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EVALUATION OF INFRASOUND SENSORS

Richard P. Kromer and Timothy S. McDonald (Contractor)
Monitoring Technologies Department
Sandia National Laboratories

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ABSTRACT

Sandia is evaluating the performance of various infrasound sensors that could be used as part of the International Monitoring Systems (IMS). Specifications for infrasound stations are outlined in CTBT/PC/II/1/Add.2 [1]. This document specifies minimum requirements for sensor, digitizer and system.

The infrasound sensors evaluation task has the following objectives:

- Provide an overview of the sensors presently in use.
- Evaluate these sensors with respect to the requirements of the IMS.

Chaparral Physics: Sandia is working with Ed Bullard, Chaparral Physics, to evaluate the Chaparral Physics Model 5 prototype infrasound sensor to CTBT/PC/II/1/Add.2.

CEA: The French infrasound sensor (CEA MB2000) specifications were reviewed. There are uncertainties as to how the units were specified in the catalogue.

Validyne: Sandia is working with Chris Hayward, Southern Methodist University (SMU), to evaluate the SMU implementation of a few commercial differential high pressure sensors from Validyne Inc. Sandia has performed a cursory evaluation of the Validyne (P55D) that supercedes the model used by SMU at Lajitas, TX. A new implementation of the Validyne DP350 is being developed by SMU to increase sensitivity with reduced noise.

Key Words: infrasound, sensor, evaluation, instrumentation.

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OBJECTIVE

Sandia is evaluating the performance of various infrasound sensors that could be used as part of the International Monitoring Systems (IMS). Specifications for infrasound stations are outlined in CTBT/PC/II/1/Add.2[Ref 1]. This document specifies minimum requirements for sensor, digitizer and system.

The infrasound sensors evaluation task has the following objectives:

- Provide an overview of the sensors presently in use.
- Evaluate these sensors with respect to the requirements of the IMS.

RESEARCH ACCOMPLISHED

Sensor Overview:

Chaparral Physics

Sandia worked with Ed Bullard, Chaparral Physics, to evaluate the Chaparral Physics Model 4.1.1 and Chaparral 5 prototype infrasound sensor to the specifications outlined in Reference 1, CTBT/PC/II/1/Add.2. The Chaparral 5 has a smaller backvolume and a modified electronics that includes a lower gain option. The long term sensitivity stability performance of the Chaparral 4.1.1 was studied using the internal step-cal.

CEA

The French infrasound sensor (CEA MB2000) specifications were reviewed. There are uncertainties as to how the units were specified in the catalogue[Ref 2]. A mathematical sensor self-noise model was developed using information from the catalogue.

Validyne

Sandia is working with Chris Hayward, Southern Methodist University (SMU), to evaluate the SMU implementation of a few commercial differential high pressure sensors from Validyne Inc. Sandia has performed a cursory evaluation of the Validyne (P55D) that supercedes the model used by SMU at Lajitas, TX. A new implementation of the Validyne DP350 is being developed by SMU to increase sensitivity with reduced noise. Only preliminary test results were available.

Sensor Performance and IMS Requirements:

Different sets of units are in common use. An attempt was made by Sandia to define key IMS requirements in the different units and provide a mechanism for understanding the conversions. Comparison of IMS requirements to sensor performance was made.

Key Infrasound Specifications
(CTBT/PC/II/1/Add.2)

Characteristics	Minimum Requirements
Resolution	≥ 1 count / 1 mPa
Sensor Noise	≤ 18 dB below minimum acoustic noise[11]
Calibration	≤ 5 % in absolute amplitude[12]
Dynamic Range	≥ 108 dB

[11] Minimum noise level at 1 Hz: ~ 5 mPa
[12] Periodicity: once per year (minimum)

Resolution Requirement:

≥1 count/mPa

Digitizer Resolutions are indicated in the Table below.

Sensor/System Specifications	IMS Infrasound Requirements	Chaparral 4.1.1 400 mV/Pa	Chaparral 5 proto. 80 mV/Pa	CEA MB2000 20mV/Pa	Validyne P55D 6 mV/Pa
Resolution (count)	≥ 1 count/ mPa	100 count/mPa	20 count/mPa	1.05 count/mPa	N.A.

Sensor Noise Requirement:

18 dB below minimum acoustic noise of 5 mPa at 1 Hz

Interpretation:
The specification of 5 mPa at 1 Hz as minimum acoustic noise is interpreted as 5 mPa (rms)/√Hz at 1 Hz. The 5 mPa/√Hz at 1 Hz is a point on the PSD plot below. 18 dB below 5 mPa/√Hz at 1 Hz is 0.6 mPa/√Hz. Sensor noise is indicated in the table below.

