Frequency Response Analysis of Microphone Preamplifiers in the Audible and Ultrasonic Regime

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Abstract

This report presents an investigation on the frequency response of two types of electret microphone preamplifiers currently in use with SotonArray, Southampton University's wind tunnel microphone array system. The investigation is presented as a comparison between the response of an electret microphone coupled to the preamplifiers and a reference instrumentation-grade microphone and preamplifier assembly. The results show that electret microphones can potentially be used above their rated frequency range of 20 kHz; in fact no degradation in signal was noticed up to 48 kHz. The results also show that the newly-built SES preamps have a much better high-frequency performance than the original ISVR preamps.

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1 Introduction

At the University of Southampton, microphone array measurements are carried out using electret microphones, such as the Panasonic WM-60A and WM-61A. These low-cost alternatives are quoted to be as good as the much more expensive Class A condenser microphones in the audible frequency range (20 - 20000 Hz),[1] however very little information exists on their performance above 20 kHz. Furthermore, these microphones have to be coupled with custom-build preamplifiers, which provide a constant voltage to power the microphones and amplify the weak microphone signals to line levels. These preamplifiers form an active part in the signal path, and therefore have an influence on the frequency response of the acquired data.

A standard part of the beamforming software involves correcting for the frequency response of a whole input channel path. This is done by first calibrating each channel with respect to a calibrated reference instrumentation-grade microphone, and then applying the relevant calibration curves to the respective channel data. The calibration involves subjecting the two microphones (reference and test) to the same sound field, and measuring the transfer function between them.

In this report these calibration curves are used to evaluate the performance of the two types of microphone preamplifiers currently in use at the School of Engineering Sciences (SES) and the Institute of Sound and Vibration Research (ISVR). The two types of preamplifiers were designed for different purposes: the "old" (ISVR) type was primarily designed for the audible frequency range (20 - 20,000 Hz), particularly the lower frequencies for jet-noise measurements. They offer independently-controlled channels and a wide range of gains (0 - 60dB). The "new" (SES) preamps were specifically designed for microphone array measurements in wind tunnels, with an ultra-wide frequency range (up to 80 kHz), a more limited gain range (0 - 40dB) and an option for a high pass filter with an adjustable cut-on frequency of 0/300/800 Hz. Channels can be controlled in groups to save time as well as lower the potential for error.

It is of interest to investigate the following features:

- whether the frequency response of the "new" preamps does indeed go beyond 20 kHz without any noticeable degradation in the signal;
- how the frequency response of both preamps changes with different gain settings;
- the effectiveness of the high-pass filter;
- how much does the frequency response of different channels within the same preamp vary between each other;
- how much does the frequency response of different channels within the two different preamps vary between each other;
- how much does the frequency response of different microphone capsules vary between each other,

  and following from the last three points,

- how important it is to include both the preamp circuit and microphone capsule in the calibration path.

2 Experimental Setup

The calibration session was carried out in the Flight Simulator laboratory, which is a rectangular room measuring (approx.) $10 \times 4 \times 3$ metres, with a large number of absorbing/diffusing objects scattered around the room. The sound field in the room can be assumed to be reasonably diffuse at frequencies above 200 Hz. The reference and test microphones were clamped tightly together and positioned approx. 300 mm above the surface of a bench, and 800 mm in front of a passive nearfield studio monitor speaker (Tannoy Reveal 6P), as shown in figure 1. This speaker was chosen specifically for a wide frequency response up to 51 kHz. The speaker was driven by white noise from a SoundLab GO97 power amplifier. The noise signal was generated using Labview software and fed to the power amplifier through an analog output

