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Chaparral Model 2 Microphone Modification for 12 Volt Operation

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Western US Experiment
Instrumentation Note

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Introduction

As originally purchased, the Chaparral Model 2 microphones are configured for 24-volt operation. The Chaparrals were purchased with the belief that they could be powered across the RefTek ±12-volt sensor power, since this would generate 24 volts (Figure 1). Although this will power the sensors, it results in a signal that is difficult to interface to the RefTek recorders. The Chaparral output is single-ended, referenced to the low side of the power supply. Thus for a 3 volt output signal, the signal input connectors at the RefTek see a minus 12 volt common mode signal (a signal common to both +signal and –signal connectors). Since the RefTek handles at most a ±5 volt common mode signal, the preamplifier would saturate, producing no usable signal.

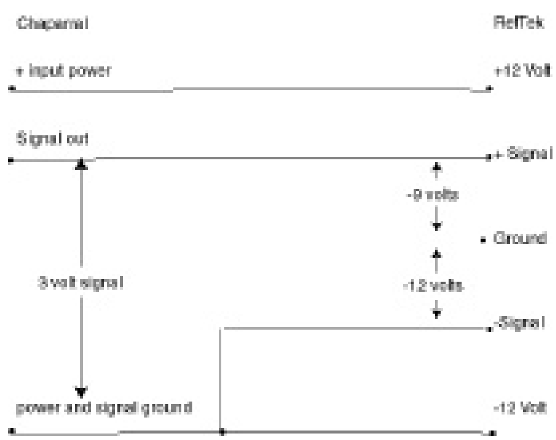

Figure 1. Originally proposed Chaparral to RefTek wiring diagram showing a 3 volts signal output of the Chaparral.

With the configuration at hand, we elected to operate the Chaparrals on separate 24-volt power supplies such that the Chaparral power ground could be connected to the RefTek ground.

In the McKinney noise test and the Lajitas temporary deployment sensors are powered from separate 24-volt battery systems. The batteries are operated as primary supplies; when they are exhausted the experiment ends. In the case of Lajitas, we estimate that batteries should last several months. Such systems also complicate deployment. The extra Chaparral batteries are a substantial part of the total system weight. After the deployment of the temporary system at Lajitas with 12 additional automotive lead-acid batteries, it became apparent that it would be important to modify the Chaparrals such that future work could be done with 12-volt power, preferably from the same battery as is used to power the RefTek’s.

Other Chaparral users when faced with this problem have typically used prepackaged 12 to 24 volt DC-to-DC converters. Besides boosting the supply voltage, these converters also isolate the sensor ground from that of the RefTek, a useful characteristic when 100-meter signal cables are used in difficult areas (e.g.

under power lines). The disadvantage is that many prepackaged converters raise the sensor power requirements substantially (a factor of 10 to 20). An alternative method, used for some of the experimental Validyne power supplies, is to boost the voltage using a switched capacitor voltage doubler. These tend to be more efficient devices, but are not typically prepackaged and may require the user to connect three or four individual components. Their use does result in a common sensor and RefTek signal and power ground and requires more attention to signal lead shielding.

During laboratory testing we experimented with operating the Chaparrals directly from a 12-volt power supply. Although this changed the sensitivity, the microphones appeared to operate reliably. A 12-volt configuration was tried during the Harris-Methodist deployment. In this case the Chaparrals were wired to the RefTek power supply using the same cables as are normally used with the Validyne sensors. In this configuration, the sensor output was contaminated with noise associated with RefTek operation, assumed to be due to disk drive and GPS power cycling. Except for large signals, the output was useless.

An examination of the Model 2 schematic indicates that the Chaparral internal power supply is regulated at approximately 20 volts by a simple series pass regulator made up of the reference formed by D17 and amplifiers Q12 and Q13. When the input voltage drops below 21 volts, and voltage fluctuations in the input power supply appear as noise in the output probably coupled through the low cut filters.

