Appendix A. PTS guidelines for an IMS infrasound site survey

The PTS document CTBT/PC/III/WGB/PTS/INF.3 lists numerous requirements for a good infrasound site. The main points are summarized below. The survey is to find the location that, to the greatest degree, satisfies these requirements.

- Within 0.05° of the nominal station location listed in Annex 1 to the Protocol of the CTBT.
- Minimal wind and infrasonic noise between 0.02 to 4 Hz.
- Relatively flat terrain where view to the horizon is not obstructed by more than 20°.
- Individual array element sites must be flat enough to accomodate a filter of ~ 10000 m^2.
- Adequate space to deploy 4 to 7 array elements spaced at 1 to 3 km at the same elevation.
- Individual array elements not near sources of cultural noise (e.g. airports) or structures.
- Array elements located if possible at least 5 km from the coast.
- If possible locate each array element in a forest with thick ground cover.
- Site not subject to flooding or other environmental hazards.
- Site in an area easily accesssed at all times of the year.
- Direct access to power and data telecommunications facilities.
- If possible co-locate with other IMS stations (e.g. seismic).
- All array element sites preferably will have a line of site to a central recording site.
- It should be possible to install the equipment at each array site to a depth of 1 m.
- Continuous signals are to be transmitted to a central recording site and then to the IDC.

The main requirements for the site survey are as follows:

- Select four promising sites for the survey by reviewing topography, ground cover, land ownership maps and meterological data.
- Measure infrasonic background noise levels and wind speed, direction and temperature simultaneously at the four sites for a period of at least 2 weeks.
- Deploy the same equipment at all four sites. Ensure that the sensors are calibrated to give equal digitized output for equal input.
- Use portable wind-noise-reducing filters at each site.
- Digitize the infrasonic noise at 20 sps.
- Locate the anemometers at each site at a height of 2 m. Deploy the temperature sensor on the same mast at a height of 1m.
- Locate mast and any other equipment (such as solar panel) downwind from the infrasound sensor.

Appendix B. Survey Site Photos

At each survey site, several photographs were taken with a Kodak digital camera to provide a record of local topography, vegetation and the equipment we deployed at each location. We include a subset of these photographs in this section.

Figure B.1 Site 1

Figure B.2 Site 2

Figure B.3 Site 3.

Figure B.4 Site 4.

Appendix C. Survey equipment specifications

C.1 MB2000 Microbarometer

DASE / COM / 005 A97

DÉPARTEMENT ANALYSE ET SURVEILLANCE DE L'ENVIRONNEMENT

Infrasound detection in the atmosphere

MICROBAROMETERS

The MB2000 microbarometer (figure 1) measures small variations in atmospheric pressure such as those created by aerial explosions at long distances. A barometric aneroid bellows is deformed under atmospheric pressure change. This deformation is measured by an LVDT (Linear Variable Differential Transformer) displacement sensor. The sensor is sensitive and easy to implement. The electronic noise level is 2 mPa rms in the 0.02-4 Hz band.

The filtered signal output bandwidth is from 0.01 to 27 Hz. It can be modified very easily. For instance, the bandwidth has already been extended to 0.001 to 40 Hz in similar equipment designed by the CEA.

Correct operation is validated by atmospheric pressure check.

DESCRIPTION

The barometric aneroid bellows is made of Durinval. The LVDT-type displacement sensor, associated with a low-noise electronic circuit, measures bellows deformation with atmospheric pressure change. The cell displacement sensor design eliminates temperature-induced drift.

The cylindrical microbarometer body has a diameter of 15 cm, a height of 32 cm, and weighs 7 kg.

The lower part makes up the measurement chamber, containing the bellows and the LVDT displacement sensor. The chamber is connected to the ambient atmospheric pressure through four nozzles. Each nozzle can accept a microporous pipe to form a filtering system for microbarometric background noise reduction.

The upper part is watertight and accepts two electronic boards.

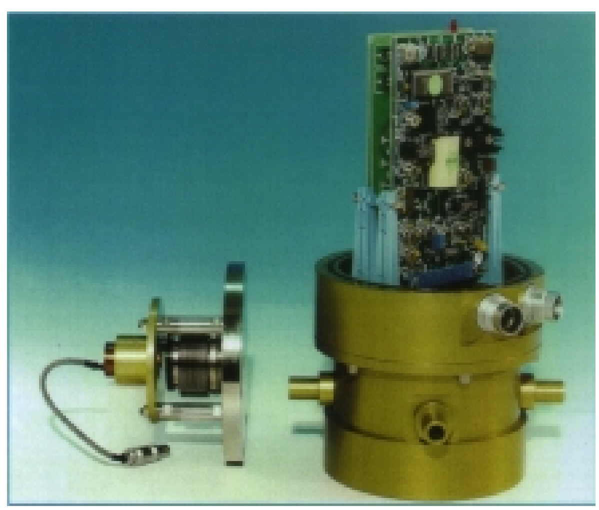


Figure 1 *The MB2000 microbarometer. On the left, the cell-displacement sensor. On the right, the electronic boards.*

CHARACTERISTICS

■ Aneroid bellows characteristics

The Durinval aneroid bellows has a very low thermal expansion coefficient.

Operating range: 400 to 1200 hPa.

Mechanical sensitivity: 35 nm/Pa.

■ Electronic board characteristics

- Quartz oscillator with ultrastable frequency and voltage.
- LVDT primary winding excitation frequency: 8 kHz.
- LVDT excitation voltage: 15.6 V peak-to-peak.

■ Microbarometer characteristics

- Standard operating pressure with ambient atmospheric pressure: ± 100 hPa
- Sensitivity before filtering (DC to 40 Hz band): 1 mV/Pa, i.e. ± 10 volts for ± 100 hPa.

Filtered output

The characteristics of the standard filtered output are summarized in Table 1. They are compared with the Working Group B Specifications (WGB/TL/8 - April 97).

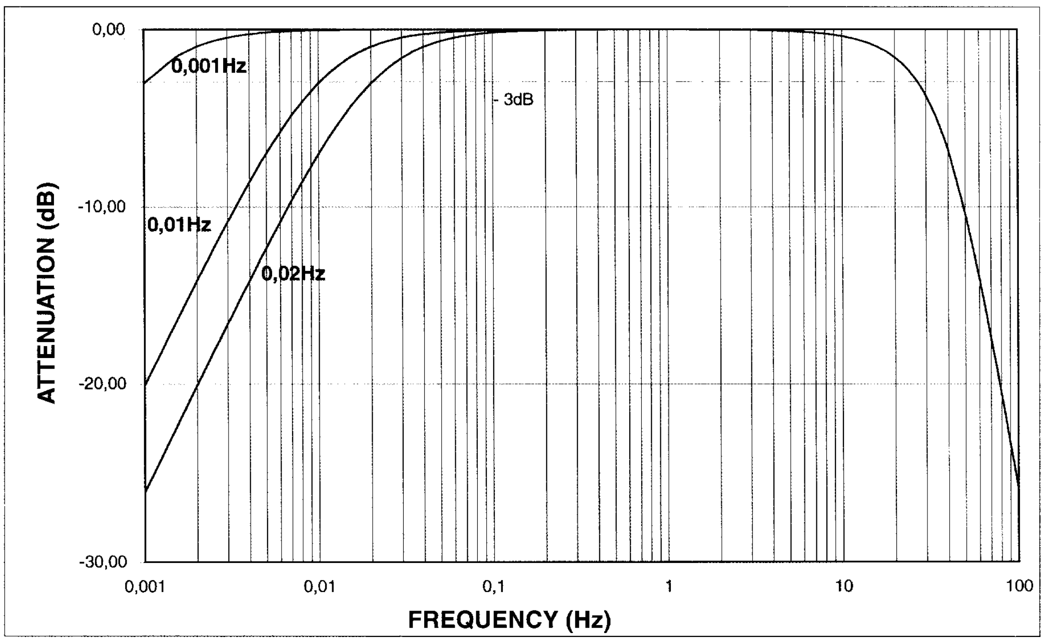
- Passband flat up to 27 Hz (figure 2).
- Standard high-pass filter cut-off frequency: 0.01 Hz.
- Cut-off frequency options: any value down to 0.001 Hz.
- For 16-bit ADC:
  . standard sensitivity after filtering: 100 mV/Pa
  . full scale: ± 100 Pa
- For 20-bit ADC:
  . standard sensitivity after filtering: 20 - 100 mV/Pa
  . full scale: ± 500 Pa
- For 24-bit ADC:
  . no filtering necessary in the microbarometer
  . standard sensitivity: 1 mV/Pa
  . full scale: ± 100 hPa
  . flat response from DC to 27 Hz, enabling any kind of digital post-processing

Table 1
Comparison between the CEA infrasound station spécifications and the specifications defined by the WGB/TL/8

(1) 18 dB below minimum acoustic noise (5 mPa @ 1 Hz)
(2) 1/2 Full scale/Noise.

