

CALPLUS v4.0

***Interactive Calibration Software
Using SMART-24 and DL-24 Internal Calibration Boards***

User's Guide

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Dallas, Texas**

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1 GENERAL

The purpose of the CalPlus calibration package is to use the calibration capabilities of the SMART-24 and DL-24 digitizers equipped with an internal calibrator board to compute the absolute sensor and system sensitivity, as well as the complex transfer function of the seismometer or accelerometer.

Characteristic to CalPlus is that the calibration programs use the output of the seismometer to be calibrated, and in the same time the output of the calibrator board, which is the input to the calibration circuit of the seismometer.

With the DL-24 digitizer, the calibration signal is always digitized on the 'next' channel: channel 2 if seismometer output is digitized on channel 1, channel 3 for channel 2, and channel 1 for channel 3. If the unit has 6 channels, then channel 5 is used if seismometer output is digitized on channel 4, channel 6 for channel 5, and channel 4 for channel 6.

With the SMART-24 recorder, it is the user responsibility to enable recording of the calibration signal ('loopback' calibration) on one of the data channels. This is the last channel used, e.g., if the calibrated sensor output is digitized on channels 1, 2 and 3, the calibration signal should be digitized on either one of the channels 4, 5 or 6 (typically on channel 4). Also, it can also be the first channel used, e.g., if the calibrated sensor output is digitized on channels 2 and 3, the calibration signal should be digitized on channel 1. CalPlus requires the calibration signal amplitude recorded on the SMART-24 instrument to be at least 100,000 counts.

This approach has the advantage that the only information needed is the value of the LSB of the digitizer, and this can be precisely determined. The disadvantage is that the response of the digitizer itself cannot be determined, but again, the manufacturer released anti-aliasing filter coefficients are very well known.

There are two calibration procedures in the CalPlus package that complement each other. One is meant to determine the absolute sensor sensitivity (in $V/(m/s)$) and based on it the absolute system sensitivity (parameter `calib` in $nm/count$) at a certain calibration period (parameter `calper` in seconds). This is achieved by running a sine wave calibration session on the SMART-24 or DL-24 instrument and uploading the calibration file(s) on the local computer using an FTP client (for the SMART-24) or the D-Series setup and real time display utility software (for the DL-24), followed by running the CalPlus sine wave calibration processing function. The second procedure is meant to determine the (normalized) response function of the seismometer. This is achieved by running the random binary calibration session on the SMART-24 or DL-24 instrument and uploading the calibration files on the local computer using an FTP client (for the SMART-24) or the D-Series setup and real time display utility software (for the DL-24), followed by running the CalPlus random binary calibration processing function. The absolute calibration function is given by the normalized calibration function (with the value 1.0 at `calper`) multiplied by `calib`. The calibration function contains values at 100 frequencies between f_{min} and f_{max} defined in file `rbcal.def` (see § 3.5).

Although CalPlus is a standalone calibration procedure, it is easily linked to the Geotech's SMARTAutoDRM system. The SMARTAutoDRM module `imscal` knows how to search the

time-dependent calibration database, how to extract information from the calibration results files, and how to output the results in the GSE2.0/IMS1.0 format.

All programs are 32-bit applications for the Microsoft Windows 7/Vista/XP/2000/NT/98 operating systems. A GUI allows the user an easy and convenient access to the calibration processing functions and results.

In this manual, the following terminology is used (see Table 1):

The seismic or infrasound 'Station' designates an array of instruments recording and/or transmitting data. Each instrument is referred to as a 'Site'. Each instrument can have one or several 'Channels', for example each component of a seismometer corresponds to a different channel.

Table 1. Terminology correspondence between this manual and traditional seismological convention.

This manual	Seismological convention
Station	Network / Array
Site	Station
Channel	Component

2 INSTALLATION

First, choose a name for the home directory of CalPlus (e.g. C:\calplus). *Do not use a directory name containing the blank or dot character.*

Then, open the compressed CalPlus Install file e.g. 'CalPlus v3.9 Install.zip' from the CalPlus directory of the distribution CD using e.g. Windows Explorer, and extract all files to the chosen CalPlus home directory. The install procedure will generate all files necessary to run CalPlus, and will create the following subdirectories in the local CalPlus directory:

cal\ -	contains the time dependent database of calibration results (see section §3.3). The index file <code>stationcal.ndx</code> contains the list of all calibration files included in the database (not all calibrations need to be included in the database). This calibration database can be accessed automatically by the <code>imscal</code> module of the AutoDRM-NT system.
cal\files\ -	contains the calibration files automatically copied from the user selected source directory for later access. When copied, they will be stored in subdirectories by year.
messages\ -	hosts temporary files created by CalPlus software.
tmp\ -	contains the results of the calibration processing. If desired, selected calibration files can be moved using the <code>update</code> function to the <code>cal\</code> subdirectory and thus included in the calibration database.

It is recommended that you create a shortcut to the `C:\CALPLUS\CALPLUS.exe` program on your Desktop.

The CalPlus software is license protected. For versions 3.6 and earlier, the license key, either temporary for a CalPlus trial version or permanent for a CalPlus full version, is distributed from the factory as email attachment or on the distribution CD. After the CalPlus installation, the license key file has to be copied into the CalPlus home directory.

For versions 3.7 and above, the application can run as trial version for a limited period of time (typically 30 days) after first time it is executed. It can be activated anytime into full permanent version, which is locked to the PC it is activated on, following the steps described below.

Starting with Windows Vista, and including Windows 7, first time only, run the CalPlus program as an administrator.

The first time when executing the program, and everytime before activation, the window shown in Figure 1 is displayed.

To run the trial version click on the 'Evaluate CalPlus' link and the application will be started (see §3).

To activate CalPlus, click on the 'Activate CalPlus' link and the activation dialog will open as shown in Figure 2 (top). Submit to Geotech the two user codes displayed in this dialog. Upon receipt of the activation number(s) from the factory, go to the activation dialog and enter the activation code(s) (if only one code is received enter it as 'Activation Code 1'),

then press Continue. A window as in Figure 2 (bottom) confirms a successful activation; press Continue to start the application.

After activation, CalPlus application starts directly to its main window as described next.

