# VIBROCALC, Seismometer frequency response elaboration software

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## ABSTRACT

The VIBROCALC software is presented, VIBROCALC is a computer program written using MATLAB 7.5 graphical interface for frequency response calculations (module and phase) of seismic sensors, geophones, seismometers and accelerometers. The new and practical amplitude module and phase response curves corresponding to one sensor are shown, as example of this solution. To obtain this result, shake table is used from the "Centro di Ricerche Sismologiche" (CRS), "Istituto Nazionale di Oceanografia e Geofisica Sperimentale" (OGS).

**Keywords:** Seismometer, calibration, shake table, frequency response

# VIBROCALC, Programa de elaboración y cálculo de la respuesta en frecuencia del sismómetro

## RESUMEN

Se presenta el programa de cálculo VIBROCALC, un programa escrito usando la interface gráfica de MATLAB 7.5 para el cálculo de la respuesta en frecuencia (módulo y fase) de diferentes sensores sísmicos, geófonos, sismómetros y acelerómetros. Las curvas de módulo y fase para un tipo de sismómetro son mostradas usando como prototipo la mesa vibratoria de calibración diseñada y construida en el "Centro di Ricerche Sismologiche" (CRS), "Istituto Nazionale di Oceanografia e Geofisica Sperimentale" (OGS).

**Palabras clave:** Sismómetro, calibración, mesa vibratoria, respuesta en frecuencia

## 1. Introduction

The essence of calibration is the calculation of the instrument transfer function used for ground movement record, because of his influence on the signal is not linear and follows a second order equation. It means that seismometer has a complex response in frequency domain.

Calibrating a seismometer means measuring its transfer properties and expressing them as a complex frequency response or one of its mathematical equivalents. For most applications the result must be available as parameters of a mathematical formula, not as raw data; so determining parameters by fitting a theoretical curve of known shape to the data is usually part of the procedure.

The calibration of a seismograph establishes knowledge of the relationship between its input (the ground motion) and its output (electric signal), and is a prerequisite for a reconstruction of the ground motion. The parameters of the transfer function must be determined from the response of the system to a known input signal. Precisely known ground motions are, however, difficult to generate. The calibration methods evolution has not been untied of the technological developments and has grown up in complexity and accuracy. At the same time, new more compact sensors have arisen with expanded dynamic range and a great number of electronics cards inside in order to obtain more accurate characteristics. In this sense we can divide the methods in those where have been found the values of the sensor own constant as a mass-spring type mechanical structure with physical parameters easy to obtain directly and others used in the modern seismic instrumentation, where generally does not have any access inside sensors and are, in almost all cases, sealed units with electronic amplifiers and other signal processors.

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The last methods consider the sensor as a "black box" where it is necessary to find the transfer function excluding his physical model, knowing the magnitude of the input signal and recording the sensor output in order to find the relation between both of then.