		Specifications WGB/TL/8 April 1997	CEA Sensor for 16 bits ADC	CEA Sensor with 20 bits CEA ADC	CEA Sensor with 24 bits CEA ADC
MB 2000 Sensor	Range		200 hPa pp	200 hPa pp	200 hPa pp
	Bandwidth (Hz)		0 - 40	0 - 40	0 - 40
	Sensitivity		1 mV / Pa	1 mV / Pa	1 mV / Pa
	Electronic noise @ 1 Hz	(1) ≤ 0.63 mPa/$\sqrt{Hz}$	0.6 mPa/$\sqrt{Hz}$	0.6 mPa/$\sqrt{Hz}$	0.6 mPa/$\sqrt{Hz}$
	Electronic noise (0.02 - 4 Hz)		2 mPa rms	2 mPa rms	2 mPa rms
	Dynamic range (2)		134 dB	134 dB	134 dB
MB 2000 Signal output	Range		200 Pa pp	1000 Pa pp	20 000 Pa pp
	Bandwidth (Hz)	0.02 - 4	0.01 - 27	0.01 - 27	0 - 40
	Sensitivity		100 mV / Pa	20 mV / Pa	1 mV / Pa
	Electronic noise (0.02 - 4 Hz)		2 mPa rms	2 mPa rms	2 mPa rms
	Dynamic range (2)		94 dB	108 dB	134 dB
Digitizer	Antialiasing filter (Hz)	≥ 4 Hz	4 Hz	4 Hz	4 Hz
	Sampling Frequency	$\geq$ 10 Hz	10 Hz	10 Hz	10 Hz
	Digitizing range		20 V	20 V	32 V
	Input range		20 V	20 V	20 V
	Digitizing output		16 bits	20 bits	24 bits
	count	≈ 1 mPa	3.05 mPa	0.95 mPa	1.91 mPa
	Digitizing noise (0.02 - 4 Hz)		1.5 mPa rms	0.57 mPa rms	2.1 mPa rms
	Dynamic (2)		96 dB	119 dB	134 dB
System	Full Scale		200 Pa pp	1000 Pa pp	20 000 Pa pp
	Noise		2.5 mPa rms	2.1 mPa rms	2.9 mPa rms
	Dynamic (2)	$\geq$ 108 dB	92 dB	108 dB	131 dB

Figure 2
The MB2000 microbarometer frequency response.



The electronic noise of the sensor is significantly below the natural background noise. Figure 3 shows a comparison with natural background noise measured at a French station under low-wind conditions: electronic noise is 20 dB below natural background noise over the entire frequency band.

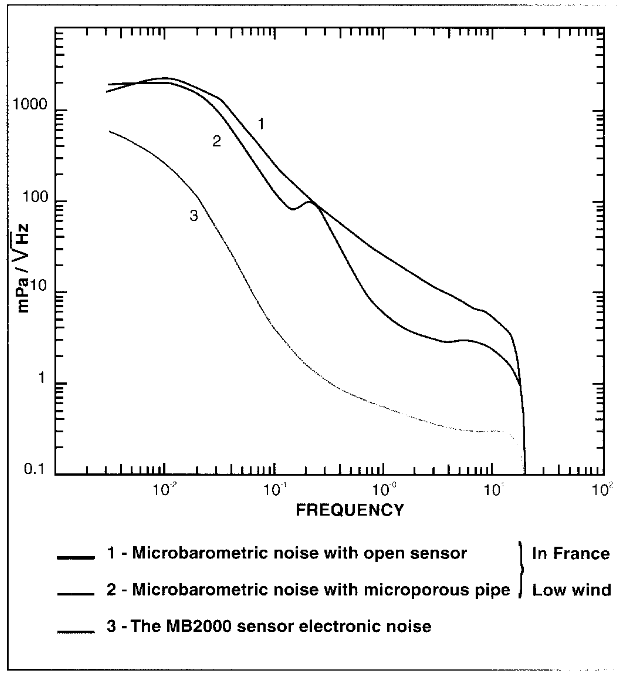


Figure 3 *Electronic noise of the sensor compared with the natural background noise.*

Atmospheric pressure (AP) output

Correct operation is validated by continuous monitoring of atmospheric pressure. To do this, the amplitude of the signal before filtering, representative of the atmospheric pressure, is reduced by a factor of 100, giving a sensitivity of 1 mV/hPa. This output also checks the correct operation of the sensor.

■ Temperature characteristics

Sensors are calibrated and compensated in order to reduce their thermal sensitivity. After compensation, the temperature-induced drift is less than 0.1 hPa/°C at the AP output (temperature range -25 to +85 °C).

Within the filtered band (0.01 - 27 Hz), the sensitivity variation is -7% at a temperature of -25 °C and +7% at a temperature of 60 °C.

PRESSURE CALIBRATION

Although calibration is normally performed in the laboratory, it can also be carried out in the field.

A low pressure calibrator (-1 to 2 bars) is used. The air inlets of the sensor are connected to the calibrator using hoses that are thick enough to be insensitive to any change in microbarometric pressure.

With 100 hPa overpressure, the amplification is adjusted to obtain a voltage of -10 volts, while at a negative pressure of 100 hPa it is adjusted to obtain a voltage of +10 volts. The calibration precision is about 1%.

The atmospheric pressure output is then compared with the reference barometer output and the LVDT sensor is adjusted.

Recalibration in the field is not usually necessary. The sensors installed by the CEA under variable environmental conditions have been operating for several years without any change in sensitivity.

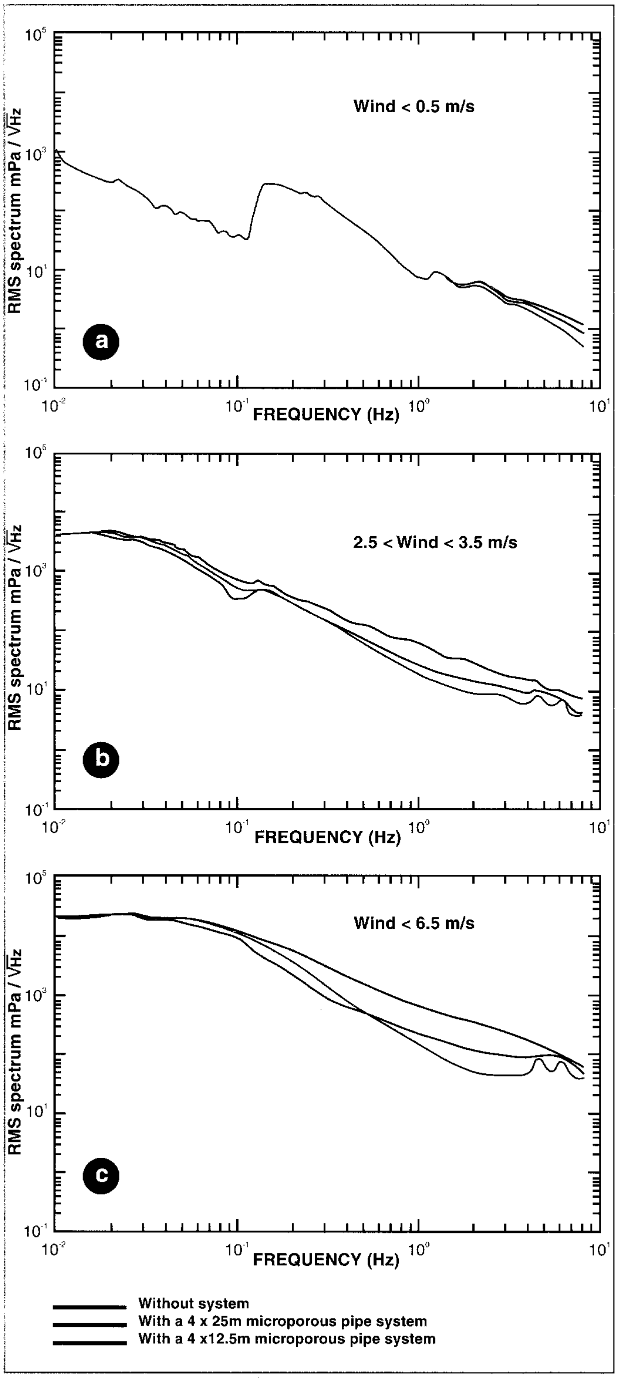


Figure 4 *Influence of a microporous pipe network on the background noise.*

Moreover, the measurement and comparison of the atmospheric pressure on different sensors of a network provide a good check of their calibration. The measurement of microbaroms also provides a relevant relative reference.