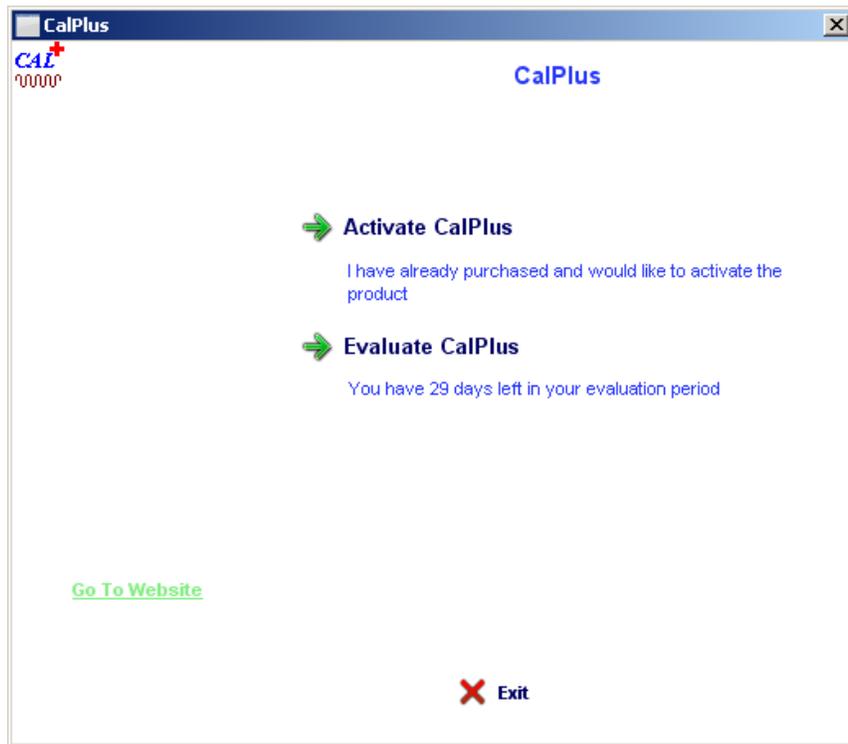


Figure 1. CalPlus Initial Window

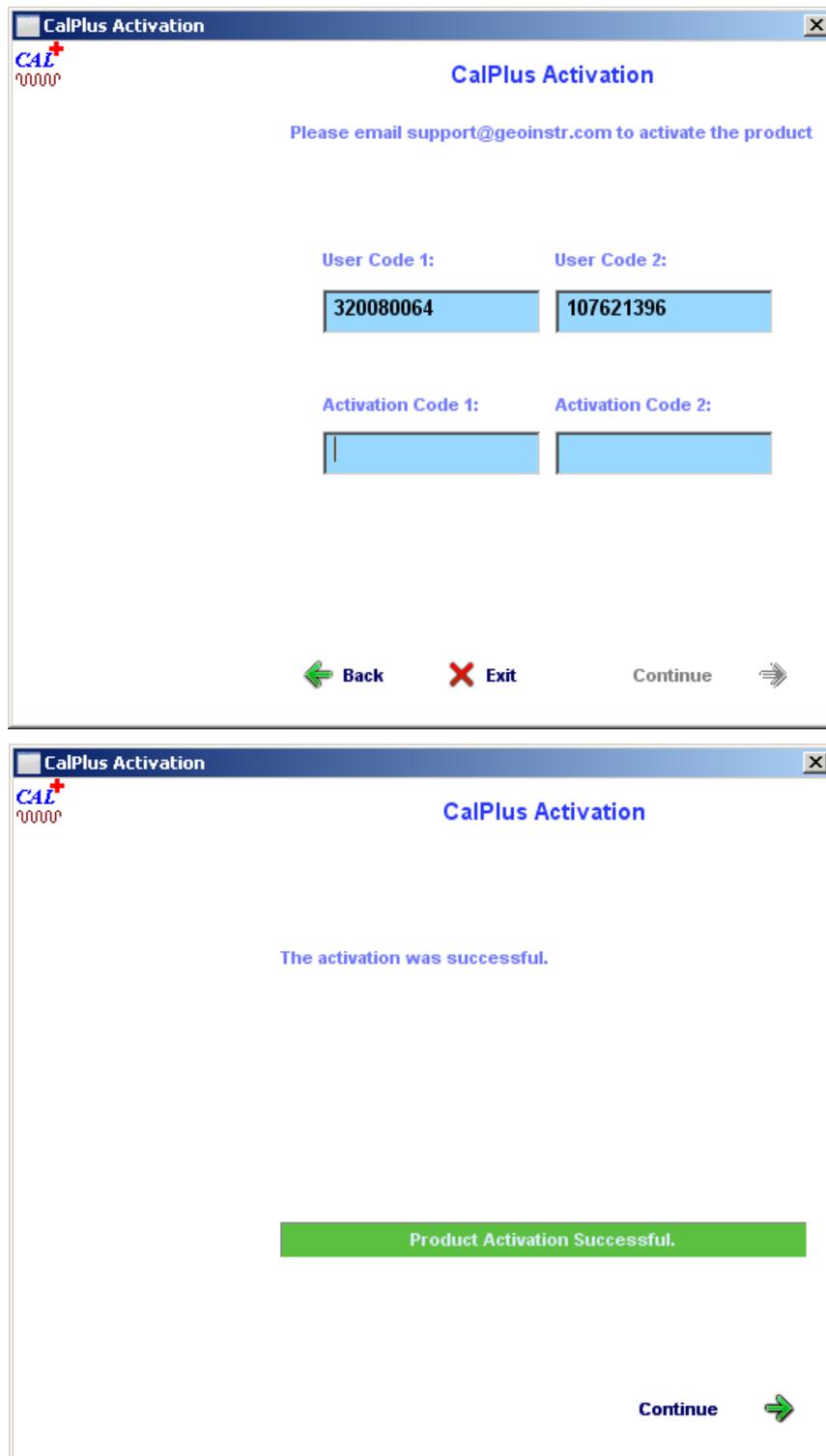


Figure 2. CalPlus Activation Dialog (top) and Successful Activation Window (bottom)

3 OPERATION

To start CalPlus, double click on the CalPlus icon on the Desktop. The Graphical User Interface shown in Figure 3 will be displayed. Commands and operations are selectable from the three program windows:

The “SMART-24 Data Recorder” allows the user to process calibration data recorded with a SMART-24 instrument (Figure 3). The “DL-24 Data Recorder” window allows the user to process calibration data recorded with a DL-24 instrument (Figure 4). The third window, entitled “Calibration Files”, offers modalities to access calibration results and database files.

The first operation to be done after installation is to **initialize the calibration database** by creating the first absolute station calibration file. This is done by selecting the “Calibration Files” window and entering the name chosen for the first station calibration file in the appropriate edit box (see Figure 5), including the absolute path name which should point to the `cal` subdirectory of the CalPlus home directory. The file name has to follow the naming convention described in Table 4. The date and time contained in the file name has to be earlier than that of any calibration data that you will need to process.

