>>	3	Calc 1/R from polynomial output	1/R Error [Calc - Actual]	Calc.Cond. from final polynomial	Cond. Error [Calc-Actual] mS/cm	Acceptable Error	Pass/Fail
				Parameter	Value						
62	62.557	36987	0.0159854	a0	-4.639238E-04	0.015985292	-1.2944E-07	83.28000493	-0.001	±0.01	Pass
70	70.767	32829	0.0141309	a1	4.431983E-07	0.014131227	3.46685E-07	73.62071684	0.002	±0.01	Pass
82	82.570	28295	0.0121109	a2	4.777838E-14	0.012110719	-2.1739E-07	63.09429499	-0.001	±0.01	Pass
99	99.678	23628	0.0100323	a3	-1.723829E-19	0.010032366	6.15219E-08	52.26651218	0.000	±0.01	Pass
124	124.590	19119	0.0080263			0.008025844	-4.81857E-07	41.81295999	-0.003	±0.01	Pass
165	165.530	14657	0.0060412			0.006041755	5.54022E-07	31.47627154	0.003	±0.01	Pass
248	248.480	10117	0.0040245			0.004024625	1.5642E-07	20.96744987	0.001	±0.01	Pass
496	496.930	5583	0.0020124			0.002011912	-4.44308E-07	10.48163561	-0.002	±0.01	Pass
AIR		1047	0.0000000			1.56997E-07	1.56997E-07	0.000817923	0.001	±0.01	Pass

Enter polynomial fit from graph in cell D21: y = -1.723829E-19x3 + 4.777838E-14x2 + 4.431983E-07x - 4.639238E-04

Stage 2: Cell Gain determination and Conductivity polynomial fit

			Polynomial fit for Conductivity	
Autosal temp	°C [IPTS 68]	30	Order	3
Double from Autosal		2.24917	a0	-2.416945E+00
Autosal Salinity	PSU	39.97350	a1	0.00230897
Bath temp	°C [IPTS 90]	15.3130	a2	2.48915E-10
Conductivity from Salinity	mS/cm	48.65593	a3	-8.98079E-16
Bath Salinity (Check)	PSU	39.97350		
Counts from instrument		22071		
Calc.1/R from Counts & Poly fi	1/Ohms	0.009339327		
Cell Gain [Conductivity per 1/R]		5209.789453		

Stage 5: Check readings after calibration entered

		In bath	In air
Autosal temp	°C [IPTS 68]	30	
Double from Autosal		2.24917	
Salinity	PSU	39.97350	
Bath temp	°C [IPTS 90]	15.3130	
Cond. from Sal.	mS/cm	48.65593	0.000
Bath Salinity	PSU	39.97350	
Rdg from instr.	mS/cm	48.652	0.006
Error [Rdg - Act]	mS/cm	-0.004	0.006
Acceptable Error	±0.01	Pass	Pass

Name: PJT
Date: 10.07.03

Stage 3: Enter calibration string: #024;10;1;15;0.000000e+00;0.000000e+00;-8.980786e-16;2.489153e-10;2.308970e-03;-2.416

Stage 4: Enter Gain and Offset values: #035;10;1;500;-20000

Signed

COND7619 — Calibrated to Valeport's procedures using test equipment with calibrations traceable to NAMAS or national standards — 11/07/2003 08:45

Instrument Serial Number	21001				**Calibration Equipment used**					
Transducer Type, mm	100			**Instrument**	**Type**	**Serial No**				
Transducer Ser No	10903			Temp Bridge	ASL - F26	14-005				
PCB Part No	0400524A			PRT	S17915/A T25/62	X1984A/ITE MA/93				
PCB Ser No	8610									
SV Firmware Version	1.05									
Stage 1: First order fit		Temp	Temp	True SoS from DGM	Measured ToF	Coefficients	Calc SoS from coefficients	Error (Calc - True)	Acceptable Error	Pass/Fail
		degC90	degC68	m/s	nsec*100		m/s	m/s	m/s	
		2.0063	**2.0068**	**1412.265**	**14210996**	**7.377900E+04**	1412.265	**0.000**	±0.001	**Pass**
		15.3318	**15.3355**	**1467.100**	**13682594**	**5.008641E+06**	1467.100	**0.000**	±0.001	**Pass**
Stage 2: Enter calibration string		#024;12;1;15;0;0;0;0;5.008641e+06;7.377900e+04								
Stage 3: Check point		Temp	Temp	Actual SoS	Measured SoS	Error SoS Reading-Actual	Acceptable Error	Pass/Fail		
		degC90	degC68	m/s	m/s	m/s	m/s			
		15.3295	15.3332	**1467.092**	1467.092	0.000	±0.005	**Pass**		
							Date:	09.07.03		
							Name:	PJT		
							Signature:			

650CALworksheet8610 Calibrated to Valeport's procedures using test equipment with calibrations traceable to NAMAS or national standards 11/07/2003 08:46

Sensor Calibration Record — **PRESSURE** — **Valeport Ltd**

PCB	Serial no.	10053	**Pressure sensor**		
	Part no.	0400507E	Type	PDCR 4000	
	Firmware	0400700K	Serial no.	1599575	
Module address set		20	Tx Range	600	dBarAbs
			Set Tx Range	1000	dBarAbs

Calibration Equipment used		
Instrument	Type	Serial No
DWT	Budenburg	480L/24175/317E/3295
Barometer	F Darton	J 665

Stage 1: Determine Local pressure conditions

Air temperature	27.2	degC
Grid reference	286362 East, 051466 North	
Height above sea level	122	metres
Local Gravity	9.81095	M/sec^2
Gravity standard for barometer	9.80665	M/sec^2
Atmospheric pressure	761.700	mmHg
	10.1146	dBar

Stage 2: Obtain Calibration data and Polynomial fit

Deadweight weight	Deadweight pressure	Atmospheric Pressure	Counts (nnnn)	Total pressure absolute	Polynomial fit for raw data		Polynomial calculations				
					Order >>>>	2	Calc Press from poly. output	Press Error [Calc - Actual]			
dBar	dBar	dBar	nnnn	dBarA	Parameter	Value	dBarA	dBar	%FS	Acceptable Error	Pass/Fail
0	0.000	10.115	3403	10.115	a0	-6.567846E+01	10.136	0.022	0.002	±0.1	Pass
200	200.127	10.115	12386	210.241	a1	2.228041E-02	210.212	-0.029	-0.003	±0.1	Pass
400	400.253	10.115	21375	410.368	a2	-4.865529E-10	410.343	-0.025	-0.002	±0.1	Pass
600	600.380	10.115	30370	610.494			610.529	0.034	0.003	±0.1	Pass
800	800.506	10.115	39365	810.621			810.636	0.015	0.001	±0.1	Pass
1000	1000.633	10.115	48363	1010.748			1010.731	-0.017	-0.002	±0.1	Pass

Enter polynomial fit from graph in cell E27: y = -4.865529E-10x2 + 2.228041E-02x - 6.567846E+01

Stage 3: Enter calibration string: #024;20;1;15;0;0;0;-4.865529e-10;2.228041e-02;-6.567846e+01