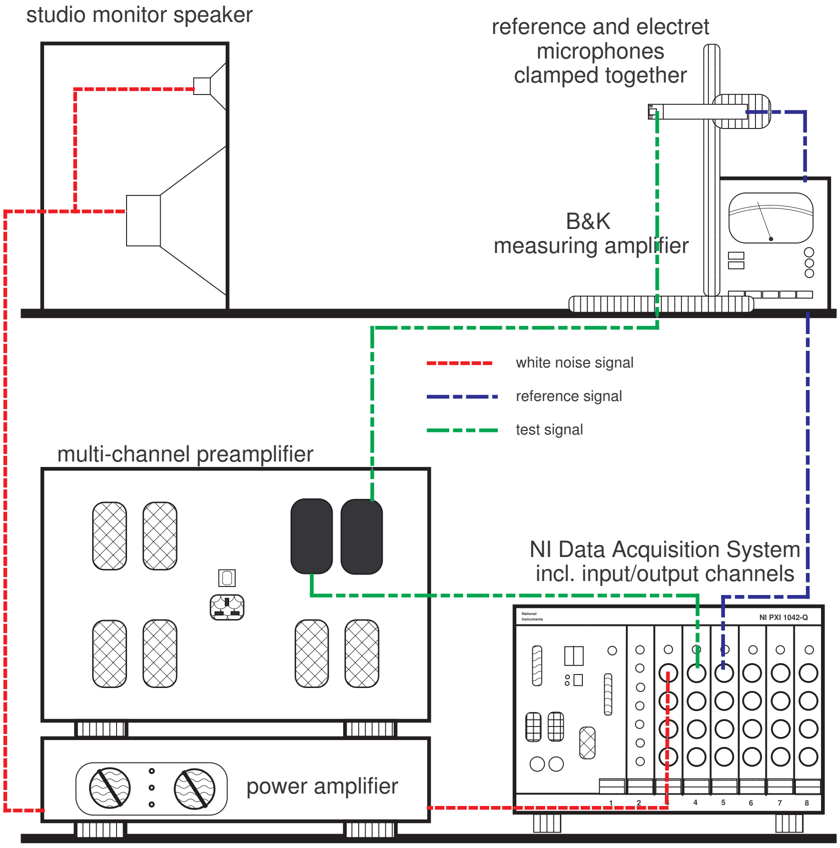

Figure 1: Schematic of hardware setup used to generate the frequency response calibration curves.

channel of a National Instruments PXI-4461 DSA card using an unbalanced audio cable.

The reference microphone consisted of a Brüel and Kjær 1/2″ free-field microphone with an attached 1/2″ preamplifier connected to a measuring amplifier type 2609, set on 30 mV. The sensitivity of the microphone amplifier assembly was equal to 2.68 V_{peak}/Pa.

Data from the reference and test microphones was acquired using two PXI-4462 National Instruments DSA cards, situated in the same PXI-1042Q chassis as the PXI-4461 card generating the noise signal. The whole calibration sequence was controlled by a custom-designed Labview program which initialises and synchronises both input channels, generates the white noise and feeds it to the output card, waits a pre-defined number of seconds for the sound field in the room to stabilise and then start the acquisition, streaming the raw data to disk. The raw data is then passed to an averaged frequency response function processing block, which computes the magnitude, phase and coherence of the transfer function between the two signals. When the averaging procedure is completed, the acquisition is terminated, the three computed quantities are stored to disk and the white noise signal is switched off.

In order to be able to evaluate the performance at the ultrasonic frequencies, all data except for the high-pass filtering test-case was acquired at a sample rate of 96 kHz. With the block size in use of 16384 this gives a frequency interval of 6 Hz. The 96 kHz sampling rate was a limitation of the data acquisition hardware, and means that data can only be analysed up to 48 kHz.

2.1 Known issues

The power amplifier driving the sound source, the reference microphone and accompanying preamplifier are only rated up to 20 kHz. This means that high frequency data has to be analysed with caution. For the purpose of these tests, the coherence was used as a measure of the validity of the measurements above 20 kHz. Surprisingly it was found that the coherence at frequencies above 20 kHz was very close to unity for both types of amplifiers, as can be seen in figures 2 and 3. One explanation can be that audio equipment seldom has a sharp drop-off in response beyond 20 kHz, and the signals registered by both microphones due to the generated noise was sufficiently louder than background noise. The lack of coherence at approximately 4, 6 and 8 kHz cannot be explained, although one can speculate that it is due to tonal noise from a source present in the room during the measurements. Of more concern is the fluctuating nature of the frequency response curve above 1 kHz. However the response shape is repeatable, which means that as long as FRF calibration is implemented in the SotonArray software, this should not be of particular concern.

In the case of the ISVR preamps, vertical lines in the phase response denote a phase switching from positive Pi to negative Pi or vice-versa (due to phase wrapping), and in most cases occurs only at frequencies with poor coherence.

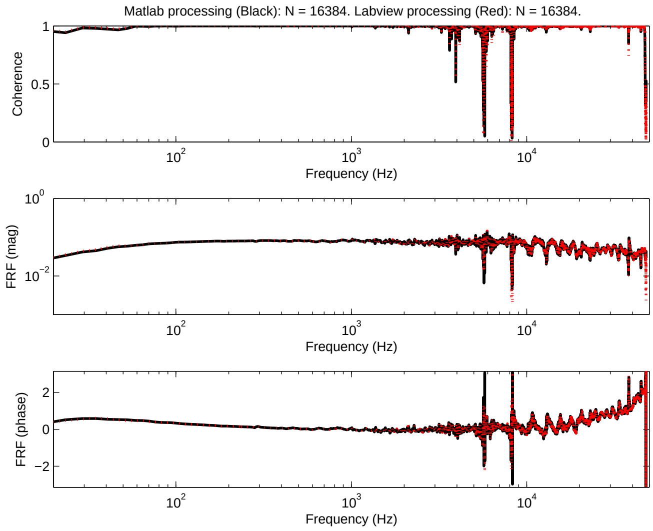

Figure 2: Frequency response between reference and test microphones corresponding to the new preamp.