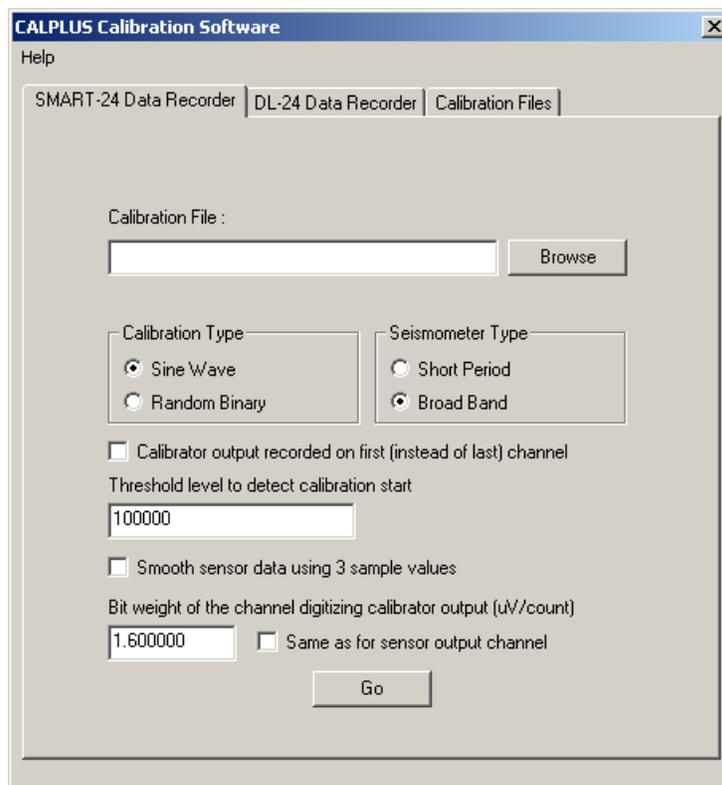


Figure 3. CalPlus GUI with the SMART-24 Data Recorder window

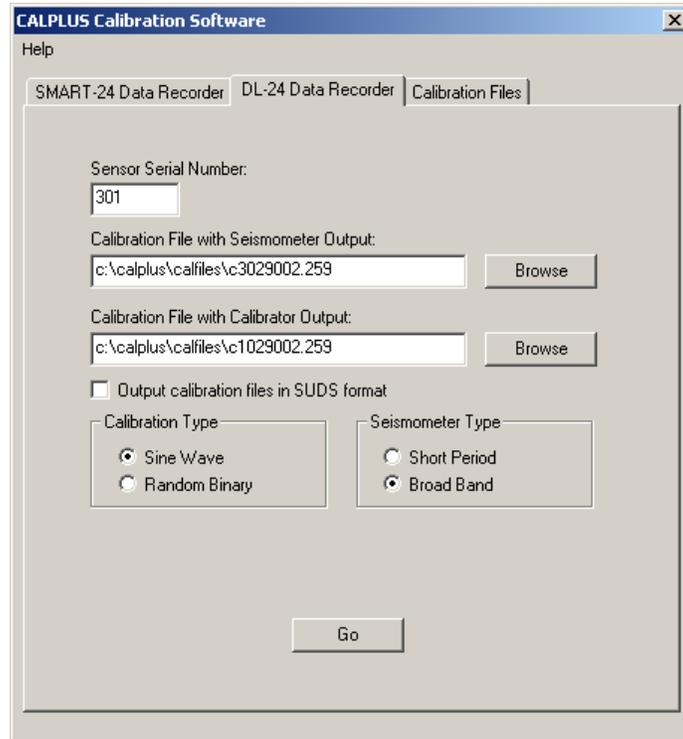


Figure 4. CalPlus GUI with the DL-24 Data Recorder window

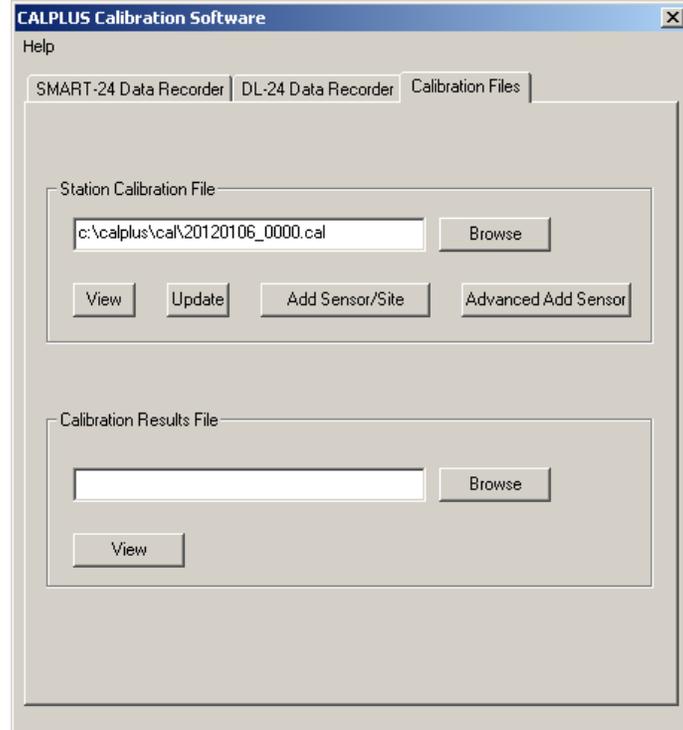


Figure 5. The Calibration Files window

After entering the station calibration file name, press the “Add Sensor/Site” or “Advanced Add Sensor” button to start entering basic or augmented information about your stations and sensors.

When choosing the “Advanced Add Sensor” option, a window as shown in Figure 6 is displayed for entering full calibration parameters of each new sensor. Press Save to save the entered information to the calibration file and go to next channel, or press Cancel to finish entering sensors and close the “Advanced Add Sensor” window. The information saved in the calibration file for all stations can be visualized by pressing the View button (see Figure 5). Once it saves the first calibration file, CalPlus also creates (or updates, if already existing) the database index file `cal\stationcal.ndx`.

The “Add Sensor/Site” button performs a similar function, but allows entering only a subset of basic calibration parameters (most frequently used) for new sensors and sites. The window shown in Figure 7 is displayed for entering sensor’s calibration parameters in groups of up to three channels. Press Save to save the information to the calibration file and go to next sensor, or press Cancel to finish entering channels and close the “Add Sensor/Site” window.

Every new sensor/site to be calibrated should be the first time entered into the calibration database as described above. To add new channels to an existing calibration database, just go to the “Calibration Files” window and press on the Add Sensor/Site or Advanced Add Sensor button leaving the Station Calibration File field empty; by this, new channels will be added to the newest calibration file (its name is shown in the window title).

Figure 6. The Advanced Add Sensor Window.

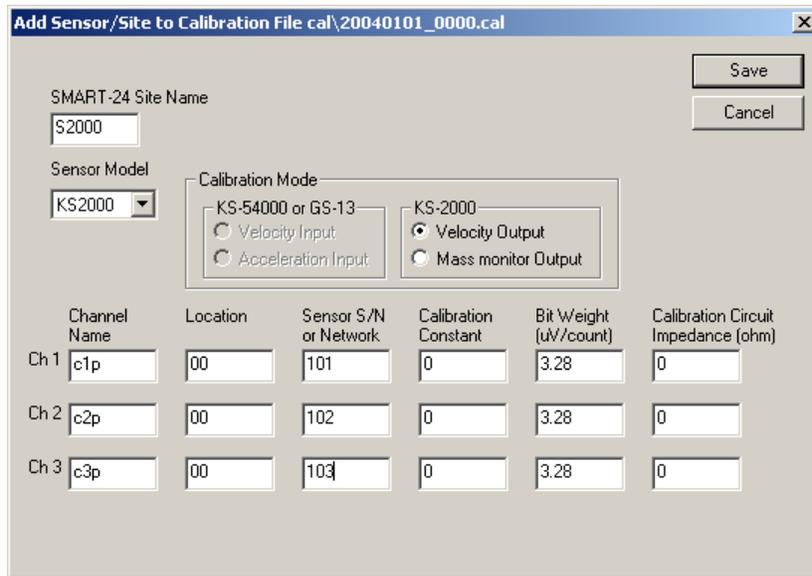


Figure 7. Add Sensor/Site Window

The various parameters in the station calibration file are to be entered in the format and units shown in Figure 6 and Figure 7 and in the header of `example.cal` (see Appendix B). SMART-24 site name has up to five characters, channel name up to three characters (e.g. 'BHZ', 'BHN' or 'BHE'), and network name (or Sensor S/N) has up to nine characters, see Table 2. The code of the seismometer is a 6-character code (as defined in the IMS documentation).

The SMART-24 site name, channel name and sensor model are mandatory to be entered.