## 2. Calibration methods

Some authors have presented calibration alternatives for electromagnetic type seismographic channels, Murphy *et.al* (1952) obtained the response final curves for diverse types of seismographic channel combinations using Sprengnether seismometers and galvanometers with different periods, by test and adjustment practical methods considering, like premise, that both elements, seismometer and galvanometer, had critical damping equals values and thought sinusoidal waves injection method. Morencos (1966) proposed the determination of system damping coefficient and in this way, the parameters calculation which define the seismometer response considering sensors with one or two coils.
In the Eaton (1957) paper the effect of the reaction of the galvanometer in the seismometer and vice versa is analyzed, introducing this parameter for the calculation of the final spectral response. Chakrabarty *et al* (1961; 1964; 1988) papers refer to the system response variations for specific cases due to different damping values and seismometer generation constant. Since those methods are empirical, Murphy & Cloud (1952), Espinosa *et al* (1962) and Mitchell & Landisman (1969) described the mathematical main principles of the method, adapting a seismometer with electromagnetic transducer to a galvanometer. They are found for each one the individual parameters and made the final response from the superposition of curves.
For seismometers with single coil, the most used classical method was the proposed by Willmore (1959) and modified by White (1970) where the sensor constitutes the four element of a resistor balanced bridge.
On the same way, Mitronovas & Wielandt (1975) described the use of the Lissajous figures for the measurement of phase shrift between two sinusoidal signals; one is injected in the calibration coil and second is the seismometer output voltage. For sensor oscillation natural frequency value, the shift between the ground acceleration and coil voltage output goes to zero.
Pavlis & Vernon (1994) explained that is possible carry out the calibration with relative precision using the ground noise as input signal, thought the use of two seismometers, one with well known frequency response and another, the candidate to calibrate, nearby one to another, and assumed that both are under the same excitement.
Rodgers (1992) and Rodgers *et al* (1995) papers have shown the harmonic calibration method based on the calculation of sensor response to step impulse, caused by injection of a step current into calibration coil. In case of single coil seismometers he explain how to achieve the same objective through the coil terminals commutation, in a sense, to excite the sensor with a known current and in a second time, to carry out the system response record.
On the same way, Berger *et al* (1979) estimations are used for broad band seismometers calibrations, where it is shown that, exciting the calibration coil with a binary pseudo-random signal, the calculation of electromagnetic generation constant is possible.
Concerning to absolute and harmonic calibration there are diverse methods based on the different signals injection to the seismometers calibration coil. Wiedlant (1983) and Havskov & Alguacil (2004) described some of used methodologies.
Also, Bormann (2002) described an alternative way to simulate the ground movement using mechanical devices, which allow to put a seismometer to a vertical much known amplitude movement, in a time domain, and to register the sensor response signal. The method, called "stepwise motion", calculates simply the displacement response by means of the de-convolution, interpolation and subsequent integration of the recorded signal.
Using a shake table is the most direct way of obtaining an absolute calibration. The VIBROCALC software is part of the calibration system used at the “Centre di Ricerche Seismologiche (CRS)”, of the “Osservatorio Geofisico Sperimentale (OGS)” for seismic sensors calibration in order to obtain the seismometer response curve (module and phase) of the seismic network sensors. The shake table is exciting with white noise signal which produce displacement movement equivalent to ground motion with high precision controlled amplitudes; the seismometer voltage output is recorded and processed.

## 3. Discussion and results

This software work connected to a shake table according to the block diagram shown in Figure 1, all its parts are described within the technical report from Di Bartolomeo *et al* (2005) and the current paper is limited to the final step of the system, the elaboration software.

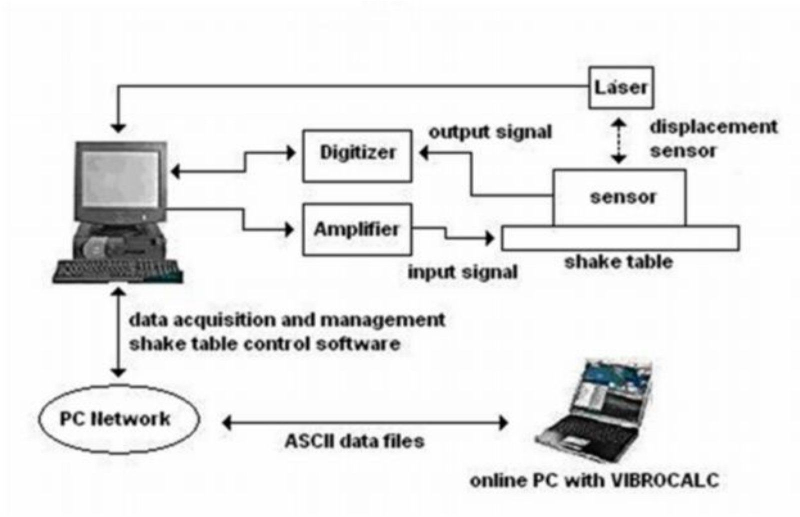



***Fig. 1: Block diagram of calibration method developed at CRS***

VIBROCALC is a script written under MATLAB 7.5 platform that allow users the creation of relatively friendly graphic interface and compatible in form and design with WINDOWS environment. The script yields the transfer function between two input signals called channel A and channel B. In case of the system implemented at CRS, they refer to files with extension ASC which include the signals previously recorded; one is the signal obtained from sensor coil under test and another, to the laser position sensor which checks the effective seismometer displacement.

In both cases, it's possible to choose any type of signal available from the digitizer; its means sensor components under test or sensor laser output. If any of them is not selected, the system will not work correctly and an error message will be appear. Both inputs are referred to ASCII files which are recorded in specific locations of the PC that contains the shake table management software and are available for any computer installed around the Intranet.