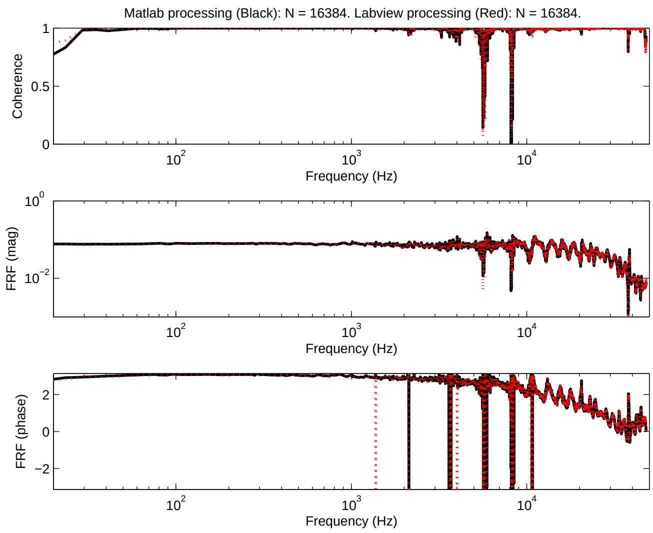

Figure 3: Frequency response between reference and test microphones corresponding to the old preamp. Same microphone and gain setting as in figure 2.

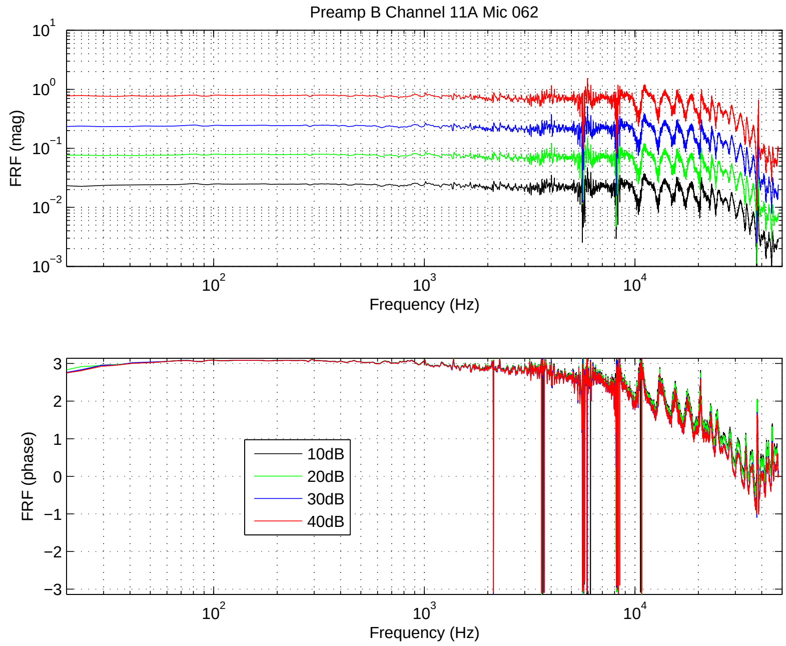

Figure 4: Frequency response of ISVR preamp at different gain settings. Logarithmic frequency scale.

3 Results and Discussion

3.1 Frequency response at ultra-sonic frequencies and influence of gain

The results in this section will be direct answers to the outline specified in the introduction. We start by analysing the frequency response of both old and new preamplifiers within the frequency range between 0 Hz and 48 kHz, for different gain settings – see figures 4 to 7. The same microphone was used in each case. Figures are presented as two sub-plots showing the magnitude and phase of the measured frequency response function between the test and reference microphones. Moreover, two figures will be shown for each case, one with frequency plotted on a logarithmic scale and the other with frequency as a linear axis. This was necessary in order to analyse the response within such a large bandwidth.

There are some interesting observations to be made from these plots. The frequency response (magnitude) of the ISVR preamps is linear up to 2 kHz, after which it becomes characterised by regular peaks and troughs. Above 20 kHz the response drops-off with a constant gradient of approximately 15 dB/octave. This behaviour was expected, since the preamplifiers