Table 2. Parameters format requirements

Parameter	Number of characters
SMART-24 Site Name	Up to 5
Channel Name	Up to 3
Network name or Sensor Serial Number	Up to 9
Seismometer code	6, see Table 3

The calibration resistor should be given in ohms, and the 'calibration constant' must be entered in the units given by the manufacturer of that seismometer, as follows in Table 3.

Table 3. Seismometer Code, Constant and Calibration Resistor

Seismometer Model	Seismometer Code (6 characters)	Approximate calibration constant (units)	Calibration coil impedance (ohms)
Geotech KS-54000	KS5400	No calibration constant necessary; set calibration mode to 'R' for velocity or 'C' for acceleration	51
Geotech KS-2000	KS2000	10.7 (N/A); set calibration mode to 'V' for velocity or 'M' for mass position calibration	-
Geotech S-13J	S-13J*	0.29 (N/A)	29
Geotech S-13	S-13**	0.1975 (N/A)	23
Geotech GS-13	GS-13*	4.5 (N/A)	29
Geotech GS-21	GS-21*	4.5 (N/A)	24
Geotech 23900	23900*	0.1975 (N/A)	24
Geotech 20171A	20171A	0.1975 (N/A)	24
Streckeisen STS-1	STS-1*	0.002 (g/mA)	-
Streckeisen STS-2	STS-2*	0.002 (g/mA)	30
Guralp CMG-3	CMG-3*	0.004 (A/(m/s ²))	10,000
Guralp CMG-3T	CMG-3T	0.004 (A/(m/s ²))	10,000
Guralp CMG-3N	CMG-3N	0.004 (A/(m/s ²))	10,000
Guralp CMG-3E	CMG-3E	0.004 (A/(m/s ²))	10,000
SMART-24A®	S-24A*	0.4 (g/V) for ±2g full scale	-

Where “*” is a **required SPACE** in Seismometer Code

!!! WARNING !!!

No other seismometer model is currently implemented.
 For other seismometer models, one of the equivalent models above must be used or consult Geotech (info@geoinstr.com) for details.

3.1 File Naming Conventions

The following file naming convention has been used as listed in Table 4 below.

Table 4. CalPlus File Names

File Type	Naming Convention
Calibration data files recorded by the SMART-24 instrument, copied to the <code>cal\files\YYYY</code> subdirectory by CalPlus	YYYYMMDD_hhmmss_B_STACO.cd11, Where 'YYYY' stands for year, 'MM' for month, 'DD' for day of month, 'hh' for hour, 'mm' for minute and 'ss' for the second of calibration start time, and 'STACO' for station identifier. The \YYYY subdirectory is automatically created by CalPlus if it does not exist.
Calibration data files recorded by the DL-24 instrument, copied to the <code>cal\files\YYYY</code> subdirectory by CalPlus	tcsssnnn.doy, Where 't' stands for file type (is 'C' for calibration data files), 'c' for channel identifier (a number between 1 and 6), 'sss' is the last three digits of the unit's serial number, 'nnn' is the file sequence number (reset every day to 001) and 'doy' is the day of the year. The \YYYY subdirectory is automatically created by CalPlus, if it does not exist.
Absolute station calibration files, as generated initially by CalPlus in <code>tmp\</code> or moved by the Update command to <code>cal\</code>	YYYYMMDD_hhmm.cal (an example is given in Appendix B).
Normalized station calibration files, as produced initially by CalPlus in <code>tmp\</code> or moved by the Update command to <code>cal\</code>	YYYYMMDD_hhmm_STATCO_Chn.dat, where in addition to the above explanations, 'STATCO' stands for station code and 'Chn' stands for the channel identifier as entered in the station configuration.
Plot files of the normalized station calibration files, as produced by <code>grapher</code> in <code>tmp\</code> or moved by the Update command to <code>cal\</code>	YYYYMMDD_hhmm_STATCO_Chn.grf
Results files for the absolute station calibration, as produced by CalPlus in <code>tmp\</code> or moved by the Update command to <code>cal\</code>	YYYYMMDD_hhmm_STATCO_Chn.txt An example is given in Appendix C.
Database index file, as produced by the Add Channels, Add Sensors or Update commands in <code>cal\</code>	stationcal.ndx
Template files for <code>grapher</code> in <code>cal\</code>	response.grt and response0.grt

3.2 CalPlus Programs

The following programs are part of CalPlus package. All the programs are started from the CalPlus GUI.

Table 5. CalPlus Programs

Input files	Program	Output files
tcsssnnn.doy or YYYYMMDD_hhmmss_B_STACO.cd11 (calibration data files) cal*.cal cal*.dat stationcal.ndx	CalPlus <hr/> GUI	*.cal in tmp\ and/or cal\ *.dat in tmp\ and/or cal\ *.txt in tmp\ and/or cal\ *.grf in tmp\ and/or cal\ copy of the input files in folder cal\files\YYYY\
tcsssnnn.doy or YYYYMMDD_hhmmss_B_STACO.cd11 (calibration data files) cal*.cal stationcal.ndx sincal.calib (if existing)	SINCAL <hr/> (performs 'sine wave' calibration)	tmp*.cal tmp*.dat tmp*.txt copy of the input files in folder cal\files\YYYY\ messages\sincal.message
tcsssnnn.doy or YYYYMMDD_hhmmss_B_STACO.cd11 (calibration data files) cal*.cal cal*.dat rbcald.def (optional) stationcal.ndx	RBCAL <hr/> (performs 'random binary' calibration; is called by RBCAL1.BAT)	tmp*.cal tmp*.dat copy of the input files in folder cal\files\YYYY\ messages\rbcald.message
tmp*.dat or cal*.dat	GRAPHER <hr/> (displays automatically results of the random binary calibration)	tmp*.grf

3.3 Calibration Database Description

The calibration database resides in the `cal\` subdirectory. The absolute and normalized station calibration files appear always in pairs. This is achieved by copying the old `.dat` file (with a new name), each time a new `.cal` file is created, and vice versa. A pair of absolute and normalized station calibration files shares the same date and time, as shown in their names: `YYYYMMDD_hhmm.cal` and `YYYYMMDD_hhmm_STATCO_Chn.dat`.

The sine wave calibration (see §3.4) or the random binary calibration (see §3.5) of a channel can be repeated until operator satisfaction. However, it is obligatory that the operator saves the results to the database following the chronological order in which calibrations were performed (older calibrations should be saved first). If two calibrations are ran less than 1 minute apart, the second will override the first one.

The user is prompted to save or not calibration results to the time-dependent database after the calibration processing is completed and the results are displayed on screen. Also, an Update function is available in the “Calibration Files” window to help the user save calibration results to the database at a later time after the calibration processing was completed. Using the Browse button, the user can select from the `tmp\` subdirectory the station calibration file (`*.cal`) corresponding to the calibration that is to be included in the database. Once the selected station calibration file is entered in the appropriate edit box (see Figure 5), press the Update button. Based on the calibration date and time in the selected file, CalPlus will automatically determine the name of all calibration files to be moved from `tmp\` to `cal\` subdirectory, and will append the new calibration date and time in the `cal\stationcal.ndx` index file. The files saved to the `cal\` subdirectory are the absolute and normalized calibration file (`*.cal` and `*.dat`, respectively) and the corresponding results file (`*.grf` for a random binary calibration or `*.txt` for a sine wave calibration).

3.4 Sine Wave Calibration

The sine wave calibration procedure assumes that one calibration data file in SMART-24 internal (CD1.1) format or a pair of files in DL-24 internal (HLCP) format is already available with names as described in Table 4.