Stage 4: Enter System Gain & Offset: #035;20;1;40;-20000

Stage 5: Post Calibration Check

Deadweight weight	Deadweight pressure	Atmospheric Pressure	Measured pressure	Total pressure	Error [Reading - Actual]			
dBar	dBar	dBar	dBarA	dBarA	dBar	%FS	Acceptable Error	Pass/Fail
0	0.000	10.115	10.150	10.115	0.035	0.004	±0.1	Pass
200	200.127	10.115	210.325	210.241	0.084	0.008	±0.1	Pass
400	400.253	10.115	410.500	410.368	0.132	0.013	±0.1	Pass
600	600.380	10.115	610.575	610.494	0.081	0.008	±0.1	Pass
800	800.506	10.115	810.725	810.621	0.104	0.010	±0.1	Pass
1000	1000.633	10.115	1010.700	1010.748	-0.048	-0.005	±0.1	Pass

Name PJT
Date 09.07.03
Signed

Sensor Calibration Record **TEMPERATURE** **Valeport Ltd**

PCB	Serial no.	10053	Temperature sensor	
	Part no.	0400507E	Type	PRT
	Firmware	0400700K	Serial no.	N405
	Thermistor Type	DS18B20		
Modus address set		20		

Calibration Equipment used

Instrument	Type	Serial No
Temp Bridge	ASL - F26	14-005
PRT	S17915/A T25/62	X1984A/TE MA/93

PCB internal temperature calibration

Stage 1: Obtain PCB temperature calibration data

PCB therm read'g. degC [internal]	Output counts	Best fit slope	Best fit intercept	Correction formula		Times 10	Normalised counts [20] counts	Reading counts	Temp degC
5	35142	-0.231	35143.651	Gain =	0.231	23	35139	35141	25
26	35139			Offset =	-3.468	-347			
38	35134								

Stage 2: Enter calibration string: #085;20;23;-347

PCB/Sensor calibration

Stage 1: Obtain Calibration data and Polynomial fit

Counts	Bath temp	Polynomial fit for raw data		Polynomial calculations			
		Order >>>>	2	Calc Temp from polynomial output	Temp Error [Calc - Actual]		
nnnn	DegC [90]	Parameter	Value	DegC [90]	DegC [90]	Acceptable Error	Pass/Fail
24404	2.053	a0	-2.189302E+01	2.053	0.000	±0.005	Pass
37860	15.324	a1	9.779915E-04	15.324	0.000	±0.005	Pass
57497	34.778	a2	1.330186E-10	34.778	0.000	±0.005	Pass

Enter polynomial in cell E27: y = 1.330186E-10x2 + 9.779915E-04x - 2.189302E+01

Stage 2: Enter calibration string: #024;20;2;15;1;0;0;1.330186e-10;9.779915e-04;-2.189302e+01

Stage 3: Enter System Gain & Offset #035;20;2;1000;-20000

Name: PJT
Date: 09.07.03

Stage 4: Post Calibration Check

Reading DegC [90]	Bath temp DegC [90]	Error [Reading-Actual] DegC [90]	Acceptable Error	Pass/Fail
34.777	34.780	-0.003	±0.005	Pass

Signed

TEMP10053A

Calibrated to Valeport's procedures using test equipment with calibrations traceable to NAMAS or national standards

11/07/2003 08:46

Appendix B - AUAR Instrument Tests.

Instrument Tests for Autonomous Underwater Acoustic Recorder (AUAR)

General performance and calibration tests can be conducted on the equipment to verify consistent performance from recorder to recorder and to calibrate the response of each unit. This can be accomplished with a low distortion sine wave oscillator (if available, otherwise a regular sine wave oscillator may be used), and a rms voltage meter or oscilloscope. In general, all units should have the same response. The equipment specifications are listed at the end of the document; all units should meet these specifications.

System Noise Tests

At the connector where the hydrophone typically mates to the unit, terminate the two pins with a 'short' or a small resistor (the resistance should be approximately equal to the effective output impedance of the pre-amplifier), record data for 30 to 60 seconds. Software analysis should produce rms and DC Offset results along with a spectral analysis. The noise characteristics and levels for all recorders must meet the instrument test specifications.

System Dynamic Range

20 Hz, 200 Hz, 500 Hz, 2 kHz and 5 kHz oscillator signals can be generated, set (using the RMS meter or oscilloscope) at the maximum input signal level of the preamplifiers, to determine an approximate dynamic range of the recorder. The signal should be input prior to the first pre-amplifier. The signal level will be increased in 10 dB steps from the minimum input signal level to the maximum[84], and data will be recorded for 300 seconds.

[84] One possibility is to use a calibrated attenuator with 10 dB steps inserted between the test oscillator and the pre-amp input. The output of the oscillator can then be set initially at a voltage above the expected dynamic range limit and the attenuator stepped down in -10 dB steps to check the pre-amp linearity and distortion as a function of input level. Conversely, the attenuator can be set to provide an input level within the accepted dynamic range of the pre-amp and the attenuation reduced in 10 dB steps to check the overload characteristics of the pre-amp.

If possible the oscillator should be connected to all of the recorders at the same time using a spider cable. The recorded data should be a smooth sine wave, not clipped or distorted at the peaks. Software analysis should produce approximately the same rms values as measured on the rms meter or the same peak values as viewed on the scope. Use the best rms record and the System Noise record to determine the System Dynamic Range. A spectral analysis should show the oscillator signal fundamental and very small harmonics (if any). If harmonics are high then either the signal is clipped or the oscillator is not low distortion. A distortion analysis can be made with software to see the quality of the recorded test signal. All units should have about the same peak levels and should meet the instrument test specifications.

System Filter Response

The amplitude response of the system can be verified and aliasing identified using an oscillator with fixed frequencies throughout the pass band. (5, 10, 20, 100, 500 Hz, and 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10.1, 10.3, 10.5, 11, 12, 13, 14, 15, 15.1, 15.3, 15.5, 16, 17, 18, 19, 20 kHz). The signal should be input prior to the first pre-amplifier and data recorded for 60 seconds. Also record a 300-second record with a broad band white noise input signal.

The tonal signal tests need only be conducted once per unit; the combined results from the tonal signal test and white noise test will be used to define a filter response for each unit. This filter response will be compensated for as the data is processed. The white noise test is the standard filter response test. If the system filter response does not replicate the initial tonal signal test a further tonal test should be conducted.

For both of these tests if possible, pulse all recorders at the same time using a spider cable. Spectral results from these tests should be used to determine the amplitude responses of all the recorders.

Cross-calibration Tests

All recorders should be cross-calibrated at the beginning and end of the program. If significant changes are made to a recorder or recorders they should be cross-calibrated with an unchanged recorder of the same type when possible.

Test Schedule

All recorders should have a full set of instrument tests prior to initial deployment and at the end of the program. These tests should be written to disc.

Before and after each deployment of a recorder the gains, sample rates and key recording settings should be evaluated and written to disc to ensure parameter stability. A new set of instrument tests (not including a cross-calibration test) should be recorded before each deployment.