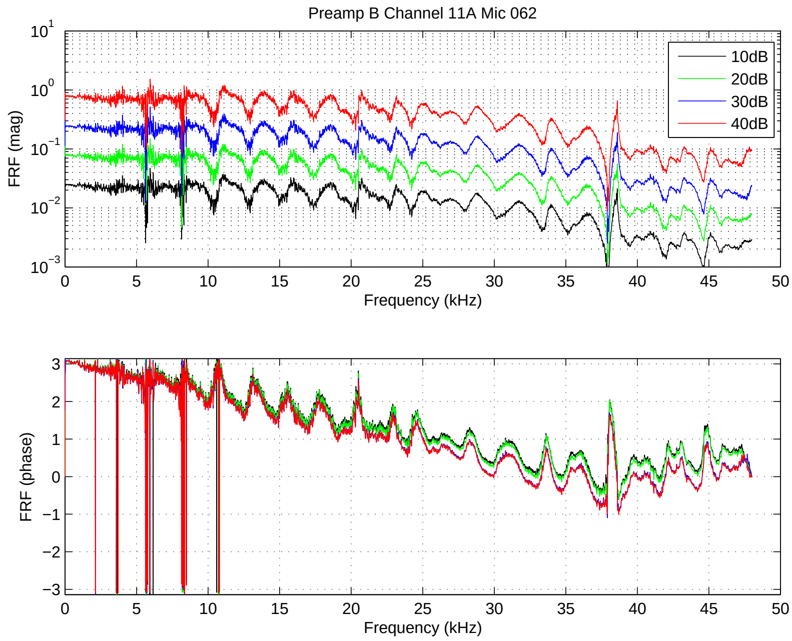

Figure 5: Frequency response of ISVR preamp at different gain settings. Linear frequency scale.

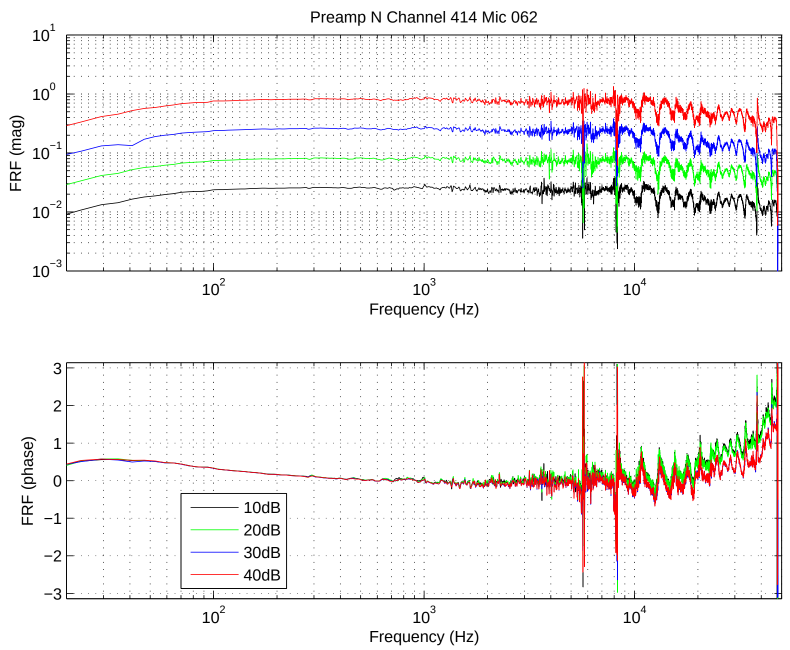

Figure 6: Frequency response of SES preamp at different gain settings. Logarithmic frequency scale.

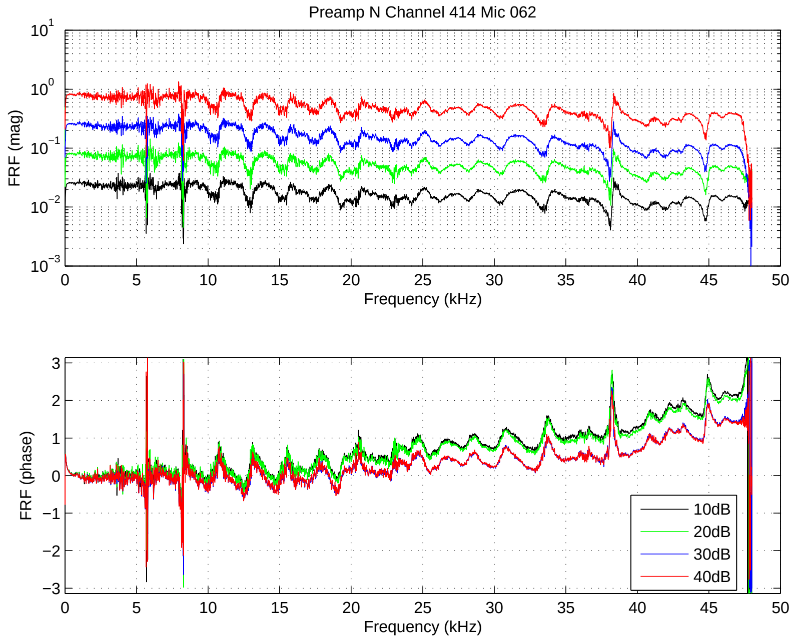

Figure 7: Frequency response of SES preamp at different gain settings. Linear frequency scale.

were designed for a linear response up to 20 kHz. The phase relative to the reference microphone is a fairly constant Pi radians out of phase up to 2 kHz, after which it becomes less and less out of phase. The "oscillating" nature of the response which was evident in the magnitude plot is still exhibited in the phase curves.