For the SMART-24 instrument, the file can be created from within the SMART24Config configuration and control program by starting a sine wave calibration session. Several (typically three) sensor channels can be calibrated at the same time, and processed in the same CalPlus session. Please note that CalPlus requires the calibration signal to be recorded on last channel used e.g., if the calibrated sensor output is digitized on channels 1, 2 and 3, the calibration signal should be digitized on channel 4 (or 5, 6), or on the first channel used, e.g., if the calibrated sensor output is digitized on channels 2 and 3, the calibration signal should be digitized on channel 1. The calibration data file recorded on the SMART-24 storage media can be transferred to the local computer by FTP (any FTP client can be used on the local computer for file upload).

For the DL-24 instrument, a pair of files can be created from within the DL-24 setup program, starting a sine wave calibration session, recorded on the DL-24 storage media,

and transferred to the local computer by using the File Upload function of the same utility software. In this case, only one calibrated sensor channel can be processed at a time in a CalPlus session.

In the "SMART-24 Data Recorder" window (see Figure 3), the user should enter in the appropriate box (most convenient using the Browse button) the name of the SMART-24R calibration data file, and check the appropriate checkbox if the calibrator output is recorded on the first data channel (by default, the last data channel is used).

In the "DL-24 Data Recorder" window, the user should enter in the appropriate boxes (most convenient using the Browse button) the names of the two calibration files with the seismometer output and calibrator output, respectively (see Figure 4). The sensor serial number, if entered, will be appended to the calibration results (DL-24 only).

The Calibration Type should be set to Sine Wave. Also, set Seismometer Type to Short Period or Broad Band as suitable for the calibrated sensor, to ensure that the most adequate processing options will be used.

The bit weight on the calibrator output channel should also be entered, or choose the option to use same value as on sensors channels if applicable. This information is stored in a temporary file on disk (`sinca.calib`) in the CalPlus home folder. Only the last entered value (station independent) is stored and used for absolute station calibration computation.

The calibration start and finish is detected by the software on the calibrator output channel, using a threshold level as entered by the user. This value (in counts) should be less than the amplitude of the calibration signal, but larger than the ambient noise signal amplitude before and after calibration. The default value is 100,000 counts. Another option is to smooth the sensor data using a 3 data samples average, by default turned off.

Once all processing options are set, click on the Go button to start calibration processing.

The absolute station calibration file (of the form `yyyyMMdd_hhmm.cal`, as shown in Appendix B), is first created in the `tmp\` subdirectory. **This file contains the new system sensitivity (*calib*), *calper* and sensor sensitivity values.** The *calper* parameter is determined by the processing module `sinca`, after mean removal, from the zero crossings of the calibration signal. The first and last 5% of the data are not used to avoid transient signals. This file can be moved into the database immediately after completing processing if choosing when prompted the Save option, or later with the Update command, and it can be visualized with the View command (see §4).

Also, the absolute calibration results, consisting in: station and channel name, sensor serial number, sensor sensitivity in Volts*sec/m for a seismometer or in g/count for the SMART-24A® accelerometer, and the calibration period in seconds, are output (as shown in Appendix C) to a text (ASCII) file named `YYYYMMDD_hhmm_STATCO_Chn.txt` in the `tmp\` subdirectory, and displayed on screen using the Windows editor Notepad. The user can print the file using the Notepad print menu. When the Save option or Update command is being used, this file will be moved in the `cal\` subdirectory together with the database files. Also, a View command can be used to visualize the content of this file at any later time (see §4).

3.5 Random Binary Calibration

CalPlus uses the random binary calibration program `rbcal` based on the SPECTRAL program by David Russel and Eric Haug (1987). Geotech's implementation of the random binary calibration procedure assumes that one calibration data file in SMART-24 internal (CD1.1) format or a pair of files in DL-24 internal (HLCP) format is already available with names as described in Table 4.

For the SMART-24 instrument, the file can be created from within the SMART24Config configuration and control program by starting a random binary calibration session. Several (typically three) sensor channels can be calibrated at the same time, and processed in the same CalPlus session. Please note that CalPlus requires the calibration signal to be recorded on last channel used e.g., if the calibrated sensor output is digitized on channels 1, 2 and 3, the calibration signal should be digitized on channel 4 (or 5, 6), or on the first channel used, e.g., if the calibrated sensor output is digitized on channels 2 and 3, the calibration signal should be digitized on channel 1. The calibration data file recorded on the SMART-24 storage media can be transferred to the local computer by FTP (any FTP client can be used on the local computer for file upload).

For the DL-24 instrument, a pair of files can be created from within the DL-24 setup program, starting a random binary calibration session, recorded on the DL-24 storage media, and transferred to the local computer by using the File Upload function of the same utility software. In this case, only one calibrated sensor channel can be processed at a time in a CalPlus session.

In the "SMART-24 Data Recorder" window (see Figure 3), the user should enter in the appropriate box (most convenient using the Browse button) the name of the SMART-24R calibration data file, and check the appropriate checkbox if the calibrator output is recorded on the first data channel (by default, the last data channel is used).

In the "DL-24 Data Recorder" window, the user should enter in the appropriate boxes (most convenient using the Browse button) the names of the calibration files with the seismometer output and calibrator output, respectively (see Figure 4). The sensor serial number, if entered, will be output on the calibration results plots (DL-24 only).

The Calibration Type should be set to Random Binary. Also, set Seismometer Type to Short Period or Broad Band as suitable for the calibrated sensor, to ensure that the most adequate processing options will be used.

The calibration start and finish is detected by the software on the calibrator output channel, using a threshold level as entered by the user. This value (in counts) should be less than the amplitude of the calibration signal, but larger than the ambient noise signal amplitude before and after calibration. The default value is 100,000 counts.

Once all processing options are set, click on the Go button to start calibration processing.

The `rbcal` can also be run interactively from a Command Prompt window, using the calling sequence shown below:

```
RBCAL v1.2 - Random binary signal calibration
Copyright 2000, Geotech Instruments, Dallas, Texas
Based on the program SPECTRAL, Copyright 1987,
by David R. Russell, Eric J. Haug
```

Saint Louis University, St. Louis, Missouri)

Usage: RBCAL InputFile1 InputFile2 /Iinmdir /Mm /Cn /Ln
 /Dn /Hn /Bn /Rn /Sn /Op

Where: InputFile1 is the seismometer output signal
 InputFile2 is the calibrator output signal
 /Iinmdir is the input directory [working]
 /Mm operation mode (m=A or m=M) [M]
 /Cn aliasing removal (0=no, 1=yes) [no]
 /Ln no. of FFT samples for LP processing [no. data]
 /Dn LP decimation factor as a power of 2 [no LP d]
 /Hn high-pass filter applied (0=no, 1=yes) [yes]
 /Bn bias correction applied (0=no, 1=yes) [yes]
 /Rn no. of SP time windows (0=no dec) [whole file]
 /Sn no. of FFT samples for SP processing [512]
 /Op output prop. to vel. (p=V) or acc. (p=A) [V]

The default values of the switches are given in square brackets. An important switch is the last listed one: it relates the calibration signal to the output of the seismometer. **For example, in the case of passive seismometers, the calibration at constant voltage corresponds to constant equivalent ground acceleration, and the switch must be /ov (the default value). The same is true for all active seismometers listed in Table 3, except the Geotech KS-54000 seismometer. For this seismometer, this switch should be used only if the velocity output is digitized and if the calibration is done in resistive mode. It is assumed that in those cases where the acceleration output is digitized, the calibration is done only in resistive mode, and then the switch must be /OA.**

