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4aNS10. On the use of prepolarized microphone systems in rocket noise measurements

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The acoustic field near large-scale solid rocket motors represents a harsh, high-amplitude noise environment rich with high-bandwidth acoustic shocks. Type-1 prepolarized microphones may be used in these environments with the benefit of reduced cost and measurement because they require only a constant-current supply available in many data acquisition systems. However, there are two potential issues related to microphone response that should be considered. The first is a well-known RC-lowpass filter effect that is associated with using insufficient current to drive long cables with relatively high capacitance. The second has to do with temporary failure of the constant-current supply due to an insufficiently fast response time in representing rapid voltage changes at shocks, which results in spurious, capacitive-like effects in the waveform data that are also manifest as a low-frequency roll-up in the spectrum noise floor. An experiment was conducted to identify under what circumstances these waveform effects arise. Data were measured from a solid rocket motor using several combinations of transducer, cable type, cable length and constant current supply. Results and mitigation methods found from the experiment are discussed. These include increasing the supply current, using low-impedance cables, and selecting microphones with low sensitivities.

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Introduction

Development of next-generation launch vehicles have sparked renewed interest in source characterization and near-field propagation models of rocket noise. Brigham Young University has been involved in the development of an energy-based acoustic probe suitable for these rocket noise fields[1]. One challenge is that near-plume rocket noise measurements represent a harsh environment for microphones. High peak amplitude and large-bandwidth measurements must be made in the presence of heat, entrained-flow-driven debris, and vibration.

The noise from large rocket motors has a shaped broadband spectrum, with significant frequency content from below 10 Hz to above 20 kHz that need to be recorded accurately. Figure 1 shows an example of rocket noise data containing this large bandwidth. Note that peak pressure levels within near-field waveforms can exceed 180 dB re 20 μPa with RMS values 15-20 dB lower.

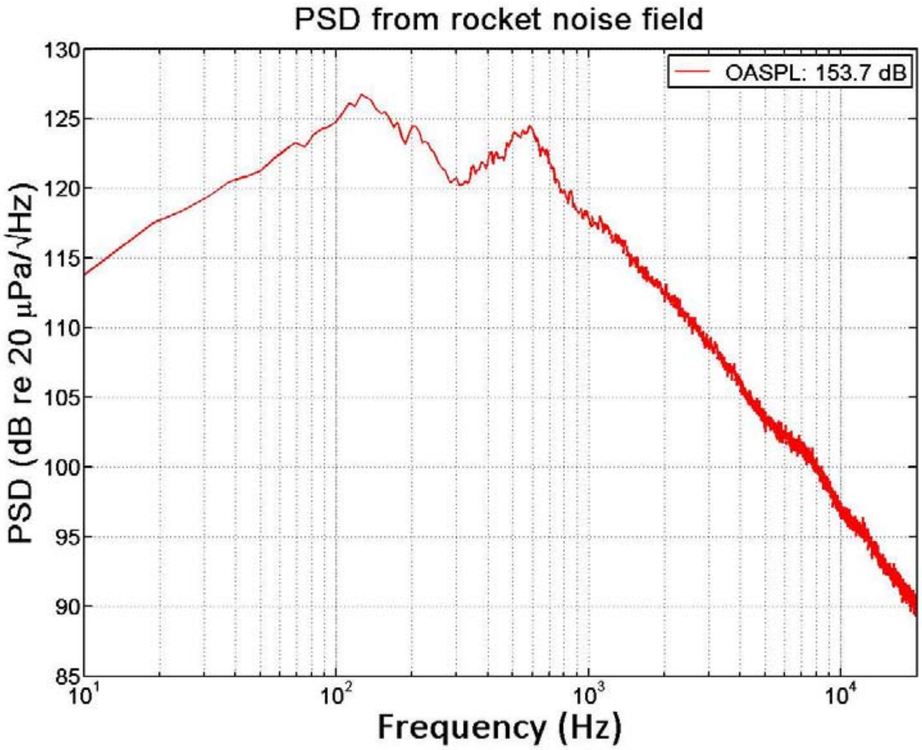

Figure 1 The PSD of data taken from a rocket noise field test where a large bandwidth must be represented.

Traditionally, externally-polarized condenser microphones have been used in rocket noise field tests. As the name implies, they require an external power source to provide a 200 V polarization to the microphone, which is usually located near the microphone and is subjected to substantial vibration. The sensitive electronic components and additional connections represent additional possible points of failure in the data collection chain.