INFRASOUND FILTERING SYSTEMS

The microbarometer noise level is highly dependent on local weather conditions. The sensors should be sheltered from the prevailing winds. Microporous pipe systems have demonstrated their effectiveness in reducing microbarometric noise and improving signal detection.

Other solutions may be considered: for example, an array of four sensors separated by about ten metres, or a combined solution using microporous pipes.

■ Microporous pipe systems

The background noise spectra of three microbarometers, set up at a site in Normandy (Flers), are compared in figure 4:

- a sensor without a pipe system is used as a reference,

- a sensor with its outlets connected to a microporous pipe system in a cross configuration with four 12.5 m arms,

- a sensor with its outlets connected to a microporous pipe system in a cross configuration with four 25 m arms.

Each figure corresponds to different wind conditions.

Figures 4a to 4c show:

1) a microporous pipe system reduces the background noise,

2) a 4x12.5 m system is more efficient toward high frequencies than a 4x25 m system,

3) conversely, a 4x25 m system is more efficient at low frequencies.

These results are shown in a different form in figure 5:

The curves show the attenuation of the background noise provided by the different filtering systems at various wind velocities. At each wind velocity, the attenuation values are given by 20 log(A/B) and 20 log(A/C), where A, B and C are the background noise spectrum amplitude values for, respectively:

- a sensor without filtering system,
- a sensor with a 4x25 m filtering system,
- a sensor with a 4x12.5 m filtering system.

The maximum attenuation, 16 dB, is recorded at f = 2 Hz with a wind speed greater than 6.5 m/s in the case of a 4x12.5 m system; the filtering is relatively selective. Under the same conditions, and again at 2 Hz, the 4x25 m system provides an attenuation of only 10 dB, but the response is flatter.

The minimum attenuation (at approximately 0.2 Hz) is due to the microbarom signal; it is not attenuated by the pipe networks, and is visible particularly during periods of weak winds.

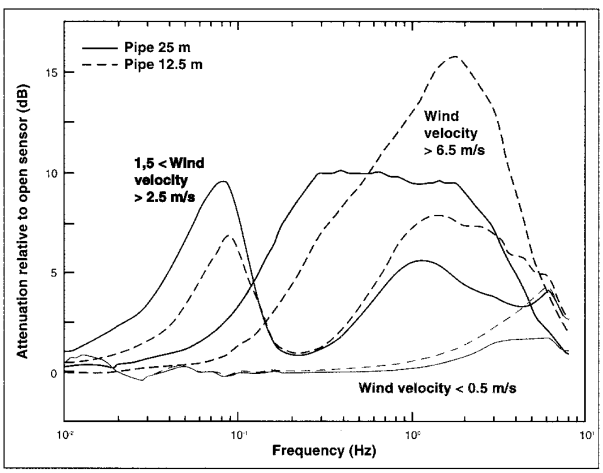


Figure 5 *Influence of a microporous pipe network on the background noise.*

■ Sensor array

An array of microbarometers consists of n sensors separated by about ten metres. The average signal is calculated from the n sensors before being digitized. A gain of several dB is obtained with this solution. Although the initial cost of the installation is a little higher, it is easier and cheaper to run: pipe systems need more space and require periodical replacement.

■ Combined solution

A combined solution can also be considered, composed of an array of several sensors associated with a microporous pipe system. It exhibits the same advantages and disadvantages as the previous two solutions.

Pole-zero representation of MB2000 microbarometer transfer function

R. Widmer-Schnidrig (e-mail: widmer@epicenter.ucsd.edu)

The microbarometer MB-2000 (Laboratoire de Géophysique) provides two output signals: a *raw* and a *filtered* one. The raw channel is proportional to pressure down to DC. The filtered signal is derived from the raw signal and is simply a band-passed version of the former.

From the manufacturer we received the coefficients in the following description of the transfer function.

Raw channel, H:

$$H(s) = \frac{b_1 s + b_0}{a_6 s^6 + a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + 1} \tag{1}$$

Band-pass filter, H_s:

$$H_s(s) = \frac{b_1 s}{a_2 s^2 + a_1 s + 1}$$

Since the coefficients, a_i, in the denominator polynomial of equation (1) span 14 orders of magnitude a pole-zero representation is preferable from a numerical standpoint. This representation has also been adopted widely in the global seismology community.

A pole/zero representation of the transfer function has the following form:

$$H(s) = A_0 \frac{\prod_{n=1}^{N_z} (s - z_n)}{\prod_{m=1}^{N_p} (s - p_m)}$$

where $s = i\omega = 2\pi i f$ is the Laplace transform variable and f the frequency.

With the appended MATLAB script we find for the raw channel, H:

A_0	$1.1286e8$		leading coefficient
N_z	1		number of zeros
z_1	$-4.6882e5$	$+0i$	zero
N_p	6		number of poles
p_1	-4.0	$+1116.7i$	pole
p_2	-4.0	$-1116.7i$	pole
p_3	-4.3	$+819.6i$	pole
p_4	-4.3	$-819.6i$	pole
p_5	-177.7	$+177.8i$	pole
p_6	-177.7	$-177.8i$	pole

and for the band-pass filter, H_s:

A_0	$4.1339e3$		leading coefficient
N_z	1		number of zeros
z_1	$+0$	$+0i$	zero
N_p	2		number of poles
p_1	-206.69	$+0i$	pole
p_2	-0.06283	$+0i$	pole

Finally, the filtered output is the product of the above two stages. The amplitude and phase spectra are plotted in the figure below.

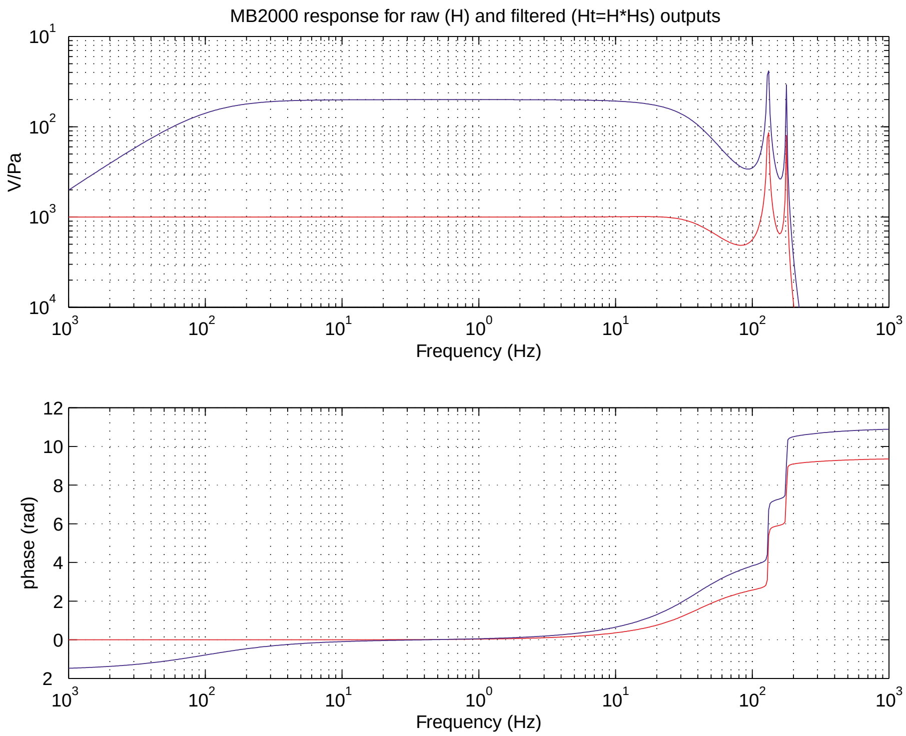


Figure 1: Transfer function of MB2000 microbarometer. The raw channel, $H(f)$, is shown in red and the filtered channel, $H(f) \cdot H_s(f)$ in blue.

