HASP Student Payload Application for 2014

Payload Title:
Quantifying Atmospheric Infrasound with a Free Flying Acoustic Array

Payload Class: (check one) X Small ☐ Large	Institution: UNC Chapel Hill, Boise State University, New Mexico Tech	Submit Date: 12-18-2013

Project Abstract

The generation and propagation of acoustic waves provide valuable constraints on source processes (e. g. volcanoes, meteorites, and severe storms) as well as atmospheric structure. However, existing acoustic and infrasound arrays, in nearly all cases, lie on the surface of the Earth and thus neglect the three dimensional radiation pattern of acoustic energy. We propose to address this shortcoming with a balloon-mounted acoustic array. The payload will consist of an acoustic array, a high altitude GPS, and an instrument deployment system. The array will include infrasonic microphones with attached data loggers separated by 12 m of wire; this system will be deployed in-flight and will extend below the payload module. This experiment will test the accuracy of existing infrasound propagation models that lack constraints in the atmosphere, search for acoustic waveguides at the tropopause, and potentially detect never-before recorded signals that do not reach the Earth's surface. The atmospheric propagation models will be evaluated by recording mine blasts from southwestern New Mexico. The existence of waveguides will be tested as the balloon transits the tropopause. The long flight time will give ample opportunities for recording novel signals in the mid-stratosphere.

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Quantifying Atmospheric Infrasound with a Free Flying Acoustic Array

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Abstract

The generation and propagation of acoustic waves provide valuable constraints on source processes (e. g. volcanoes, meteorites, and severe storms) as well as atmospheric structure. However, existing acoustic and infrasound arrays, in nearly all cases, lie on the surface of the Earth and thus neglect the three dimensional radiation pattern of acoustic energy. We propose to address this shortcoming with a balloon-mounted acoustic array. The payload will consist of an acoustic array, a high altitude GPS, and an instrument deployment system. The array will include three infrasonic microphones with attached data loggers separated by 12 m of wire; this system will be deployed in-flight and will extend below the payload module. This experiment will test the accuracy of existing infrasound propagation models that lack constraints in the atmosphere, search for acoustic waveguides at the tropopause, and potentially detect never-before recorded signals that do not reach the Earth's surface. The atmospheric propagation models will be evaluated by recording mine blasts from southwestern New Mexico. The existence of waveguides will be tested as the balloon transits the tropopause. The long flight time will give ample opportunities for recording novel signals in the mid-stratosphere.

Contents

1 Experiment

Volume change and mass displacement create acoustic waves in fluids. The interaction of these waves with the horizontally heterogeneous, vertically stratified, temporally evolving atmosphere produces complex radiation patterns in three dimensions (Negraru et al. (2010)). Quantification of these radiation patterns sheds light on atmospheric structure as well as the location, timing, and magnitude of the energy source that produced the acoustic wave. However, almost all acoustic studies to date have deployed sensors on the surface of the Earth, which neglects the third dimension (Figure 1). Recognizing that some volcanic eruptions produce directional acoustic radiation (e. g. Buckingham and Garcés (1996)), our team performed several pilot experiments to test the feasibility of balloon-mounted microphone systems. These initiatives consisted of an array of differential pressure transducers attached to tethered helium balloons. Results suggest that airborne arrays can faithfully record acoustic signals (Figure 2), and data from the second experiment are included in a publication to be submitted to a peer reviewed journal in January 2014. However, tethered balloons are limited by the weight and strength of the suspension system and are vulnerable to wind. A free-flying acoustic array does not have such limitations.