Newer prepolarized condenser microphones may be used in place of externally-polarized condenser microphones. There are advantages with their use. First, instead of external polarization, they require a constant current power source, which most modern data acquisition systems can conveniently provide. This basically makes a prepolarized microphone system a simple plug-and-play system with less equipment, cabling, and potential failure points. Additionally, these systems cost less than the traditional externally-polarized microphone systems.

However, there are challenges with using prepolarized microphones relative to their externally-polarized counterparts. With such a large bandwidth and peak level requirements, three potential problems can arise that prevent an accurate measurement in constant current systems. The first of these is that these microphones have a relatively low maximum voltage that they can accurately record. The next problem is a low-pass filter effect caused by driving long coaxial cables. The final problem is providing sufficient instantaneous power to the microphone system in order to accurately record large changes in voltage over small changes in time, i.e. acoustic shocks. These challenges are discussed in turn.

Maximum Voltage Limitations

The first challenge that prepolarized microphones have is an 8-12 V peak limitation. To avoid clipping when measuring rocket noise, microphones with very low sensitivities must be selected. Table 1 shows how much voltage would be needed to accurately record 10400 Pa, a characteristic peak pressure level that we see in a rocket noise field near the motor, for three different sized microphones with typical sensitivities. The 3.18 mm microphone approaches the 10-12 V limitation at this particular pressure. The 6.35 mm microphone and the 12.7 mm microphone exceed the voltage limitation and peak clipping would occur. The voltage requirement for the 12.7 mm (free-field) microphone exceeds the limitation by so much it would not be feasible to use a 12.7 mm microphone to record rocket noise.

Peak Pressure (Pa)	Microphone Size (mm)	Standard Prepolarized Microphone Sensitivity (mV/Pa)	Voltage Required (V)
10400	3.18	0.7	7.28
	6.35	1.6	16.6
	12.7	50	520

Table 1. Voltages required for three different sized microphones, with their standard sensitivities, to display a typical peak pressure in a rocket noise field without clipping.

To avoid this problem, we typically use prepolarized microphones custom made with lower sensitivities fabricated by GRAS Sound and Vibration. Table 2 shows the voltage requirements for a 3.18 mm and a 6.35mm microphone that were made with lower sensitivities. The voltage requirements for these microphones are well below the 10-12 V limitation.

Peak Pressure (Pa)	Microphone Size (mm)	Custom Prepolarized Microphone Sensitivity (mV/Pa)	Voltage Required (V)
10400	3.18	0.33	3.43
	6.35	0.51	5.30

Table 2. Voltage required for custom made pressure microphones with lower sensitivities for the same peak pressure as in Table 1.

Low-pass Filtering

The second challenge encountered when using a prepolarized microphone system driven by a data acquisition system is they have high-frequency limitations simply due to cable length. This is of particular concern in measurements where the recorder needs to be located a long distance from the microphones. The cutoff frequency of the low pass filter, f_{max}, may be calculated as

$$f_{max} = \frac{10^9(I-1)}{2\pi CV} \text{ [2]} \tag{1}$$

where C is total cable capacitance in picofarads, I is current in milliamps, and V is the maximum peak output from the microphone in volts. $(I-1)$ is used in Eq. (1) because 1 mA current is assumed to be used to power the transducer electronics. A more accurate expression can be found if the actual transducer power consumption is used. A few examples show how this affects rocket noise measurement. Because of its lower capacitance per foot, RG-59 cable (68 pF/m) is used in place of RG-58 cable (100 pF/m). The drive current used is 10 mA, the higher current setting on the National Instruments 446x series PXI cards that we typically use for data acquisition. First, if a typical 12.7 mm microphone with a 50 mV/Pa sensitivity is used with a 10 mA drive current and RG-59 cable, then the frequency response would be limited to 1.3 kHz at a 10 kPa pressure amplitude on a 30.5 m cable. If the cable were 305 m, the frequency response would be limited to 132 Hz. This extreme example further precludes the use of 12.7 mm microphones for measuring rocket noise fields.

Next, if a custom built 6.35 mm microphone with a 0.5 mV/Pa sensitivity was used with a RG-59 coaxial cable and 10 mA drive current, then the frequency response would be limited to 132 kHz at a 10 kPa peak amplitude on a 30.5 m cable. With the 305 m cable, the frequency response would be limited to 13.2 kHz. Note that f_{max} = 132 kHz exceeds the microphone frequency response, so short cable runs with the low sensitivity microphones powered by high current are not an issue.