C.1.2. Matlab script for calculating poles and zeros of MB2000

```
%
% MB2000 transfer function        r. widmer-schnidrig 11/17/99
%
%  first stage of response
%
% numerator polynomial coefficients
b1 = [2.133e-9 1.0e-3]';
% denominator polynomial coefficients
%    note: the constant term is NOT the product of all the roots
%            hence we correct with A1 below.
a1 = [1.89e-17 7.03e-15 3.757e-11 1.321e-8 1.823e-5 5.645e-3 1.]';
z1 = -b1(2)/b1(1)     % zeros
p1 = roots(a1)        % poles
% leading coefficient of H
A1 = b1(1)*prod(p1);
NZ1 = length(z1);       % number of zeros
NP1 = length(p1);       % number of poles
%
%  second stage of response
%
% numerator polynomial coefficients
b2 = 318.31;
z2 = [0.];             % zeros
% denominator polynomial coefficients
a2 = [0.077 15.92 1.]';
p2 = roots(a2)      % poles

NZ2 = 1;               % number of zeros
NP2 = length(p2)       % number of poles
A2 = b2*prod(p2)

%
% evaluate and plot transfer function
%
freq = 10 .^ [-3. : 0.01 : 3.]';    % logarithmically spaced frequency axis

H  = A1*ones(size(freq));
for k = 1:NZ1, H = H .* (2*pi*i*freq - z1(k)); end
for k = 1:NP1, H = H ./ (2*pi*i*freq - p1(k)); end

Hs = A2*ones(size(freq));
for k = 1:NZ2, Hs=Hs .* (2*pi*i*freq - z2(k)); end
for k = 1:NP2, Hs=Hs ./ (2*pi*i*freq - p2(k)); end

Ht = H .* Hs;    % combined transfer function

subplot(211),loglog(freq,abs(H),'r',freq,abs(Ht),'b')
title('MB-2000 response for raw (H) and filtered (Ht=H*Hs) outputs')
xlabel('Frequency (Hz)')
```

```
ylabel('V/Pa')
axis([1.e-3 1.e3 1.e-4 0.1])
grid

subplot(212),semilogx(freq,phase(H'),'r',freq,phase(Ht'),'b')
xlabel('Frequency (Hz)')
ylabel('phase (rad)')
axis([1.e-3 1.e3 -2 12])
grid
print -depsc resp.ps
save MB2000_pz A1 z1 p1 A2 z2 p2 -ascii
```

C.2 Handar Air humidity and temperature equipment

Handar
A TSI® Company

Model 435C Relative Humidity/Air Temperature Sensor Models 442C and 442E Solar Radiation Shields

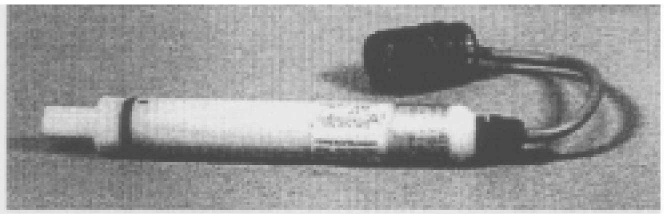


Figure 1–A The Model 435C Relative Humidity/Air Temperature Sensor

Table 1–A Specifications

Temperature	
Sensor Type	Platinum resistive temperature device (RTD)
Output Range/Signal	-30°C to +70°C/0.00 to +1.00 V
Accuracy	±0.3°C
Linearity	0.2°C from -20° to +55°C
Humidity	
Sensor Type	Hygroscopic film capacitor
Output Range/Signal	0 to 100% Relative Humidity/0.00 to +1.00 V
Accuracy	±1% RH over range 1 – 100 %
Linearity	0.7% RH over full range
Repeatability (includes hysteresis)	±0.6% RH or better
Long-term stability	1% RH or better over one year.
Time constant, Temperature and Humidity	10 sec or less
Power requirements	4.8 to 26.5 VDC, 10 mA typ
Dimensions	1.0 in diam. x 7.7 in long (25 x 195 mm)
Weight	1.5 lb (0.68 kg)
Models	435C: sensor with metal cable connector 435CP: sensor with plastic cable connector
Radiation Shields	442C for 435C 442CP for 435CP 442E for 435C

C.3 Handar Ultrasonic Wind Sensor

Handar
A TSI® Company

Model 425 Series of Ultrasonic Wind Sensors

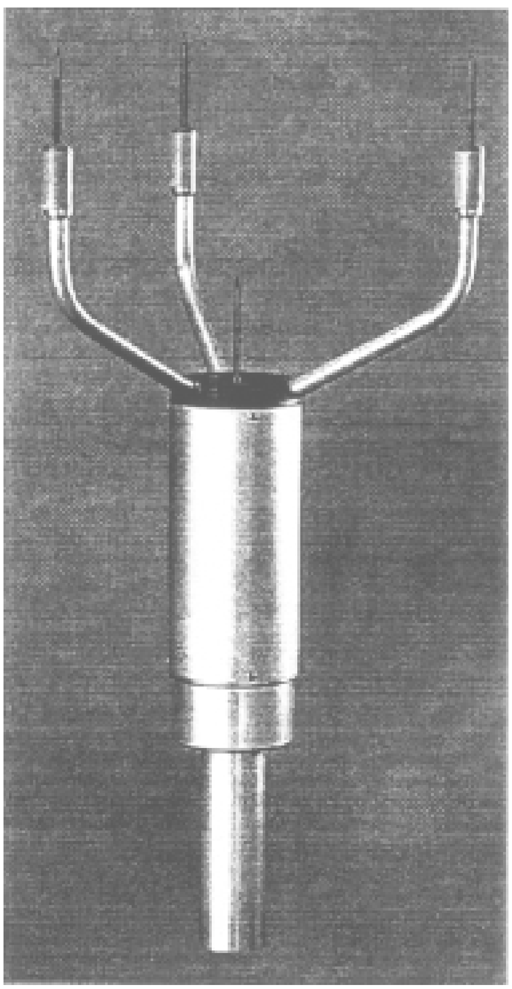


Figure 1.1 Model 425A ultrasonic wind sensor

The sensor features:

- Communication with a wide range of data acquisition systems using:
  - Digital output for RS232 and SDI-12 serial data interfaces
  - Analog outputs (Models 425A and 425AH only)
- No moving parts
- Power-on self-tests of RAM and ROM
- Contamination and corrosion resistance since exposed surfaces are stainless steel and anodized aluminum
- Simple alignment to true north
- A built-in heater for the Models 425AH and 425AHW
- Heater diagnostics to diagnose to the lowest replaceable unit (power supply or wind sensor) for the Model 425AHW with Handar power supply, part number 425-7006.

Handar
A TSI® Company

Model 425 Series of Ultrasonic Wind Sensors

Specifications

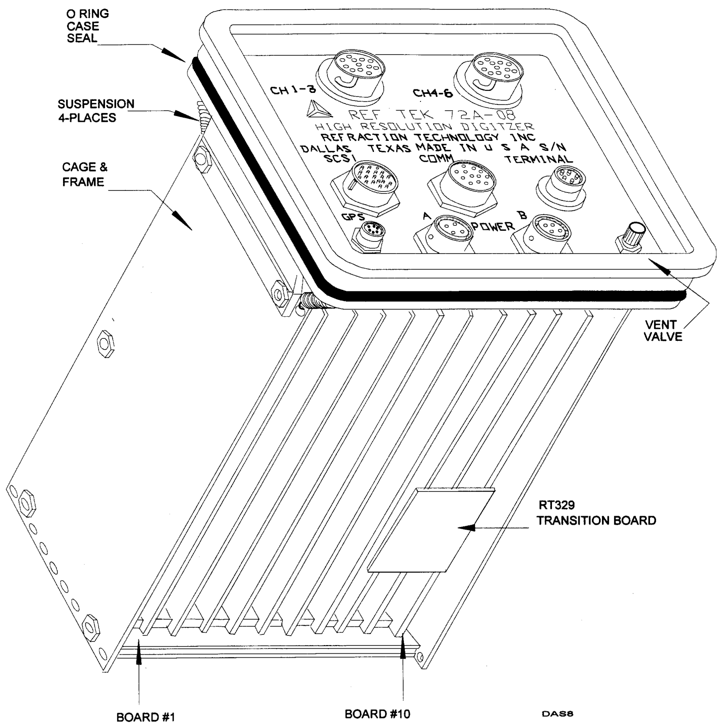
Type	Ultrasonic 100 KHz. Fully compensated for temperature, humidity, and altitude.
Mean time between failure (MTBF)	26 years calculated per the standard assumptions of MIL-HDBK-217, Revision E.
Range	Operating: 0 to 144 miles per hour (0 to 65 meters per second — 125 knots) Survival: 0 to 180 miles per hour (0 to 81 meters per second — 156 knots)
Response characteristics	Maximum reading rate: 1 per second Sonic measurement time: 0.2 second Signal processing time: 0.15 second Response time: 0.35 second
Accuracy	Wind speed: ±0.3 miles per hour (0.135 meters/second — 0.26 knots) or ±3% of reading, whichever is greater, for readings up to 110 miles per hour (49.5 meters/second — 95.52 knots) ±5% of reading for readings of 110 miles per hour or greater Wind direction: ±2 degrees
Resolution	Wind speed: 0.1 miles per hour (0.1 Km/hour — 0.1 meters/second — 0.1 knots) Wind direction: 1 degree
Power	10 to 15v dc Operating: 12 milliamperes (analog) Quiescent (standby): 200 µAmp typical (SDI-12) (See Table 1.1 on page 1-4.) Heater (Models 425AH): 36v dc ± 10%, 0.7 Amp Heater (Models 425AHW): 36v dc ± 2%, 0.7 Amp
Heater	(Models 425AH and 425AHW only) Thermostatically controlled in the transducer heads prevent freezing rain or snow build up.
Heater diagnostics	(Model 425AHW only) 1. Measures incoming heater supply voltage and tests against upper and lower limits. 2. Measures heater current to compute heater resistance. If any of the three heaters have failed, the test fails. 3. Measures received signal. If too small, it indicates that either the sensor failed or there is an obstruction in the ultrasonic path, such as a windblown plastic bag wrapped around a transducer head.
Available averages:	1 to 9 seconds (RS232) 3 to 3,600 seconds (SDI-12)