Special features of the original program SPECTRAL by Russel and Haug (1987), preserved in *rbc*al, are:

- No limitations on the length of the RB (random binary) signal. The program reads the input and output of the instrument off of disk in blocks of 1/2 the FFT length used for processing. Auto and cross covariance functions are calculated in the frequency domain, and an overlapped stacking procedure is used to smooth the functions. The transfer function is calculated as the ratio of the smoothed cross/auto covariance functions.
- Reduced biasing of the cross-covariance function by aligning the RB input signal with the output signal. The phase alignment is calculated by the maximum amplitude of the cross-covariance function.
- For broadband applications, the program can be run with a large time window for low frequencies, and a small time window for high frequencies. This allows FFT calculations for very long periods, while preserving a high stacking multiple for short periods. In addition, an efficient recursive IIR algorithm is used to decimate long time windows, in order to reduce FFT computations for long periods. The algorithm uses an 8-pole causal Butterworth anti-aliasing filter, which has special provisions to annihilate edge effects due to time window truncation. The causal phase shift

vanishes when the transfer function ratio of cross/auto covariance is made. The maximum value for these switches is 65536. No LP decimation was found necessary.

- Another broadband feature is the optional inclusion of an IIR causal high-pass filter for short time windows. This can be useful in cases where the maximum broadband instrument acceleration response occurs at very long periods (such as the Streckeisen). Without high-passing the signal, the short time windows can "float" on the very long period response, resulting in edge effects due to time window truncation.

The normalized station calibration file (`yyyyMMdd_hhmm_statco_chn.dat`) is first created by `rbcal` in the `tmp\` subdirectory. It can be moved into the database immediately after completing processing if choosing when prompted the Save option, or later with the Update command. This file contains the normalized station calibration as three columns and 100 rows, for 100 frequencies. The three columns are for frequency (in Hz), normalized amplitude, and phase (in degrees). The maximum and minimum frequencies can be set in file `rbcal.def`, for each seismological spectral band, where the designator in the first column should match the first character in the channel name; otherwise the default values of 100 Hz and 0.005 Hz are used. The program limits the maximum frequency by 80% of Nyquist frequency. However, there will be only 100 frequency values between the minimum and maximum frequency.

The program `rbcal` generates also the following ASCII files with more detailed information on the processing (this information is kept until the next random binary calibration of that channel):

<code>tmp\rb_param_STATCO_Chn.out</code> -	with various internal parameters used;
<code>tmp\rb_complex_STATCO_Chn.out</code> -	with the frequency, real part of complex response function, imaginary part of the response function, and the standard deviation of it;
<code>tmp\rb_ampl_STATCO_Chn.out</code> -	with the frequency, amplitude, amplitude minus one standard deviation, and amplitude plus one standard deviation;
<code>tmp\rb_phase_STATCO_Chn.out</code> -	with the frequency, phase, phase minus one standard deviation, and phase plus one standard deviation;
<code>tmp\rb_coherency_STATCO_Chn.out</code> -	with the frequency and coherency function,

where `Chn` stands for the channel identifier as entered in the station configuration (e.g. 'BHZ', 'BHN' or 'BHE').

In case `rbcal` is called from CalPlus a batch file `rbcal1.bat` is provided to allow the user to customize the various command line switches of the `rbcal` program. The first and last 5% of the data are not used to avoid transient signals.

4 DISPLAYING RESULTS

After processing a random binary calibration, the `grapher` program is called by CalPlus to display the normalized amplitude and phase response functions. A plot is automatically generated and displayed, based on a template that knows how to read channel data (frequency on column 1, amplitude on column 2, and phase on column 3). Depending on the actual data range of the phase response, CalPlus uses one of the two template files available (`cal\response.grt` for phase between -180 and 180 degrees, `cal\response0.grt` for phase between 0 to 360 degrees). **Also automatically, *Grapher* stores the plot file in `tmp\` subdirectory under the same name as the calibration data file, but adding the extension `.grf`. (*)**

The name of the station and channel appears on the plot, as well as the sensor serial number and the name of the calibration data file, so that the date and time of the calibration stays with the plot file. The graphs can be printed if a printer is available, or can be stored for later display and analysis. **When the Save option or the Update command is being used, this file will be moved in the `cal\` subdirectory together with the database files.**

Two examples of final plots are given in Appendix A.

A **View function** is available in the "Calibration Files" window (see Figure 5) to help the user display calibration results files at any later time. Using the Browse button, the user can select from the `tmp\` or `cal\` subdirectory any calibration results file, that can be either a plot file (`*.grf`) for a random binary calibration or a text file (`*.txt`) for a sine wave calibration. Once the selected calibration results file is entered in the appropriate edit box, press the View button. CalPlus will then display the results calling `Grapher` program for a plot file or Windows editor `Notepad` for a text file, respectively.

Another **View function** is available in the "Calibration Files" window (see Figure 5) to help the user display station calibration files (`*.cal`) at any later time. Using the Browse button, the user can select from the `tmp\` or `cal\` subdirectory any station calibration file. Once the selected calibration file is entered in the appropriate edit box, press the View button. CalPlus will then display the content of the calibration file in a new Station Calibration Info window, as shown in Figure 8. If pressing the **View** button leaving the station calibration file field empty, the newest calibration file is displayed.

Station Calibration Info

File: cal\20041028_0155.cal

Stat. Code	Channel Nam/No/C	Network	Latitude (S<0)	Longitude (W<0)	Elev. (m)	Depth (m)	Sensor Type	Start <> Stop R yyymmdd/yyymmdd C	CalConst.	CalRes (ohm)	Calib (zm/count)	CalPer (sec)	Hanq deg	Vanq deg	LSB (V/count)	Samp. Rate	Coord. System	Sensitivity (V/m/sec)	
EXAMPL	bha	00 1	Ahodefghi	-12.1234	-123.1234	1234.	1234.	KS5400	990101/001231 R	.403510e-2	29.	.123456e-1	1.	-1.	0.	.377759e-5	40.	WGS-84	2000.
V0320	c1p	00 1	559	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.109e+001	0.	.26040E+00	1.000	-1.	0.	3.280e-006	0.	WGS-84	2005.
V0320	c2p	00 1	580	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.105e+001	0.	.25877E+00	1.000	0.	90.	3.280e-006	0.	WGS-84	2017.
V0320	c3p	00 1	581	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.078e+001	0.	.24842E+00	1.000	90.	90.	3.280e-006	0.	WGS-84	2101.
V0000	c1p	00 1	101	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.100e+001	0.	0.000e+000	1.00	-1.	0.	3.280e-006	0.	WGS-84	0
V0000	c2p	00 1	102	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.100e+001	0.	0.000e+000	1.00	0.	90.	3.280e-006	0.	WGS-84	0
V0000	c3p	00 1	103	0.0000	0.0000	0.	0.	KS2000	000101/990101 V	1.100e+001	0.	0.000e+000	1.00	90.	90.	3.280e-006	0.	WGS-84	0

Figure 8. Station Calibration Info window.