We hypothesize that airborne acoustic arrays are an effective means of quantifying three dimensional radiation patterns and for detection of long range acoustic signals. Such high altitude arrays will also place

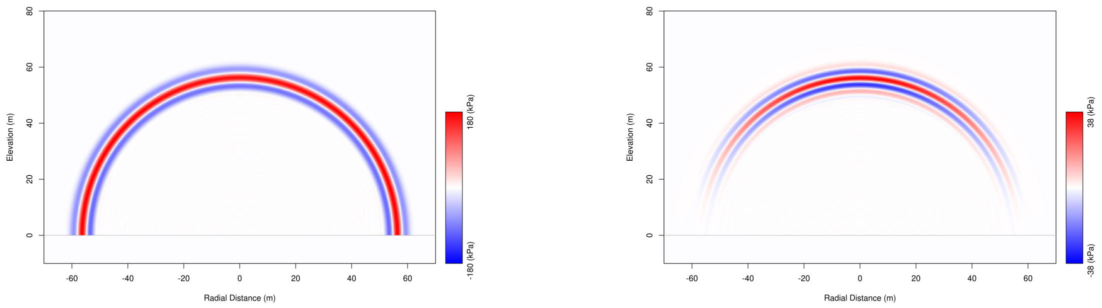


Figure 1: A. A monopole source produces isotropic acoustic radiation. B. A vertical dipole source produces no acoustic radiation at the surface and a powerful signal at high altitude angles. Figures courtesy of Keehoon Kim, UNC Chapel Hill.

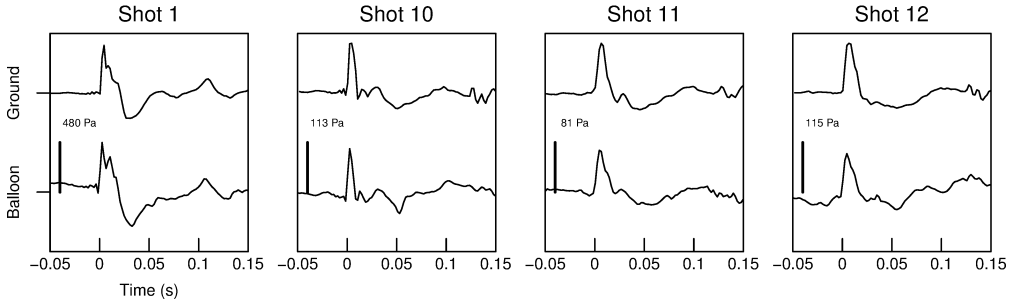


Figure 2: Acoustic signals recorded on ground microphones and microphones on tethered helium balloons. Signals are from chemical explosions during an experimental volcanology initiative in Buffalo, New York.

constraints on mid-atmospheric acoustic propagation models. We will test these assertions by simultaneously recording mine blasts on the airborne acoustic array and on a ground acoustic array near Socorro, New Mexico operated by Sandia National Laboratories (Jones et al. (2013)). The sound speed minimum at the tropopause should act as a waveguide, and we predict a rise in ambient acoustic amplitude as the balloon crosses this boundary. Since sound waves refract away from the Earth in the troposphere, it is possible that a stratospheric array may record novel acoustic signals that never reach the surface. Our engineering objective is to demonstrate the effective operation of an airborne acoustic array in low temperature and low pressure conditions. We also expect significant wind noise during the ascent and descent phases. Quantifying the source and magnitude of wind noise will assist in the design of next-generation airborne acoustic networks for future flights on HASP and elsewhere.

1.1 Experimental Objectives

- Record continuous acoustic data from the surface of the Earth to the mid-stratosphere
- Correlate acoustic signals between the airborne array and a ground array near Socorro, New Mexico
- Determine the intensity of the waveguide at the tropopause
- Quantify the presence or absence of novel mid-atmospheric signals
- Evaluate sources and severity of instrument and wind noise during the ascent, neutral buoyancy, and descent phases of the flight

