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Report on the Test and Evaluation of the Chaparral Physics Model 4.1.1 Prototype Microbarograph for CTBT Infrasound Array Application

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Report on the Test and Evaluation of the Chaparral Physics Model 4.1.1 Prototype Microbarograph for CTBT Infrasound Array Application

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Abstract

The Sandia National Laboratories has tested and evaluated the Chaparral Physics Model 4.1.1 prototype infrasound sensor to CTBT specifications. The sensor was characterized by using a piston-phone chamber to set and measure sensor sensitivity. Multiple sensor side-by-side coherence analysis testing provided a measure of sensor relative gain and phase; sensor self-noise was computed using this technique. The performance of the sensor calibration circuitry was evaluated. Sensor performance was compared to CTBT specifications. The Chaparral sensor met or exceeded all CTBT specifications.

Acknowledgments

The authors would like to acknowledge the efforts of the infrasound prototype sensor development team. The team included from Los Alamos National Laboratory, Rod Whitaker, Tom Sandoval, Doug ReVelle and Tom Armstrong; from Sandia National Laboratories, Dick Kromer; and Tim McDonald from Applied Physics Incorporated. Rod Whitaker managed the project. Rod, Tom and Dick developed the test procedures and conducted the test and evaluation of the microbarograph sensors. Rod and Tim developed the models for sensor acoustic and electronics performance. Insight into the operation of the microbarograph was provided by Ed Bullard of Chaparral Physics. Pres Herrington and Dale Breding from Sandia National Laboratories provided comments and recommendations in reviewing this report. Blood flow was liberal.

Funding was provided by the U.S. Department of Energy, Office of Nonproliferation and National Security, Office of Research and Development, Comprehensive Test Ban Treaty Research and Development Program.

Table of Contents

Table of Figures

1. Executive Summary

This document describes the results of the test and evaluation of the Chaparral Physics Model 4.1.1 (previous reports had mistakenly identified the sensor as model 4.11) prototype microbarograph as a vault-installation infrasound sensor as part of the Infrasound Prototype for a Comprehensive Test Ban Treaty (CTBT) International Monitoring System (IMS) station installed at Los Alamos, NM.

The Chaparral Physics Model 4.1.1 prototype microbarograph should be an excellent infrasound sensor for the CTBT IMS. All sensors met the resolution specification. Three of the four sensors met the dynamic range specification. All sensors met the bandwidth specification. Three of the four sensors met the sensor noise specification.

A few issues need resolution:

1. The sensitivity of the sensors was set to within 15% of the nominal value (400 mV/Pa). To improve the accuracy of the settings, a calibrated pressure gauge needs to be connected to the piston-phone chamber to accurately measure the piston-phone signal. Process control improvements need to be made to assure valid sensitivity settings on the sensors. The long-term stability of sensor sensitivity should be determined.

2. Sensor self-noise varied significantly (25 dB variation between the four sensors). The electronic components causing the noise need to be identified and replaced with lower noise components.

3. The sensor was not designed to interface directly to the Teledyne-Brown digitizer used in the Infrasound Prototype CTBT IMS station installed at Los Alamos, NM. The following changes could be made to match the interface: a.) Use the +/-12 volt sensor power provided by the digitizer; b.) Lower the output impedance to avoid having to provide an impedance matching amplifier in the digitizer; c.) Provide a balanced output for connection to the Teledyne-Brown balanced input digitizer. Changes to the digitizer could be made to match the commercial version of the sensor.

2. Introduction

2.1 Purpose

The purpose of the test and evaluation of the Chaparral Physics Model 4.1.1 prototype microbarograph was to evaluate the technical performance of the Chaparral microbarograph to determine its overall performance. The specifications of Conference on Disarmament/ad hoc committee on Nuclear Test Ban/Working Paper .224/.283 were the original set of specifications that were used in defining requirements for the Infrasound Prototype CTBT IMS Station. These specifications were superseded by the Preparatory Commission (PrepCom) Working Group B (PrepCom WGB/TL/8 (Rev.4)) specifications as detailed in CTBT/PC/II/1/Add.2. Based on these specifications, this report describes the results of the testing and evaluation of the Chaparral 4.1.1 Microbarograph as a vault-installation infrasound sensor as part of the Infrasound Prototype CTBT IMS station installed at Los Alamos, NM, as described in References 1, and 2.

3. Microbarograph Testing

3.1 Chaparral Physics 4.1.1 Microbarograph Description

The Chaparral Physics Model 4.1.1 (CP 4.1.1) prototype microbarograph is a Chaparral Model 100 microbarograph redesigned to meet the needs of the CTBT infrasound instrumentation.

The CP 4.1.1 is a variable capacitance microphone sensor. The mylar capacitive diaphragm modulates a multi-kilohertz oscillator. Small movements of the diaphragm, caused by small changes in pressure produce an FM signal which is demodulated, filtered and amplified to provide a single-ended output. The output is capacitive coupled to remove dc offset. It should be noted that the coupling capacitor and the input impedance of the recorder will form a high-pass filter. If the sensor is connected to a low impedance recorder (< 2M ohms), an impedance matching amplifier must be provided to avoid affecting the sensor's low frequency coupling. An overview of the sensor response is provided in Appendix A. Internal electronics are powered by 24 Vdc at 7 ma. Two selectable sensitivities are provided; a sensitivity of 2 volts/Pa is provided for interfacing to VCO-based low dynamic range recorders and a sensitivity of 400 mV/Pa is provided for interfacing to high dynamic range recorders.

A selectable step cal provides a step calibration signal to the sensor electronics. This step cal signal can be used to determine changes to the response and gain of the sensor electronics.

The CP 4.1.1 is designed for surface vault applications. It has a 6338 cc. backing volume/calibrated leak to set the low corner frequency of the sensor to CTBT specifications. The sensor electronics are flat to 100 Hz. In the field, the high frequency response is limited by the use of porous hoses on the input [Reference 3]. The microbarograph interfaces to the high dynamic range Teledyne-Brown DR-24 Data Acquisition System as part of the Infrasound Prototype.