Since the Chaparral uses a charge pump to measure the capacitance associated with the diaphragm position, reducing the charge voltage also reduces the pressure sensitivity of the instrument. All other things being equal, the pressure sensitivity is roughly proportional to the regulated supply voltage minus a few diode drops (0.7 volts per diode).

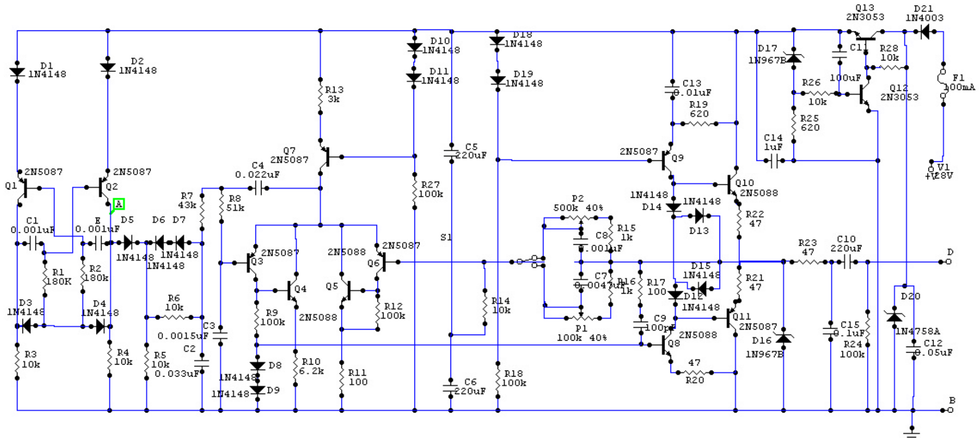

Figure 2. Schematic circuit diagram for Chaparral Model 2.

Modification

By changing D17, listed as a 1N967B, to a 9.1 volt Zener, a 1N5239B, the regulator voltage is dropped to 9 volts, a level below the lowest measured excursions of the 12-volt RefTek supply furnished on the input connector pins. These power supply droops are associated with the large inrush current demanded by disk drive spin-up and the associated loss in the wiring, cables, and connectors.

Reducing the internal power supply to 9.1 volts also reduces the pressure sensitivity and the maximum output signal. An unmodified sensor has a specified output signal of ±9 Volts. With a pressure sensitivity of 200 mV/µbar on the high gain setting and 40 mV/µbar on the low gain setting, this output level is equivalent to a clip level of ± 45 µbar and ± 225 µbar respectively. Since the RefTek has a specified signal range of ±10 Volts, this default power setting gives the maximum signal dynamic range. With such a configuration, the RefTek LSB of 1.9 µVolts is equivalent to 9.5 x 10^{-6} µbar at high gain and 47 x 10^{-6} µbar at low gain. Since at high gain this LSB is ridiculously below the lowest expected infrasound noise, raising the LSB should have no effect on conclusions generated from field data.

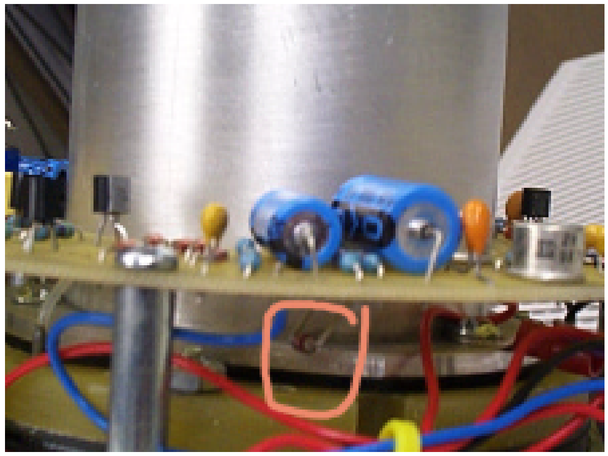

Figure 3. Additional diode is circled. The circuit board is removed and the diode tack soldered in parallel with diode D17 hidden between the two electrolytic capicaters.