The input channels structure is shown in the Figure 2.

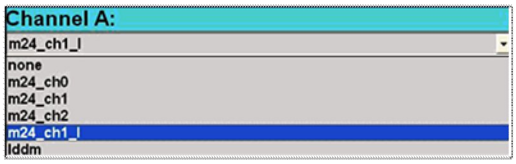



***Fig. 2: Channel A selection***

In the "Channel A" window, it's possible the selection of laser sensor output signal, which correspond to the effective displacement of the shake table and sensor as well. In the "Channel B" window, signal from coil output of the seismometer is recorded, but you can select another combination as well for different research purposes.

Once the signals are checked on the information boxes for each channel data loaded, the software allows you verified that they correspond to the expected signals. Other possible adjustments for the input signals are possible before the transfer function elaboration. There are the following:

- ✓ Phase change of channel A and B.
- ✓ Necessary adjustment for simultaneous calibration of tri-axial sensor's horizontal components ($45^o$ adjustment).

Then, it's necessary to defined, which type of sensors are being used; it means laser, seismometer or accelerometer. This is because of the automatic adjustment of the measurement units (see Figure 3). The programs also carry out the automatic adjustment of the source file length. In fact the mathematical models used inside the script need the same length in any combinations.

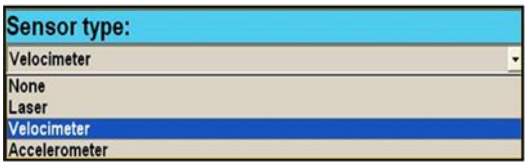



***Fig. 3: Type of sensor selection popup menu***

For each channel selected, the following values are shown:

- ✓ Reference channel name.
- ✓ Path of file.
- ✓ Type of digitizer.
- ✓ Channel of the digitizer.
- ✓ Sampling frequency used.
- ✓ Recorded dates.
- ✓ Time of the first sample.
- ✓ Number of samples.
- ✓ Type of sensor.
- ✓ Measurement units.

Furthermore the program enables you plot the different input signals, channel A and/or B or laser, or any other combination. During the plot session its necessary choose the signal plot in time or frequency domain. The input control allow users to know if the signals concerning to sensors under test have been supplied correctly to the calculation program.

The transfer function calculation is carried out using 6 different mathematical methods; each of then has a specific parameters. It is possible to select among these methods as well as to change the calculation parameters, see Figure 4**.** According to Math Works Inc (2009) the mathematical methods which are use for the calculation of the frequency response can be selected by using a set of definite MATLAB algorithms.

They are the following:

- ✓ (TFE), Transfer Function Estimate.
- ✓ (TFE modified).
- ✓ (SPA), Spectral Analysis.
- ✓ (EFTE), Empirical Estimate.
- ✓ (N4SID), State-space Model Estimate.
- ✓ (PEM), Linear Model Estimate.

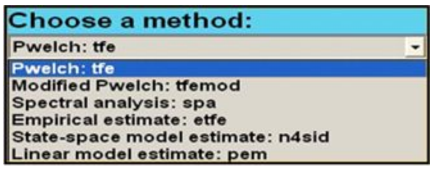



***Fig. 4: Mathematical method selection popup***

According to the specific interests of each analysis, the program allows you to select the more powerful method for the elaboration. For each of then the parameters can be introduced manually, otherwise they are assumed according to default values established in the algorithm.

The result of the elaboration, after the previous adjustments and settings, is stored in some MATLAB temporary variables and added to a list which can contain different results came from calibrations previously made. The program enables the user to introduce some additional information which will be inserted in the graphics plots and final reports, they are the following:

- ✓ Name of the sensor (identification).
- ✓ Serial Number.
- ✓ Limits of frequency for which the report is desired.