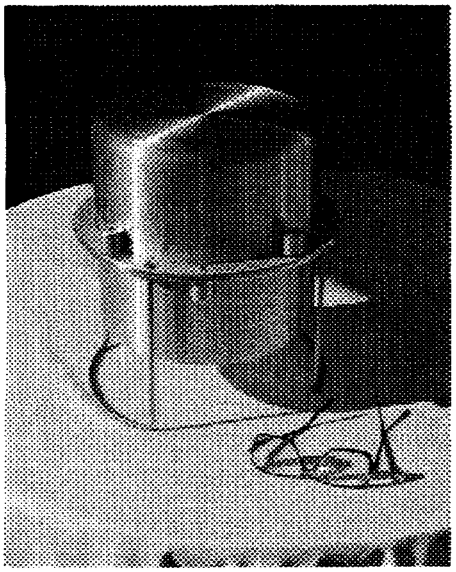
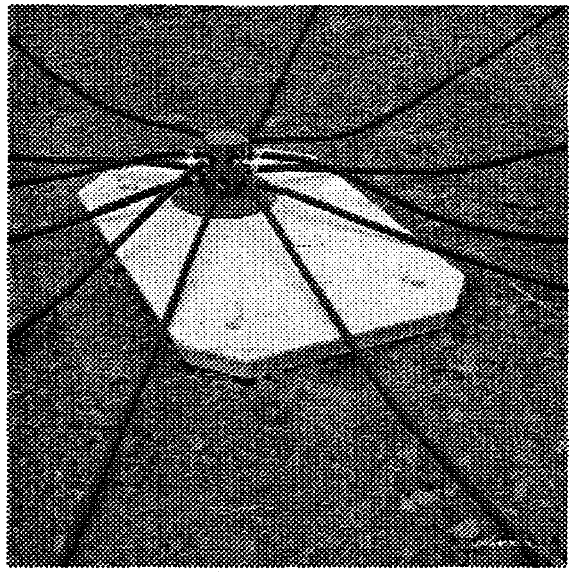
 

Figure 3.1 - 10" diameter CP 4.1.1 Microbarograph (left), Sensor installed with porous hoses (right)

3.2 CP 4.1.1 Testing

Four prototype CP 4.1.1 microbarographs were tested during the months of June-August 1997 at Sandia National Laboratories (SNL), Albuquerque, NM, and Los Alamos National Laboratories (LANL), Los Alamos, NM.

3.3 CTBT Infrasound Instrumentation Specifications

3.3.1 CD/NTB/WP.224/.283

The specifications of Conference on Disarmament/ad hoc committee on Nuclear Test Ban/Working Paper .224/.283 were the original set of specifications that were used in defining requirements for the Infrasound Prototype CTBT IMS Station. These specifications were superseded by the Preparatory Commission (PrepCom) Working Group B specifications as detailed in CTBT/PC/II/1/Add.2.

The specifications of CD Working Paper 224/283 related to the infrasound sensor are:
Resolution: 0.01 Pa @1 Hz.
Dynamic Range: $\geq$ 80 dB.
Passband: flat 0.02-5.0 Hz.

3.3.2 PrepCom WGB/TL/8 (Rev.4)

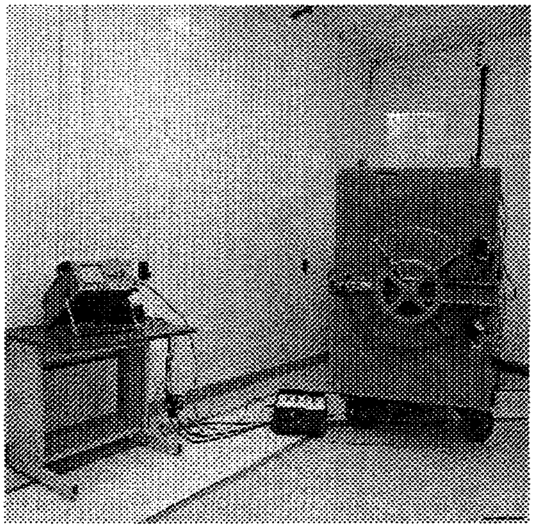
The specifications of Working Group B related to the infrasound sensor are:
Resolution: 0.001 Pa (≥1 count/mPa).
Dynamic Range: ≥ 108 dB.
Sensor Noise: ≤ 18 dB below minimum acoustic noise (~5mPa rms@1Hz).
Passband: flat 0.02-4.0 Hz.

3.4 Test Setup

The CP 4.1.1's which were tested included serial numbers 49, 50, 51, and 55. The CP 4.1.1 sensors were connected to a Refraction Technology RT72A-08 data logger. All four sensors were tested simultaneously at either 20 or 40 samples per second.

3.5 CP 4.1.1 Preliminary Tests

Preliminary tests include adjusting the sensor sensitivity and determining the sensor self-noise.



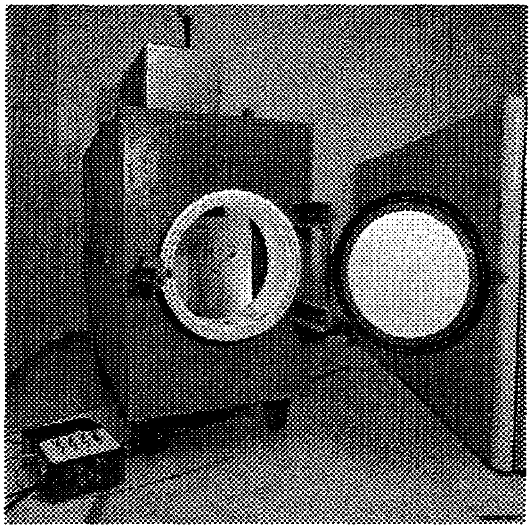


Figure 3.2 - LANL Piston-phone Chamber - The LANL Piston-phone chamber has a volume of approximately 1 million cubic centimeters. The motion of the piston changes the volume by approximately 30 cubic centimeters peak to peak causing a sinusoidal signal to be generated of approximately 3.1 Pa peak to peak.