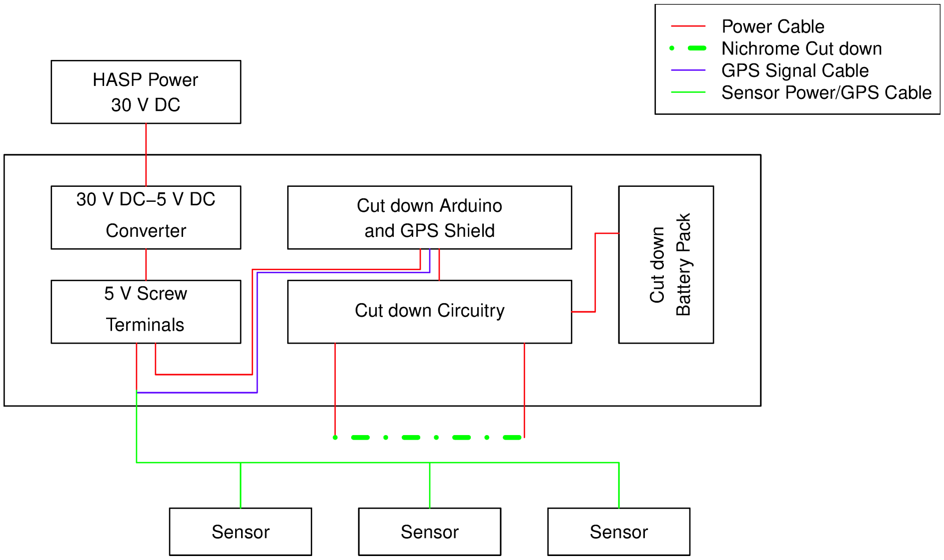


Figure 3: Airborne acoustic array payload schematic.

1.2 Flight Event Sequence

The array will begin recording as soon as HASP system power is turned on. The cut down will activate at an altitude of 5 km, deploying the array beneath the HASP payload. The network will continue recording data after landing until the HASP power supply fails or is turned off.

1.3 Expected Results

We expect to record one to three mine blasts originating from southwestern New Mexico. The array will likely detect other coherent signals from commercial aircraft and other sources. Exotic signals from high altitudes (e. g. bolides) or great distances (e. g. volcanic eruptions) may be recorded as well. Acoustic energy will increase as the balloon crosses the tropopause. Wind noise will be significant during the ascent and descent, but should decrease with increasing altitude due to lower air density. There will be very little wind noise during the neutral buoyancy portion of the flight.

2 Payload Design

The payload will occupy one of the small payload platforms. A box will be bolted to the payload mechanical interface plate. The box will contain foam blocks with slots cut out for the voltage converter, the Arduino Uno High Altitude GPS shield, and the cut down circuit board. The foam will shield the electronics from mechanical damage as well as insulate them from the extreme cold at altitude. Holes will be drilled through the payload interface plate for the cut down wire and acoustic array. At launch, the acoustic array will be bundled beneath the payload plate. At 5,000 m, the cut down module will deploy the array, and it will hang below the payload plate for the duration of the flight. The experiment will rely on the HASP module for power. A 30 V DC-5 V DC converter will provide the appropriate voltages to the data logger and cut down Arduinos. See Figure 3 for a diagram of the payload design.

2.1 Array

The array will consist of three sensor packages connected via braided nylon rope (50 lb tensile strength) and power/GPS timing wires. One package will be located directly beneath the interface plate. The next will be 12 m below the interface plate, and the final microphone will lie 24 m below the interface plate. This configuration serves the following purposes:

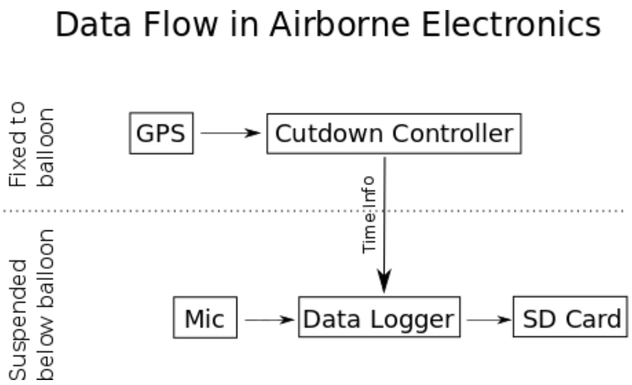


Figure 4: Sensor package design and integration.