Instrument tests should be primarily evaluated in the range from 1Hz to 15kHz.

Appendix C - Cross-calibration Results.

At the start of the 2005 expedition a cross-calibration of all 16 AUARs as well as the two digital and four analog sonobuoys used on the *Academik Lavrent'ev and Academik Oparin* for the 2005 field program was conducted on the *Academik Lavrent'ev*. All AUARs and sonobuoys were calibrated by comparing the synchronous spectra of broadband and tonal signals generated by the *Academik Lavrent'ev* and the HF broadband sound transducer.

The field cross-calibration was conducted by tying a number of hydrophones together in a bundle (Figures C.1 and C.4), and deploying them from the *Academik Lavrent'ev* at a depth of 10-15 m while it was drifting in greater than 30 m of water. The hydrophones were divided into groups due to the large number of hydrophones being calibrated and the potential for crossfeed between the sonobuoys during cross-calibration due to the close proximity of the units. One digital sonobuoy DRB-D.2 was used as a control for all the groups. The AUARs and sonobuoys on the *Academik Lavrent'ev* synchronously recorded the signals from these hydrophones. The purpose was to simultaneously record the same signal on all the units, allowing the relative calibrations of the AUARs and sonobuoys to be confirmed[85]. Data was recorded using the operational configurations for the equipment. All spectra were corrected for amplitude and frequency (using the instrument response of each system determined by instrument tests in the laboratory), so the absolute acoustic level of the signal was calculated for the specified frequencies.

Figure C.1 shows how the cross-calibration was conducted on 16 AUARs and one digital sonobuoy (DRB-D.2) and gives a spectral density *G(f)* plot illustrating the results of the cross-calibration in the frequency range from 5 to 2000 Hz. Figure C.2 displays spectra showing the results of the cross-calibration of the 16 AUARs from 5 Hz to 15 kHz.

Analysis of the acoustic field measurements made with the 16 AUARs indicate that in the frequency band 1-600 Hz there is clear narrowband noise generated by the *Academik Lavrent'ev* and at frequencies greater than 1 kHz the acoustic field is dominated by the noise signal from the broadband transducer.

[85] These cross-calibrations allowed the amplitude response (with frequency) of the analog circuits of the AUARs and sonobuoys to be compared with the laboratory measurements. They also allowed the calibrations of the hydrophones to be confirmed.

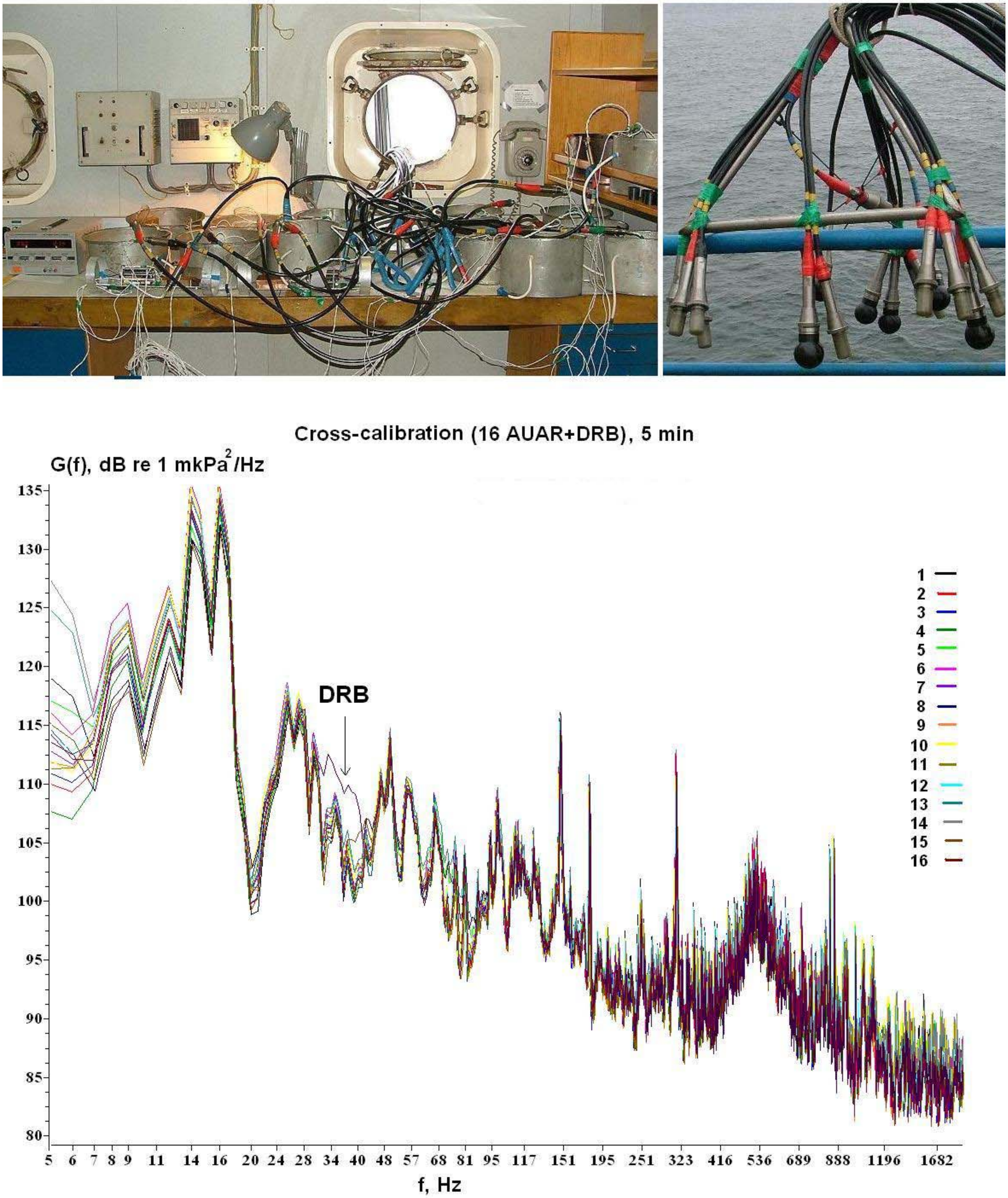


Figure C.1 – Cross-calibration of the 16 AUARs and one digital sonobuoy on the *Academik Lavrent'ev.*