Finally, the best case scenario occurs when a custom built 3.18 mm microphone with a 0.3 mV/Pa sensitivity is used. The maximum frequency would be 220 kHz for a10 kPa pressure amplitude on a 30.5 m cable. With the 305 m cable, the frequency response would be limited to 22 kHz. Figure 2 shows other maximum response frequencies at several different capacitances.

One solution to the bandwidth problem is to keep total capacitance low, but this is not always possible when dealing with rocket noise measurements because long cable runs are a necessity. However, cable length should be kept to a minimum. The solution currently is to have a high drive current with low-sensitivity microphones to minimize the $V/(I-1)$ ratio in Figure 2.

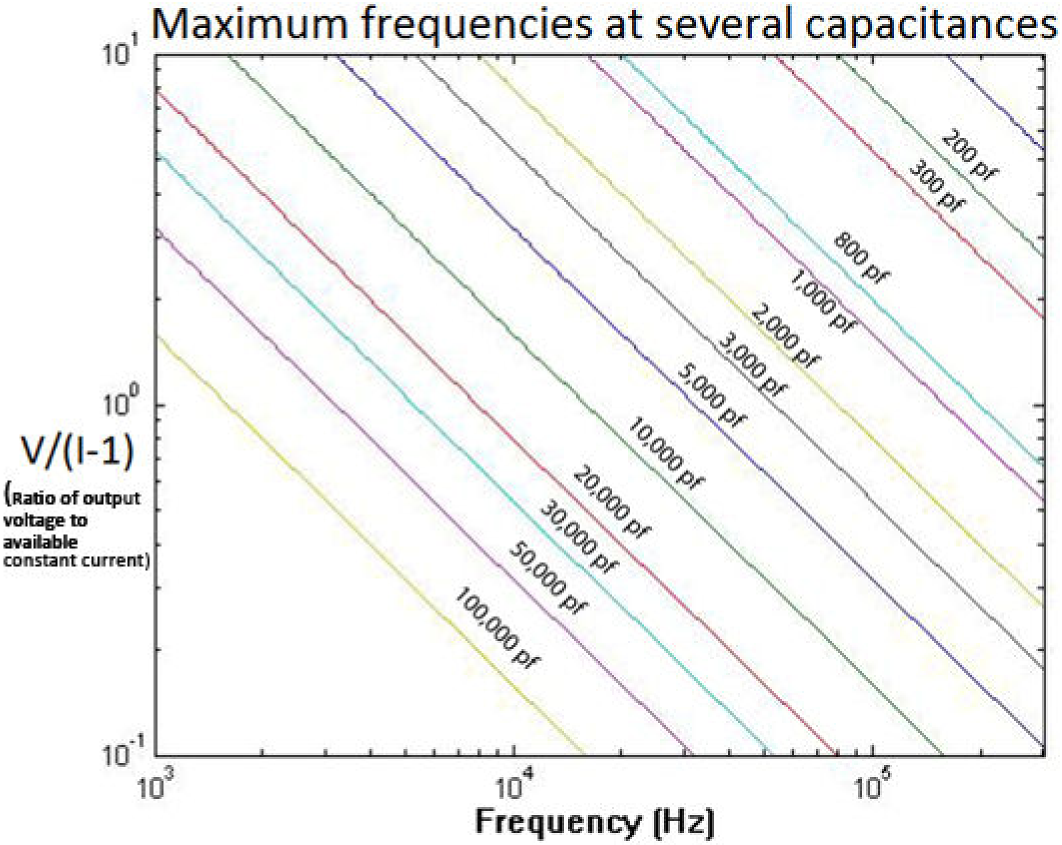

Figure 2 shows the maximum frequencies at several capacitances vs. the ratio of output voltage to available constant current. High output voltage, high capacitance, and low current will all limit the frequency response.