C.4 RefTek Recording system

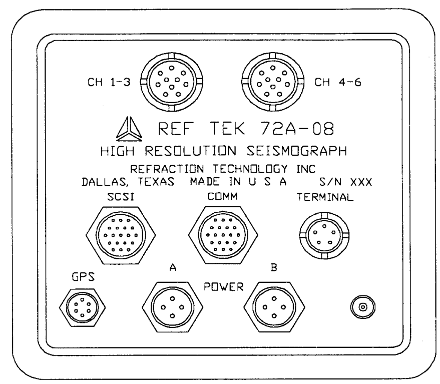
REFTEK

TECHNICAL INTRODUCTION
to the
72A SERIES DATA ACQUISITION SYSTEMS

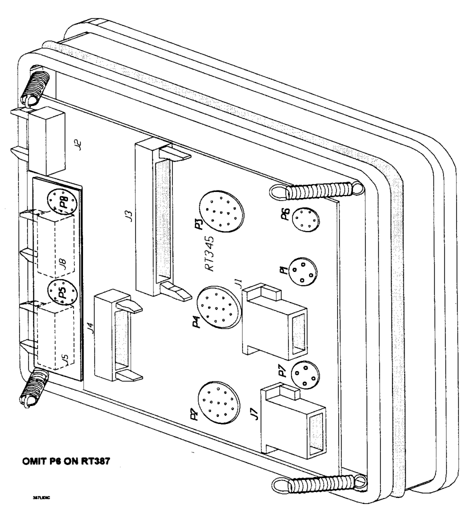
December 1996



72A-08 - Structural Arrangement



Front panel &
Interface board



Technical Introduction to the REFTEK 72A Series DAS

The REFTEK 72A series Data Acquisition System (DAS) is a versatile, portable, data digitizer/recorder of ruggedized construction for unattended field use. Refraction Technology manufactures a range of these instruments in different configurations, each having its own special characteristics. Due to modular construction methods, much of the hardware, and software also, is common to multiple product configurations. These DAS models share many of the same basic functions and applications. The general usage, control and operation that is common to all units is described more fully in REFTEK's "*Operations Reference Manual for the 72A Series DAS*".

A common feature of the 72A Series DAS configurations is that they all have hardware, firmware and software that complies with the requirements of the "Program for Array Seismic Studies of the Continental Lithosphere" (PASSCAL).

This document provides a brief introductory overview and a model comparison of the range of 72A series DAS's. It is arranged as follows:

- A general introduction to the 72A-07 and 72A-08 models
- A list of REFTEK standard DAS units
- A list of the circuit boards comprising each "standard" DAS model
- A features comparison listing of the 72A series DAS units

General Introduction

The 72A series DAS is a microprocessor-based high resolution instrument that uses either a Motorola or Toshiba 68HC000 type microprocessor. A 72A series DAS contains a set of erasable, programmable, read-only memory chips (EPROMs) that contain the firmware instructions for the microprocessor. In the DAS, the microprocessor is always located on the RT319 CPU board.

A user controls the basic operation and data recording functions of a DAS by establishing a set of control parameters then downloading them to the DAS via a DOS-based interface. REFTEK recommends the use of its "Field Setup Controller" (FSC) program that runs on a PC, workstation, laptop or palmtop as the control interface. For detailed information refer to REFTEK's "*Field Setup Controller Operations*" document. Generally, the DAS data recording function is controlled by carefully selected trigger parameters, by time settings, by continuous recording, or by combinations of these features. Various internal data recording options are available on the -07 model. The -08 requires an external recorder. Several options are available for high accuracy DAS timekeeping.

Each 72A series DAS model has a specific configuration of internal circuit boards and unique features. The exact recording capabilities of each model are determined by its hardware configuration and the CPU control code.

This document reviews the "standard" configurations and briefly summarizes their abilities. Information on hardware that is identical across multiple configurations is also provided. A more comprehensive DAS review is provided in the "*Technical Overview*" which pertains to the particular version a user has ordered.

When supplied with power from a REFTEK 72A-04 Auxiliary Power Subsystem, a 72A series DAS can operate unattended for more than three days. By using a 12-volt car battery, you can extend the operating period to a month. Solar panel arrays complete with chargers can also be supplied for long-term instrument deployment in remote locations

Technical Overview of 72A-08 DAS

REFTEK

Physical & Performance Specifications

Size	12.75" x 8.25" x 7.75" (325 x 210 x 197mm)
Weight	about 15 pounds (6.25 kg) depending on configuration
Case Type	Cross-linked polyethylene - field gray
Temperature	Operating -20° to +60° C Storage -40° to +70° C
Case Integrity:	Watertight. Tested with air over-pressure at 2.5 psi and immersion for 48 hours under six feet of water. Unit is buoyant
Shock	36" drop on any axis will not cause mechanical or operational failure
Vibration	A 5 to 500 Hz sine wave acceleration, 5g peak, 30 minutes on each axis, will not cause mechanical or operational failure
Power Requirements	
In Sleep mode	0.5 milliWatts
CH 1-3 operating	2.2 Watts
CH 4-6 operating	2.5 Watts
Supply Voltage Range	10 to 15 VDC
Configuration	
Input Channels	3 @ 24-bit + 3 @ 16-bit, **or** 6 @ 24 bit, **or** 3 @ 24-bit resolution
Data Streams	8
Sample Rates	Variable across data streams (DSP); from 1 to 1000 sps
Gain	Programmable per channel; 24-bit channels have either unity or 30 dB gain; 16-bit channels have gains of either 1, 18, 30, 42, 54, 66, or 78 dB
Internal RAM	512k RAM - see options
Timekeeping	Internal oscillator (VCXO) with 5×10^{-7} accuracy
FIR Filters	Passband = 80% Nyquist Stopband = -130 dB (first filter), -100 dB(2nd filter, used for re-sampling)
Full Scale Input	
24-bit channels	20 volts, peak-to-peak, differential (at unity gain)
16-bit channels	7.5 volts, peak-to-peak, differential (at unity gain)
Other Standard Features	Sensor calibration function
Options	
Configuration Options	Six input channels, all with 24-bit resolution RT336 internal modem RT301 low-noise preamplifier board (for 16-bit channels)
RAM Expansion	+1-2 megabytes on RT344 power supply +1-4 megabytes per RT284 mass memory Total 12 megabytes maximum possible
Primary Data Storage Options	External SCSI recording disk (REFTEK 72A-05) with a minimum of 1 Gigabyte and automatic data transfer from RAM
Timekeeping Options	External 111A GPS clock or 111B Master clock for high precision timekeeping. Internal GPS is possible but **not** advisable.
Power Supply Options	72A-04 Auxiliary Power Subsystem. Solar panel, battery and charger setup