Sensor/System Specifications	IMS Infrasound Requirements	Chaparral 4.1.1 & 5 proto. 400 & 80 mV/Pa	CEA MB2000 20 mV/Pa	Validyne P55D 6 mV/Pa
Electronic Noise @1 Hz	0.6 mPa/√Hz	0.2 mPa/√Hz	0.6 mPa/√Hz	5.4 mPa/√Hz

CEA Sensor Electronics Noise

The specifications for sensor noise were derived from the CEA MB2000 sensor.

The plot taken from the CEA MB2000 data sheet indicates the minimum acoustic noise and a value 18 dB below the minimum acoustic noise from data acquired in France.

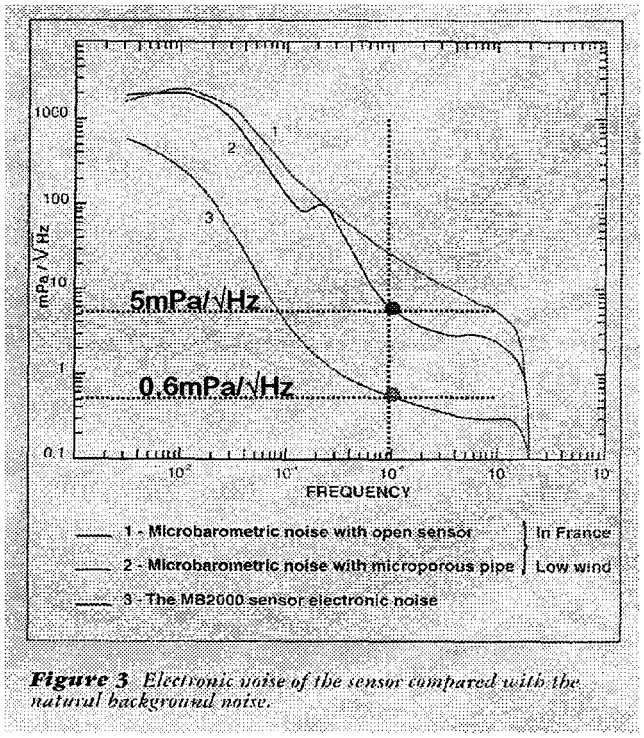
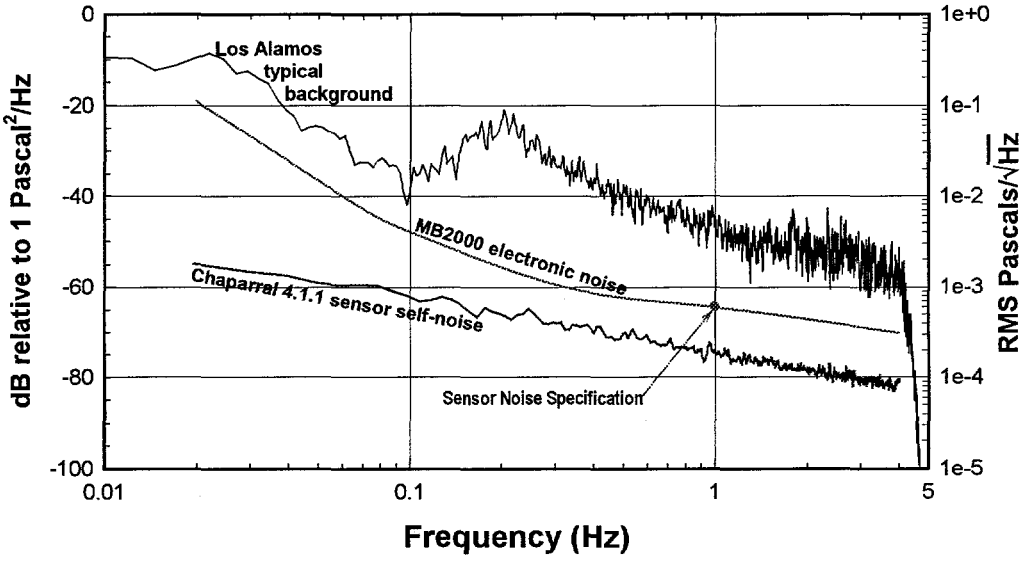
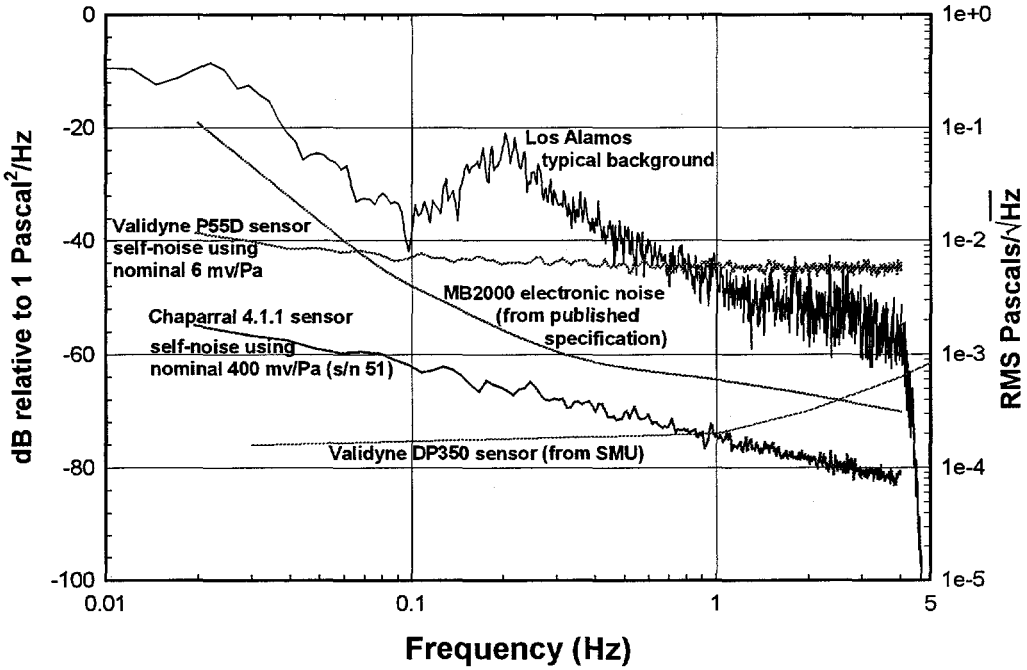


