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Systems for reception and recording of vibroseismic signals

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Reception and recording systems called VIRS-M and ROSA developed at the Institute of Computational Mathematics and Mathematical Geophysics (ICM&MG), SB RAS, are considered in this paper. They are designed for scientific investigations of vibroseismic fields and calibration of seismic stations and seismic traces with the use of powerful seismic vibrators.

At the present time, the solution of the methodological problem of search for sensitive methods of deep vibroseismic sounding of the Earth and detection of changes in its depth under the influence of geodynamic and other processes becomes more and more important.

This problem cannot be successfully solved if another problem closely related to it, that is, the problem of creation of technical facilities specially oriented to the sought-for methods, is not solved.

For the purpose of monitoring, it is necessary to create a mobile distributed reception–recording system with a maximal distance of 2 and more kilometers between the seismometers and the central module of the station. The use of the traditional seismic cable for the reception of vibroseismic signals is not justified, because this requires a lot of efforts for its maintenance. Besides, this prevents sensitive reception of signals, because a seismic cable of such a length becomes a radio antenna, which receives a lot of electromagnetic noise.

For this reason, one should give up using the seismic cable and try to use other systems for the reception of vibroseismic signals that are more convenient in exploitation. For this purpose, we can formulate the following three principles of reception of distributed signals:

- acquisition of signals based on the time compression of channels into one channel with the reconstruction of signals at the receiving point of the acquisition line;
- acquisition of signals based on the time compression of channels into one channel without the reconstruction of signals at the receiving point of the acquisition line;
- acquisition of signals with the use of digital technologies.

Unfortunately, no reception-recording systems for scientific investigations of vibroseismic fields from superpowerful vibrators in a frequency range of 1–12 Hz are produced now. This is due to specific requirements to such systems. For seismic prospecting systems, these requirements are as follows: a relatively low-frequency range; the signal received should be many times less than the microseismic noise level, and this requires special detection systems.

It should be pointed out that the requirements to these systems do not exclude the possibility that they can receive signals from explosions and earthquakes.

By now, several systems for the reception and recording of vibroseismic signals have been developed at ICM&MG, and some of such systems are under development. They are based on different principles of acquisition of vibroseismic signals.

1. The reception-recording system VIRS-M is designed for deep investigation of the Earth and processing of the data collection directly in the field.

VIRS-M, a mobile vibroseismic measuring-recording station, was developed on the basis of the existing system VIRS [1–3]. In this system, the principle of reception of vibroseismic signals is based on the time compression of channels into one channel, with the reconstruction of signals at the receiving point of the acquisition line.

The structure chart of the VIRS-M station is shown in Figure 1. This system includes 5 three-component SK1-P seismometers with a fundamental resonant frequency of 1 Hz and electromechanical transformation coefficient of 150 V/(m/s).

Taking into account the requirements of vibroseismic investigations, the entire receiving-recording system is divided into two parts. The first (receiving) part consists of 5 linear modules, which are climatically protected. They are located directly at the seismometers. In the scheme, these are elements from *1* to *5*, the second (processing) part, and elements *6*, *9* are in the field laboratory. In the first part, the received signals are amplified (remote adjustment of the gain coefficient is used), frequency limited, and transmitted to central module *6* for the acquisition of seismic signals via a coaxial cable (the principle of time compression of channels is used to transmit signals). In this module, all signals from 15 channels are reconstructed, amplified again, and frequency filtered.

It should be noted that the distributed telemetric system for the acquisition of seismic signals (elements *1–6* in the scheme) works not only as an acquisition system, but also as a 15-channel antialiasing filter. The presence of aliasing is necessary at their analog-to-digital conversion due to the sampling of signals. Besides, at such data transmission method, when