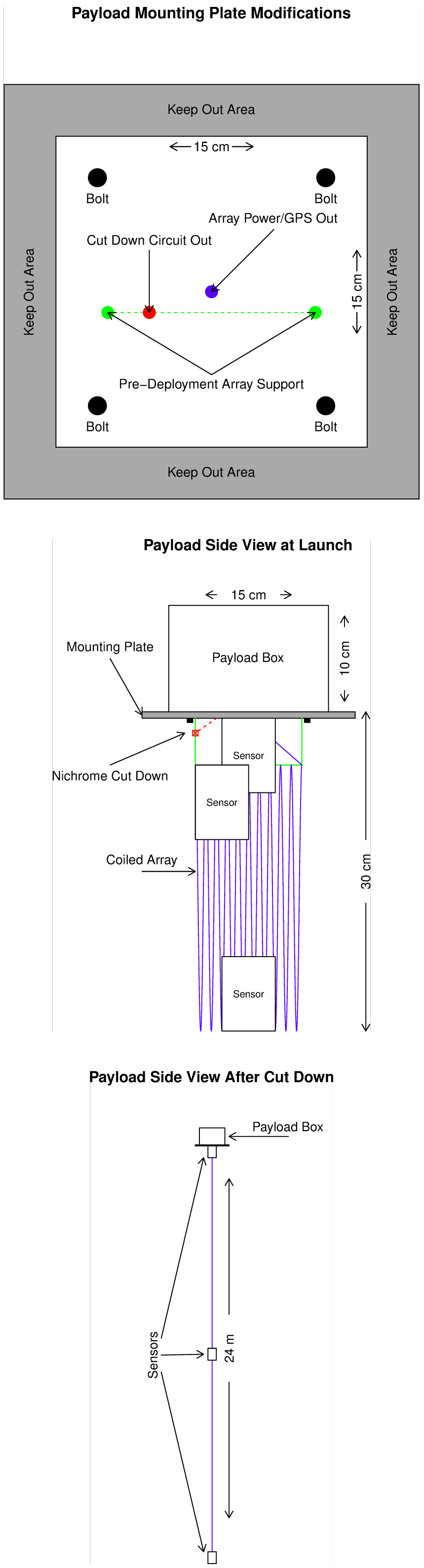
- Multiple microphones allow easy discrimination between true signals and random fluctuations from wind noise
- Acoustic traces can be stacked to increase the signal to noise ratio
- The incident angle of incoming acoustic waves can be calculated, allowing us to discriminate between signals from below and above the array

2.2 Sensor Packages

We will fly three sensor packages inside insulated thermal bags. Each consists of two connected circuit boards: a data-logging Arduino Uno, and a custom board including a digital infrasonic microphone, terminals to receive power and GPS timing information, and an SD card writer (Figure 4). The Arduinos will receive timing information from the cut down controller Arduino, and will sample the microphone at 100 samples per second. Acoustic, timing, and cut down data will be written to rugged SD cards that can operate reliably in the cold environment. See Appendix for a detailed description of the infrasonic microphones.

2.3 Cut down

The acoustic array will be deployed when the balloon ascends above 5,000 m using a nichrome wire cut down system. During launch and initial ascent, the array will be coiled beneath the interface plate, held together with nylon string (Figure 5). An Arduino Uno attached to the Adafruit Ultimate GPS Shield will monitor the ascent. When the payload reaches the specified elevation, the Arduino Uno will trigger the nichrome cut down device (Figure 6), melting the string and allowing the array to uncoil. The cut down circuit will draw power from a dedicated battery pack to avoid drawing excessive amperage from the HASP power supply. A stiff spring attached to the payload interface plate will absorb the sudden deceleration of the array when it reaches its full length. The cut down circuit and software was tested and validated during a high altitude balloon launch in Minnesota. The payload successfully separated from a weather balloon at the requested altitude of 20,000 m (Figure 7).



Payload Mounting Plate Modifications

Payload Side View at Launch

Payload Side View After Cut Down

Figure 5: Diagrams of anticipated modifications to mounting plate, side view of payload prior to array deployment, and side view of payload after array deployment. Note changes in scale between diagrams.