Physical & Performance Specifications

Size	12.75" x 8.25" x 7.75" (325 x 210 x 197mm)
Weight	about 15 pounds (6.25 kg) depending on configuration
Case Type	Cross-linked polyethylene - field gray
Temperature	Operating -20° to +60° C Storage -40° to +70° C
Case Integrity:	Watertight. Tested with air over-pressure at 2.5 psi and immersion for 48 hours under six feet of water . Unit is buoyant
Shock	36" drop on any axis will not cause mechanical or operational failure
Vibration	A 5 to 500 Hz sine wave acceleration, 5g peak, 30 minutes on each axis, will not cause mechanical or operational failure
Power Requirements	
In Sleep mode	0.5 milliWatts
CH 1-3 operating	2.2 Watts
CH 4-6 operating	2.5 Watts
Supply Voltage Range	10 to 15 VDC
Configuration	
Input Channels	3 @ 24-bit + 3 @ 16-bit, **or** 6 @ 24 bit, **or** 3 @ 24-bit resolution
Data Streams	8
Sample Rates	Variable across data streams (DSP); from 1 to 1000 sps
Gain	Programmable per channel; 24-bit channels have either unity or 30 dB gain; 16-bit channels have gains of either 1, 18, 30, 42, 54, 66, or 78 dB
Internal RAM	512k RAM - see options
Timekeeping	Internal oscillator (VCXO) with $5x10^{-7}$ accuracy
FIR Filters	Passband = 80% Nyquist Stopband = -130 dB (first filter), -100 dB(2nd filter, used for re-sampling)
Full Scale Input	
24-bit channels	20 volts, peak-to-peak, differential (at unity gain)
16-bit channels	7.5 volts, peak-to-peak, differential (at unity gain)
Other Standard Features	Sensor calibration function
Options	
Configuration Options	Six input channels, all with 24-bit resolution RT336 internal modem RT301 low-noise preamplifier board (for 16-bit channels)
RAM Expansion	+1-2 megabytes on RT344 power supply +1-4 megabytes per RT284 mass memory Total 12 megabytes maximum possible
Primary Data Storage Options	External SCSI recording disk (REFTEK 72A-05) with a minimum of 1 Gigabyte and automatic data transfer from RAM
Timekeeping Options	External 111A GPS clock or 111B Master clock for high precision timekeeping. Internal GPS is possible but **not** advisable.
Power Supply Options	72A-04 Auxiliary Power Subsystem. Solar panel, battery and charger setup

Feature	**72A-08**
Input Channels	3 or 6 @ 24-bit resolution or 3 @ 24-bit + 3 @ 16-bit resolution
Broadband Dynamic Range	130dB at 1 to 125Hz sample rate
Data Streams	8 maximum
Sample Rates	programmable stream-to-stream at 1,2, 4, 8,10 20, 25, 40, 50, 100, 125, 200, 250, 500, or 1000 sps
Gain Settings	On 24-bit channels - each channel programmable at unity or 30dB. On 16-bit channels - programmable at 0, 18, 30, 42, 54, 66 or 78dB
Internal RAM	512K minimum (expandable)
Primary Data Storage	external SCSI disk of 500Mb or greater with auto data transfer from RAM
Timekeeping	Either VCXO or external GPS
FIR Filters	Passband = 80% Nyquist Stopband = -130dB (1st filter) = -100dB (2nd. filter - for resampling)
Full Scale Input	20 vpp differential @ unity gain 7.5 vpp differential @ unity gain for 16-bit channels
Triggers	continuous timed time list level event (STA/LTA) remote (or external) radio cross stream
Other Features	Standard sensor calibration function

Figure C.1. The microbarometer and space filter deployed at site 4 in the Pinon Flat survey is shown in the photo at the top. The recording system enclosures are shown in the lower photo. To the left is the mast with the met sensors and the solar panel.

Figure C.2. An MB2000 inside the mini vault.

Appendix D. Microbarometer calibration

Since we lacked the necessary equipment for absolute calibration of the sensors we conducted a "huddle" test in the laboratory in California in collaboration with Dick Kromer (Sandia). In the main experiment we connected 3 of our sensors to the same manifold. The fourth sensor was connected to a second manifold located beside the first. Both manifolds were open to the atmosphere. With the sensors in this configuration we collected noise data for 35 minutes on day 189, 1999 (from 16:20 to 16:55, GMT). In Figures D.1 and D.2, we display timeseries and power spectra from the four sensors. The timeseries appear to be identical. The power spectral densities from the four sensors are essentially identical from 100 s to 20 Hz.

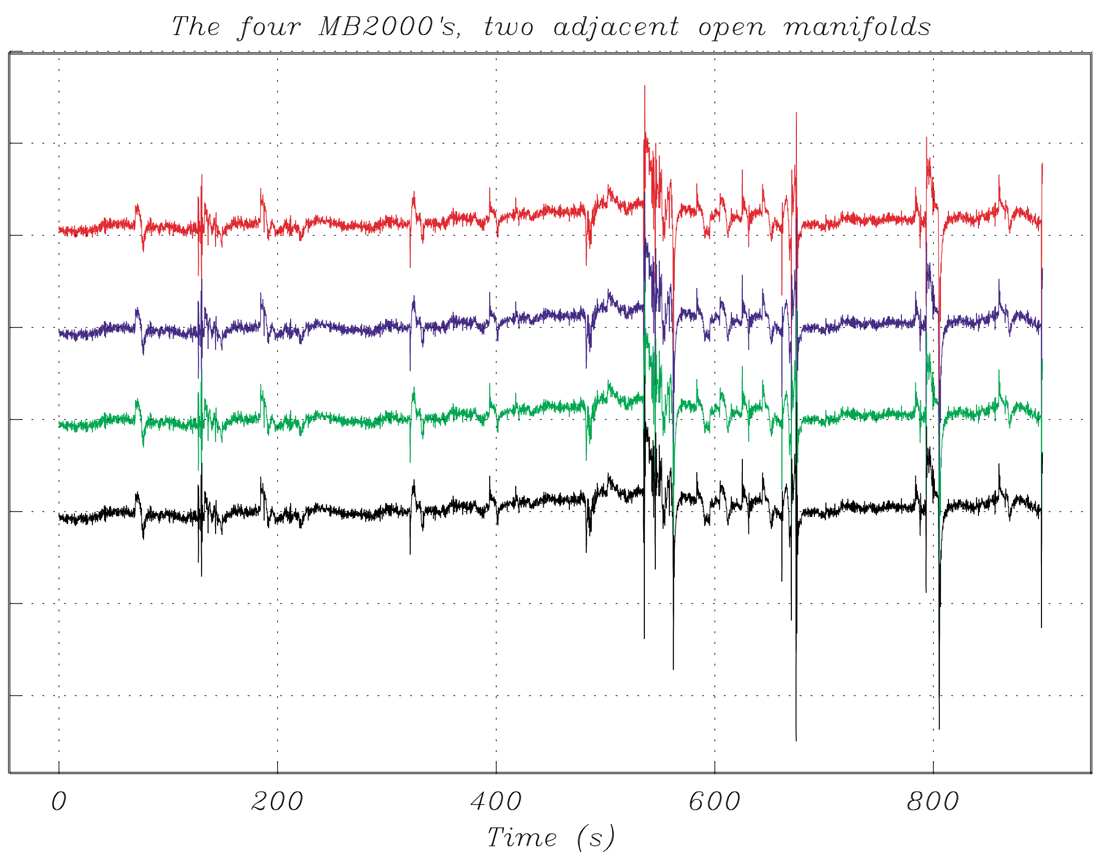


Figure D.1. 900 seconds of noise data collected during the calibrationn test in the laboratory. The signals are from doors being opened or closed in nearby offices in the lab.