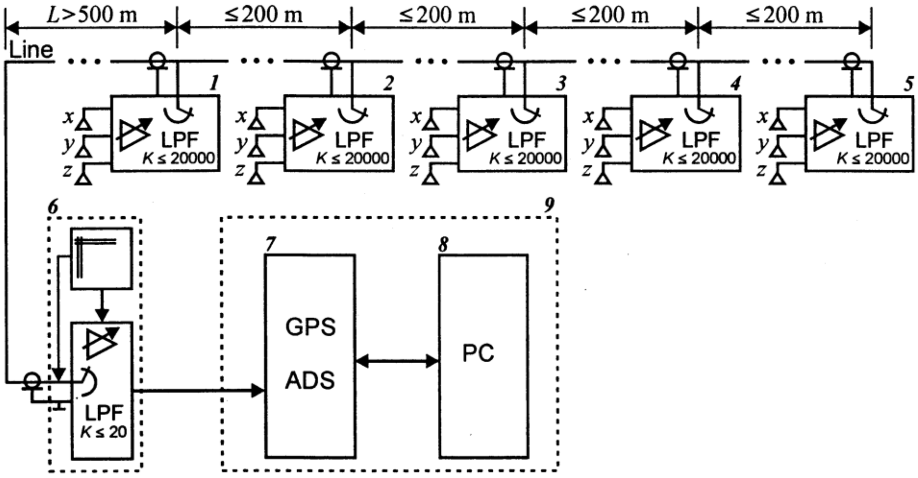

Figure 1. Measuring-recording VIRS-M station

the signals in block *6* are reconstructed to their original form, relative time shifts between channels can be avoided. After the reconstruction, analog signals come to the A-D conversion module *7* of measuring-recording system *9*, where all signals come to the 15-channel analog-to-digital converter (ADC), and then transmitted in the digital form for digital recording and further processing to personal computer (PC) *8*. The software specially developed controls the processes of conversion, acquisition, and recording of signals, and the synchronizing of samples with the GPS-system.

The personal computer was chosen as a basic element of the recording system. The use of a personal computer makes it possible to employ its operating system and corresponding software for reliable recording of data onto the hard disk with a capacity of more than 3 Gb. Since the hard disk is a part of the PC hardware, the data must be rewritten onto another external storage device, for instance, a CD-ROM.

The VIRS-M system also makes it possible to obtain the frequency response of the system itself. The main characteristics of the station that most fully describes its sensitivity is the spectral density of the native noise at the system inlet with the inputs loaded with electrical equivalent resistance of the SK1-P seismometers used. Measurements show that the spectral density of the VIRS-M equipment in the effective range does not exceed, on average, $20\ \mathrm{nV}/\sqrt{\mathrm{Hz}}$.

The main technical parameters of the input channel:

- Recorded parameter: displacement velocity;
- Seismometer type: SK1-P;
- Conversion coefficient: 150 V/(m/s);

- Effective frequency range of the channel: 1–11 Hz;
- Filter types:
  - Two high-pass Butterworth filters of the 3rd order, cutoff frequency 0.5 Hz, total roll-off at low frequencies 120 dB/decade;
  - Two low-pass Chebyshev filters of the 4th order, operating bandwidth 0–11 Hz, total roll-off at high frequencies 160 dB/decade;
- Output voltage range of terminal amplifier: ± 3 V;
- Maximum gain coefficient 400000.

The measuring-recording system is designed for the conversion of input analog signals into the digital form and their recording on HDD or flash disk with synchronizing with unified time, UTC.

The measuring block consists of:

1. IBM PC-compatible controller or computer;
2. Interface block:
   - temperature-controlled quartz oscillator (OCXO);
   - frequency divider;
   - GPS receiver;
   - start-up circuit;
   - 12-bit analog-to-digital converter with a 32-channels analog multiplexer and Sample&Hold device;
   - station control register;
3. Axon software.

The system can work with any IBM PC-compatible controller or a computer having standard parallel and serial ports and a data storage device (HDD or flash-disk). The block scheme is shown in Figure 2.