Providing Power at Shocks

The third challenge is that prepolarized microphone systems sometimes do not have enough instantaneous current to accurately reproduce a large change of voltage over a very small change in time, i.e. an acoustic shock. Equation 2 expresses the relationship between current available, system capacitance, and the maximum voltage change per unit time.

$$\left(\frac{dV}{dt}\right)_{MAX} = \frac{I}{C} \tag{2}$$

where I is the current in amps, C is the capacitance in farads and V is the voltage value of the shock. The smaller the available current or the greater the capacitance, the smaller the voltage change that can be faithfully reproduced. In addition, the latency ("slew rate") of the constant current supply comes into question in its ability to provide sufficient current instantaneously. Figure 3 shows a shock where there was enough instantaneous current provided to represent the shock accurately. When the instantaneous current is insufficient to represent the shock, the microphone system saturates and a capacitive-like discharge can be seen in the data. Figure 4 shows what this looks like. The blue curve behaves like it would be expected to. However, the green curve does not reach the same peak level that the blue curve does at the shock. It follows the same waveform, but the pressures recorded are initially well below those of the blue curve. Over time the data of the green curve "rolls" back up to match up with the data on the blue curve. When the blue curve in Figure 4 is subtracted from the green curve, the resulting curve is similar to a capacitor recharging, as seen in Figure 5. When another shock of sufficient strength occurs, the process is repeated. When this problem was first encountered, the cause was not apparent, and was the motivation for the subsequently described experiment.

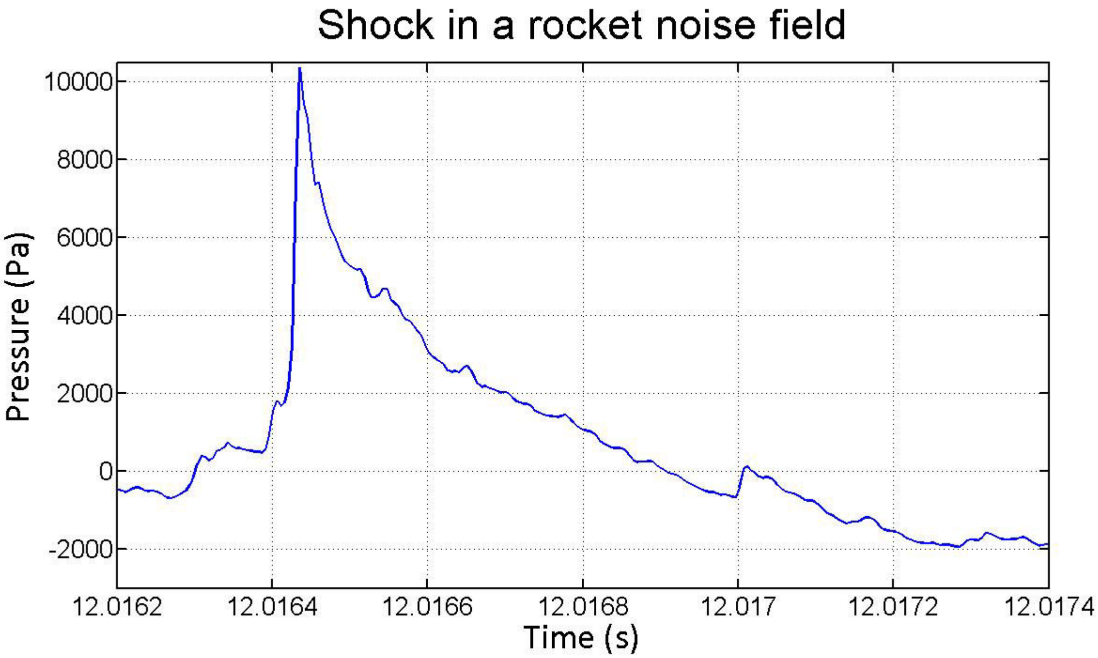

Figure 3. Shock with a peak pressure of just over 10 kPA. The microphone system was provided with 10 mA of constant current.