3.5.1 Microbarograph Sensitivity

Since the sensors were to be interfaced to the high dynamic range Teledyne-Brown DR-24 recorders, the sensitivity of 400 mV/Pa was selected for maximum sensor dynamic range.

The sensors were installed in the LANL piston-phone chamber (Figure 3.2) and connected to a calibrated Refraction Technology 72A-08 data logger.

The piston-phone was set to approximately a 1 Hz piston rate. The sensor gains were adjusted to 400 mV/Pa nominal. Other frequencies (0.16 and 4.0 Hz) were programmed to measure sensor response flatness. Results are shown in Figure 3.3.

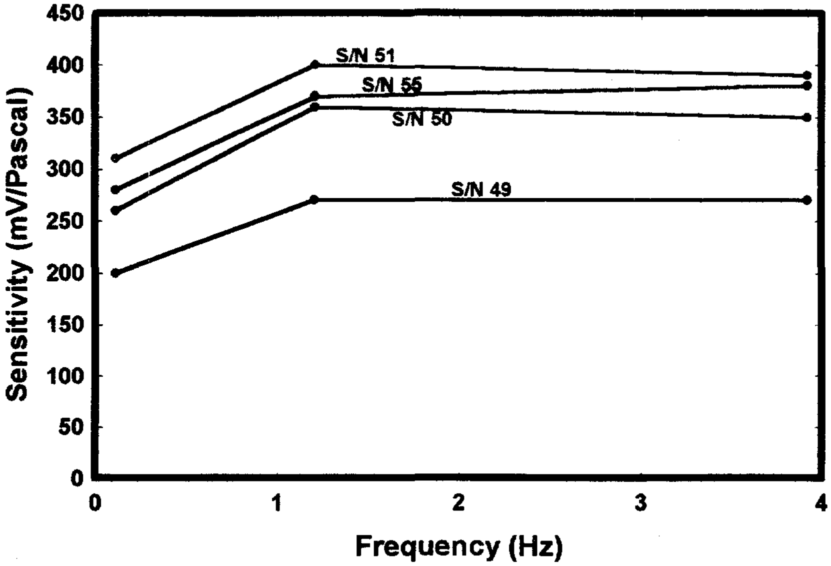


Figure 3.3 - CP 4.1.1 Piston-phone Calibrations

Results indicate that the sensor sensitivity can be set to within 15% of nominal value (400 mV/Pa) at 1 Hz using the piston-phone chamber. The sensitivity of sensor 49 was readjusted and set to within 15% of nominal. The procedure for setting sensitivity was time consuming; the chamber needed to be opened to make small adjustments. After closing the chamber, the wait for the sensor to stabilize was as long as an hour. Small, local weather system, low frequency, atmospheric changes affect the settings as the chamber cannot completely isolate the sensors. At the lower frequency settings on the piston-phone, the generated pressure signal was distorted because of leakage around the piston seals. An absolute pressure gauge would be useful for measuring the actual piston-phone chamber signal. Process control improvements need to be made to assure valid sensitivity settings on the sensors under test. While the absolute sensitivity of the sensor can vary up to +/-15%, it should be measurable to +/- 5%.

3.5.2 Sensor Self-Noise

One of the critical parameters in measuring sensor performance is the determination of the sensor self-noise. The self-noise of any pressure sensor is difficult to obtain as the ability to isolate the sensor from any naturally occurring signals is difficult. For the CP 4.1.1, we were able to partially isolate the sensors in the piston-phone chamber. Small, local weather system, low frequency, atmospheric changes were still seen on the sensor outputs as well as some high frequency peaks that could be attributed to seismic coupling to the chamber. These signals were well correlated. Background signals were acquired on a Refraction Technology 72A-08 data logger and the data were processed using coherence analysis techniques [Reference 5]. The quietest sensor, S/N 50, was used as a reference for determining the self-noise of the remaining sensors. Sensor self-noise is shown in Figure 3.4.

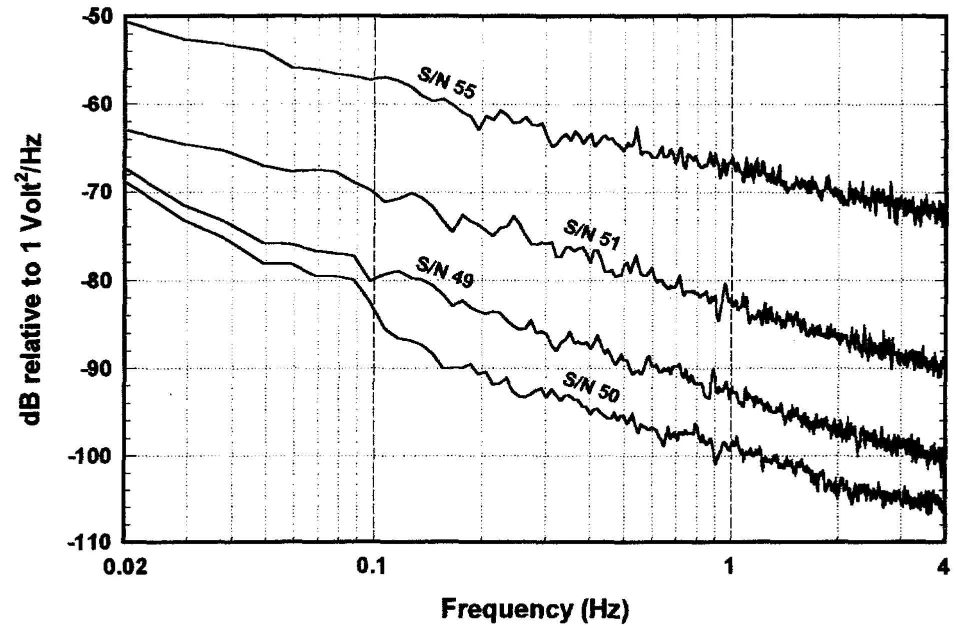


Figure 3.4 - CP 4.1.1 Self-noise Plots

The manufacturer claimed that the sensor self-noise was electronic only and that the diaphragm itself contributed little noise. Using coherence analysis, the self-noise of one sensor was determined relative to S/N 50. The diaphragm was replaced by an equivalent capacitance and the electronics self-noise measured. The two self-noise measurements agreed, confirming that electronic noise dominated the sensor self-noise.