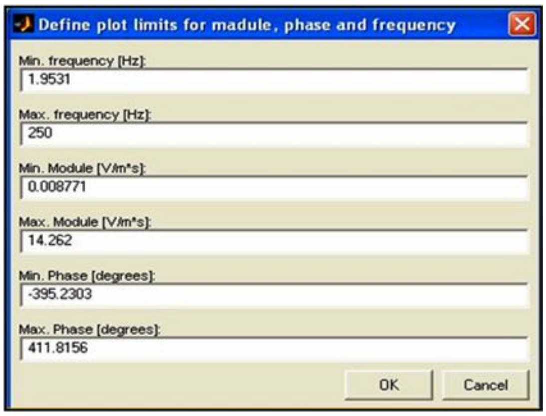



***Fig. 5: Elaboration limits for plot***

This dialog box is designed to allow user set up the diagram limits; it means minimum and maximum frequency, module and phase, see Figure 5. It's necessary to remain the fact that the user must be sure about these limits especially in case of short period seismometers which has a limited band pass and in which, outside this bandwidth, can expect unusual or wrong draws. Despite that the program take into account as a reference the name of the used method, you may change it as you want. The dialog box also contains fields for other information, for example: sensor name or manufacturer name, serial number as well as the lower and the upper limits used to record the elaborated data.

Otherwise, the program has some expanded features very useful for most calibration procedures. From the list, it is possible to carry out a lot of functions as follow:

- ✓ Plot the frequency response curve in module and phase with options to rescale the plot (e.g. maximum and minimum values).
- ✓ Save the results in a recognizable by the program file for further analysis.
- ✓ Load saved calibration files.
- ✓ Erase files from calibration list in case of error or disagreement with obtained results.
- ✓ Generation of ASCII report in TXT file.

Furthermore, the generation of "TXT file" report including input channel data and final calibration values generates automatically, a new dialog box in which it is possible to choose the variables that it is going to be registered in this report, and it can be use as selected as follow, see Figure 6:

- ✓ Include or not in the final report the data coming out from input signals, by default (N) the program does not include then.
- ✓ Define a set of spans where the frequency response is going to be extrapolated. In each span you can choose different frequency steps defined in the next point. If you leave the value to NONE, the program will not perform any extrapolation.
- ✓ To choose the extrapolation frequency step as mentioned before.

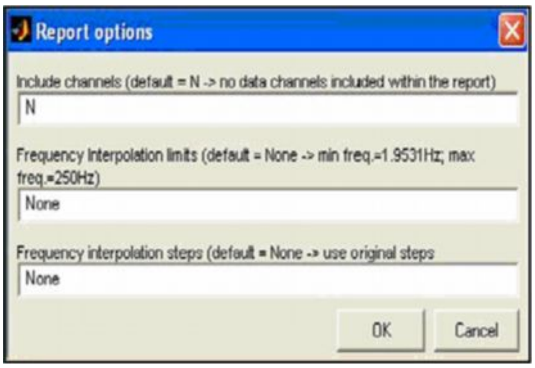
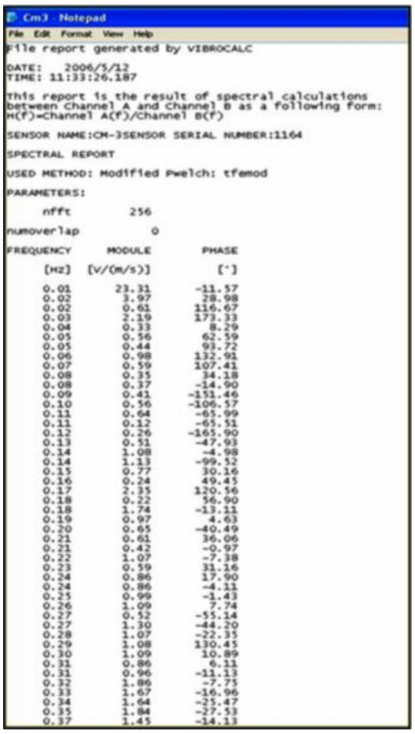



***Fig. 6: Dialog box for TXT final report***

When the elaboration is done, the result is presented as part of the result list with the reference name you're choosing in the previous box and the reports are recorded like ASCII files (.TXT) in the path: MATLAB\work\. TXT and their structure is shown in the Figure 7.