Figure 3 *Electronic noise of the sensor compared with the natural background noise.*

Sensor Electronics Noise:
Chaparral 4.1.1, CEA MB2000



Sensor Electronics Noise:
Chaparral 4.1.1, CEA MB2000, Validyne P55D, DP350



Calibration Requirement:
<5% in absolute amplitude

- For a differential sensor, 5% calibration is difficult to perform, especially in the field.
  - Sensor temperature and electronics need to stabilize after each calibration adjustment
  - Atmospheric changes affect sensitivity during calibration

Calibration Study of Chaparral 4.1.1 Microbarograph

- The sensor has the capability of performing a step-cal on the sensor electronics
- The step-cal is generated by shifting the carrier frequency derived from the sensor diaphragm capacitance
- The step-cal gives an indication of the electronics board gain and response – it does not calibrate in volts/Pa
- Over time, the step-cal provides an indication of electronics' sensitivity stability
- If the sensor is calibrated in a pistonphone chamber and the step-cal gain and response measured, a field step-cal can confirm that the electronics is calibrated to <5%
- A study of step-cal amplitudes was conducted over a 5 month period on the prototype sensors deployed at Los Alamos
- A technique was developed to analyze the step-cal in the presence of background signals
  - The technique uses sample first-differences shifted by two samples
  - The positive and negative peaks were averaged
- Results indicate sensor electronics sensitivity stability of better than 1.5% of nominal over the study period

S/N	Average Step Response Magnitude (counts)	Std. Deviation (counts)	Std. Deviation (% of average)	Range (% of average)
49	416773	1429	0.3%	2.1%
50	244110	2627	1.1%	4.7%
55	640767	9391	1.5%	9.4%

Dynamic Range Requirement:

≥ 108 dB

Interpretation:

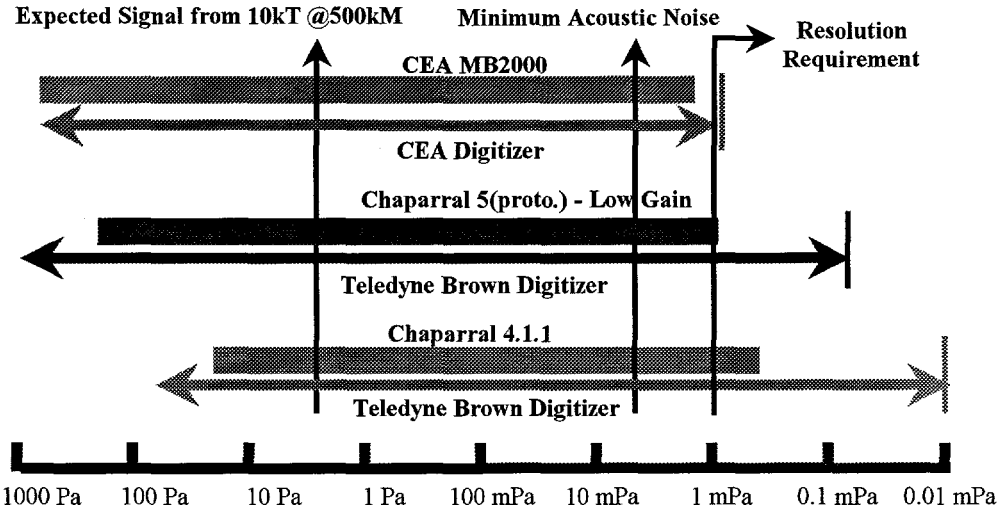
The Dynamic Range of a sensor usually refers to the ratio of some maximum output value to some minimum output value, usually RMS noise. For microbarograph dynamic range *Sandia uses the ratio of the RMS value of the maximum sensor output to the RMS value* of the sensor self-noise in the specified IMS passband (0.02-4 Hz).