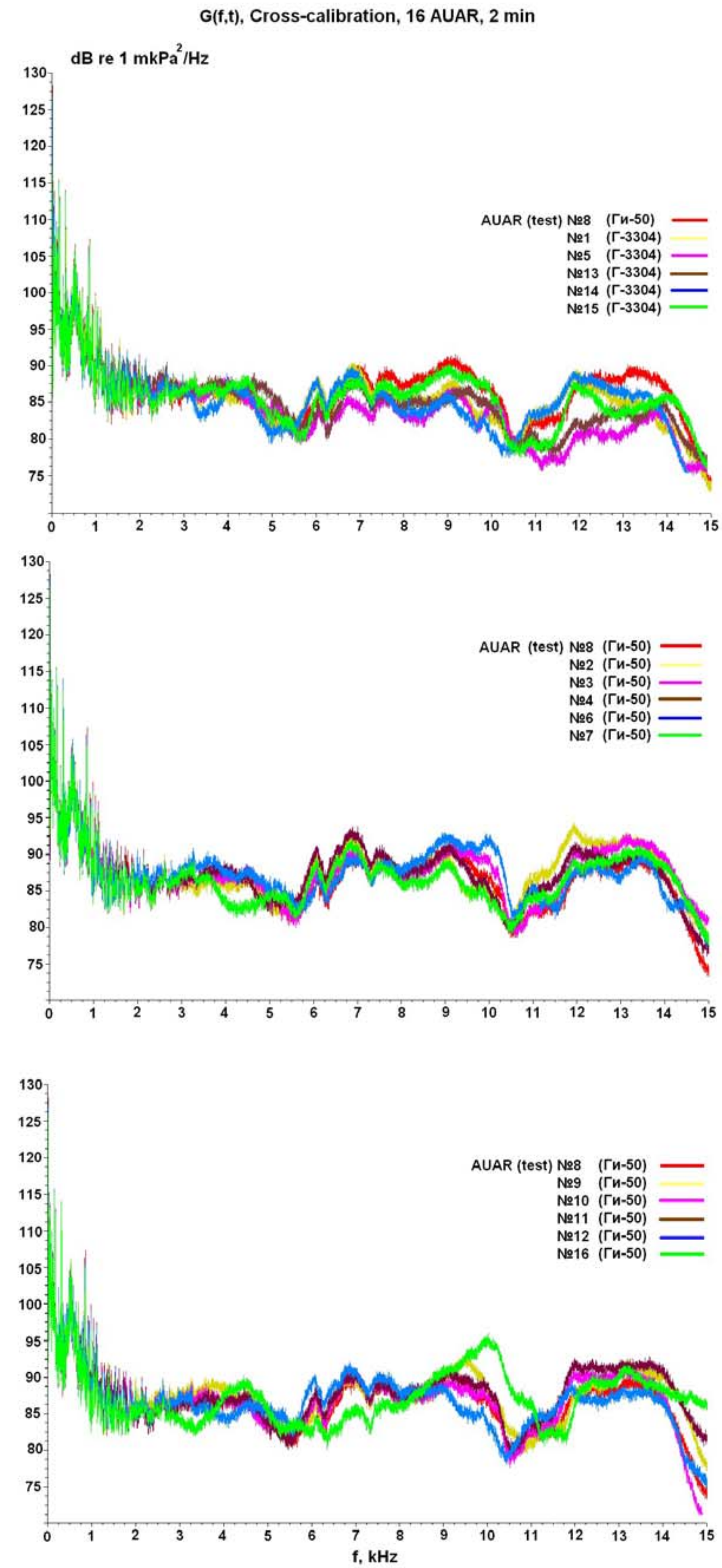


Figure C.2 - Cross calibration analysis - Spectra of signals generated by the *Academik Lavrent'ev* as well as a broadband transducer and synchronously measured by the sixteen AUARs (after instrument response [amplitude-frequency] correction).

Since the acoustic energy is not evenly distributed throughout the frequency band, calculations of the relative errors for the 16 AUARs were made in the following frequency bands: 10-100 Hz, 100-2500 Hz, and 2500-14500 Hz.

Table C.1 is a statistical analysis of the cross-calibration data showing the relative errors in the acoustic field measured by the 16 AUARs and one digital sonobuoy (DRB-D.2) during the cross-calibration; the results were calculated using the following methodology:

1. For each AUAR the integrated power spectral density for the specified frequency band [dB] is calculated using Equation (C1):

$$D_i(\Delta f_j) = 10\log\left(\int_{f_1}^{f_2} G_i(f)df\right) \qquad \text{(C1)}$$

   Where:

   i is the AUAR number,

   j is the frequency band number,

   $G_i(f)$ is the power spectral density of the acoustic field measured by AUAR i at frequency f (Figure C.2),

   f_1, f_2 are the limits of the frequency band j in which the comparative analysis is performed.

   Δf_j is f_2 - f_1

2. The average value [dB] of the spectral density within the frequency band for n AUARs/sonobuoys is calculated using Equation (C2):

$$\overline{D}(\Delta f_j) = \frac{\sum_1^n D_i(\Delta f_j)}{n} \qquad \text{(C2)}$$

   Where:

   n is the number of AUARs/sonobuoys in the group

3. The relative error for AUAR number i in the frequency band Δf_j is calculated using Equation (C3):

$$\sigma_i^{\Delta f_j} = \left|D_i(\Delta f_j) - \overline{D}(\Delta f_j)\right| \qquad \text{(C3)}$$

Table C.1 - Cross-calibration - statistical relative error analysis in the frequency bands 10-100 Hz, 0.1-2.5 kHz and 2.5-14.5 kHz.

	$\sigma_i(\Delta f_j)$ [dB]		
	Δf_1	Δf_2	Δf_3
AUAR #	**f_1 = 10 Hz f_2 = 100 Hz**	**f_1 = 100 Hz f_2 = 2500 Hz**	**f_1 = 2500 Hz f_2 = 14500 Hz**
1	2.9	0.24	1.21
2	1.5	0.16	1.01
3	1.7	0.06	1.21
4	1.4	0.06	0.41
5	1.5	0.14	1.49
6	1.7	0.16	2.69
7	0.9	0.26	0.49
8	2.1	0.14	0.99
9	1.6	0.14	0.99
10	2.6	0.04	0.39
11	2.1	0.04	0.41
12	1.0	0.14	0.89
13	1.1	0.34	0.19
14	0.8	0.06	1.91
15	2.7	0.06	2.21
16	0	0.46	0.81
Mean	1.6	0.156	1.14
DRB-D.2	2.3	0.34	

Figure C.3 displays spectra of acoustic noise generated by the *Academik Lavrent'ev* and tonal signals generated by the HF transducer. These signals are measured approximately synchronously by the radio transmission and recording channels of a T-AUAR. Precise synchronization is not possible between acoustic data recorded by an AUAR and data arriving via its radio link. Analysis of power spectral density levels for these narrowband and tonal signals gives a calibration error between the two channels of less than 3 dB at infra-low frequencies and less than 2 dB in the frequency range from 200 to 2000 Hz.