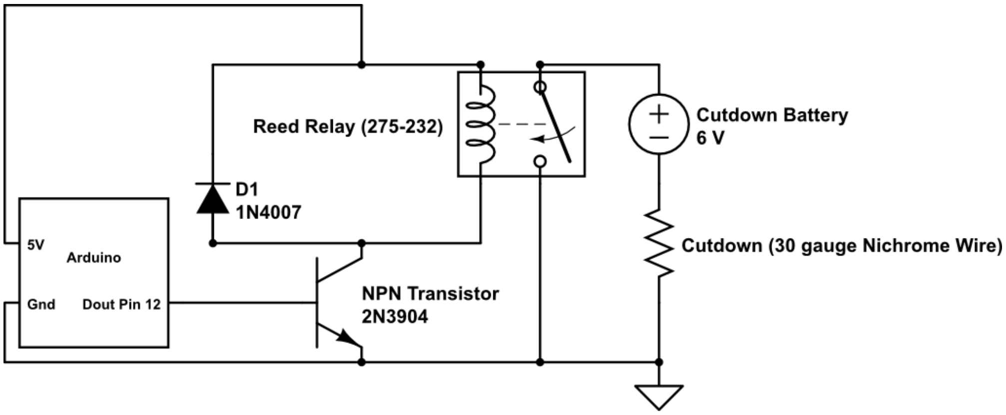


Figure 6: Cut down circuit diagram.

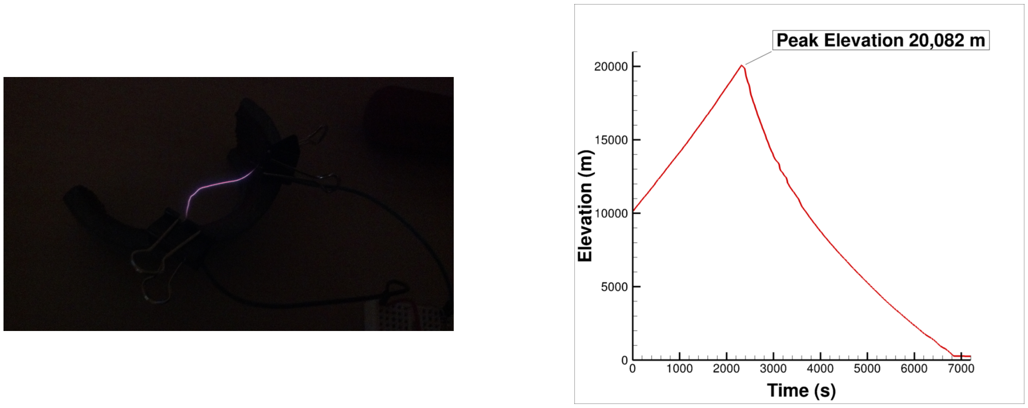


Figure 7: A. Cut down system in operation. B. Test of cut down system during a high altitude launch in Minnesota; cut down was triggered at 20,000 m.

2.4 System Development and Testing

Development and validation of the instrumentation will consist of the following tasks:

- Assemble array and data loggers; record continuous data for 24 hours. This verifies that the instrumentation works as designed over the necessary time period.
- Place sensor packages in a dry ice bath; record continuous data for 24 hours. The dry ice simulates the extreme cold at altitude (approximately -78 degrees Celsius).
- Place sensor packages in vacuum chamber, demonstrate continuous operation for at least 6 hours. The vacuum chamber test ensures that equipment will not overheat due to poor thermal dissipation at altitude.
- Develop and test array deployment with nichrome cut down. We will test the array release system by suspending the interface plate between two buildings and performing a timed cut down. This will ensure that the array uncoils properly while avoiding damage from the rapid deceleration when it reaches its full length.
- Validate altitude based cut down. The cut down system will fly to 5,000 m on a helium or solar balloon, at which point it will release itself from the balloon and parachute back to Earth.

3 Project Management

The team consists of three graduate students, one undergraduate student, and one faculty advisor. In addition, Kyle Jones (Sandia National Laboratories) will assist with integrating data from the ground array and the airborne array. Our team will also consult with Paul Norman (University of Minnesota), the developer of the cut down. Scientific results will be shared with all members of the team. If data are returned from the flight, the team will prepare a manuscript for submission in a peer-reviewed journal.