The instrument was modified with the following procedure (Figure 1):

1. Remove the three screws securing the case and remove the outside cap.

2. Remove the three screws retaining the circuit board and locate D17 (between C11 and C12).

3. Turn the circuit board over and parallel the existing D17 with a 1N5239B zener diode on the backside of the circuit board. The cathode (black band) should point toward the center hole.

4. Remount the board with the three retaining screws. Check the 1N5239 anode to make sure that it does not touch the backing volume.

5. Power the sensor from a 12-volt supply and measure the internal power supply voltage at the D17 cathode (or at the positive pin of C11). This should be reasonably close to 9 volts.

6. With a pencil, note the power supply voltage on the outside of the cap.

7. Using a spectrum analyzer, determine the transfer function between the modified sensor at high gain and an unmodified calibrated sensor at low gain using ambient room noise. The two sensors should be positioned close together and their input ports pointed the same direction. The two sensors should be run from separate power supplies. Be sure that the gain switch is on high. Set the high gain adjustment P2 at the midpoint of its ranger (10 turns). Adjust R15 and P2 such that the transfer function between the calibration reference and test sensor is 0 dB ±0.25 dB. Replace R15 if necessary such that P2 has sufficient adjustment to allow recalibration (do not leave P2 on the stops).

8. Reassemble the instrument and repeat the calibration test.

Instrument tests

Three instruments were modified for testing. Two were modified with the 9.1-volt 1N5239B diodes and one was modified with a 5.1-volt 1N4733A Zener diode. The following tests were done:

- A modified 5.1-volt sensor and unmodified sensor were run overnight with the input ports plugged. The system was setup to write to disk every 120 seconds.
- An unmodified sensor was run with voltages from 20 to 4 volts and compared against the 5.1-volt sensor.
- An unmodified sensor run from a bench power supply was compared against a sensor modified for 5.1-volt operation driven from the RefTek power available on the sensor connectors.
- Two modified 9.1-volt sensors were driven from the RefTek internal power supply and compared with an unmodified 24-volt sensor operated from batteries.

The purpose of the tests was to compare the instrument characteristics before and after modification to determine if the modifications introduced any unexpected problems.

Sensor vs. RefTek power supply noise

The RefTek disk drive has an inrush current of several amps during initial spin-up. Small resistive losses in the power cables result in power supply drops of several volts. Most of this drop occurs in the power cable between the battery and the RefTek recorder. If the sensor is connected directly to the battery rather than to the recorder (ground referenced to the battery minus), the RefTek recorder then sees this voltage drop as a common mode signal. Although the common mode rejection is good (> 60 dB) such large voltage swings are still observable on the recorded data. If the sensor is connected through the RefTek sensor power connector (ground referenced to the RefTek recorder rather than battery minus) these voltage swings will not be presented to the RefTek. However, the sensor will then see an input voltage swing when the disk is turned on.

For this test, the sensor was connected directly to the battery supplying the RefTek (ground referenced to battery minus) for the 5.1-volt sensor. The unmodified sensor was powered from a bench supply. Both sensors had their input pressure ports capped to reduce the pressure noise.[1]

The spike in figure 4 below 0.01 Hz clearly shows the noise resulting from disk drive activity. Although the spike is below the principle band of interest, 0.1 to 20 Hz, it may still be visible in the time series as a filtered step offset. Later tests were all powered through the input connector power supply and hence do not show the disk drive activity spike.

[1] Capping the sensors only reduces the background noise. Pressure signals continue to be coupled through the compliancy in the backing volume container and compliant seals connecting the backing volume to the housing. It is likely that in some units the seals around some of the wires have broken down as well and contribute to the leaky response.