The main technical parameters of the system:

- Number of input channels 15;
- Input range ± 10 V;
- ADC code length 12 bits;
- Sampling rate ≤ 200 Hz;
- Dynamic range 73 dB;
- Differential nonlinearity ≤ 1 LSB;
- Data Sample Time Tag Accuracy of UTC synchronization $\pm 10\ \mu s$;

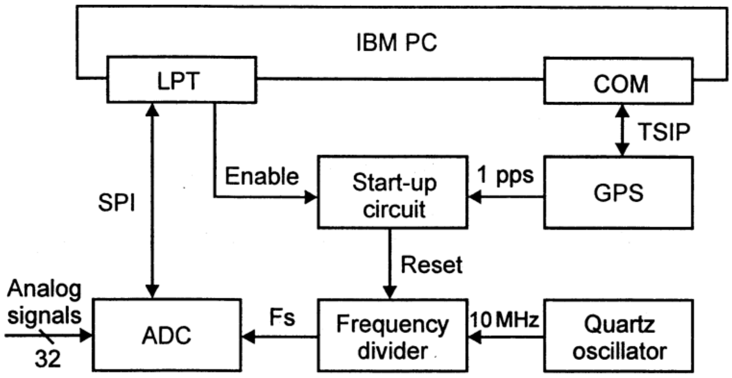

Figure 2. Block scheme of the measuring block

- Consumed power ≤ 1 W not taking into account the computer.

The regime of control and accurate setting of the nominal value of the quartz oscillator frequency with the use of a 1 pps-signal as a reference one is provided.

In the calibration experiments at the Bystrovka vibroseismic test site, VIRS-M received seismic signals from distributed delayed explosions at the Taldinsky, Kaltansky, Bachatsky, and other quarries of the Kemerovo region. Also, vibroseismic signals from the CV-100 seismic vibrator located at the above mentioned test site were received in the regions of these explosions. As an example, the results of the experiment for the Taldinsky explosion and the CV-100 vibrator are shown in Figures 3 and 4.

The digital distributed system for the recording of seismic signals ROSA. Most recorders of seismic signals produced now are broadband (BB). These are portable digital devices that can record signals in a frequency range of 0–400 Hz. The area of application of BB recorders is from regional seismic prospecting to fundamental scientific experiments on the investigation of the Earth's internal structure, including the recording of signals from powerful seismic vibrators and industrial explosions. The technical parameters of BB recorders that are recommended are listed in the documents of the PASSCAL program (Program for the Array Seismic Studies of the Continental Lithosphere). This is the main instrumental program of the organization IRIS (Incorporated Research Institutions for Seismology). The best known producers of BB recorders are Refraction Technology, Inc. (USA), Quanterra, Inc. (USA), Nanometrics, Inc. (Canada), Lennartz electronic GmbH (Germany), and some others.

Oversampling with subsequent digital filtration and decimation are used to achieve the required characteristics in the signal conversion sections of BB recorders of all models. This conversion method is fully realized at the

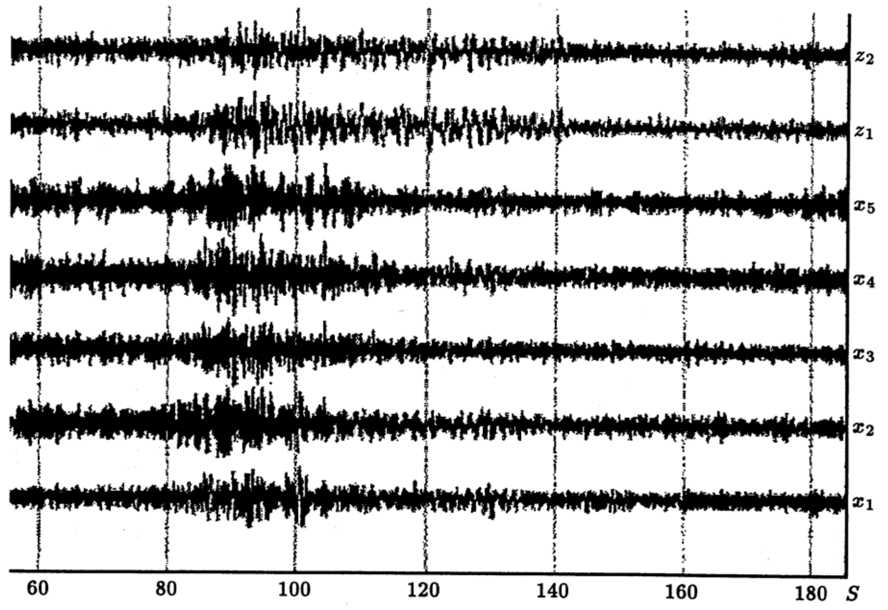

Figure 3. Explosion seismograms, Taldynsky–Bystrovka, 297 km, $M = 51.6$ t. VIRS-M, Bystrovka, August 9, 2001