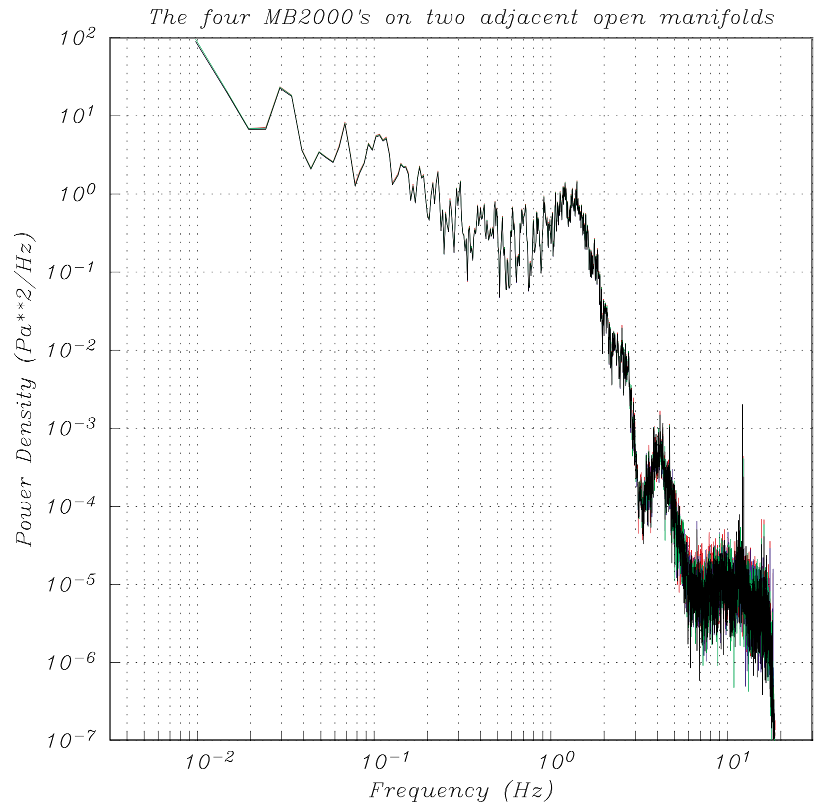


Figure D.2. Power spectra from the timeseries shown in Figure E.1. There is no noticeable difference between the data collected by the four sensors we used in the field.

Appendix E. Log of field measurements

As shown in Figure E.1, data were collected between day 219 and day 256, 1999. Continuous collection at all four sites began on day 236.

Appendix F. Calculation of absolute power density spectra

Welch power density spectral estimates were calculated using the MATLAB routine "PSD". All power spectral results displayed in this report were derived from an average of 4 estimates. Each estimate was taken from 204.8 s of filtered infrasound pressure. Each window of 4096 points was tapered using a Hanning function. There was no overlap between adjacent windows. The Power spectral density, Pxx, obtained from the PSD routine is multiplied by 2 to account for the power at negative frequencies and divided by the sample rate (Fs = 20 sps). Throughout this report we therefore display 2 Pxx/Fs.

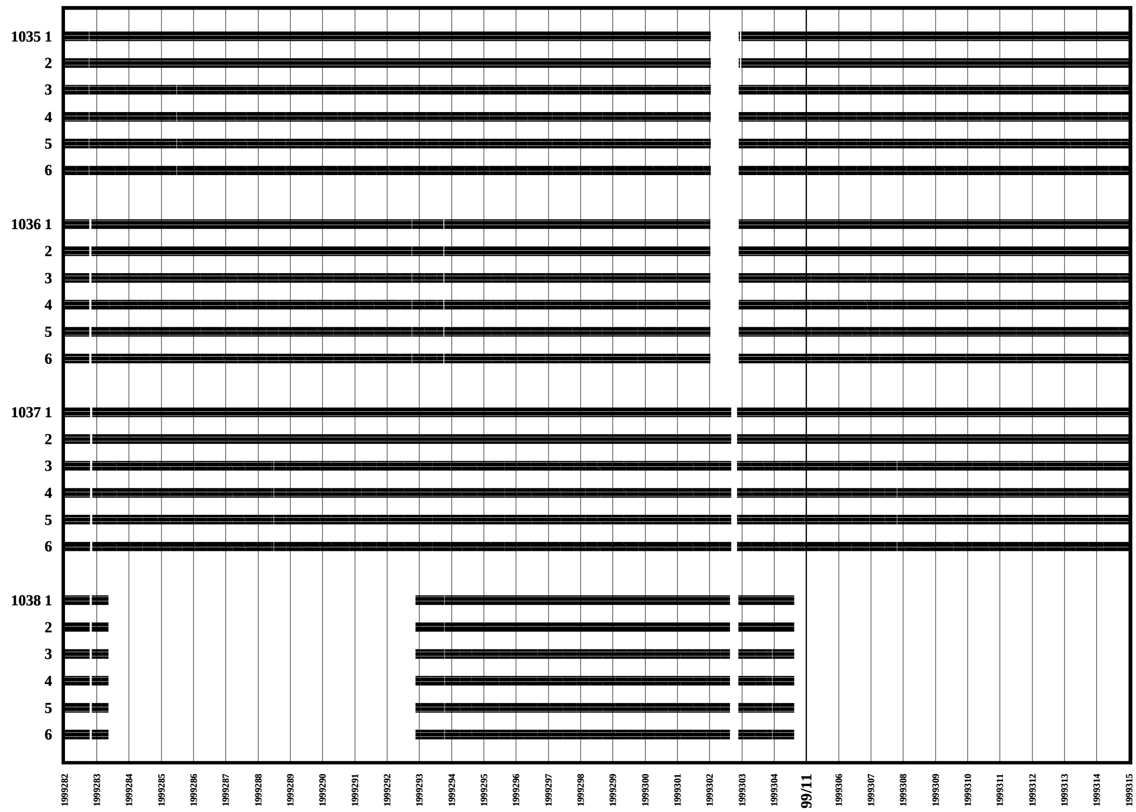


Figure E.1. Data coverage during the Newport site survey. Channels 1 and 2 at each site are the unfiltered and filtered data. Channels 3 through 6 are wind speed, direction, air temperature and humidity respectively.

Appendix G. Photographs of Recommended Central Processing Facility

In this section we show photos of the central facility we recommend for the IMS infrasound array at Newport, WA. Photos of the element locations are given in Appendix B. All sites in the proposed array lie on federal land in the Colville National forest.

Figure G.1. The "Russian" seismic compound is shown on top. The building we recommend for the central processing facility is shown on the bottom.

Appendix H. Recommended space filter

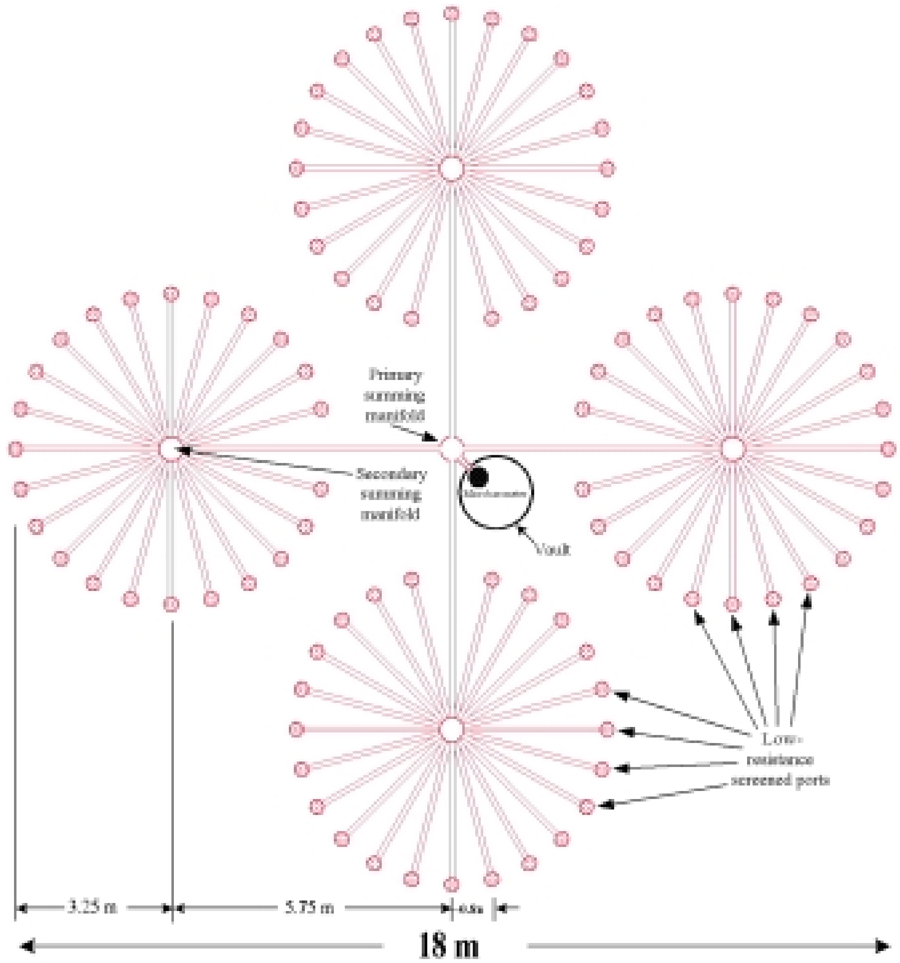


FIGURE H.1. 92-port 18 m diameter wind-noise-reducing pipe array with high-frequency capability for use at short-period-optimized array elements at stations located in higher wind areas or at all array elements at stations located in low wind areas. This figure and caption are courtesy of Doug Christie.