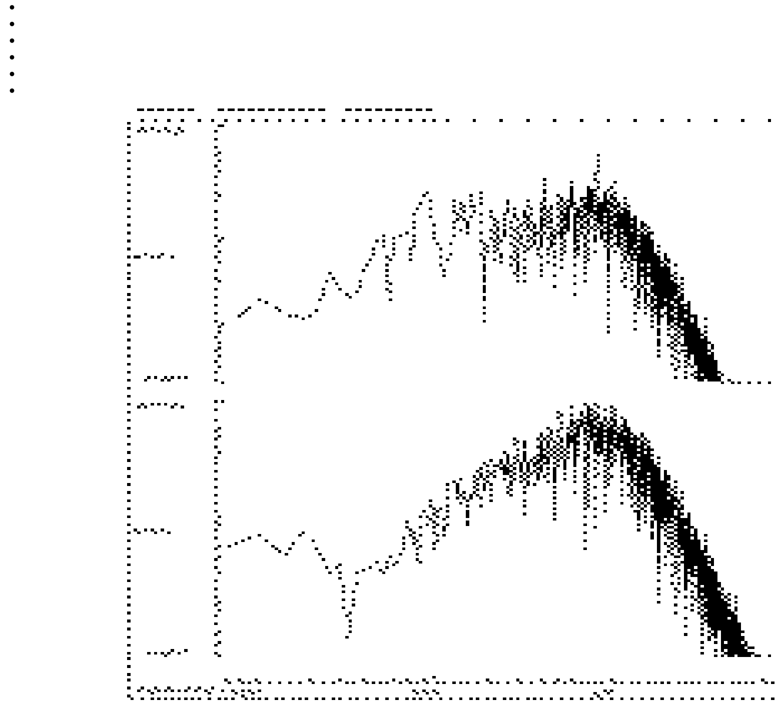

Figure 4. Spectra from the battery referenced ground test.

Power supply voltage vs. gain test

To make the power supply vs. gain test, a modified 5.1 volt sensor was used as a reference. An unmodified sensor was connected to a lab power supply and the operating voltage varied in 4-volt steps. The voltage was measured at the input of the Chaparral internal power supply regulator, at the collector of Q13. At each voltage, slamming the door to the room a few times created a few large signals. The gain was calculated by comparing the signal recorded by the reference sensor to that recorded by the variable sensor in the 2-4 Hz signal band. At higher frequencies the coherence begins to break down as a result of the spacing between the sensors and room resonance. At lower frequencies thermal effects begin to interfere with the signals. The variable sensor backing volume container was exposed to room air and hence sensitive to stray thermal signals (such as a hand moving near the voltmeter probe).

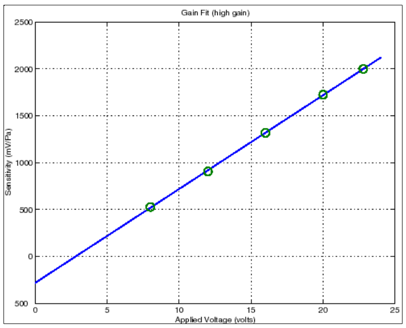

Figure 5. Chaparral gain as a function of internal supply voltage.

The results of the test are shown in Figure 5 that plots sensitivity in Volts/Pa against internal supply voltage. From the graph, it is apparent that pressure sensitivity is a linear function of the supply voltage. A linear equation was fit to the lower four voltages[2]:

100 * (Power Supply Voltage) – 280 = sensitivity in mV/Pa

[2] The upper, nominal voltage was not used since at 24 volts the internal power supply regulator was active while at lower operating voltages is was in saturation.

Comparison of a 5.1-Volt sensor against an unmodified sensor

To compare the dynamic response of the modified and unmodified sensors, the response of a 5.1 volt sensor was compared to that of an unmodified sensor to a large signal created by slamming a door (Figure 6). The sensors record nearly identical signals. The difference magnified by a factor of 10 is also plotted. The long period difference is assumed to be due to differences in temperature between the two sensors. The differences in the high frequency portions of the signals are assumed to be due to room resonance and the difference in separation between the two sensors.