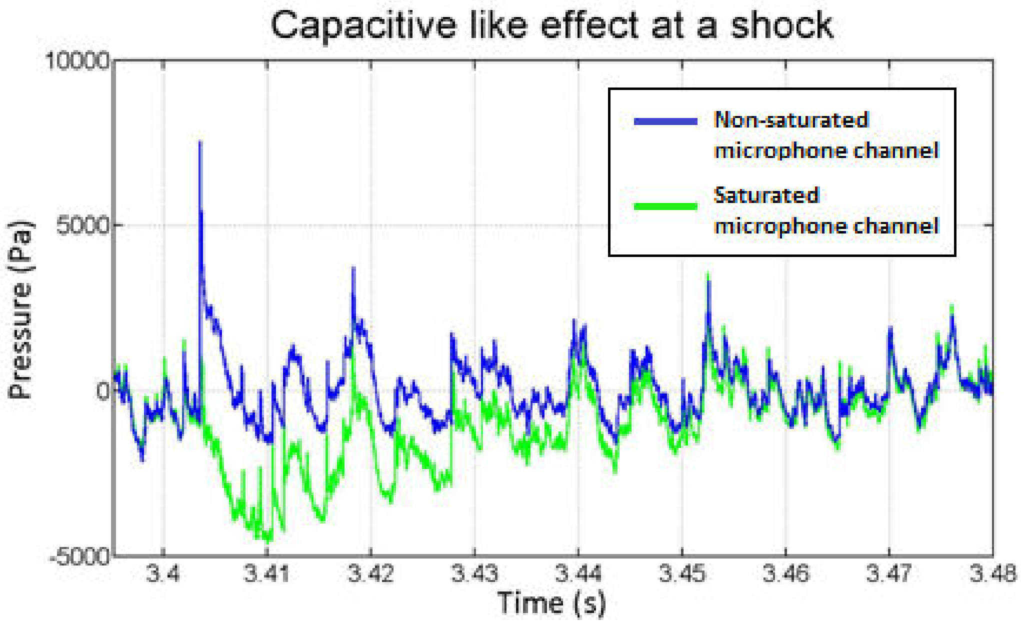

Figure 4. Example of the capacitive-like discharge seen recorded by two closely spaced microphone systems during a rocket noise tests.

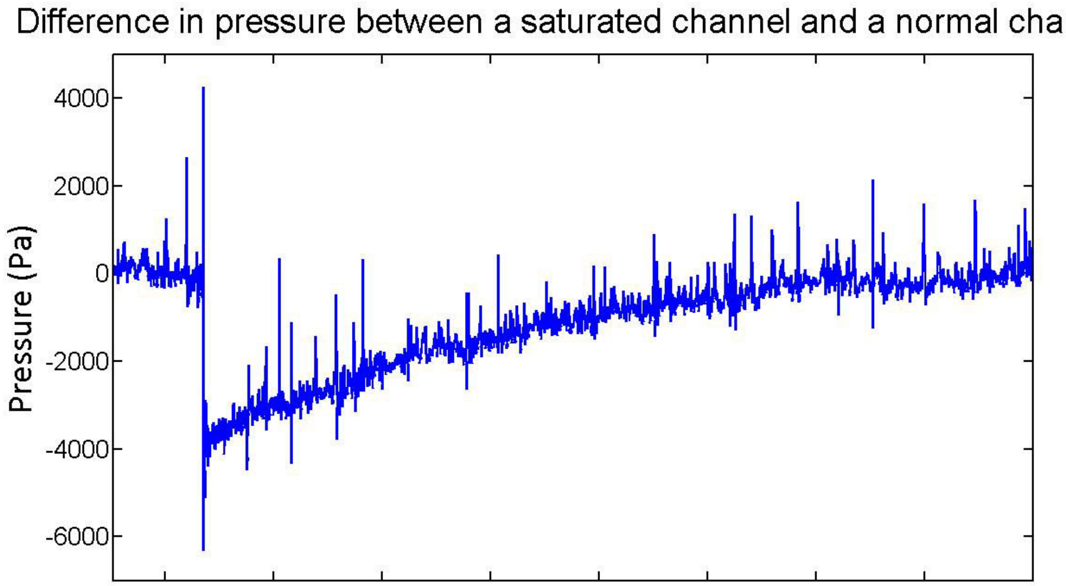

Figure 5. Difference between the green curve and the blue curve in Figure 4. The result is similar to the curve of a capacitor charging. The spikes in the data are due to the fact that the two microphones recording the data were at two different locations and therefore recorded slightly different waveforms.

Experiment

To test under what conditions this capacitive-like discharge occurs, an experiment was setup at ATK Aerospace Systems in Promontory, UT using a decommissioned KEI missile motor to provide the rocket noise field. It is a three stage missile that burns solid fuel. Stages one and two make up the propulsion system of the missile[3]. In this case Stage 2 was tested. The stage 2 motor of the KEI is a fast burning motor, lasting only about 30 seconds. Three stations were set up with different microphone types, different cable types and lengths, oriented at grazing incidence or perpendicular incidence, and provided with different power sources. As a control, some stations were purposefully set up to have problems. Table 3 shows the setup of each station and Figures 6a and 6b show pictures of the test setup.