The different gain settings clearly increase the magnitude of the response in a constant manner, without altering much the shape of the curve. Up to 20 kHz the gain setting has very little influence on the phase of the response; at higher frequencies, the phase are distinctly grouped in pairs of 10 - 20 dB and 30 - 40 dB. This is probably due to the physical design of the preamp circuit. The response also shows some sort of discontinuity in both magnitude and phase at a frequency of approximately 38 kHz, which is well beyond its designed operating frequency range.

The magnitude of the response of the SES preamp shows some deviations from that of the ISVR preamp. A roll-off is present as the frequency goes below 100 Hz. Between 100 Hz and 10 kHz it is fairly linear, except for some discontinuous behaviour at the frequencies with poor coherence. Above 10 kHz, the "oscillating" behaviour is apparent in this case as well, together with a slight fall-off in response of roughly 5 dB per octave. The shape of the magnitude curve does not change with different gain settings, similarly

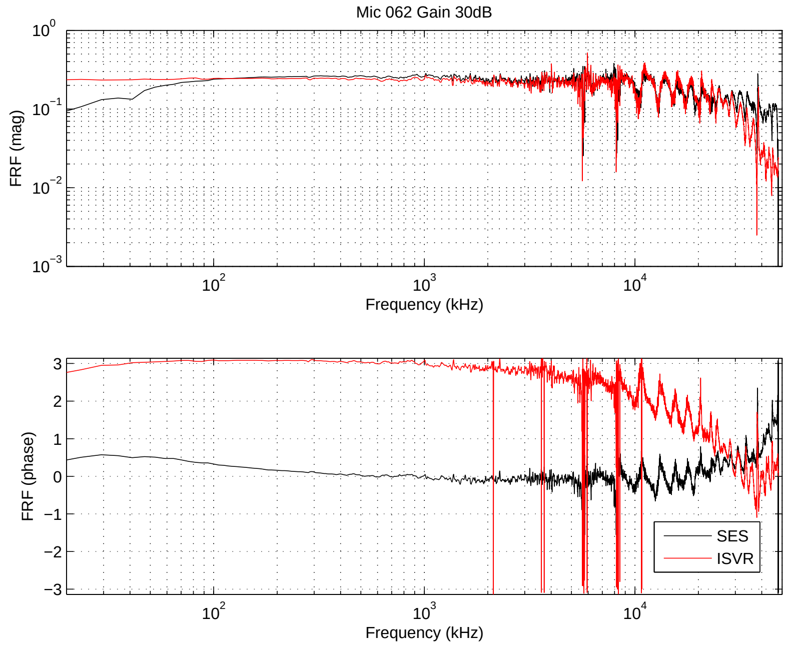

Figure 8: Frequency response of SES and ISVR preamps for the same microphone. Gain = 30 dB, logarithmic frequency scale.

to the ISVR preamps.

The SES preamp response was in phase with the reference microphone up to 10 kHz, after which it became increasingly out of phase. The grouping of the 10 - 20 dB and 30 - 40 dB phase responses, together with the discontinuity at roughly 38 kHz are evident also in this case. Whereas the former is most likely due to the physical layout of the preamp circuit, the latter can well be because of some resonance in either the microphone capsule or the response of the B&K microphone or its matching preamplifier.

Figures 8, 9 and 10, 11 show a more direct comparison between the ISVR and SES preamp response for the same microphone, for gain settings of 20 dB and 30 dB respectively. The most distinctive differences are the phase response and the magnitude of the response above 20 kHz.

3.2 Influence of Preamplifier Channel and Microphone

It is well known that the frequency response varies between the channels of a microphone array, however it is not obvious if the change is due to the microphone capsule, the preamplifier, or both. Figures 12 and 13 show the response of the same microphone capsule connected to three different amplifier channels on the ISVR preamp, all set to 20 dB gain. Channels 11A

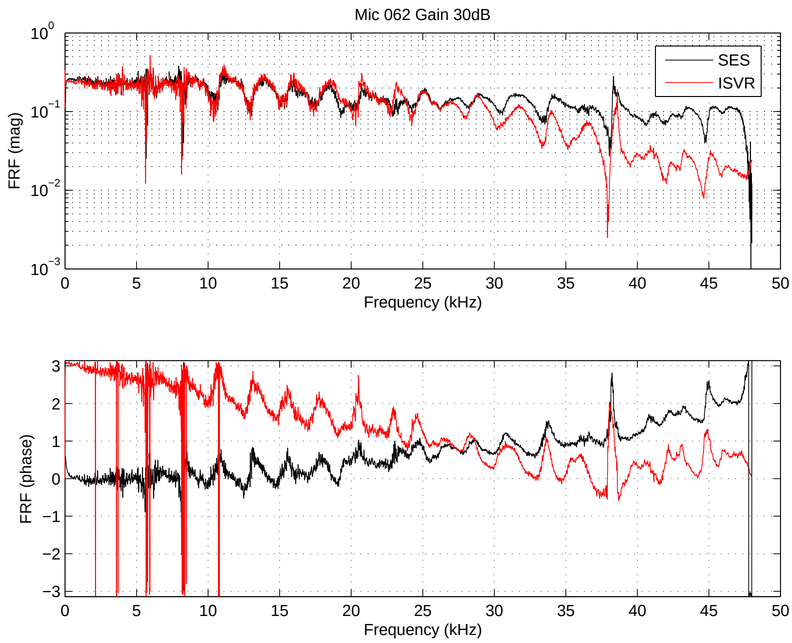

Figure 9: Frequency response of SES and ISVR preamps for the same microphone. Gain = 30 dB, linear frequency scale.