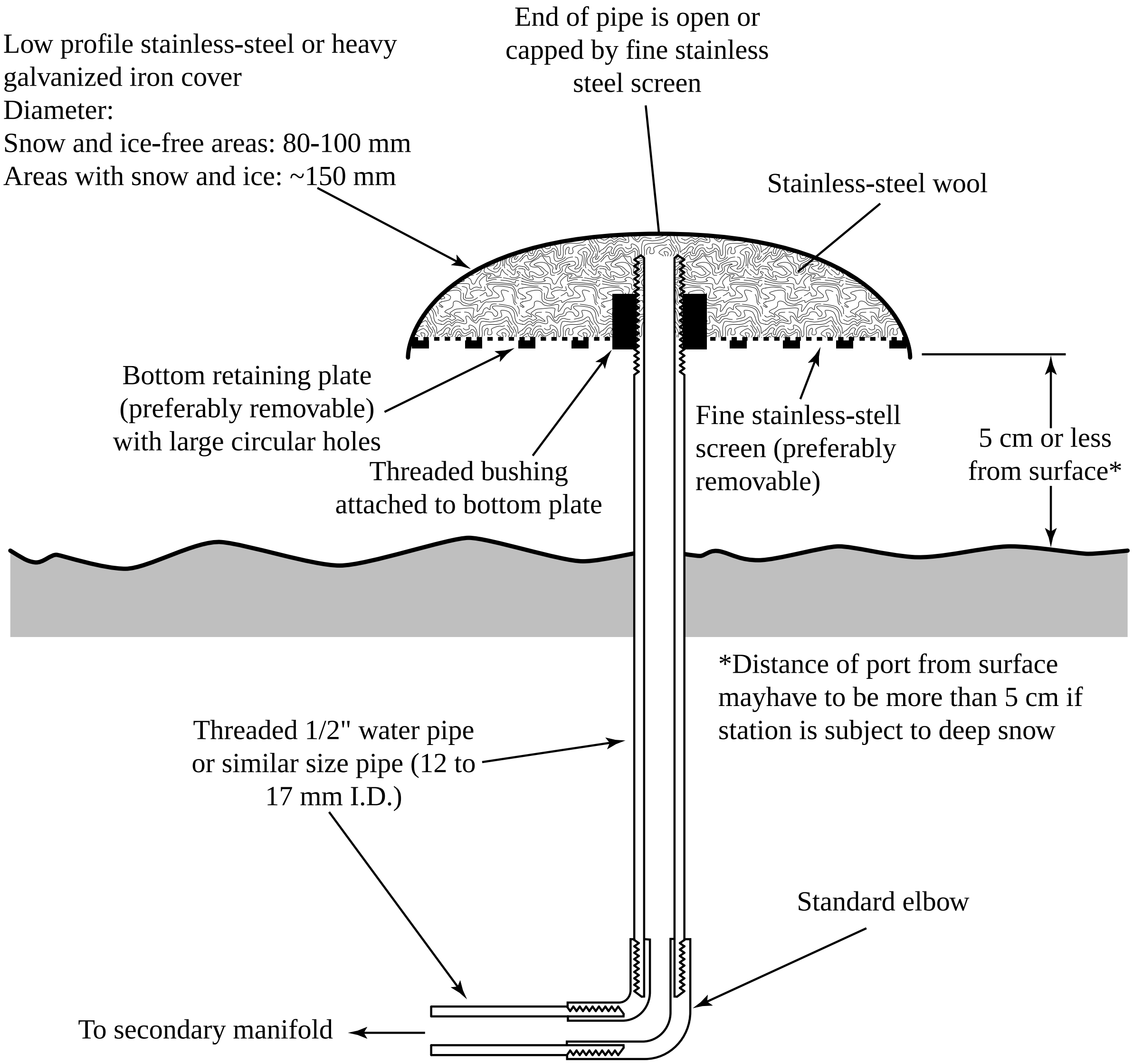


Figure H.3. Cross section of a single port. Drawing and labels are courtesy of Doug Christie (PTS/CTBTO). This port is attached to a buried pipe system.

Appendix I - Principal contacts for IS56

Technical support

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Appendix J - Format of archived data

Relational database formalisms are used to express the infrasound survey data. Datascope, the database software distributed by Boulder Real Time Technology, was originally intended for use by the seismic community for the acquisition, processing and archiving of seismic data. The schema or format used to implement the database is css3.0, a product of the Center for Seismic Studies (CSS). For a tutorial of Datascope, see *http://www.brtt.com/datascope/datascope.html*. The following is a list of the main tables, in css3.0 format, used in Datascope for the presentation of the infrasound data (for a complete description of the css3.0 schema, see the attached file CSS3.0/description). The text that follows was taken from documentation for the datascope software (dbdoc) or from Mary Templeton at PASSCAL (IRIS).

Relation **affiliation**

Fields	net sta lddate
Description	“Network station affiliations”
Detail	This is an intermediate relation by which stations may be clustered into networks.

Relation **arrival**

Fields	sta time arid jdate stassid chanid chan iphase stype deltim azimuth delaz slow delslo ema rect amp per logat clip fm snr qual auth commid lddate
Description	"Summary information on a seismic arrival"
Detail	Information characterizing a 'seismic phase' observed at a particular station is saved here. Many of the attributes conform to seismological convention and are listed in earthquake catalogs.

Relation **calibration**

Fields	sta chan time endtime stream calib calper fc units lddate Description "Station-Channel calibration parameters"
Detail	This table provides a record of updates in the calibration of a station-channel for a specific time interval are provided here. There is one entry for each calibration period. Calib, calper, and units are given for the complete system response.

Relation **instrument**

Fields	inid insname instype band digital samprate ncalib ncalper dir dfile rsptype lddate
Description	"Generic default calibration information about a station"
Detail	This table serves three purposes. It holds nominal one-frequency calibration factors for each instrument. It holds pointers to the nominal frequency-dependent calibration for an instrument. Finally, it holds pointers to the exact calibrations obtained by direct measurement on a particular instrument. See sensor.

Relation **network**

Fields	net netname nettype auth commid lddate
Description	"Network description and identification"
Detail	This relation gives general information about seismic networks. See affiliation.

Relation **sensor**

Fields	sta chan time endtime inid chanid jdate calratio calper tshift instant lddate
Description	"Specific calibration information for physical channels"
Detail	This table provides a record of updates in the calibration factor or clock error of each instrument, and links a sta/chan/time to a complete instrument response in the relation instrument.

Relation **site**

Fields	sta ondate offdate lat lon elev staname statype refsta dnorth deast lddate
Description	"Station location information"
Detail	Site names and describes a point on the earth where seismic measurements are made e.g. the location of a seismic instrument or array. It contains information that normally changes infrequently, such as location. In addition, site contains fields to describe the offset of a station relative to an array reference location. Global data integrity implies that the sta/ondate in site be consistent with the sta/chan/ondate in sitechan.

Relation **sitechan**

Fields	sta chan ondate chanid offdate ctype edepth hang vang descrip lddate
Description	"Station-channel information"
Detail	This relation describes the orientation of a recording channel at the site referenced by sta. This relation provides information about the various channels e.g. sz, lz, iz that are available at a station and maintains a record of the physical channel configuration at a site.

Relation **stage**

Fields	sta chan time endtime stageid ssident gnom iunits ounits gcalib gtype izero decifac samprate leadfac dir dfile lddate
Description	"filter stage calibration parameters"
Detail	Information characterizing an individual stage of the total calibration of a station-channel. Stageid provides the specific ordering in the system response for the stage. gnom, gcalib, and gunits are given for the stage. Combining all records having the same sta-chan-time will provide calib in the calibration table. This table can describe analog or digital stages. Each record provides pointers to files which contain the actual poles/zeros or digital filter coefficients.

Relation **wfdisc**

Fields	sta chan time wfid chanid jdate endtime nsamp samprate calib calper instype segtype datatype clip dir dfile foff commid lddate
Description	"Waveform file header and descriptive information"
Detail	This relation provides a pointer or index to waveforms stored on disk. The waveforms themselves are stored in ordinary disk files called wfdisc or.w files, containing only a sequence of sample values usually in binary representation.