Cm3 - Notepad

File report generated by VIBROCALC

DATE: 2006/5/12
TIME: 11:33:26.187

This report is the result of spectral calculations between Channel A and Channel B as a following form:
H(f)=Channel A(f)/Channel B(f)

SENSOR NAME:CM-3SENSOR SERIAL NUMBER:1164

SPECTRAL REPORT

USED METHOD: Modified Pwelch: tfemod

PARAMETERS:

nfft 256

numoverlap 0

| FREQUENCY | MODULE | PHASE |
|---|---|---|
| [Hz] | [V/(m/s)] | [°] |
| 0.01 | 23.31 | -11.57 |
| 0.02 | 3.97 | 28.98 |
| 0.02 | 0.61 | 116.67 |
| 0.03 | 2.19 | 173.33 |
| 0.04 | 0.33 | 8.29 |
| 0.05 | 0.56 | 62.59 |
| 0.05 | 0.44 | 93.72 |
| 0.06 | 0.98 | 132.91 |
| 0.07 | 0.59 | 107.41 |
| 0.08 | 0.35 | 34.18 |
| 0.08 | 0.37 | -14.90 |
| 0.09 | 0.41 | -151.46 |
| 0.10 | 0.56 | -106.57 |
| 0.11 | 0.64 | -65.99 |
| 0.11 | 0.12 | -65.51 |
| 0.12 | 0.26 | -165.90 |
| 0.13 | 0.51 | -47.93 |
| 0.14 | 1.08 | -4.98 |
| 0.14 | 1.13 | -99.52 |
| 0.15 | 0.77 | 30.16 |
| 0.16 | 0.24 | 49.45 |
| 0.17 | 2.35 | 120.56 |
| 0.18 | 0.22 | 56.90 |
| 0.18 | 1.74 | -13.11 |
| 0.19 | 0.97 | 4.63 |
| 0.20 | 0.65 | -40.49 |
| 0.21 | 0.61 | 36.06 |
| 0.21 | 0.42 | -0.97 |
| 0.22 | 1.07 | -7.38 |
| 0.23 | 0.59 | 31.16 |
| 0.24 | 0.86 | 17.90 |
| 0.24 | 0.86 | -4.11 |
| 0.25 | 0.99 | -1.43 |
| 0.26 | 1.09 | 7.74 |
| 0.27 | 0.52 | -55.14 |
| 0.27 | 1.30 | -44.20 |
| 0.28 | 1.07 | -22.35 |
| 0.29 | 1.08 | 130.45 |
| 0.30 | 1.09 | 10.89 |
| 0.31 | 0.86 | 6.11 |
| 0.31 | 0.96 | -11.13 |
| 0.32 | 1.86 | -7.75 |
| 0.33 | 1.67 | -16.96 |
| 0.34 | 1.64 | -25.47 |
| 0.35 | 1.84 | -27.53 |
| 0.37 | 1.45 | -14.13 |

***Fig. 7: TXT final report***

Finally, VIBROCALC include a friendly help file with detailed explanation of all the mathematical functions and the algorithms used.

Figures 8 and 9 are shown the VIBROCALC main window and one example of transfer function calculation for one kind of inertial seismometer respectively.