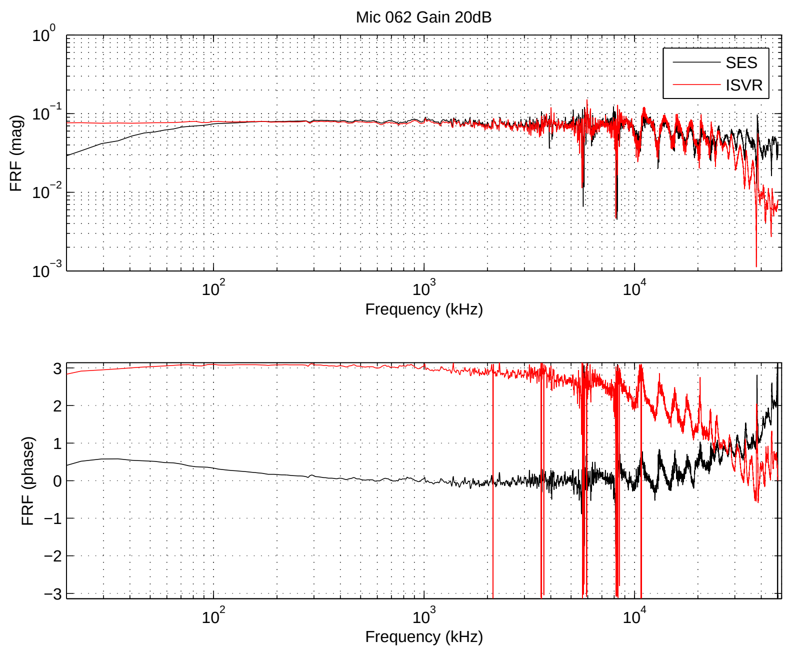

Figure 10: Frequency response of SES and ISVR preamps for the same microphone. Gain = 20 dB, logarithmic frequency scale.

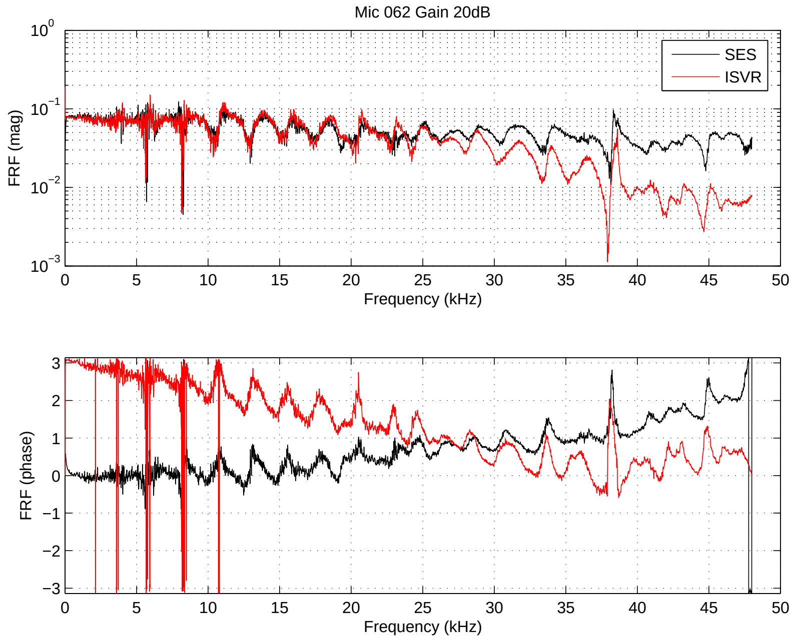

Figure 11: Frequency response of SES and ISVR preamps for the same microphone. Gain = 20 dB, linear frequency scale.

and 11B are physically present on the same PCB, whereas channel 10A is on a separate PCB in the same preamp housing.

The plots show clearly that the response of the three preamp circuits is very similar in magnitude up to 40 kHz, and in phase up to 20 kHz. Beyond these respective frequencies, the deviations are minimal. For the SES preamps, the response of the three channels shown in figures 14 and 15 is virtually undistinguishable throughout the whole frequency range. Once again the three channels chosen are a mix of two channels on the same circuit board (413 and 414) and channel 415 on a separate board. From these plots we can conclude that the response of the different preamp channels within their intended operating frequency range does not change noticeably, and can be assumed to be constant. It is worth noting that both preamps are based on an operational amplifier (opamp) with negative feedback, and both the opamp ICs and resistors controlling the negative feedback (and therefore the gain) are chosen with tolerances of less than 1%.