3.1 Students

- **Team Leader**, *Daniel C. Bowman, doctorate student in geophysics, UNC; daniel.bowman@unc.edu*
  Responsible for project management and communications with HASP personnel
  Coordinate with Sandia National Laboratories concerning data access and collaboration between HASP project and ground acoustic monitoring
  Construct payload box and instrumentation slots
  Design and demonstrate array deployment cut down system

- **Data Logging and Power Supply Engineer**, *Jacob F. Anderson, doctorate student in geophysics, BSU*
  Acquire and test infrasonic microphones
  Design and test Arduino-based data logging system
  Develop power supply interface

- **Systems Integration and Launch Prep Engineer**, *Aaron Curtis, doctorate student in geology, NMT*
  Receive payload system and verify that all components are operational
  Perform final assembly
  Assist with integrating payload with balloon
  Represent team during launch

- **Acoustic Analyst**, *Ashley D. Foguel, undergraduate in geophysics, UNC*
  Investigate acoustic signals recorded by ground microphones near Socorro, New Mexico
  Quantify number of events likely to be recorded during the launch
  Determine type and propagation distance of events recorded on the ground array

We anticipate that Daniel Bowman and Jake Anderson will assist with payload integration, and that Aaron Curtis will represent the team during the launch.

3.2 Advisors

- **Faculty Advisor**, *Jonathan M. Lees, professor of seismology, UNC; jonathan.lees@unc.edu*
  Oversee student team and act as faculty point of contact for HASP
- **Outside Advisor**, *Kyle R. Jones, infrasound geophysicist, SNL*
  Provide acoustic data from ground array and assist with interpretation of signals
- **Outside Advisor**, *Paul Norman, Ph. D. in aerospace engineering, UM*
  Assist with cut down development and testing

3.3 Timeline

January-February - Develop sensor packages, test sensor operation and logging capacity. Construct cut down system. Begin categorizing signals recorded on ground infrasonic array.
March - Construct sensor cabling, test array release systems using timed cut down.
April-May - Integrate sensor packages with cabling and construct payload module.
June - Test sensor packages and cut down in vacuum and low temperatures, modify system as needed.
July - Test altitude-based cut down by launching cut down system on helium or solar balloon.
August - Integrate payload with HASP at the Columbia Scientific Balloon Facility, with launch to follow in September.

4 Payload Specifications

We request a small payload platform for our experiment. Based on experience from past high altitude launches and instrument specifications, we expect a total payload mass of 1.6 kilograms (Table 1). The payload box, padding, and attachment system have the highest mass uncertainty, with a possible deviation of ±100 g depending on materials used. The instrumentation mass is quite precise as it is derived from specification sheets. The cabling is another area of uncertainty, also with a possible deviation of ±100 g. We estimate that the maximum weight of our payload will not exceed 2 kg.

Based on the expected current draw from the Arduino data loggers and the GPS module, we do not expect to use more than 0.212 Amps (Table 2). We will include a separate battery pack of 6 AA batteries in a designated holder to provide enough current for the nichrome wire. This is necessary because the cut down system may blow the HASP fuse if it draws from the main power supply, resulting in no data recovery above 5,000 m. Since the array will record useful data even if the cut down fails, we consider it prudent to isolate the cut down heat knife from the sensor package power. Our payload will not require serial uplink and downlink, analog downlink, or discrete command capabilities.

We will use the full 15 x 15 cm payload footprint in order to provide maximum insulation for the GPS and cut down. The payload box will be 10 cm high. The sensor array will be coiled beneath the payload mounting plate at launch. The horizontal dimensions of the array and sensor packages will be less than 15 x 15 cm, and it will hang down approximately 30 cm beneath the payload mounting plate at launch (Figure 5). However, we can reduce this amount if it interferes with HASP operations. It is imperative that the array can uncoil to its full length of 24 m beneath the payload mounting plate without coming into contact with other objects. Our examinations of previous HASP configurations indicate that this is feasible.