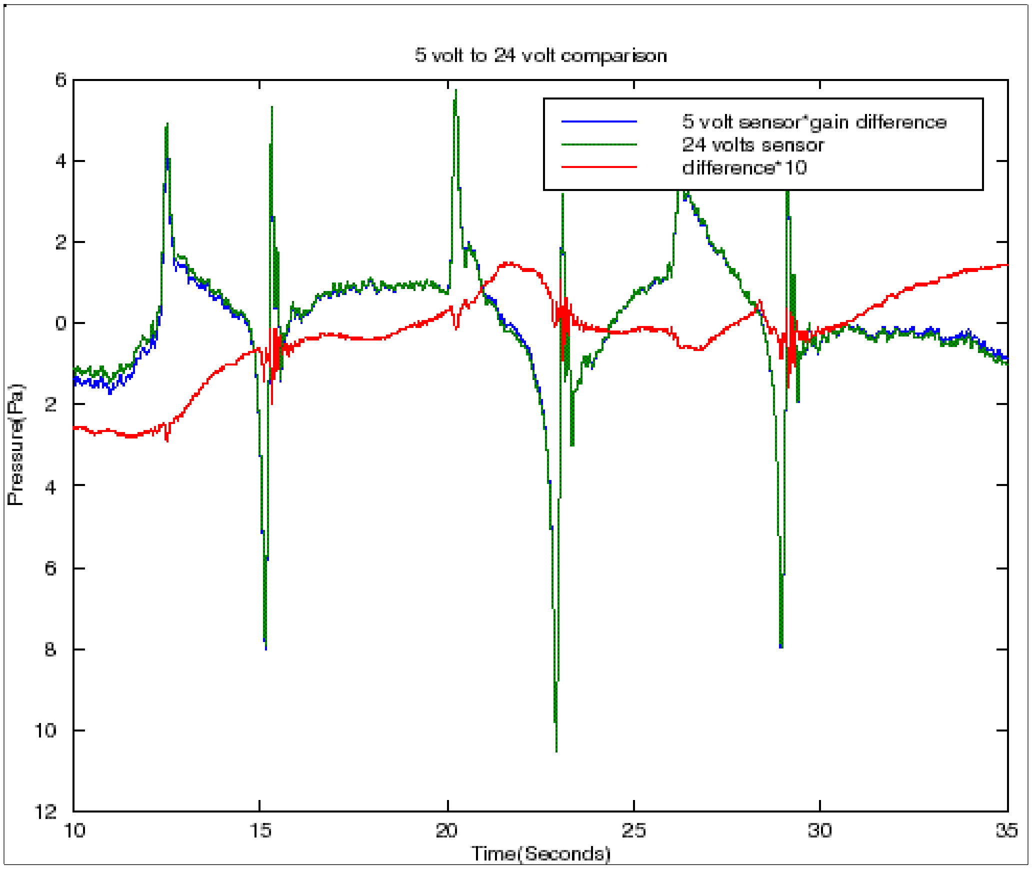

Figure 6. Comparison of signals recorded by a modified and unmodified sensor.

Comparison of 9.1-volt sensors and an unmodified sensor

Two Chaparral sensors were modified with 9.1 volt Zeners. The resulting internal power supply voltages were 9.39 and 9.51 volts.[3] These two sensors were powered from the RefTek sensor power connectors. A third unmodified sensor was powered from a set of 24-volt batteries to minimize any noise that might be introduced from the lab power supply. The sensors were run overnight and a long term spectral analysis (Figure 7) made to determine if disk drive noise was present and the sensor sensitivity.

Except below 0.1 Hz, the three spectra are nearly identical, even above 7 Hz. Below 0.1 Hz, one of the 9.1-volt sensors was less sensitive to the low frequencies. This difference in low frequency response has been previously noted in LANL reports and is assumed to be due to small leaks in the backing volume.

[3] This illustrates the variation in both the Zener diodes used and the internal Chaparral components.