The different cable types were used to vary capacitance in each microphone system. Three lengths of BNC cables were used. The RG-59 has a documented capacitance of 16.2 pF/ft, which is about 1.6 nF for the 30.5 m cables, about 4 nF for the 76.2 m cables and about 16.2 nF for the 305 m cables. The measured capacitance of the 30.5 m cables was about 2.3 nF, the 76.2 m cables was about 5 nF and the 305 m cables was about 17 nF. The cable connections can account for the slight differences in capacitance of what was measured and what is documented.

The other cable type that was used was the Spectra-Strip Skewclear 166-2699-997 infiniband cable. The infiniband cable consists of eight different cables bundled together in one cable. This cable is more convenient to use because only one cable, not several, needs to be run from the sensors back to the data acquisition system. The infiniband cable is 76.2 m long and has a measured capacitance of 2.7nF. The documented capacitance of the cable is 2.6nF[4], almost exactly what we measured.

Two different data acquisition cards were used. The first, the National Instruments (NI) PXI 4462 data acquisition card, was used to record the data from the microphones using the RG-59 cables. The other card, the NI PXI 4498 data acquisition card, was used to record data from microphones using the infiniband cable.

Microphone Station Specifications

Station Number	Channel Number	Sensor Type	Power	Cable Type and Length	Orientation	Sensitivity (mV/Pa)
1	0	1/8" IEPE	10 mA	30.5 m RG-59	Grazing	0.266
	1	1/4" IEPE	4 mA	30.5 m RG-59	Grazing	0.491
	2	1/4"	12AA	Infiniband	Normal	0.469
	3	1/4"	12AA	30.5 m RG-59	Normal	0.505
2	4	1/8" IEPE	10 mA	76.2 m RG-59	Grazing	0.311
	5	1/8" IEPE	4 mA	Infiniband	Grazing	0.334
	6	1/4" IEPE	10 mA	76.2 m RG-59	Normal	0.456
	7	1/4" IEPE	4 mA	76.2 m RG-59	Normal	0.425
	8	1/4" IEPE	4 mA	Infiniband	Normal	0.456
	9	1/4"	12AA	76.2 m RG-59	Normal	0.368
	10	1/4"	12AA	Infiniband	Normal	0.414
	11	1/4" IEPE	4 mA	305 m RG-59	Normal	0.368
3	12	1/8" IEPE	10 mA	76.2 m RG-59	Grazing	0.327
	13	1/4" IEPE	4 mA	76.2 m RG-59	Grazing	0.534
	14	1/4" IEPE	4 mA	305 m RG-59	Normal	0.501
	15	1/4" IEPE	4 mA	Infiniband	Normal	0.527

Table 3. Configurations for the different microphone stations. The microphones powered by the 12AA power supply are externally polarized. The remainder of the microphones are prepolarized.

The microphone stations were set up in a 16° line that estimated the shear layer of the rocket. Station 1 was placed 31 ft in the horizontal or x direction and 21 feet in the vertical or y direction from the motor. Station 2 was placed 34.5 ft in the x direction and 32 feet in the y direction. Station 3 was placed 47 ft in the x direction and 70 ft in the y direction, as shown in the diagram in Fig 7.

Figure 6a, on the left, shows the three microphone stations and the weather station with the KEI Stage 2 motor in the background. Figure 6b, on the right, shows microphone Station 2. Photo credit ATK.

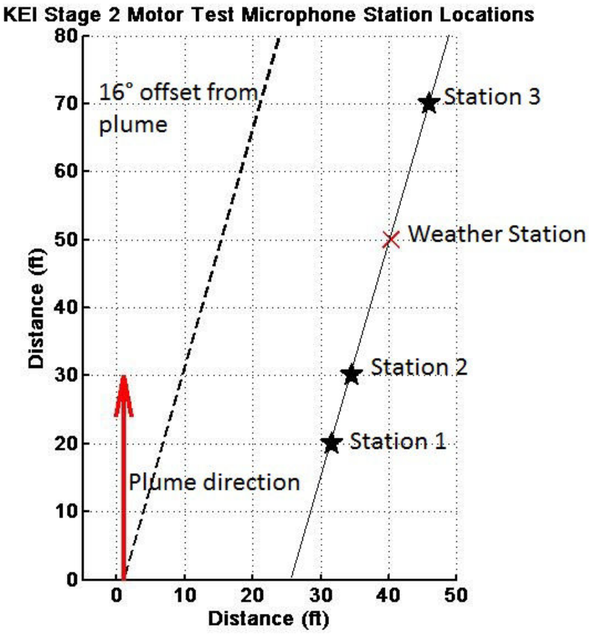

Figure 7 shows the layout of the three microphone stations in relation to the rocket motor and its plume.