Potential hazards include the inclusion of 6 AA batteries in the payload package, the high temperatures reached by the nichrome wire during cut down, and the rapid unraveling of the array as it deploys. Since the AA batteries will be protected inside the payload box for the duration of the flight, we do not anticipate a high risk of puncture. We consulted with HASP personnel about the nichrome cut down during an informational teleconference, and we understand from that conversation that this type of thermal knife is not considered a pyrotechnic. However, we will carefully test the cut down to ensure that will not damage nearby equipment when it deploys the array. The cable and sensor package system will rapidly unravel immediately after cut down. This operation may jostle the payload and also presents a slight risk of objects falling off the array. We will include a spring as a shock absorber to mitigate the sudden deceleration experienced when the array reaches its full length, and we will test the deployment system to insure that the array is strong enough to withstand the forces of deployment.

Table 1: Payload Mass Budget

Item	Quantity	Item Mass kg	Total Mass kg
Payload box, padding, attachment system	1	0.200	0.200
Arduino Data Loggers	3	0.150	0.450
Microphones and thermal protection	3	0.060	0.180
Cut down GPS	1	0.060	0.060
Cut down Arduno	1	0.028	0.028
Cut down Circuitry	1	0.020	0.020
Cut down Power Supply	6	0.020	0.120
Array Shock Spring	1	0.018	0.018
Array Support Rope (per meter)	24	0.001	0.024
Array Cables (per meter)	72	0.007	0.504
Grand Total			1.604

Table 2: Power Draw from HASP

Item	Quantity	Item Power Draw mA	Total Power Draw mA
Arduino Data Logger	3	50	150
Cut down GPS	1	20	20
Cut down Arduino	1	42	42
Grand Total			212

References

Buckingham, M. J. and Garcés, M. A. (1996). Cononical model of volcano acoustics. *Journal of Geophysical Research*, 101(B4):8129–8151.

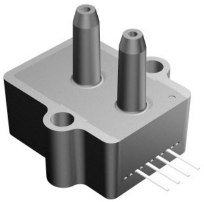
Jones, K. R., Arrowsmith, S. J., Marcillo, O., Johnson, J. B., and Hart, D. M. (2013). A permanent, three-element infrasound array installed in Socorro, NM. unpublished.

Negraru, P. T., Golden, P., and Herrin, E. T. (2010). Infrasound propagation in the “Zone of Silence”. *Seismological Research Letters*, 81(4):615–625.

5 Appendix

Amplified Very Low Pressure Sensors

AMPLIFIED Pressure Sensors



Features

- 0.25 and 0.50 In H2O Pressure Ranges
- Ratiometric 4V Output
- Temperature Compensated
- Calibrated Zero and Span

Applications

- Medical Breathing
- HVAC

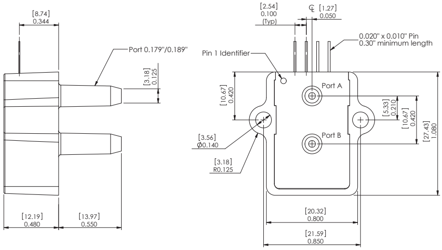
General Description

The Amplified line of low pressure sensor is based upon a proprietary technology to reduce all output offset or common mode errors. This model provides a ratiometric 4-volt output with superior output offset characteristics. Output offset errors due to change in temperature, stability to warm-up, stability to long time period, and position sensitivity are all significantly reduced when compared to conventional compensation methods. In addition the sensor utilizes a silicon, micromachined, stress concentration enhanced structure to provide a very linear output to measured pressure.

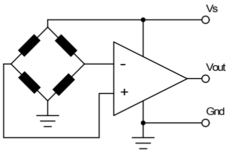
These calibrated and temperature compensated sensors give an accurate and stable output over a wide temperature range. This series is intended for use with non-corrosive, non-ionic working fluids such as air, dry gases and the like.

The output of the device is ratiometric to the supply voltage over a supply voltage range of 4.5 to 5.5 volts.