Sensor self-noise varied significantly from one sensor to another. It ranged from 51 μvolts rms to 1000 μvolts rms. Since the self-noise was determined to be dominated by electronic noise, the manufacturer should determine which components are the dominant source of noise and select lower noise components.

During testing of the sensors, coherence analysis testing indicated gain and phase differences at the low end of the passband spectra. Closer examination of the sensors showed small air leaks around the sensor diaphragms indicating manufacturing inconsistencies during assembly of the sensor. The manufacturer changed the assembly process and rebuilt the sensors with an improved seal. Additional coherence testing indicated closely matched sensors both in gain and phase.

3.6 CP 4.1.1 Testing to CTBT Specifications

The data taken in testing the CP 4.1.1 were acquired on a Refraction Technology RT72A-08 data logger. This data logger uses 24-bit high resolution digitizers and has been characterized and tested by Sandia National Laboratories [Reference 4].

Data taken by the RT72A-08 were converted to pressure units (Pa) using the nominal sensitivity of 400 mV/Pa (assumed flat across the bandwidth).

Spectral analysis of this data is labeled in pressure units of **dB relative to 1 Pascal^2/Hz**. An overview of units used in this report is provided in Appendix B.

3.6.1 Resolution

Specification:

CD/NTB/WP.224/.283	**PrepCom WGB/TL/8 (Rev.4)**
Resolution: 0.01 Pa @1 Hz	Resolution: 0.001 Pa (≥1 count/mPa)

Interpretation:
CD Working Paper 224/283 attributed resolution to the sensor performance. It was interpreted as the smallest signal that can be seen above the sensor noise. PrepCom Working Group B specification attributed resolution to system performance. System performance is reported in Reference 2.

Testing:
Self-noise Test (3.5.2) data were used to evaluate this specification.

Evaluation:
A Power Density Spectrum plot of the sensor noise converted to pressure units was overlaid with the specification.

Results:
All four sensors were able to resolve a signal of .01 Pa @ 1 Hz (Figure 3.5).

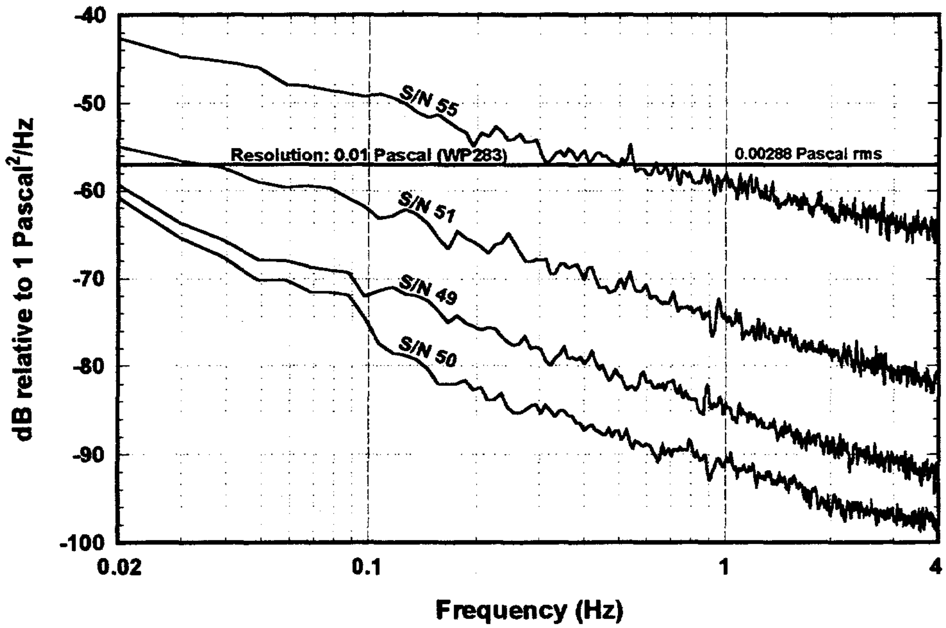


Figure 3.5 - CP 4.1.1 Resolution Plots

3.6.2 Dynamic Range

Specification:

CD/NTB/WP.224/.283	PrepCom WGB/TL/8 (Rev.4)
Dynamic Range: ≥ 80 dB	Dynamic Range: ≥ 108 dB

Interpretation:
CD Working Paper 224/283 attributed dynamic range to the sensor performance. PrepCom Working Group B was vague on definition. PrepCom Working Group B specification attributed dynamic range to system performance. System performance is reported in Reference 2.

Testing:
Self-noise Test (3.5.2) data were used to evaluate this specification.

Evaluation:
Dynamic range was calculated using the ratio of the rms of a full-scale sinusoid to the rms of the sensor self-noise over the passband of 0.02 to 4.0 Hz.

Results:
Three of the four sensors had a dynamic range of >80 dB (Table 3.1). The fourth sensor needs to have the electronics reworked as described in Section 3.5.2.

Sensor Number	RMS full-scale/RMS System Noise	Dynamic Range
49	7.07V/76.8μV	99.2 dB
50	7.07V/51.6μV	102.7 dB
51	7.07V/209μV	90.6 dB
55	7.07V/1001μV	76.9 dB

Table 3.1 - Sensor Dynamic Range

3.6.3 Passband

Specification:

CD/NTB/WP.224/.283
Passband: flat 0.02-5.0 Hz

PrepCom WGB/TL/8 (Rev.4)
Passband: flat 0.02-4.0 Hz

Interpretation:
Working Paper 224/283 and Working Group B specification for the low frequency response were the same. Typically responses are specified at the 3dB point. The high frequency response is limited by the digitizer filter. The actual CP 4.1.1 sensor high frequency response is limited by the porous hoses [Reference 3]. For the purposes of this report the digitizer response was not included.