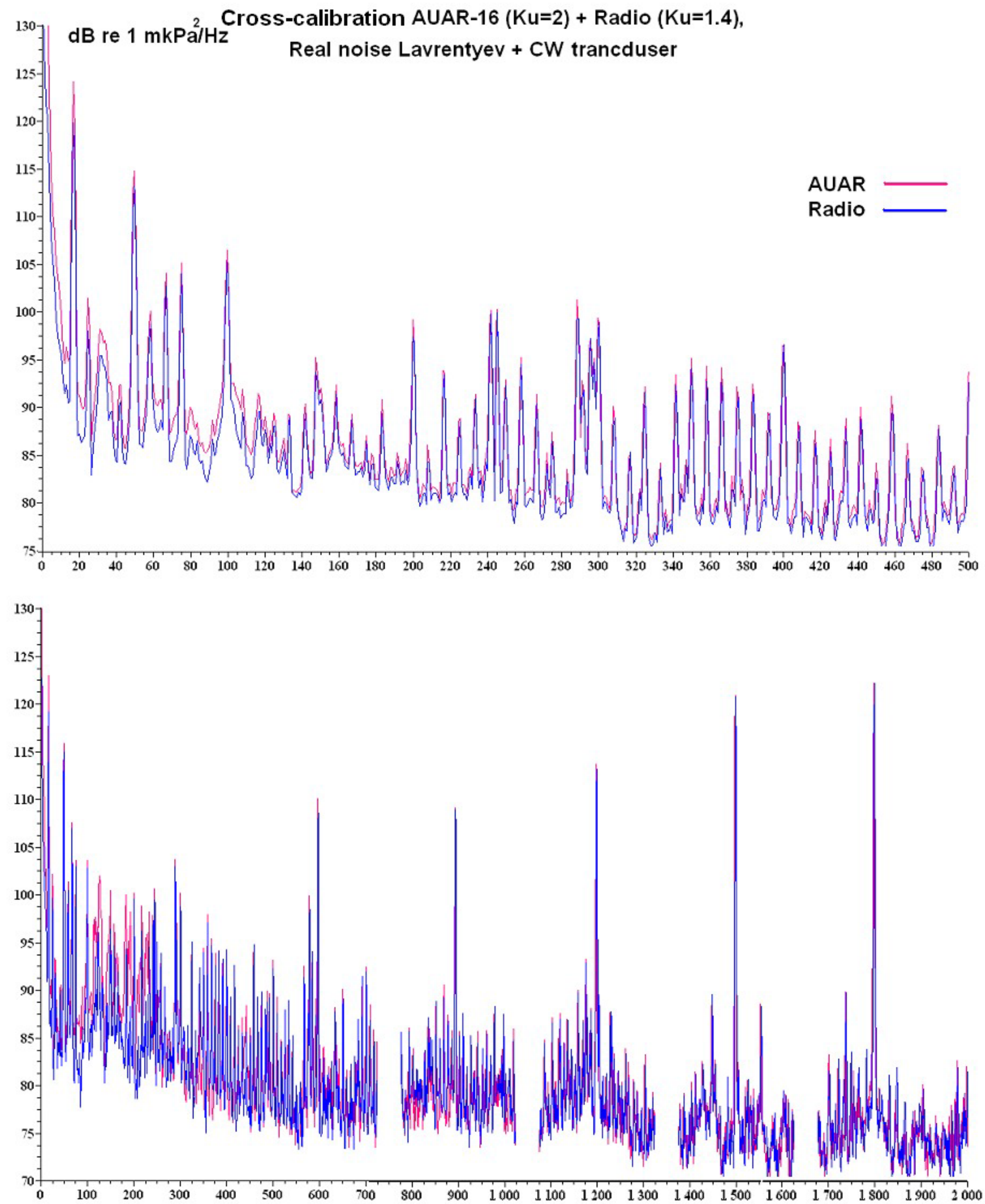


Figure C.3 - Cross calibration analysis between the direct and radio transmission channel of an AUAR - Spectra of signals generated by the *Academik Lavrent'ev* and a broadband transducer (after instrument response [amplitude-frequency] correction).

As can be seen the maximum absolute error for any AUAR from the mean is 2.9 dB in the frequency band from 10 to 100 Hz and less than 0.5 dB between 100 and 2500 Hz[86]. This is within the expected relative error limits for the equipment and the absolute calibration of the data was therefore confirmed.

The greatest difficulties encountered in cross-calibrating the sonobuoys were the crosstalk between the radio transmitters of the sonobuoys when in close proximity and the influence of currents and surface waves on the recorded data. The crosstalk can be seen in the distortion of the spectral highs and lows. High currents and surface wave conditions can cause movement of the hydrophones and cable, with a resulting increase in the levels of the flow noise spectral components. Cross-calibration was therefore conducted in calm weather with low current conditions.

The field cross-calibration was conducted by tying all the hydrophones together in a bundle (Figure C.4), which was deployed from the *Academik Lavrent'ev* at a depth of 15 m.

The sonobuoy transmitters were separated as far apart as possible to minimize crosstalk. The power plant on the *Academik Lavrent'ev* served as the acoustic source for the frequency range from 10 to 500 Hz. A broadband transducer, which generated white noise and tonal signals in the frequency range from 600 Hz to 6 kHz, was used for cross-calibration at higher frequencies. The synchronous sonobuoy signals were input to the computer through the National Instruments eighth-order low-pass elliptic filter described in Chapter 3. To reduce the crosstalk between the sonobuoys the cross-calibration was performed in three groups. In the first was analog sonobuoys ARB-1, ARB-2, ARB-3 and digital sonobuoy DRB-D.2, in the second was analog sonobuoy ARB-4 and digital sonobuoy DRB-D.2, and in the third were digital sonobuoys DRB-D.1 and DRB-D.2.

[86] The highest errors were due to the low level of the calibration signal at low frequencies.