5 FINAL REMARKS

1. All files in the database are ASCII files, so that they can be easily inspected. **Do not delete files from the database !** If however necessary, delete them only in pairs (*.cal and *.dat), and delete also the corresponding lines in the index file stationcal.ndx.
2. As of September 15, 2004, the calibration procedure was not yet tested on Geotech KS-54000 and Streckeisen STS-1/2 seismometers.
3. A separate program package SMARTAutoDRM can make automatic use of the calibration database produced by CalPlus. See SMARTAutoDRM manual for more details.

(*) A license of Grapher program by Golden Software, Inc. is provided for convenience.

Appendix A

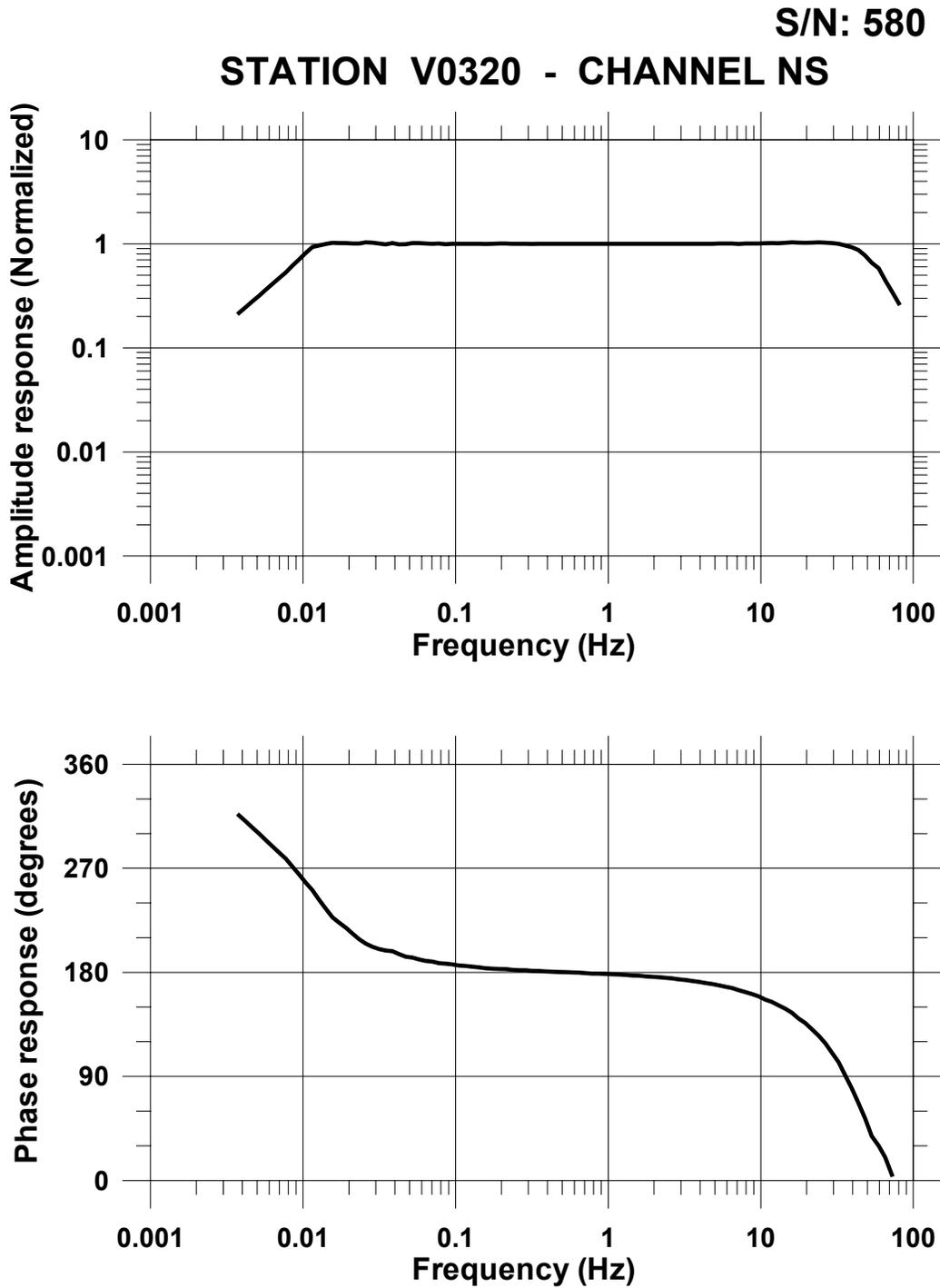
Examples of random binary calibrations as produced by CalPlus program and displayed with `Grapher` using the template `response.grt` for a virtual station with the code `V0320`.

First example was obtained for a Geotech KS-2000 broadband seismometer using the `/L65536` and `/S65536` switches for a 15-minute long signal 3 V in amplitude. The sampling frequency was 250 sps, and the results were plotted up to the Nyquist frequency (100 Hz).

Second example was obtained with a Geotech S-13 short-period seismometer using the default switches for a 10-minute long signal 0.5 V in amplitude. The sampling frequency was 40 sps, and the results were plotted up to 80% the Nyquist frequency (16 Hz).

Note in all cases the presence of the high frequency noise at the test site (Geotech facility in Dallas, Texas).

The following figures show the responses plotted relative to constant ground velocity (as they are actually computed).