Testing:
This specification is very difficult to evaluate over the entire bandwidth. The piston-phone chamber was adequate to test the high frequency response. The low frequency response is a function of the acoustic characteristics of the backing volume and calibrated leak, and the response of the sensor electronics. Sensitivity Test (3.5.1) data were used to evaluate the high frequency end of this specification. A step cal of the electronics provided the electronics response. A mathematical model of the sensor acoustic response was used to predict response of the backing volume/leak [Reference 3].

Evaluation:
All the test data responses were merged into a combined response model.

Results:
The combined responses of the tests indicated a flat response to 1dB from .02 to 10 Hz (Figure 3.6). A detailed analysis of sensor response is provided in Appendix A.

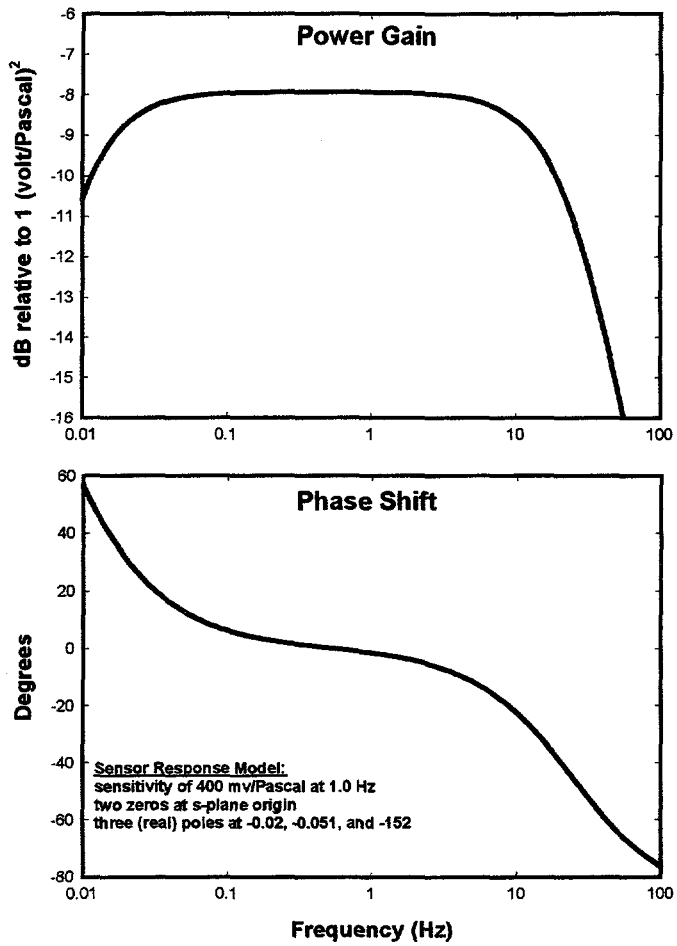


Figure 3.6 - CP 4.1.1 Combined Response

3.6.4 Sensor Noise

Specification:

PrepCom WGB/TL/8 (Rev.4)
Sensor Noise: ≤ 18 dB below minimum acoustic noise (~5mPa rms@1 Hz).

Interpretation:
This specification was interpreted as 18 dB below the minimum acoustic noise of 5 mPa√Hz rms at 1 Hz.

Testing:
Self-noise Test (3.5.2) data were used to evaluate this specification.

Evaluation:
A Power Density Spectrum plot of the sensor noise converted to pressure units was overlaid with the specification.

Results:
Three of the four sensors were greater than 18 dB below 5 mPa rms at 1 Hz (Figure 3.7). The fourth sensor needs to have the electronics reworked as described in Section 3.5.2.

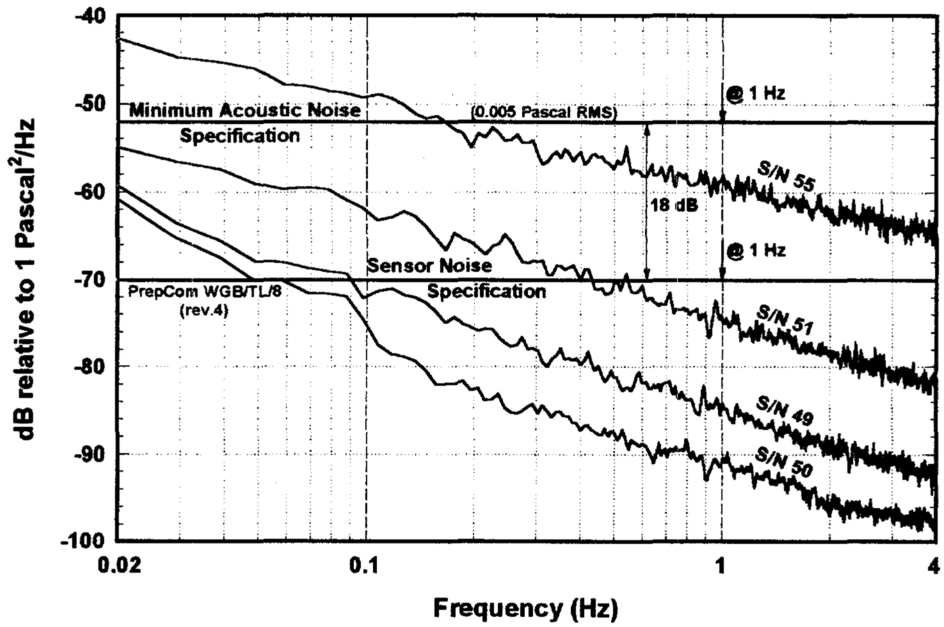


Figure 3.7 - CP 4.1.1 Sensor Noise Plots

4. Future Work

4.1 Long-term Sensitivity Stability

The long-term stability of sensor sensitivity should be determined using the sensor step cal circuitry.