Sensor/System Specifications	IMS Infrasound Requirements	Chaparral 4.1.1 400 mV/Pa	Chaparral 5 proto. 80 mV/Pa	CEA MB2000 20 mV/Pa	Validyne P55D 6 mV/Pa
Dynamic Range	108 dB	91 dB	106 dB	91 dB	94 dB

It may be difficult to find a microbarograph with a full bandwidth (0.02 – 4 Hz) dynamic range of at least 108 dB.

Dynamic Range Comparison

As shown below, the dynamic range of the Chaparral and CEA sensors is more than adequate to resolve any infrasonic signal with sufficient resolution



Alternate Dynamic Range Approach:

Chris Hayward, Southern Methodist University (SMU), has been using a technique based on the information that:

- Large infrasonic signals from chemical surface explosions, as monitored in Lajitas, TX, exhibit a bandwidth of approximately 2 octaves [Ref 3].
- The frequency of interest for IMS infrasound applications is specified by the minimum acoustic noise (5 mPa/√Hz @1 Hz) and sensor noise requirement of 0.6 mPa/√Hz @1 Hz.

Based on the above premise, it should be acceptable to compute dynamic range using the ratio of the RMS value of the maximum sensor output to the RMS value of the sensor self-noise in a two octave band around 1 Hz (0.5-2 Hz).

Using this approach, the dynamic range is improved around the 1 Hz frequency of interest:

Sensor/System Specifications	IMS Infrasound Requirements	Chaparral 4.1.1 400 mV/Pa s/n 51	CEA MB2000 20 mV/Pa	Validyne P55D 6 mV/Pa
Dynamic Range (.02 – 4 HZ)	108 dB	91 dB	91 dB	94 dB
Dynamic Range (0.5 – 2 Hz)	108 dB	98 dB	115 dB	99 dB

The Chaparral 5 electronics dynamic range improves also:

Chaparral dual-gain prototype 6/98

Sensor Number	Chaparral (400 mV/Pa) BW (.02 – 4 HZ)	Chaparral (400 mV/Pa) BW (0.5 – 2 Hz)	Chaparral (80 mV/Pa) BW (.02 – 4 HZ)	Chaparral (80 mV/Pa) BW (0.5 – 2 Hz)
72	91.5 dB	98.8 dB	105.4 dB	112.5 dB
73	78.5 dB	87.0 dB	95.2 dB	102.3 dB **
74	93.3 dB	99.7 dB	106.0 dB	113.1 dB
75	----	----	107.3 dB	113.4 dB

** sensor noise is at limit of 0.6 mPa/√Hz @ 1 Hz

CONCLUSIONS AND RECOMMENDATIONS

Chaparral Physics

The Chaparral Physics 4.1.1 met the IMS requirements for resolution, sensor noise, and calibration. The dynamic range requirement was not met. High winds clipped the sensor at Los Alamos. The Prototype Chaparral 5, with reduced gain, met all IMS requirements.

CEA

The French infrasound sensor (CEA MB2000) met all IMS requirements.

Validyne

The Southern Methodist University (SMU) implementation of the Validyne (P55D) did not meet the IMS requirements for sensor noise or dynamic range. A new implementation of the Validyne DP350, being developed by SMU to increase sensitivity, met the IMS requirements for sensor noise. At this time, only preliminary test results were available from SMU.

REFERENCES

1. Report of Working Group B to the Second Session of the Preparatory Commission for the Comprehensive Nuclear Test-Ban Treaty Organization, CTBT/PC/II/1/Add.2, 16 May 1997.
2. MB2000 Microbarometer Product Manual; CEA/Departement Analyse et Surveillance de l'Environnment, October 1997.
3. Hayward, C.; Preliminary Report: Characteristics of Acoustic Sensors, Southern Methodist University, 8/28/96.