Physical Dimensions



Equivalent Circuit



pin 1: Vsupply

pin 2: Common

pin 3: Voutput

pin 4: do not connect

Pressure Sensor Ratings

Supply Voltage, Vs	+4.5 to +5.5 Vdc
Common-mode pressure	-10 to +10 psig
Lead Temperature, max (soldering 2-4 sec.)	270°C

Environmental Specifications

Temperature Ranges

Compensated	5 to 50° C
Operating	-25 to 85° C
Storage	-40 to 125° C
Humidity Limits	0 to 95% RH (non condensing)

Standard Pressure Ranges

Device	Operating Range	Proof Pressure	Burst Pressure	Nominal Span (5)
0.25 INCH-D-4V	±0.25 inH2O	40 inH2O	80 inH2O	±2.0 V
0.25 INCH-G-4V	0.25 inH2O	40 inH2O	80 inH2O	4.0 V
0.5 INCH-D-4V	±0.5 inH2O	40 inH2O	80 inH2O	±2.0 V
0.5 INCH-G-4V	0.5 inH2O	40 inH2O	80 inH2O	4.0 V

Performance Characteristics for: 0.25 INCH-D-4V NOTE 1

Parameter, NOTE 1	Minimum	Nominal	Maximum	Units
Output Span NOTE 5	±1.90	±2.0	±2.1	V
Offset Voltage @ zero differential pressure	2.15	2.25	2.35	V
Offset Temperature Shift, NOTE 2	-	-	±60	mV
Offset Warm-up Shift, NOTE 3	-	±20	-	mV
Offset Position Sensitivity (±1g)	-	±20	-	mV
Offset Long Term Drift (one year)	-	±20	-	mV
Linearity, hysteresis error, NOTE 4	-	0.05	0.25	%FSS
Span Temperature Shift, NOTE 2	-	-	±3	%FSS

Performance Characteristics for: 0.25 INCH-G-4V NOTE 1

Parameter, NOTE 1	Minimum	Nominal	Maximum	Units
Output Span NOTE 5	3.9	4.0	4.1	V
Offset Voltage @ zero gage pressure	0.15	0.25	0.35	V
Offset Temperature Shift, NOTE 2	-	-	±60	mV
Offset Warm-up Shift, NOTE 3	-	±20		mV
Offset Position Sensitivity (±1g)	-	±20	-	mV
Offset Long Term Drift (one year)	-	±20	-	mV
Linearity, hysteresis error, NOTE 4	-	0.05	0.25	%FSS
Span Temperature Shift, NOTE 2	-	-	±3	%FSS

Performance Characteristics for: 0.5 INCH-D-4V note 1

Parameter, note 1	Minimum	Nominal	Maximum	Units
Output Span note 5	±1.90	±2.0	±2.1	V
Offset Voltage @ zero differential pressure	2.15	2.25	2.35	V
Offset Temperature Shift, note 2	-	-	±60	mV
Offset Warm-up Shift, note 3	-	±20	-	mV
Offset Position Sensitivity (±1g)	-	±20	-	mV
Offset Long Term Drift (one year)	-	±20	-	mV
Linearity, hysteresis error, note 4	-	0.05	0.25	%FSS
Span Temperature Shift, note 2	-	-	±3	%FSS

Performance Characteristics for: 0.5 INCH-G-4V note 1

Parameter, note 1	Minimum	Nominal	Maximum	Units
Output Span note 5	3.9	4.0	4.1	V
Offset Voltage @ zero gage pressure	0.15	0.25	0.35	V
Offset Temperature Shift, note 2	-	-	±60	mV
Offset Warm-up Shift, note 3	-	±20	-	mV
Offset Position Sensitivity (±1g)	-	±20	-	mV
Offset Long Term Drift (one year)	-	±20	-	mV
Linearity, hysteresis error, note 4	-	0.05	0.25	%FSS
Span Temperature Shift, note 2	-	-	±3	%FSS

Specification Notes

note 1: All parameters are measured at 5.0 volt excitation, for the nominal full scale pressure and room temperature unless otherwise specified. Pressure measurements are with positive pressure applied to Port B.

note 2: Shift is relative to 25°C.

note 3: Shift is within the first hour of excitation applied to the device.

note 4: Measured at one-half full scale rated pressure using best straight line curve fit.

note 5: The span is the algebraic difference between full scale output voltage and the offset voltage.

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