This leaves the microphone capsule as the most likely responsible for frequency response variations. This is easily confirmed in figures 16, 17 (for the ISVR preamp) and 18, 19 (for the SES preamp), where the response for microphone capsules 61 and 62 differ from each other, albeit not by much.

As in the case of the different preamp channels, the ISVR preamp exhibits

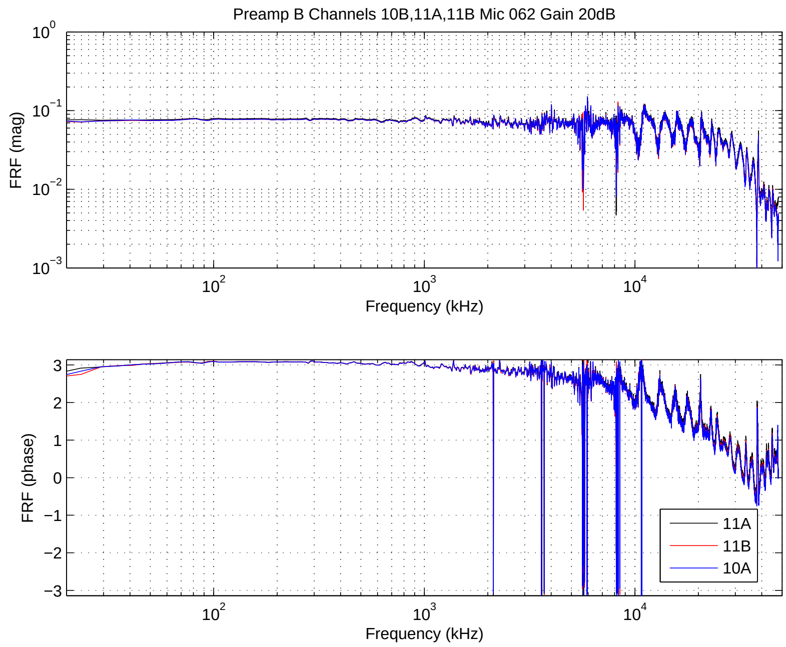

Figure 12: Frequency response of three different ISVR preamp circuits, same microphone capsule and gain setting (20dB). Logarithmic frequency scale.

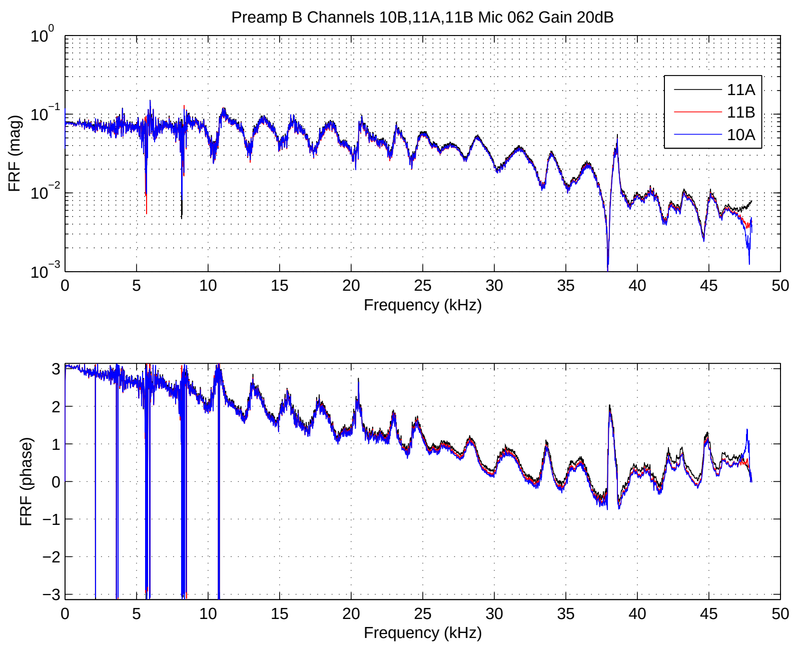

Figure 13: Frequency response of three different ISVR preamp circuits, same microphone capsule and gain setting (20dB). Linear frequency scale.