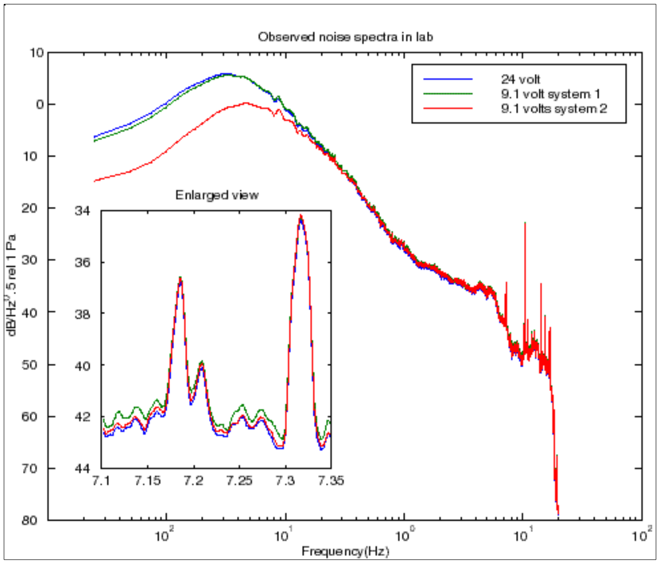

Figure 7. Long term spectra.

Vibration sensitivity

One 9.1-volt sensor was used to estimate the vibration sensitivity of the microphones. The effective mass of the diaphragm gives all microphones some degree of vibration sensitivity. Several attempts were made to find a configuration that could be used to estimate vibration sensitivity. The first setup compared the output of two sensors on a flexible table. One sensor was inverted and the other operated in normal position. Both sensors were capped. Under these conditions one would expect any residual pressure signal to have the same polarity and any signal due to vibration to have opposite polarity. Unfortunately, we found it impossible to isolate the two sensors from pressure changes. In fact one of the capped sensors had only 6 dB attenuation from an uncapped reference sensor. The second attempt was record the signal as a capped sensor was inverted. The resulting signal was clipped, indicating sensitivity too high to be realistic. Upon investigation, it was determined that compliance in the right angle hose fitting was producing the signal. The final measurements were estimated by inverting an uncapped sensor. Since the movement also creates a pressure signal, this leads to a noisy estimate (Figure 8). It is, however, a reasonable value given the expected mass density of the diaphragm.

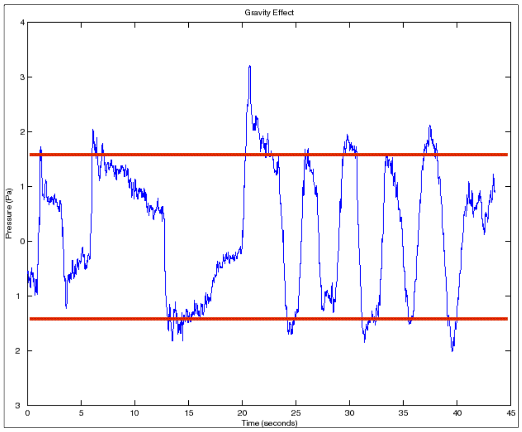

Figure 8. Signal created by inverting the sensor.

Inverting the sensor generates a signal of roughly 3 Pa, leading to an acceleration sensitivity of 1.5 Pa/g.

Discussion

The modification show in Figure 3 requires no component removal. Simply simply clipping out the additional diode will restore the Chaparral to its original configuration. Based on the anticipated nominal supply voltage available at the sensor input, a 9.1-volt Zener is the largest value that can be reliably used. Using a vanilla Zener such as the 1N5239 does lead to a problem in calibration since the Zener voltage is only specified within a ±5% tolerance (910 milliVolts). Using the sensitivity curve from Figure 5, a 910mV change in the internal reference would be equivalent to a sensitivity tolerance of roughly 100 mV/Pa. However, since the existing 1N967B is also a ±5% part, the total change could be as much as ±10%. Although precision references are available, one is still faced with the original part tolerances and compensating calibration. The inescapable conclusion seems to be that some form of calibration is needed.

Since Zener diodes are only $10.00 per 100, a reasonable alternative to adjusting the internal calibration might be to select Zeners to match a reference sensor. In this scheme, sensors could be adjusted based on their response to a reference signal, such as a swept sine wave, in the 2-5 Hz band. Diodes could be swapped in with an alligator clip adapter until the proper value is found. This way internal sensor calibration setting would be left as-is allowing the sensors to be reconverted back to their original settings.