4.2 Acoustic Modifications

Select smaller backing volume and leak to decrease sensitivity to local atmospheric backgrounds.

5. Summary Results

The Chaparral Physics Model 4.1.1 prototype microbarograph should be an excellent infrasound sensor for the CTBT IMS. All sensors met the resolution specification. Three of the four sensors met the dynamic range specification. All sensors met the bandwidth specification. Three of the four sensors met the sensor noise specification.

A few issues need resolution:

1. The sensitivity of the sensors was set to within 15% of the nominal value (400 mV/Pa). To improve the accuracy of the settings, a calibrated pressure gauge needs to be connected to the piston-phone chamber to accurately measure the piston-phone signal. Process control improvements need to be made to assure valid sensitivity settings on the sensors. The long-term stability of sensor sensitivity should be determined.

2. Sensor self-noise varied significantly (25 dB variation between the four sensors). The electronic components causing the noise need to be identified and replaced with lower noise components.

3. The sensor was not designed to interface directly to the Teledyne-Brown digitizer used in the Infrasound Prototype CTBT IMS station installed at Los Alamos, NM. The following changes could be made to match the interface: a.) Use the +/-12 volt sensor power provided by the digitizer; b.) Lower the output impedance to avoid having to provide an impedance matching amplifier in the digitizer; c.) Provide a balanced output for connection to the Teledyne-Brown balanced input digitizer. Changes to the digitizer could be made to match the commercial version of the sensor.

6. Appendix A

6.1 Infrasound Sensor/Electronics Transfer Function

The process of converting an infrasound signal into digitizer counts for computer processing involves three transfer functions: that of the sensor itself (pressure into volts), that of the electronic interface (volts-in into volts-out), and that of the digitizer/recording system (volts into counts). Models for the first two components, sensor and interface, are presented here.

6.1.1 Electronic Interface Response

Two somewhat independent methods yielded similar results for the infrasound sensor electronics interface transfer function. The first involved matching the measured step function response with a single s-plane pole, single zero ideal response by varying the pole position on the real axis, and the second was to simply use the theoretical transfer function model for the applicable portion of the interface circuit diagram, using nominal component values. As may be seen from Figures 6.1 and 6.2, the agreement between the two methods was remarkably good, especially considering the fact that precision components were not used in assembling the interface.

A few observations concerning this model should be kept in mind:

1. The assumed acquisition system is the RefTek (the recorder used for the measured response for the matching) or similar high input impedance waveform recording system. As may be seen in Figure 6.2, a lower input impedance recorder, such as the Teledyne Brown DR-24, reduces the time constant (RC value) of the response significantly.

2. There is another low-pass portion of the electronic interface, but its effect is so limited (time constant of about 5 mseconds) that it is not included here.

3. The amplitude of the step input for the measured response was not known; however, the amplitude of the response suggests that the input step amplitude corresponded to an input signal for 1 Pascal. Since combining the sensor response with the interface response and calculating an overall sensitivity constant is part of the result of a typical calibration, knowing this step amplitude is usually not critical.

4. This high-pass RC filter has the s-plane transfer function:

$$H(s) = \frac{As}{s + \frac{1}{RC}},$$

where A is the interface gain constant (it is included as part of the sensor/interface sensitivity value below) and RC is 97.5 KΩ * 200 μF = 19.5 seconds[1]. Therefore, the theoretical interface transfer function model involves one zero at the s-plane origin and one pole at -0.051 (1/RC) on the s-plane real axis.

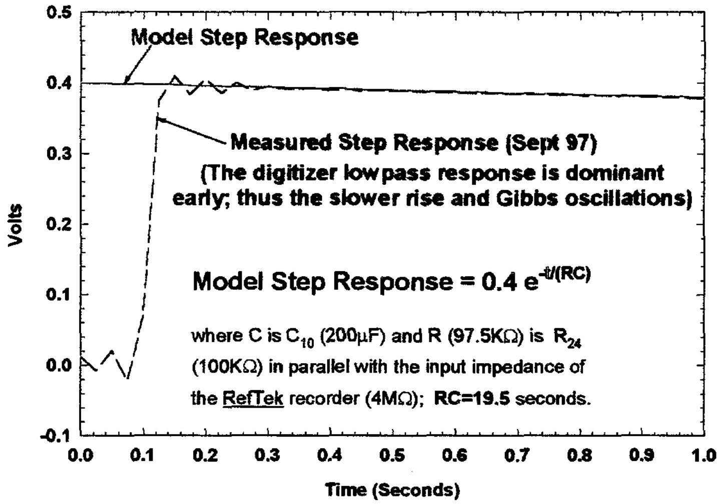


Figure 6.1 – Electronic Interface Step Response (Early Detail)

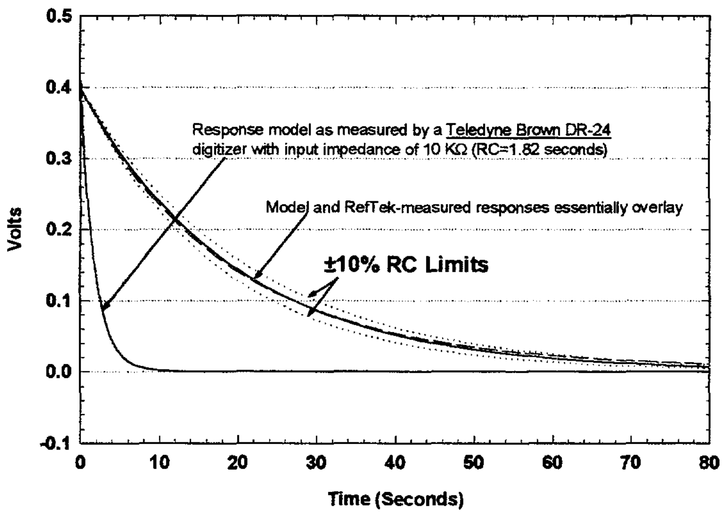


Figure 6.2 – Electronic Interface Step Response

[1] The 97.5 KΩ value is the interface R_{24} specification of 100 KΩ in parallel with the RefTek input impedance of 4 MΩ. The C value is the specification for C_{10}.