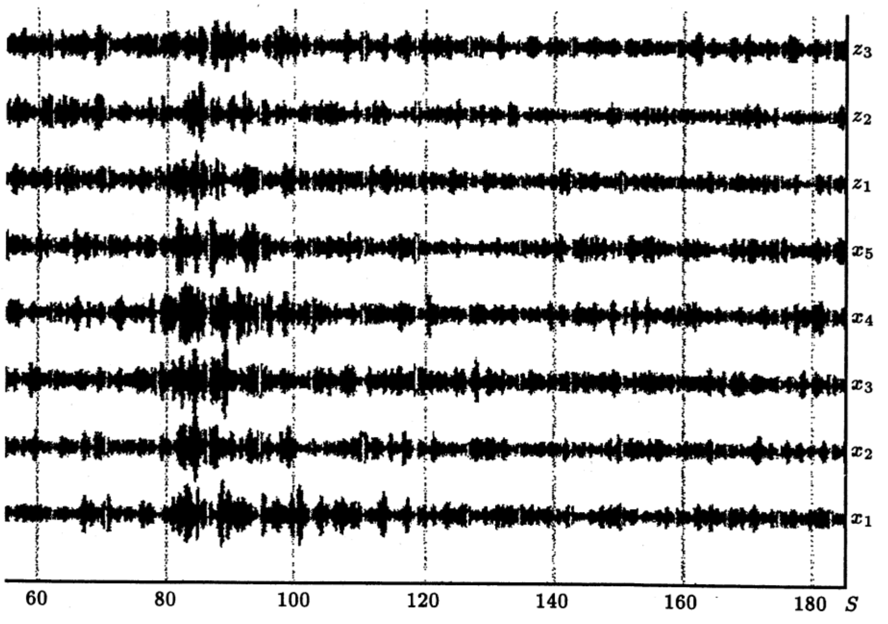

Figure 4. Seismograms of the CV-100 vibrator, Bystrovka–Taldynsky, 278 km. VIRS-M, Tychta, September 29–30, 2001

use of a sigma-delta ADC. It has the following advantages in comparison to the classical device:

- large dynamic range;
- high linearity and stability of amplitude and phase characteristics, good suppression of aliasing;
- the use of analog LPF of low order (1–3);
- the possibility of programmable selection of the sampling rate within wide limits.

The chip set of the firm *Crystal* is used in most models: CS5320/21, analog modulator, and CS5322, digital filter-decimator FIR. The following characteristics are provided in this case:

- sampling rate F_S: 1–1000 Hz, 12 items;
- frequency range: $0 \div 0.4 \cdot F_S$;
- rejection at the Nyquist frequency: 130 dB;
- dynamic range: ≥ 122 dB.

Simpler and cheaper modulators and digital filters (AD7716, HI7190, ADS1210, etc.) with preliminary analog (LPF of the 2nd and 3rd order) and/or additional digital filtration and decimation are used in recorders with smaller dynamic and frequency ranges, such as MARSlite (Lennartz), Delta-Geon (V.V. Tikhomirov GP NIIP, Russia).

From recorders produced on full scale, the miniature RefTec 125 (Refraction Technology) recorder, which is also released in various modifications by other firms, is most appropriate for operations in field conditions. The above-mentioned chipset of the firm *Crystal* and flash memory up to 64 MB is used to record data in this model. Advantages of the recorder are its small size and mass as well as small power consumed from the internal source (of about 0.4 W).

RefTec 125, as well as most other BB recorders, have no facilities for the construction, on their basis, of a distributed telemetric system for the acquisition of signals. After a recording session, RefTec 125 forming the seismic antenna must be delivered to the central point. There, the data are rewritten via a special interface unit onto a computer for further processing. Before the next session, the internal clocks of all recorders must be synchronized with GPS. After this, the recorders must be arranged in the terrain. These procedures decrease considerably the effectiveness of work, and make impossible data processing in real time, which is necessary in some experiments with the use of powerful seismic vibrators.