File: 20041028_0202_V0320__c2p.dat

Figure 9. Plot for KS-2000 Broad Band Seismometer

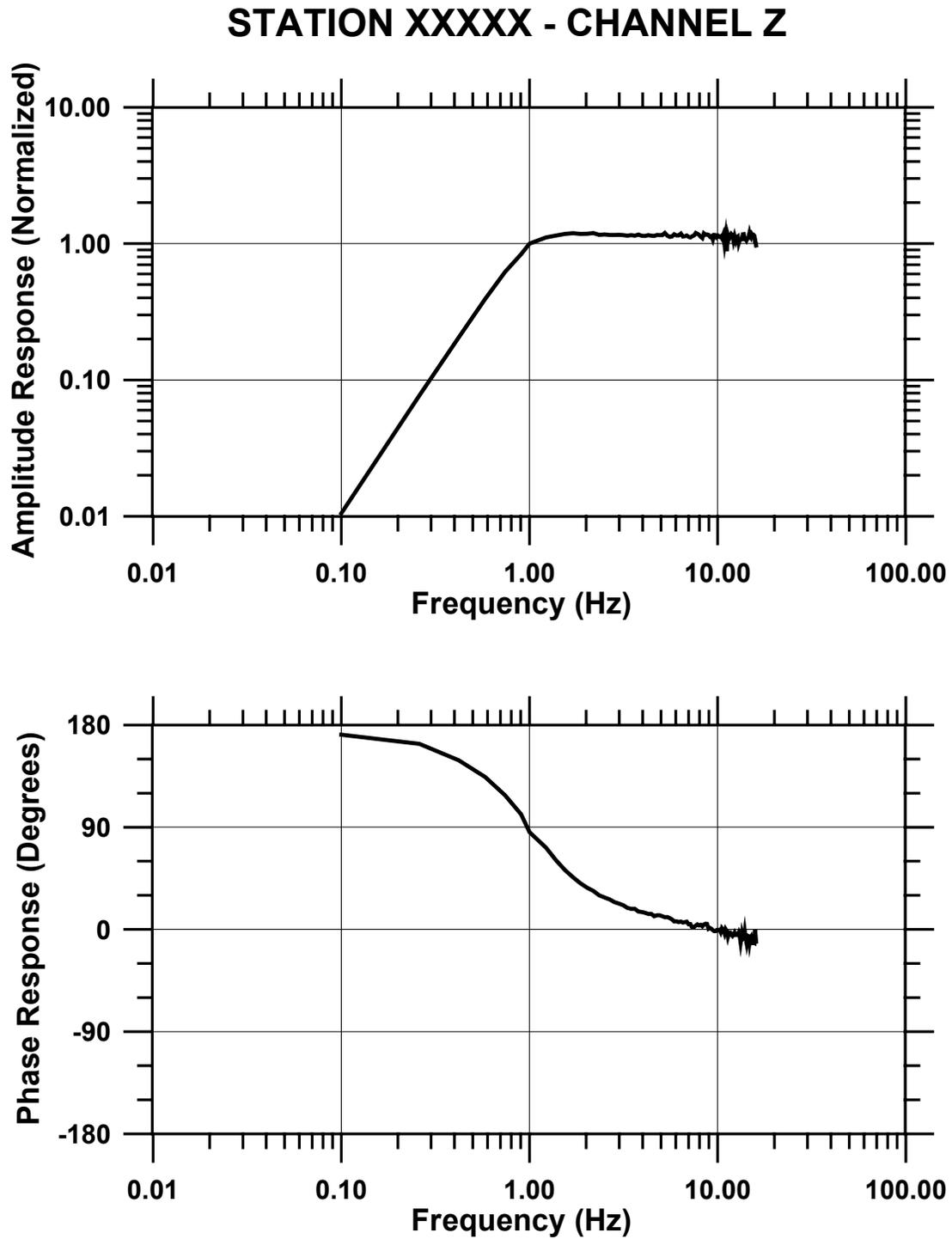


Figure 10. Plot for S-13 Short-Period Seismometer

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Appendix B

Example of an Absolute Station Calibration File

Stat. Code	Channel Nam/No/C	Network	Latitude (S<0)	Longitude (W<0)	Elev. (m)	Depth (m)	Sensor Type	Start <> yymmdd/yymmdd	Stop C	R	CalConst.	CalRes (ohm)	Calib (nm/count)	CalPer (sec)	Hang deg	Vang deg	LSB (V/count)	Samp. Rate	Coord. System	Sensitivity (V/(m/sec))
EXAMPL	bhz	00 1	Abcdefghi	-12.1234	-123.1234	1234.	1234.	KS5400	990101/001231	R	.403510e-2	29.	.123456e-1	1.	-1.	0.	.377759e-5	40.	WGS-84	2000.
V0320	c1p	00 1	559	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.109e+001	0.	.13020E+00	1.000	-1.	0.	1.600e-006	0.	WGS-84	1956.
V0320	c2p	00 1	580	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.105e+001	0.	.12938E+00	1.000	0.	90.	1.600e-006	0.	WGS-84	1968.
V0320	c3p	00 1	581	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.078e+001	0.	.12421E+00	1.000	90.	90.	1.600e-006	0.	WGS-84	2050.
V0321	c1p	00 1	560	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.087e+001	0.	.12766E+00	1.000	-1.	0.	1.600e-006	0.	WGS-84	1995.
V0321	c2p	00 1	582	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.106e+001	0.	.12915E+00	1.000	0.	90.	1.600e-006	0.	WGS-84	1972.
V0321	c3p	00 1	583	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.109e+001	0.	.13189E+00	1.000	90.	90.	1.600e-006	0.	WGS-84	1931.
V0318	c1p	00 1	557	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.087e+001	0.	.12629E+00	1.000	-1.	0.	1.600e-006	0.	WGS-84	2016.
V0318	c2p	00 1	576	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.079e+001	0.	.12308E+00	1.000	0.	90.	1.600e-006	0.	WGS-84	2069.
V0318	c3p	00 1	577	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.080e+001	0.	.12261E+00	1.000	90.	90.	1.600e-006	0.	WGS-84	2077.
V0319	c1p	00 1	558	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.070e+001	0.	.12209E+00	.992	-1.	0.	1.600e-006	0.	WGS-84	2069.
V0319	c2p	00 1	578	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.142e+001	0.	.13222E+00	.992	0.	90.	1.600e-006	0.	WGS-84	1911.
V0319	c3p	00 1	579	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.091e+001	0.	.12281E+00	.992	90.	90.	1.600e-006	0.	WGS-84	2057.
V0322	c1p	00 1	561	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.109e+001	0.	.12755E+00	.992	-1.	0.	1.600e-006	0.	WGS-84	1980.
V0322	c2p	00 1	588	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.076e+001	0.	.12226E+00	.992	0.	90.	1.600e-006	0.	WGS-84	2066.
V0322	c3p	00 1	589	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.061e+001	0.	.12050E+00	.992	90.	90.	1.600e-006	0.	WGS-84	2096.
V0323	c1p	00 1	562	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.091e+001	0.	.12443E+00	.992	-1.	0.	1.600e-006	0.	WGS-84	2030.
V0323	c2p	00 1	584	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.113e+001	0.	.12957E+00	.992	0.	90.	1.600e-006	0.	WGS-84	1950.
V0323	c3p	00 1	585	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.086e+001	0.	.12392E+00	.992	90.	90.	1.600e-006	0.	WGS-84	2039.
V0324	c1p	00 1	563	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.068e+001	0.	.12017E+00	.992	-1.	0.	1.600e-006	0.	WGS-84	2102.
V0324	c2p	00 1	586	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.141e+001	0.	.13661E+00	.992	0.	90.	1.600e-006	0.	WGS-84	1849.
V0324	c3p	00 1	587	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.073e+001	0.	.12235E+00	.992	90.	90.	1.600e-006	0.	WGS-84	2065.
V0325	c1p	00 1	564	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.092e+001	0.	.12486E+00	.992	-1.	0.	1.600e-006	0.	WGS-84	2023.
V0325	c2p	00 1	592	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.119e+001	0.	.13032E+00	.992	0.	90.	1.600e-006	0.	WGS-84	1938.
V0325	c3p	00 1	593	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.081e+001	0.	.12361E+00	.992	90.	90.	1.600e-006	0.	WGS-84	2044.
V0326	c1p	00 1	565	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.076e+001	0.	.12547E+00	1.000	-1.	0.	1.600e-006	0.	WGS-84	2030.
V0326	c2p	00 1	594	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.079e+001	0.	.12460E+00	1.000	0.	90.	1.600e-006	0.	WGS-84	2044.
V0326	c3p	00 1	595	0.0000	0.0000	0.	0.	KS2000	000101/990101	V	1.096e+001	0.	.12726E+00	1.000	90.	90.	1.600e-006	0.	WGS-84	2001.

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Appendix C

Example of an Absolute Calibration Results File for a KS-2000 Seismometer

CALIBRATION RESULTS

KS-2000 S/N : 0320

Component : Vertical

Sensor Serial No : V559

Velocity Channel Sensitivity : 2005. Volts/(meter/sec)

Calibration Period : 1.000 sec

Example of an Absolute Calibration Results File for a SMART-24A® Accelerometer

CALIBRATION RESULTS

KS-2000 S/N : 1264

Component : Vertical

Sensor Serial No : V100

Calibration Input Sensitivity: .385400 g/V

Sensor Sensitivity : .320038E-06 g/count

Calibration Period : 1.000 sec