Piezoceramic Sensors and Infrasound Technology

Carrick L. Talmadge

National Center for Physical Acoustics
University of Mississippi, Oxford MS
Potential Applications of Infrasound Sensors

- monitoring potential atmospheric nuclear tests (CTBT applications)
- natural hazard detection of volcanos, tornados, tsunamis
- monitoring natural phenomena such as hurricanes and bolides
- Atmospheric science applications such as studying structure of stratosphere, probing physics of the lower thermosphere.
Challenges of Atmospheric Infrasound

• Noise associated with atmospheric turbulence ("wind noise"), especially at frequencies below 0.1 Hz. Conventionally this is solved by adding large "wind-noise filters" to sensors. The cost of the filters typically far exceeds the cost of the infrasound sensor itself.

• Environmental exposure is a hazard to current, rather delicate microphones, so vaults are constructed to stabilize temperature and protect the instrument from environmental exposure.
Infrasound Pipe Array:

State of the Art

Wind Noise Sensor
Goals of This Instrument Development

• Replace large pipe arrays with array of infrasound sensors.

• Ruggedize sensors, and construct them to be insensitive to thermal fluctuations: Removes requirement for instrument vault.

• Make them low-cost enough ($750 vs $5000+) to make practicable multiple arrays of sensors.

• Low replacement cost also reduces risk associated with damaged or destroyed sensors.
Piezoceramic Sensors

- Resonant Frequency - 1.8 kHz (hinged condition)
- Sensitivity - 3.4 mV/Pa
- Temperature Compensation
  - Reverse bimorphs
  - Insulated enclosures, small openings
- Charge Generating
  - Must operate into a high impedance
Frequency Response of Piezoeoceramic Sensors

- Higher frequencies are strongly attenuated, phase becomes incoherent.
- Very flat amplitude/phase response below 500 Hz—ideal for long-distance sensing.
- 3-dB cut-off for 35-mm element.

Band start frequency depends on design of preamplifier. We can reliably measure pressure signals down to periods of $10^5$ s.
This 4-element design reduces effects of temperature gradients across sensors. Current design has different base plate, sensor lid. Still Chaparral 50 compatible.
Characteristics of Sensor

• highly ruggedized
• 0.0005 Hz-100 Hz operating range (3-dB). Can be calibrated to 500-Hz.
• plug compatible with Chaparral 50
• self-calibration using reciprocal calibration method has been demonstrated from 0.1–100 Hz, calibration chamber with calibrated volume source.
• Sensor can be configured as accelerometer (or dual pressure/acceleration sensor with same sensing elements).
Microphone Noise Floor

![Graph showing power spectral density and frequency distribution with signal and noise floor lines.]

- **Power Spectral Density** [re 1 Pa²/Hz]
- **Frequency** [Hz]
Comparison with C50 Microphone
Single Sensor Comparison with C50
Single Sensor Comparison
Comparison with Vaisala Pressure Sensor

![Graph comparing PSD of NCPA 505000#01 (1mHz-version) and Vaisala PT300 pressure sensors. The x-axis represents frequency in Hz, while the y-axis shows PSD in Pa^2/Hz.]
“High Frequency” Sensor

- Allow use of microphone for low-frequency sound, long-range propagation experiments.
- 0.1 Hz - 1000 Hz operating range, configurable gain
- Improved vibrational isolation (elevated sensor applications).
- More compact sensor packaging.
- Vertical (4-m, 8-element) portable towers are in development at the NCPA.
Comparison of HF Sensor to B&K 4193
NCPA Calibration Chamber:
Goals

- Allow accurate (0.05 dB) calibration from 0.01—20Hz.
- System will be enclosed within concrete outer shell & will be mounted on active vibrational isolation system.
- Allow variation of pressure, temperature, humidity & even gas content (e.g., replace atmospheric air with helium).
- Thermally stabilized volume. Calibration volume will be instrumented for air temperature, humidity, pressure, vibration.
2009 Nevada Field Deployment of Array

Nominal array locations were at 180–250 km, in 10 km steps
• All infrasound microphones were NCPA sensors.
• Outer sensors characteristics: 10 mHz–100 Hz, 0.13 V/Pa; center mike 1 mHz–100 Hz, 0.025V/Pa
• Digitizers used were Geotech SMART 24 ("even" numbered array") or Miltech Fence Posts ("odd numbered arrays").
Field-Deployed Microphone
Sources for Nevada Deployment

July 14, 2009
4 ton TNT-eq explosion

4, 20 and 80 tons-TNT equivalent explosions at the Utah Testing and Training Range (UTTR), as part of the Trident missile disposal program.
Source capture used 2 co-located microphones 23-km south of source. Assuming spherical spreading, source strength was about 70-Pa at 1 kilometer. Source capture used a Chaparral USB Digitizer.
“Scalloping” probably associated with multiple arrivals associated with propagation effects.
Vertical Sound Speed Profile

- Stationary
- With wind component added

stratospheric duct (westward propagation)
Expected Signal Transmission

- Shadow zone (expect scattering from gravity waves to partially fill this in with incoherent sound)
- Peak energy around 200-km
- IF we have net ducting
Atmospheric Absorption

![Graph showing atmospheric attenuation at different frequencies for ground and 40-km distances.](image-url)
Typical Arrival Structure
Typical Arrival Structure

2009/07/20 Site2-190W
Typical Arrival Structure

2009/07/20 Site3-200W

Pressure [Pa]

Time [sec re: 2000Z]
Typical Arrival Structure

2009/07/20 Site4 - 210W

Pressure [Pa]

Time [sec re: 2000Z]
Typical Arrival Structure

2009/07/20 Site5-220W

Pressure [Pa]

Time [sec re: 2000Z]
Typical Arrival Structure

2009/07/20 Site6-230W

Pressure [Pa]

Time [sec re: 2000Z]
Typical Arrival Structure

![Pressure vs Time Graph]

- **Date:** 2009/07/20
- **Site:** Site 7-240W
- **Levels:** +150m, +50m, 0m, -50m, -150m

**Time [sec re: 2000Z]**

**Pressure [Pa]**
Typical Arrival Structure

2009/07/20 Site8-250W

Pressure [Pa]

Time [sec re: 2000Z]
Observed Power

![Graph showing Observed Power over range][1]

**Graph Details:**
- **X-axis:** Range [km]
- **Y-axis:** RMS Pressure [0.5-20 Hz band]
- **Legend:**
  - Blue line: RMS Signal
  - Gray line: RMS Noise
- **Note:** 2009/07/20 (Stage 2 explosion)
Average Noise Floor

\[ f^{-7/3} \]

\[ f^{-1} \]

\[ fc = 20 \text{ Hz (wind noise filter)} \]
Miltech Fence posts had 3-axis geophones (Geospace GS-32CT). Arrivals were observed on these sensors coincident with the infrasound sensors.
High-frequency tail above 20-Hz was unexpected. However, it was observed at all sites with two different recording systems, and with two different technologies (infrasound mikes, seismometer)
Conclusions

• A new sensor technology incorporating piezoceramic sensors has been developed at the NCPA.

• This technology was successfully field tested in a large scale deployment in Utah/Nevada from July 13–September 22, 2009.

• Very few sensor related problems were encountered during experiment.

• Main surprise was observation of high-frequency signals which are probably associated with nonlinear propagation effects at stratospheric elevations.