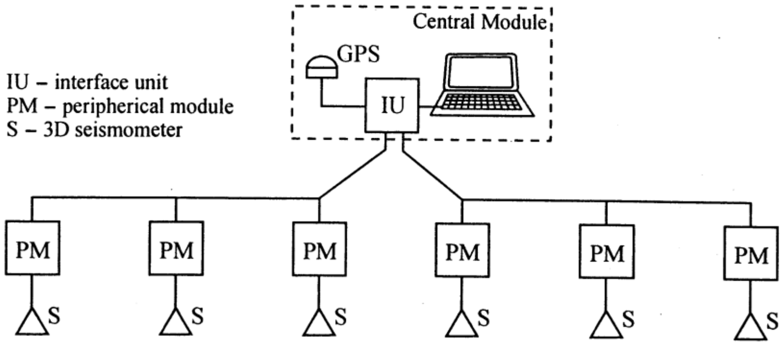

Figure 5. Block diagram of the ROSA system

The digital distributed system for the recording of seismic signals called ROSA was developed at ICM&MG for the purpose of combining the advantages of digital processing of signals and those of telemetric recording. This work was done at the support of ISTC, grant № 1067.

The ROSA system (Figure 5) consists of 3-channel peripheral modules that convert signals from seismic sensors into digital form and the central module. All modules are combined in a successive multi-point data transmission network based on the RS-485 interface.

A special protocol providing data transmission from peripheral modules to the central one was developed to organize the network interaction [4]. The maximal number of channels for data transmission in real time versus the communication line length and sampling rate is presented in Figure 6.

The central module (Figure 7) performs the functions of network controller and recorder of the data coming from peripheral modules. It includes

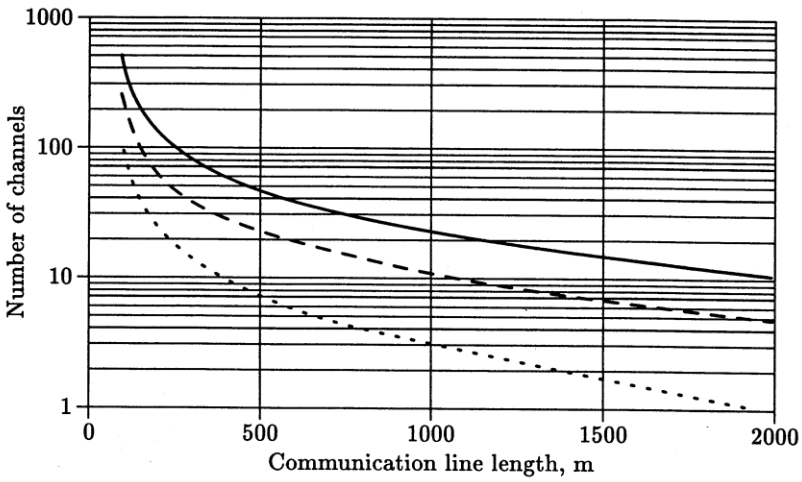

Figure 6. The maximal number of channels versus the communication line length for sampling rates of 50 (solid line), 200 (dashed line), and 500 Hz (dotted line)

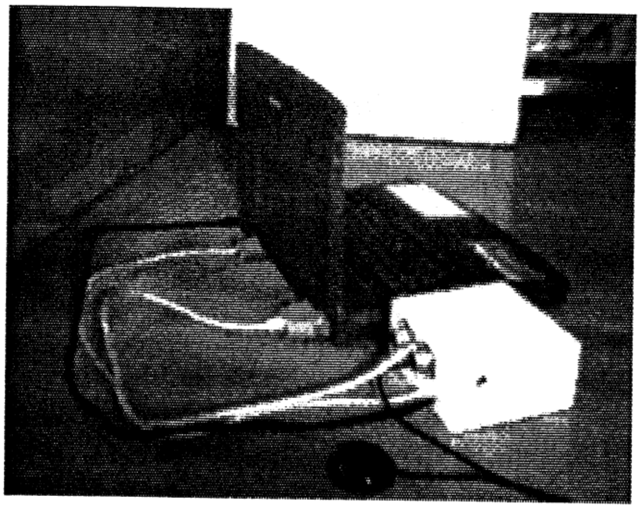

Figure 7. The central module of the ROSA system

an IBM PC compatible computer and an interface unit to connect two communication lines of the RS485 standard. Before a recording session, the peripheral modules are synchronized with the GPS-receiver of the central module. The regime of frequency tuning of the reference generators VTCXO of the peripheral modules with GPS signals is provided.