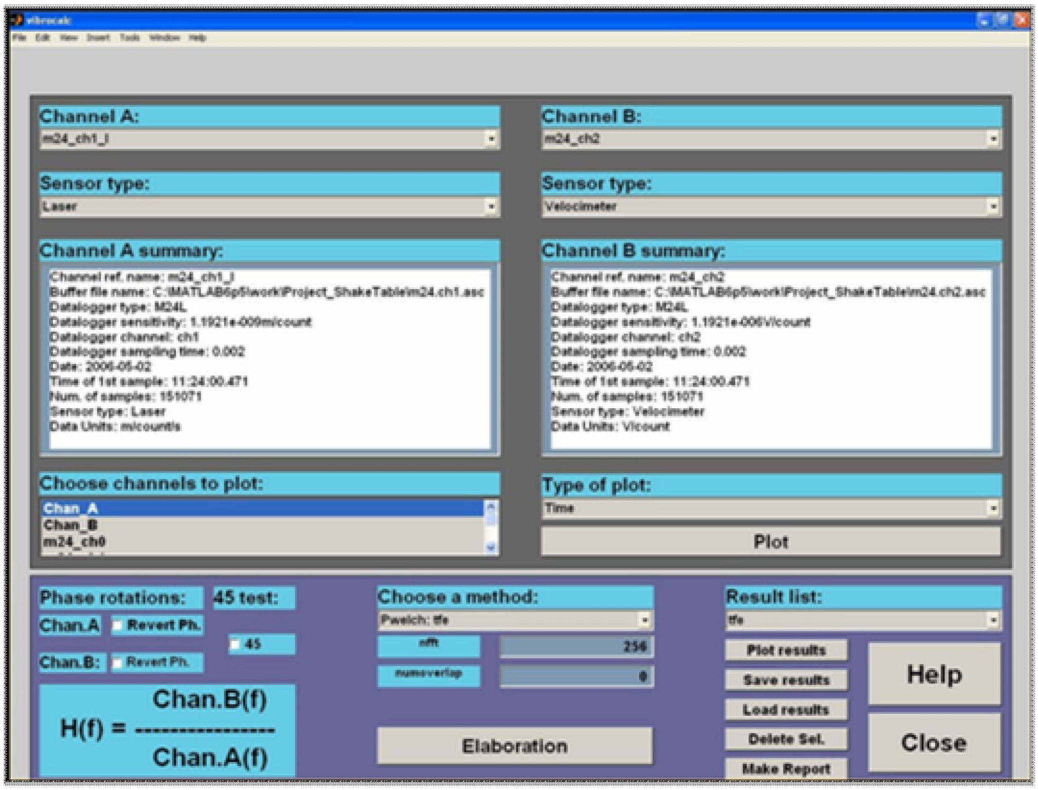



***Fig. 8: VIBROCALC main window***

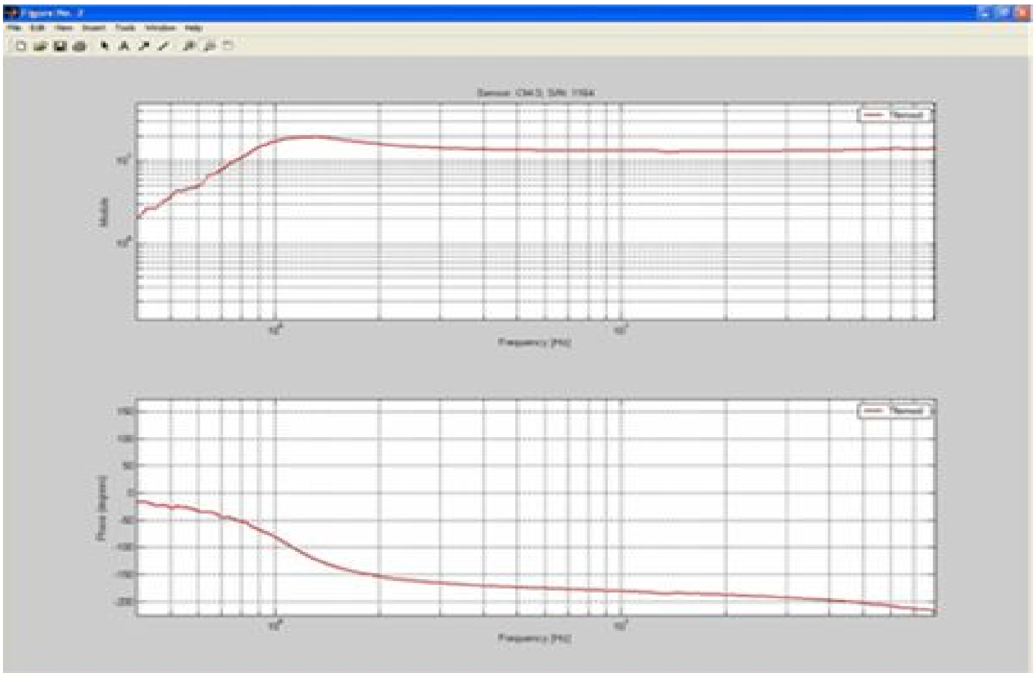


***Fig. 9: One second seismometer frequency response obtained by VIBROCALC***

## Conclusions

The VIBROCALC software is a very useful tool for the transfer function calculation of the seismic sensors currently in use with high quality and offering a friendly user interface for the seismometer channels design researchers and technicians. This program allows the reduction of the seismometer calibration process time and enlarging, at the same time, the reliability of this.

VIBROCALC is independent of which shake table model is used and it's only necessary to adjust the recording format of the input signals and those which came from the seismometer.

This software has been used, for more than a year in the "Centre di Ricerche Sismologiche" for calibration procedure. In this time, have been calibrated all short period sensors of the Friuli network and others seismometers and accelerometers used for local environment noise measurements in the framework of scientific projects. In all cases, he has shown its excellent characteristics.

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