6.1.2 Sensor Response

The transfer function for the infrasound sensor was obtained from Appendix A of the reference report[2], equations A10 to A12, which may be rewritten slightly as:

$$H_s(j\omega) = \frac{j\omega\, a\, v}{C + jD} \text{ , where}$$

$$C = \frac{a^2}{r} - \omega^2\left[RVv + abR(V+v)\right] \text{ and}$$

$$D = \omega\left[a^2 b + av + \frac{aR(V+v)}{r}\right].$$

The parameter values for the prototype sensor (see the reference report for definitions and units) are[3]:

a	=	1.4E6
b	=	1.0E-4
r	=	10749.5
R	=	0.23
v	=	6435.18
V	=	4.0E4

Using these equations and parameters and substituting s for jω, we see that the sensor transfer function has one zero at the s-plane origin and two poles, one at -152.0 and one at -0.020, both on the s-plane real axis. Note that the numerator coefficient value may not be required, since it will be included in the overall sensor/interface combined sensitivity, which should be determined by calibration (nominal is 400 mV/Pascal). The normalized power gain and the phase response for the sensor are plotted in Figures 6.3 and 6.4.

[2]Mutschlecner, J. Paul and Whitaker, Rodney W., "The Design and Operation of Infrasonic Microphones", Los Alamos National Laboratory, Report LA-13257, UC-706, May 1997.

[3] Parameter values were obtained via personal communication with Rodney Whitaker of Los Alamos National Laboratory.

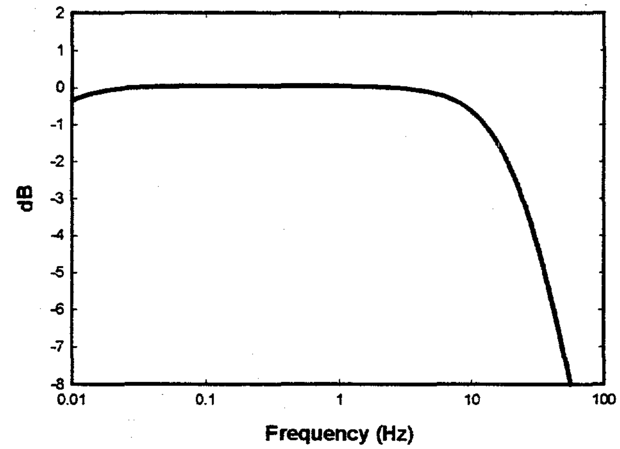


Figure 6.3 – Sensor Transfer Function, Normalized Power Gain

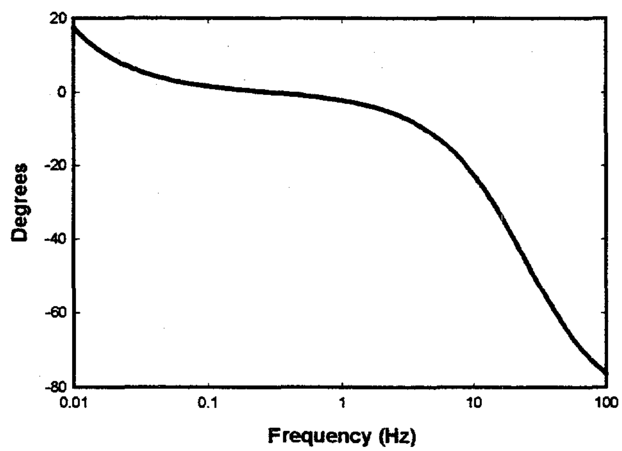


Figure 6.4 – Sensor Transfer Function, Phase Shift

6.2 Combined Sensor / Interface Transfer Function

The combined transfer function is simply the product of the sensor and electronic interface transfer functions. Scaled for the nominal sensitivity in the flat portion of the response (400mV/Pascal at 1 Hz), the power gain and phase shift are presented in Figures 6.5 and 6.6. This combined transfer function may be written as

$$H(s) = \frac{As^2}{(s+0.051)(s+0.020)(s+152.0)},$$

where the value of A is determined via calibration.