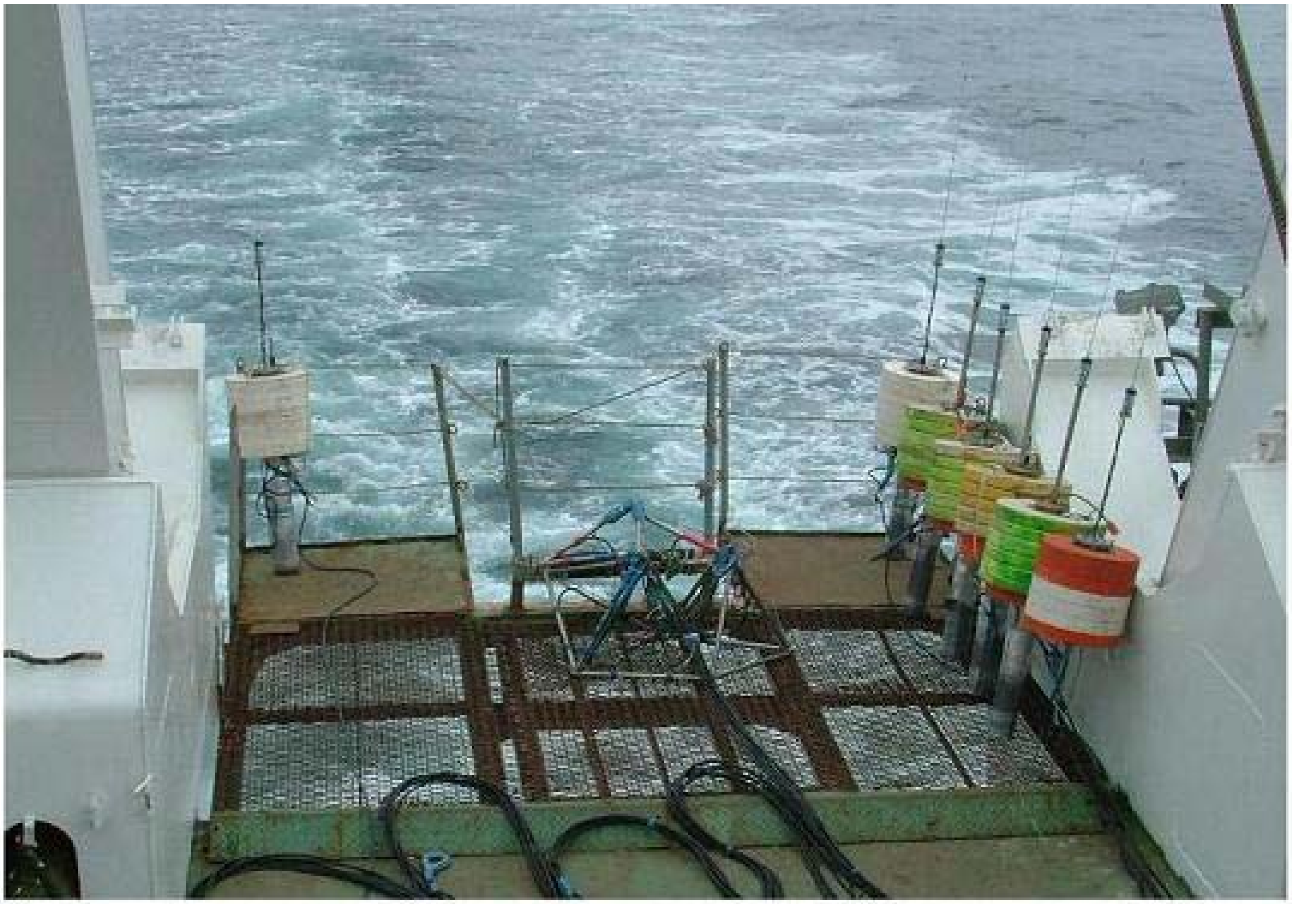
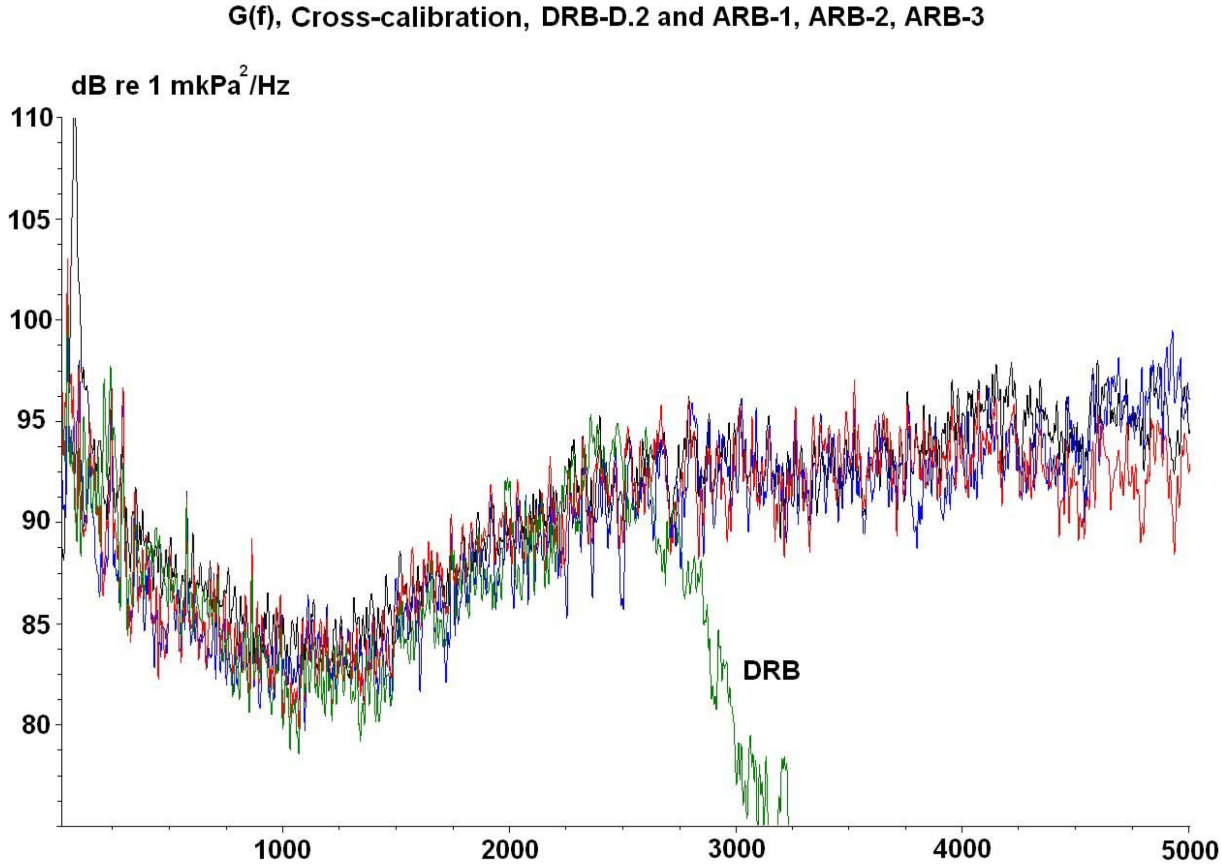


Figure C.4 - Cross calibration of analog sonobuoys, digital sonobuoys and AUARs on the *Academik Lavrent'ev*.