16-bit sigma-delta ADC with a digital LPF with a frequency characteristics of the form $(\sin x/x)^3$ are used in the conversion section of peripheral modules. The analog Chebyshev LPF of the 2nd (or, as a variant, 3rd) order improves the shape of the resulting frequency characteristics of the conversion section. In the first case, the suppression of aliasing for a work frequency band of 0–10 Hz constitutes about 80 dB, and in the second case it is 94 dB at a sampling frequency of 50 Hz.

A prototype of the ROSA system was used in field experiments in 2000–2001, and demonstrated good results. In the future, it is planned to eliminate the shortcomings detected. The correlation seismic traces obtained on 01.10.2001 at the recording of the CV-100 vibrosource at Zalesovo (distance of 156 km) are shown in Figure 8 as an example.

In the figure, the lower trace was recorded by the seismic station Zalesovo (PS-33) of the International Monitoring System. The seismometer was in a 100-m deep borehole. The upper trace was recorded by the ROSA system with a seismometer at the daily surface.

3. Software. As to the any computer-connected equipment without microprocessor built-in, program is a thing that makes the equipment to work, to operate. Furthermore, program determines capabilities of the recording system (be sure, within the framework of the equipment capabilities). Pro-

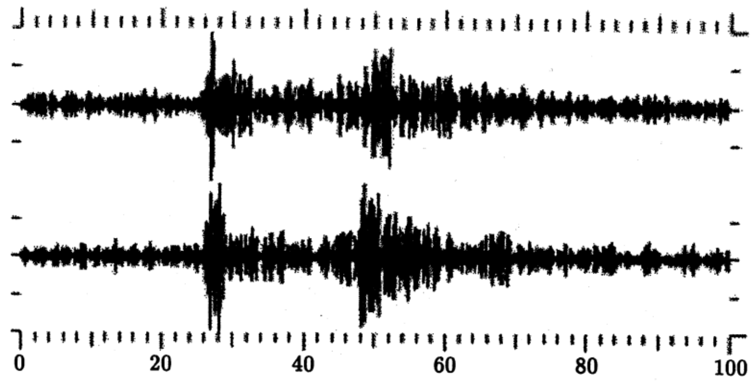

Figure 8. Correlation seismic traces

gram is also that a human operator interact with. At length, program can significantly facilitate troubleshooting and checkout procedures.

For Rosa and VIRS-M recording systems the Axon software has been developed which provides the operator with a complete set of management, troubleshooting and checkout facilities. Serious consideration was paid to the software operability and usability – for example, recording subsystem has an option to work in demo mode, i.e., without any equipment connected to the PC.

The main part of the software is the Recorder (recording subsystem) which is responsible for the normal data collecting process: data acquiring, sampling, previewing and storing on the PC's hard drive. Recorder architecture is device independent, meaning that all equipment interaction is performed through corresponding low-level driver. Thus, Recorder can be adapted, in necessity, to control equipment besides of above-mentioned types. Additionally, two subsystems should be specified: the diagnostics subsystem (including real-time mode operations) and the logging one which produces the log file – a detailed report of the Axon's activity.

Axon software specifications:

- Number of channels – up to 32, software architecture allows to increase;
- Sampling rate – up to 500 Hz, depending on CPU processing power;
- Maximal duration of continuous recording – 45 days;
- Resolution of internal clock (timers) – less than 1 us;
- Two events synchronization accuracy – 5 us typical;
- System requirements – i80486 based computer with MS-DOS;
- User interface – combined: batch-oriented (command line) and user-interactive (text-based and graphic based).

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