Results

Figures 8-10 show the power spectral densities (PSD) for Stations 1, 2 and 3, respectively. The channels where microphone saturation (where the capacitive-like discharge) occurred are circled in red. The thing that all microphones that saturated have in common is they were all prepolarized microphones and they were powered with only 4 mA constant current. No microphones saturated that were externally polarized or prepolarized provided with 10 mA constant current.

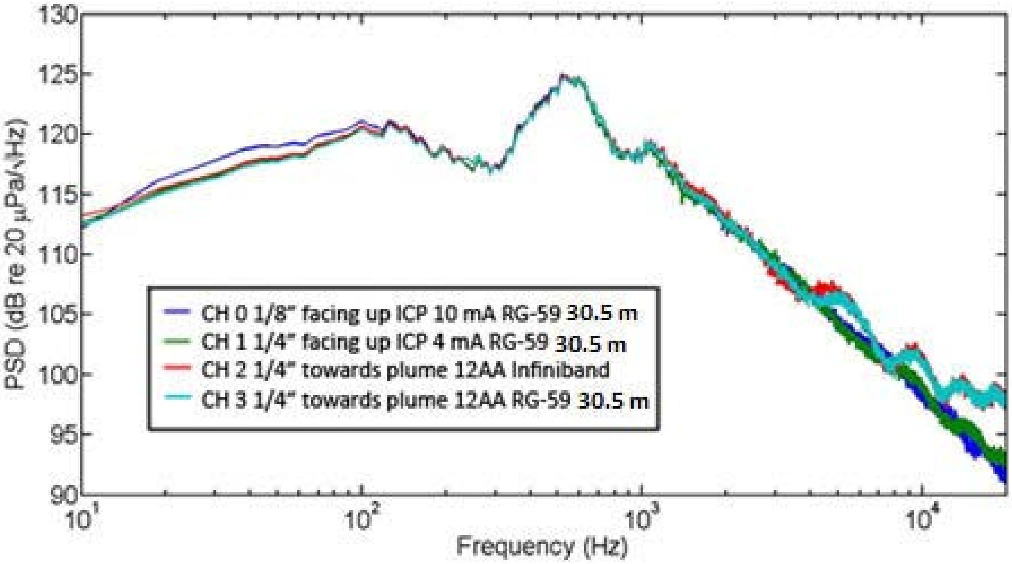

Figure 8 shows the PSD of the four microphone channels at station 1. No microphone saturation occurred at this station.

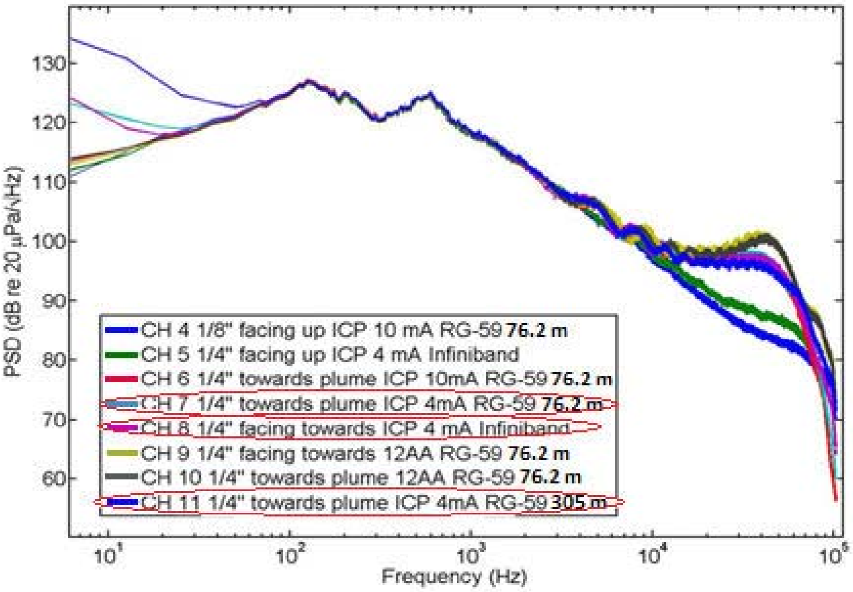

Figure 9 shows the PSD of the eight microphones at station 2. The channels that saturated are circled in red and in the data are shown have the capacitive-like roll-up at low frequencies. The bumps in the data seen in some channels in the

high frequency range occurred because of an overpressure at the face of the microphones due to the fact that they were pressure microphone oriented at nominally normal incidence.