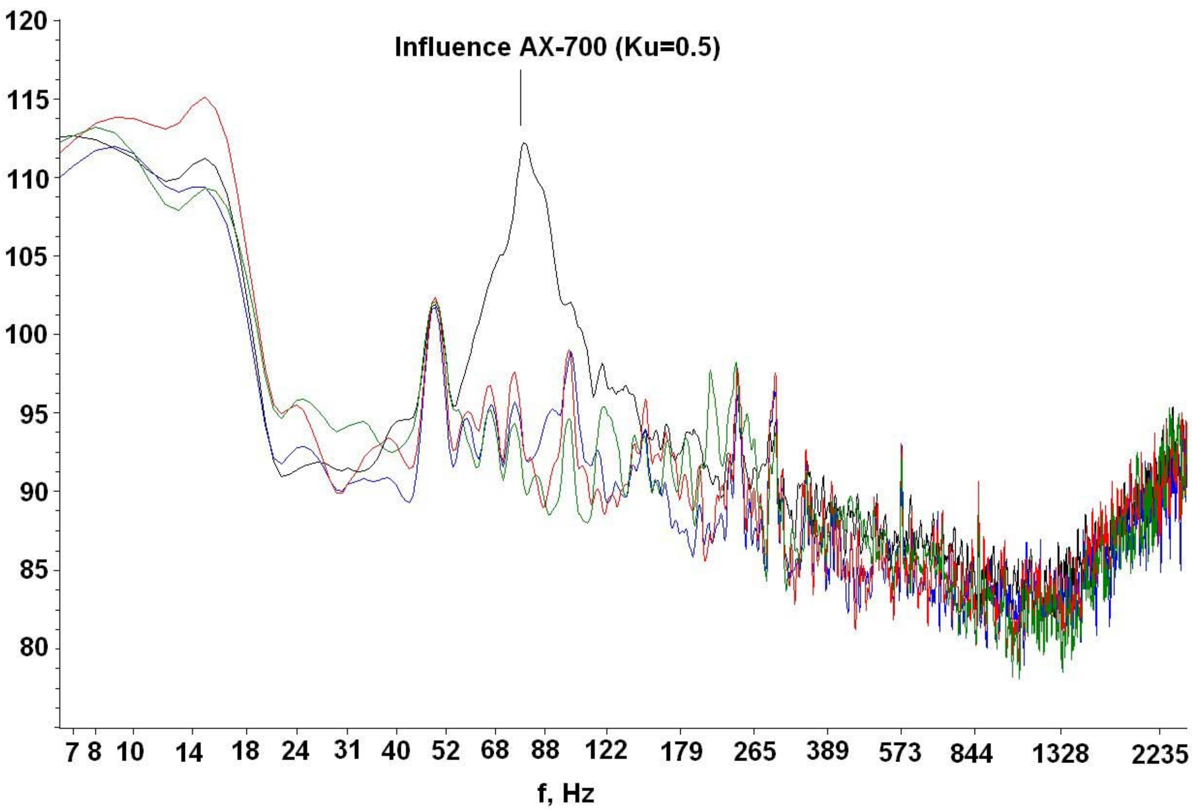


Figure C.5 - Cross calibration analysis for analog sonobuoys ARB-1, ARB-2, ARB-3 and digital sonobuoy DRB-D.2 (green) in the frequency range from 5 Hz to 5 kHz - Spectra of signals generated by the *Academik Lavrent'ev* (after instrument response [amplitude-frequency] correction).

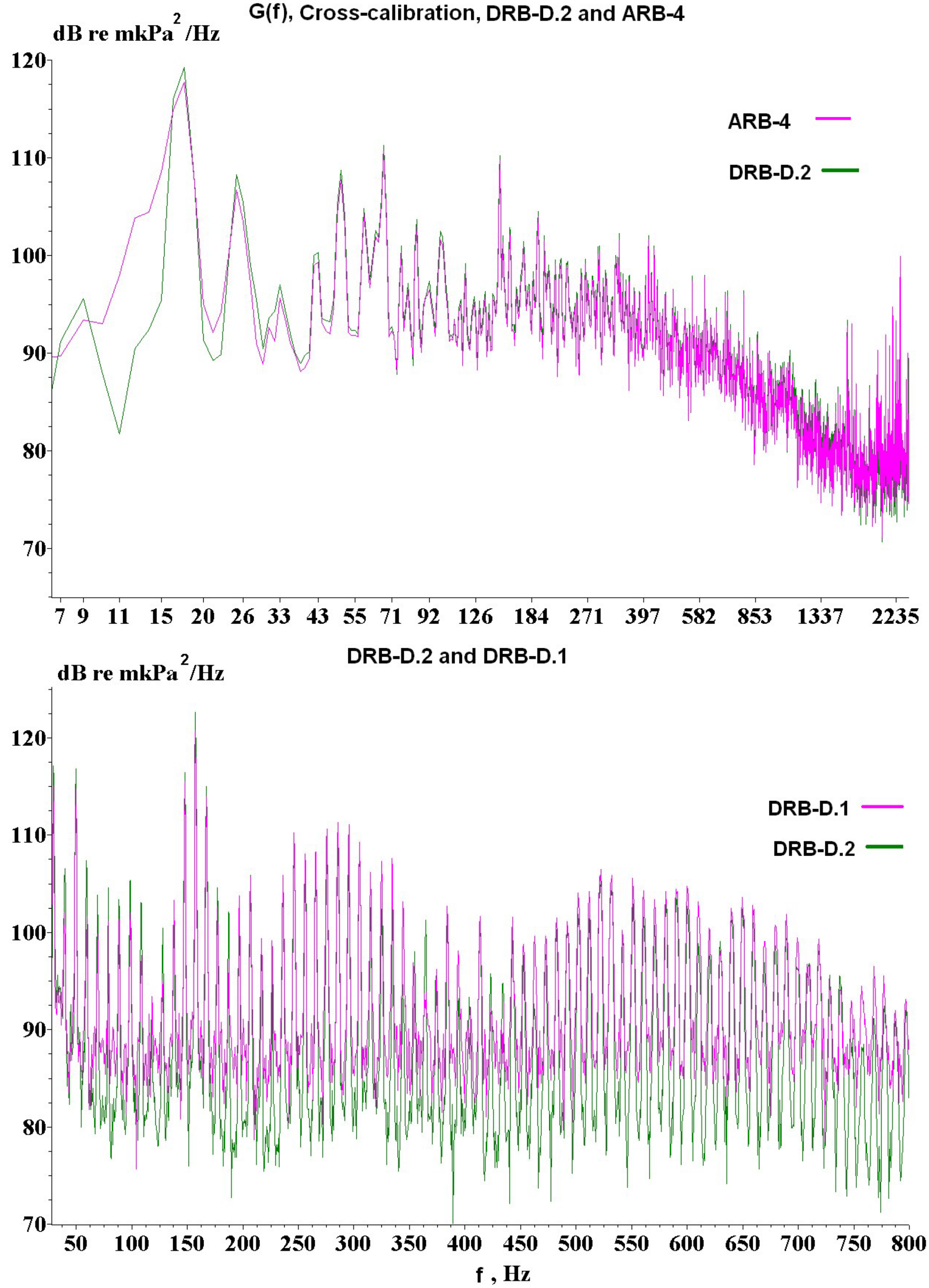


Figure C.6 - Cross calibration analysis between: (top) digital sonobuoy DRB-D.2 (green) and analog sonobuoy ARB-4 (pink) in the frequency range from 5 Hz to 2.5 kHz using signals generated by the *Academik Lavrent'ev;* (bottom) digital sonobuoys DRB-D.1 (pink) and DRB-D.2 (green) using low frequency tonal signals (after instrument response [amplitude-frequency] correction).

		$\sigma_i(\Delta f_j)$ [dB]	
		Δf_1	Δf_2
Sonobuoy #	**MHz**	**f_1 = 10 Hz f_2 = 2500 Hz**	**f_1 = 10 Hz f_2 = 5000 Hz**
ARB-1	**171.5**	1.35	1.62
ARB-2	**170.3**	1.55	0.02
ARB-3	**172.7**	0.56	1.6
DRB-D.2		0.76	

Table C.2 - Cross-calibration - statistical relative error analysis for the first group of sonobuoys in the frequency bands 10-2500 Hz and 10-5000 Hz.

		$\sigma_i(\Delta f_j)$ [dB]
		Δf_1
Sonobuoy #	**MHz**	**f_1 = 10 Hz f_2 = 2500 Hz**
ARB-4	**176.325**	0.29
DRB-D.2		0.29

Table C.3 - Cross-calibration - statistical relative error analysis for the second group of sonobuoys in the frequency band from 10-2500 Hz.