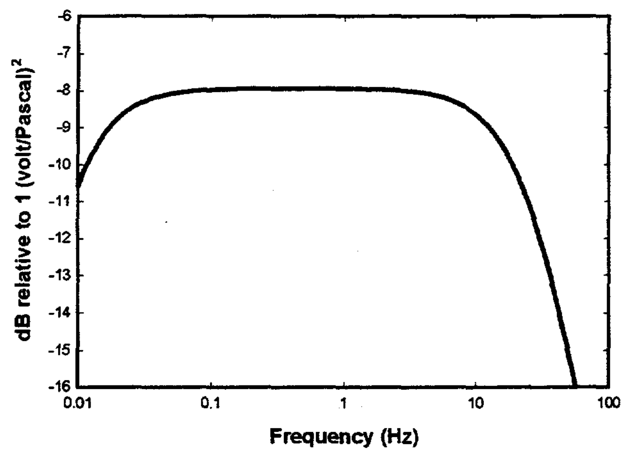


Figure 6.5 – Combined Transfer Function, Power Gain

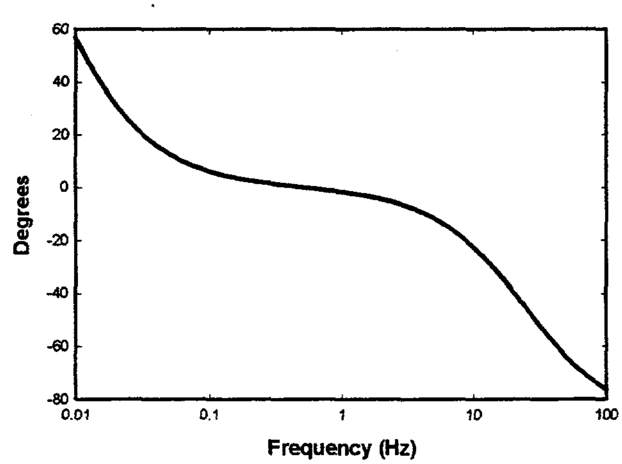


Figure 6.6 – Combined Transfer Function, Phase Shift

7. Appendix B

7.1 Infrasound Sensor Specification Interpretation

This appendix contains frequency domain interpretations of various infrasound sensor specifications. While there may be more than one interpretation possible for a given specification, the attempt here is to interpret based on standard practice and good sense. When needed, the nominal sensor sensitivity of 400 mV/Pascal has been used to convert between voltage and pressure.

7.1.1 Resolution

For the resolution specifications (1 count ≈ 0.001 Pascal [PrepCom] or 0.01 Pascal [WP283]) the interpretation used is that a resolution limit is determined by the "worst case" signal that cannot be resolved. In standard practice, this is taken in the frequency domain as the spectrum of a uniform random variate with a range of **-R**/2 to +**R**/2 (where **R** is the resolution specification) having power distributed evenly over the bandwidth **B** [Reference 6]:

$$\text{Resolution Level} = 10\log_{10}\left(\frac{R^2}{12\times B}\right)\text{ dB relative to 1 Pascals}^2/\text{Hz}$$

Then, for the WP283 resolution specification of 0.01 Pascal we get:

$$B = 4.0\text{ Hz} - 0.02\text{ Hz} = 3.98\text{ Hz and}$$

$$(\text{Resolution Level})_{0.01} = 10\log_{10}\left(\frac{0.01^2}{12\times 3.98}\right)\text{dB} = \mathbf{-57}\text{ dB relative to 1 Pascal}^2/\text{Hz.}$$

Similarly, the PrepCom resolution specification of 0.001 Pascal translates to a level of **-77** dB relative to 1 Pascal^2/Hz.

7.1.2 Sensor Noise Limit

The PrepCom specification for sensor noise limit is 18 dB below the minimum acoustic noise, which, in turn, is specified at 1 Hz as approximately 0.005 Pascal. Usually noise is expressed as an rms value; using this interpretation, and again distributing the power evenly over the bandwidth **B**, the level is calculated

$$\text{Acoustic Noise Limit} = 10\log_{10}\left(\frac{(0.005\text{ Pa})^2}{3.98\text{ Hz}}\right) = \mathbf{-52}\text{ dB relative to 1 Pascal}^2/\text{Hz}$$

The sensor noise limit is 18 dB below this value, or **-70** dB.

7.1.3 Dynamic Range

Finally, the floor for the 80 dB dynamic range specification is obtained by subtracting 80 dB from the level obtained for a -10 to +10 volt (sensor clip level) sine wave. This is calculated as (11 - 80), or **-69** dB relative to 1 volt^2/Hz, which, for a sensor sensitivity of 400 mV/Pascal across the bandwidth, becomes **-61** dB relative to 1 Pascal^2/Hz.

These specification levels along with a sample self-noise spectrum for one sensor are presented in Figure 7.1.

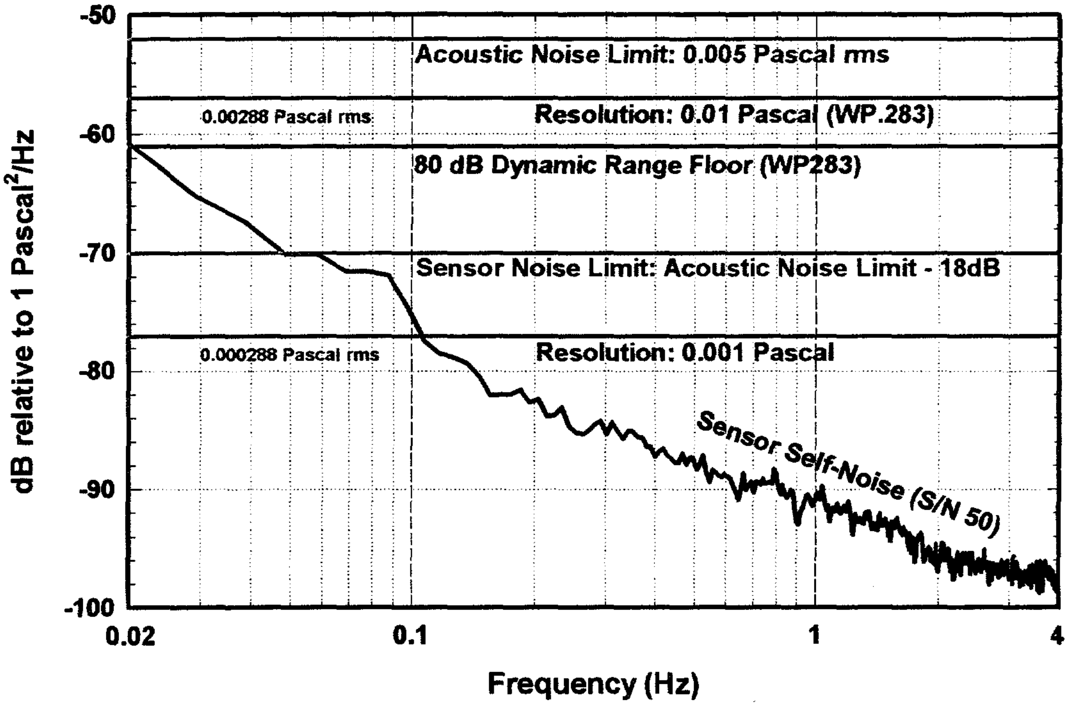


Figure 7.1 – Infrasound Sensor Specifications

References:

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