From the ground reference test (Figure 4) one concludes that the ground reference point should be the RefTek recorder, not the battery negative terminal for Chaparral sensors. The internal power supply regulation and power supply noise rejection in the sensors is apparently greater than the common mode rejection in the RefTek preamplifiers. Although the broadband seismometers used in the experiment are not signal ended, one can speculate that for low noise conditions, they also should be supplied from the input connectors rather than directly from the battery as is done now.

The power supply vs. noise curves shown in Figure 5 are confirmed at one point for a 5.1 volts used in making the comparison of Figure 6. Some sensors may not be well matched at 10-second periods and beyond. At frequencies higher than a few Hz, room, table, and wall resonance becomes a problem. This is shown by a phase difference between sensors for some high frequency signals in Figure 6.

The sensitivity calculation was made for input voltages. To convert them to Zener reference voltages, it is necessary to subtract 1.3 volts, the drop across diode D21 and saturate drop across Q13.

The characteristics of the unmodified Chaparral, the 5.1-volt modification, the 9.1 volt modification, the Validyne DP250 sensors, and the Validyne DP350 sensors are given in Table 1. Other than the unmodified Chaparral, all sensors will operate from the RefTek sensor power supply even with voltages sags caused by disk activity. The pressure sensitivity at high gain is 760 mV/Pa, twice that of the unmodified sensor at low gain. The unmodified low gain sensitivity (400 mV/Pa) has already been shown to be adequate for IMS applications below 4 Hz (Kromer and McDonald, undated SNL paper). It is interesting to note that the Validyne DP350 sensitivity of 227 mV/Pa falls between the low gain sensitivities of the unmodified and modified Chaparrals. Although the sensitivity of the Chaparral has been reduced, there is only a small change in the maximum signal, the clipping point. At low gain, the maximum pressures for the modified Chaparral is 28 Pa, a small increase from the 21.8 Pa for the unmodified version, yet substantially under the 140 Pa of the DP250 or 850 Pa of the P55D used for near source recording.

Table 1. Sensor Characteristics for Chaparral and Commonly used Validyne Sensors

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The vibration sensitivity of 1.5 Pa/g is unchanged before and after modification, less than half of that of the Validyne sensors. In the case of the Validyne, this vibration sensitivity is a fundamental sensor characteristic related to the mass density of the diaphragm. The source of the acceleration sensitivity has not been investigated in the Chaparral. Undoubtedly there is an acceleration effect on the diaphragm, but there is also an effect on compliant seals used to connect the backing volume to the microphone capsule. In any case, even 4 Pa/g is far below the seismo-acoustic coupling effect and therefore should not be a problem as long as the sensors are well coupled to the earth. The low vibration sensitivity of both the Chaparral and Validyne sensors may be compared to the 980 Pa/g for the MB-2000[4] (see Figure 9).

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Figure 9. Calculated Vibration Noise Curves. The vibration induced acoustic noise (dashed line) is seismo-acoustic response coupled at the receiver. For the MB2000, the vibration noise exceeds the acoustic noise above about 0.5 Hz. Vibration noise plotted here is for the New High Noise Model (NHNM), that seismic noise expected on island installations.

In comparing sensors, the estimated equivalent pressure noise defines the smallest signal that may be resolved by the sensors. For the Chaparral sensors, the high gain and low gain pressure equivalent noise is about the same. This strongly suggests that the noise source is prior to the gain stage of the amplifier, probably in the front-end modulator/charge pump. For all Chaparral sensors, the equivalent noise is about 20 dB lower than Validyne DP250 used in the mine and at CHNAR. The Validyne DP350 comes within 3 dB of matching the noise characteristics.[5] These noise measurements are based on a single Chaparral instrument and are in reasonable agreement with prior estimates made at SNL.[6]

The sensor dynamic range is found by subtracting the RMS amplitude of the maximum unclipped signal at 1Hz to the pressure equivalent noise. Note that for the sensors considered, the 9.1-volt modified Chaparral has the highest dynamic range,[7] nearly 120 dB, of any of the sensors considered.