	$\sigma_i(\Delta f_j)$ [dB]
	Δf_1
Sonobuoy #	**f_1 = 10 Hz f_2 = 800 Hz**
DRB-D.1	0.29
DRB-D.2	0.29

Table C.4 - Cross-calibration - statistical relative error analysis for the third group of sonobuoys in the frequency band from 10-800 Hz.

Appendix D - Methodology for Normalizing and Analyzing the Acoustic Data.

The AUARs record a discrete time series that allow the temporal, spectral and spatial properties of the acoustic field to be analyzed. The data was normalized and corrected using the following algorithms[89]:

1. Normalization of the raw data:

$$A = \frac{V}{S_H \cdot K_U} \qquad [\mu\text{Pa}] \qquad \text{(D1)}$$

Where:
A is the amplitude of the sample [μPa]
V is the output voltage from the ADC [mV]
K_U is the system gain[90]
S_H is the sensitivity of the hydrophone @ 1 kHz [mV/μPa].

2. To calculate energy and power spectral density estimates:

For a digitized pressure time series:

$$p(i\Delta t) \quad , \quad i = 0, \text{M-1} \qquad [\mu\text{Pa}] \qquad \text{(D2)}$$

Where:
M is the number of samples
T is the length of the time series (seconds)
Δt is the sample interval (seconds)

A. Calculation of the energy spectral density within the analysis window T:

$$E(k\Delta f) = 2\Delta t^2 \left|P_{FFT}(k\Delta f)\right|^2 \qquad [(\mu\text{Pa/Hz})^2] \text{ or } [\mu\text{Pa}^2\cdot\text{s/Hz}]^{91} \qquad \text{(D3)}$$

Where:
$\Delta f = \dfrac{1}{M\Delta t}$ is the frequency step (Hz)[92]

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[89] All programs for normalizing, correcting and averaging temporal and spectral data were tested. These tests used calibrated broadband and tonal signals transmitted from the hydrophone input to the output of the frequency discriminator of the radio-receiver, as well as the point where data from the ADT is input to the PC.
[90] Because the instrument responses and calibrations are estimated in the frequency domain the correction of the data to absolute spectral values is normally performed in the frequency domain after the power spectra have been computed.
[91] The FFT is a 1-sided FFT (k = 0, ... , M/2)
[92] In practice the number of samples input to the FFT are 16384 for the 20 kHz sample rate and 32768 for the 30 kHz sample rate.

The FFT algorithm should be tested to ensure it satisfies Parsevals theorem:

$$\sum_{i=0}^{M-1} p^2(i\Delta t)\Delta t = \sum_{k=0}^{M/2} E(k\Delta f)\Delta f \qquad \text{(D4)}$$

In order to satisfy Parsevals theorem there must be compensation by Δf otherwise the energies will not sum properly. In this way if the FFT is presented with a time window different than 1 second it will compensate for the window length[93].

B. Calculation of the power spectral density (energy normalized to a 1 second window):

$$G(k\Delta f) = \frac{1}{T}E(k\Delta f) \qquad [\mu Pa^2/(s\ Hz)] \text{ or } [\mu Pa^2] \qquad \text{(D5)}$$

C. Conversion of the spectra to a logarithmic scale:

$$E_{dB}(k\Delta f) = 10Log2 + 20Log(\Delta t|P_{FFT}(k\Delta f)|) \qquad \text{[dB re 1 } \mu\text{Pa/Hz]}^{94} \qquad \text{(D6)}$$

$$G_{dB}(k\Delta f) = E_{dB}(k\Delta f) - 10LogT \qquad [\text{dB re 1 } \mu Pa^2/(s\ Hz)]^{95} \qquad \text{(D7)}$$

D. Calculating average energy and power spectral density estimates over a window of length *NT* seconds by averaging spectra computed in consecutive non-overlapping windows of length *T*:

$$\overline{E}(k\Delta f) = \frac{2\Delta t^2}{N}\sum_{i=1}^{N}|P_{FFT}(k\Delta f)|^2 \qquad [(\mu Pa/Hz)^2] \text{ or } [\mu Pa^2 \cdot s/Hz] \qquad \text{(D8)}$$

$$\overline{G}(k\Delta f) = \frac{1}{T}\overline{E}(k\Delta f) \qquad [\mu Pa^2/(s\ Hz)] \text{ or } [\mu Pa^2] \qquad \text{(D9)}$$

$$\overline{G}(k\Delta f) = \frac{1}{N}\sum_{i=1}^{N} G(k\Delta f) \qquad [\mu Pa^2/(s\ Hz)] \text{ or } [\mu Pa^2] \qquad \text{(D10)}$$

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93 For this calculation it is required that the FFT is scaled so that the output of a unit spike is unity at all frequencies. The scalar $S = \frac{1}{FFT(\delta(t))}$ should be applied to ensure correct scaling of the FFT.

94 The window over which the energy estimate is calculated should be defined.

95 The -10 logT correction allows power spectral density estimates to be calculated over longer windows for statistical stability.

Although the units for power spectral density are $\mu Pa^2/(s\ Hz)$, $\mu Pa^2/s/Hz$ or μPa^2, it is common usage to define the units for power spectral density as $\mu Pa^2/Hz$ or $\mu Pa/\sqrt{Hz}$.

E. Calculating the integrated power spectral density (sound pressure level) for a given frequency range:

$$D(\Delta f) = 10\log\left(\int_{f_1}^{f_2} G(f)df\right) \qquad [\text{dB re } 1\ \mu\text{Pa}^2] \qquad \text{(D11)}$$

Where:

f_1, f_2 are the limits of the frequency band over which the spectrum is integrated.

Δf is $f_2 - f_1$

Analyzing Transmission Loss (TL) data

The main objective of the TL studies was to find the TL along defined acoustic profiles. Thus allowing a better determination of the acoustic propagation in the study area and a calibration of the acoustic models.

The TL determined in the experiments was the decrease in the Intensity of acoustic pressure measured between the AUAR location and a reference value. The reference value used in these studies was the Intensity measured at 1 m from the transducer[96]. The TL values are expressed in decibels and are determined using Equation (D12):

$$TL(r) = 10\,\mathbf{log}\frac{I(r)}{I_{1m}} \qquad \text{(D12)}$$

Where:

$I(r)$ is the Intensity at a distance r from the transducer

I_{1m} is the Intensity at a distance of 1 m from the transducer

[96] Measurement of the acoustic field at 1 m from the transducer can present some experimental difficulties. These are discussed in greater detail in section 3.4.4.

For TL analysis using noise signals generated by sources whose dimensions greatly exceed the wavelength of the acoustic energy a near field approximation is used. The measured level is back calculated to the value at 1 m assuming spherical spreading. Using Equation (D13).

$$TL_{1m} = TL(r_1) + 20\,\mathbf{log}\,r_1 \qquad \text{(D13)}$$

Where:

r_1 is the distance from the measurement point 1 m.