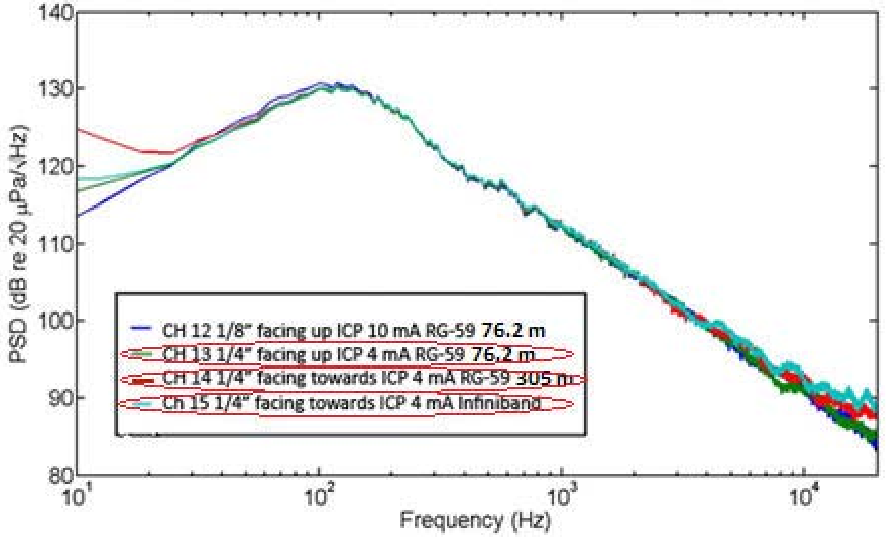

Figure 10 shows the PSD of the four microphones at station 3. The channels in red showed saturation as can be seen be shown by the capacitive-like roll-up of the data in the low-frequency range.

However, channels 1 and 5 show that not all microphones that received 4 mA of current saturated. This is because they were oriented at grazing incidence. Channel 13 was also oriented at grazing incidence and received 4 mA constant current but it did saturate. This is because channel 1 was on a 30.5 m cable and channel 5 was on the infiniband cable, both of which have a lower capacitance than the 76.2 m cable that channel 13 was on. The conclusion is that channels with a low constant current level, very high capacitance, or both show the greatest likelihood of saturation during a rocket noise test. Channels 11 and 14, both having 4 mA constant current and using 305 m cables, support this conclusion as they show the least capability to represent a large change of voltage over a short period of time.

It is also important to mention that the decrease in the PSD at higher frequencies is due to the low-pass filter effect discussed above. Cable length should be kept to a minimum to keep the roll-off at the higher frequencies to a minimum.

Conclusion

While problems have arisen while using prepolarized microphones in measuring rocket noise, solutions have been found to eliminate or greatly reduce error. To keep prepolarized microphones from exceeding their maximum voltage and clipping, low-sensitivity microphones should be used. The low-sensitivity microphones required for the very large pressure levels in a rocket-noise field usually do not come standard and must be specially ordered.

To avoid filtering out important high-frequency data, capacitance should be kept low and available constant current should be high. Control of capacitance is most achieved by the selection of a cable's type and length.

To make sure that there is enough instantaneous power to accurately represent a shock, available constant current must be high, and capacitance kept low. In the test, channels never showed saturation when they were supplied with 10 mA constant current or when an externally polarized microphone powered by a 12AA power supply was used. Generally, setting a microphone at grazing incidence will not saturate the microphone, but this may not always be the case when low constant current is used or there is high capacitance in the system.

[1] Gee, K.L., et al., *Energy-Based Acoustical Measurements of Rocket Noise*, in *15th AIAA/CEAS Aeroacoustics Conference (30th AIAA Aeroacoustics Conference)*. 2009: Miami, Florida.

[2] PCB Group Inc. (n.d.). ICP Sensors. In *PCB Piezotronics*. Retrieved 3/8/2011. From http://pcb.com/techsupport/tech_signal.php.

[3] Holliman, M., (Spectra-Strip)

[4] Kinetic Energy Interceptor. (n.d.). In Wikipedia. Retrieved July 18, 2012, from http://en.wikipedia.org/wiki/Kinetic_Energy_Interceptor