Table 2. WGB CTBT Specifications for Infrasound Sensors

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Another figure of merit sometimes used is the signal resolution, defined as the minimum broadband signal that can be resolved above the sensor noise. This is a bandwidth dependent measure. Signals of a particular power are more difficult to detect if the power is spread over a wider bandwidth. All sensors could resolve signals of 0.1 μbar (0.01 Pa), including the low gain P55D first used by SMU at Lajitas on the relatively narrow band IMS requirements (0.02 to 4 Hz). Except for the P55D, all sensors could also resolve this level for the wider 100 Hz band used for the experimental infrasound recordings.

Comparing Table 1, the sensor characteristics with Table 2, the PrepCom Working Group B (WGB) specifications for infrasound sensors yields Table 3, an evaluation of the sensor suitability relative to WGP requirements. Although these sensors are not required to meet IMS specifications, since they are used in a research program, the evaluation provides an idea of whether signal detection limits and arguments made with the research instruments would be applicable to IMS infrasound stations.[8] All of the Chaparral sensors meet all the WGB requirements except for the 0.02 Hz low frequency point. However, the Chaparral nominal response curve shows a –3 dB point at 0.02 Hz. While it technically may not meet the

[4] Rudolf Widmer-Schnidrig calculated the MB2000 sensitivity (personal communication, 2000) as 1 mbar/(m/s/s) based on the response of a closed sensor to a moderately large earthquake.

[5] The experimental DP250 matches the noise floor of the Chaparral at 1 Hz without sacrificing the 140 Pa peak pressure. It does so at the expense of a 2-watt power dissipation and more involved electronics and has not been field-tested.

[6] Tests at LANL encountered 30 dB variation in the noise levels of Chaparral sensors. These measurements of –80 dB falls on the mean of the four sensors tested at by SNL. SMU has seen variations of 10 dB in the noise levels of Validyne sensors. In the case of the Validyne sensor the variations are related to the physical construction of the microphone capsule. This has not been investigated at SMU for Chaparral sensors.

[7] Dynamic range in this study is not defined precisely as that in the earlier SNL study. The SNL compares the RMS of a maximum signal to the RMS across the operating band of all the noise. This table reports the ratio of the level of the signal to the level of the noise at one frequency point.

[8] We recognize that the site infrasound noise and infrasound noise reducer pipe array will probably dominate the recorded noise and signal detection limits, particularly in a research setting where infrasound pipe array installation effort has to be limited. It is desirable, though, that the instruments not impose a limit.

WGB requirements for flat response across the 0.02-4 Hz band, it is still highly usable at 0.02 Hz. Validyne DP250 sensors have an extended low frequency corner, but the sensor noise floor is about 9 dB above the WGB requirement. Neither of these is likely to be an issue for our research use. The noise arrays are ineffective at 0.02 Hz so acoustic noise level is high enough that we will only see the largest signals. In fact the DP250 sensors currently operating in the mines have a reduced low frequency response to avoid problems with wind and temperature noise.

Finally, the sensors may be evaluated connected to a RefTek DAS72A/08 running with a preamp gain of 0 dB (Table 4). At all sensor gains, the RefTek LSB is small enough that it will not limit the sensor performance below 250 Hz. Above 250 Hz, the RefTek analog filters (-36 dB/octave at 250 Hz) must be considered. In addition, Chaparral sensors include a 100 Hz low pass filter and Validyne sensors include a 250 Hz low-pass filter. Although strong high frequency signals may still be recorded, instrument corrections would have to be made for any sophisticated use. It is likely that the high cut filters are sufficiently variable that phase corrections might be different for each instrument. Therefore, it is suggested that if high frequency signals are detected, a broad band calibrated microphone be used to supplement the infrasound measurements.

Table 3. Evaluation against WGB Requirements.

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Table 4. Characteristics of Sensors on RefTek 72A/08 Recorders

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Conclusions

The experimental power supply modification should be made on all Chaparral sensors intended for use in the Western US portable deployments. Since it is necessary to open the sensors, remove the circuit board and add a component, there is a small risk of damaging a backing volume seal. Such modified sensors should therefore be checked for calibration and noise.