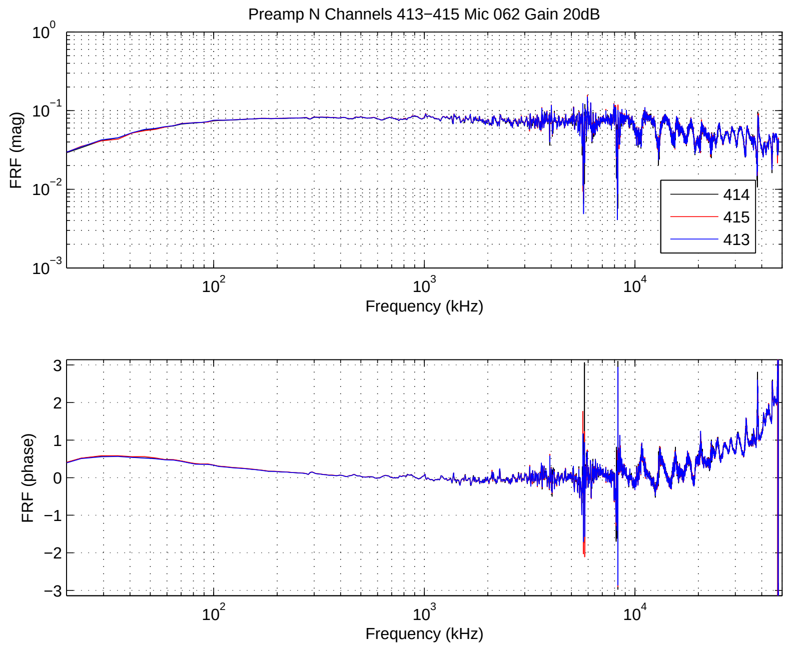

Figure 14: Frequency response of three different SES preamp channels, same microphone capsule and gain setting (20dB). Logarithmic frequency scale.

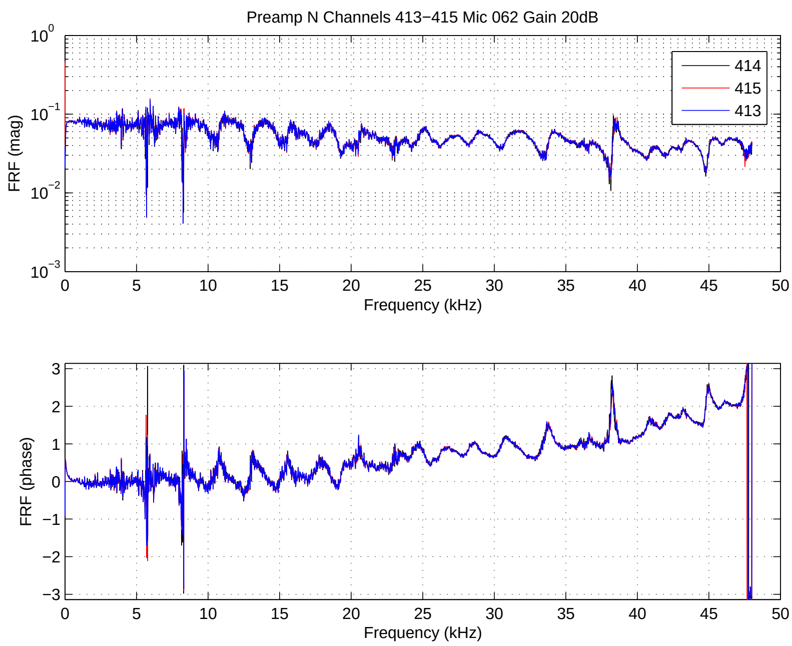

Figure 15: Frequency response of three different SES preamp channels, same microphone capsule and gain setting (20dB). Linear frequency scale.

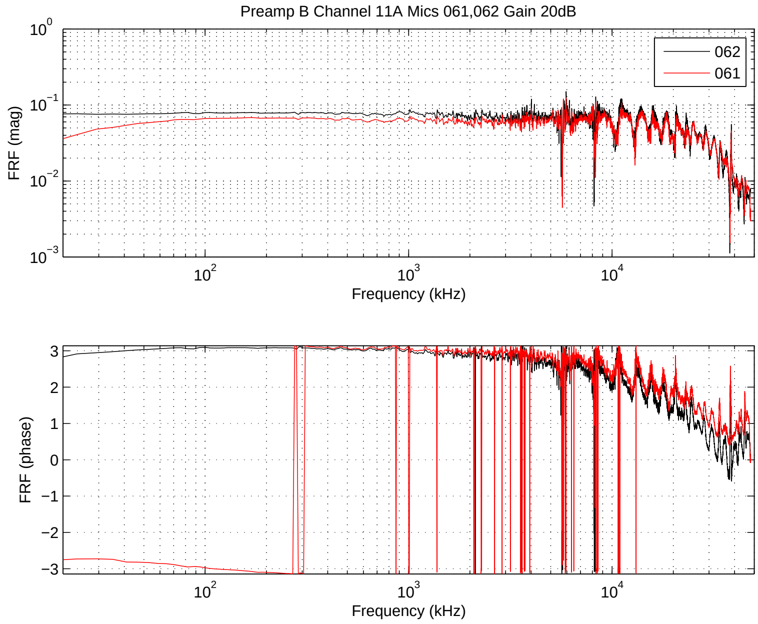

Figure 16: Frequency response of two different microphone capsule connected to the same ISVR preamp circuit; gain setting (20dB). Logarithmic frequency scale.

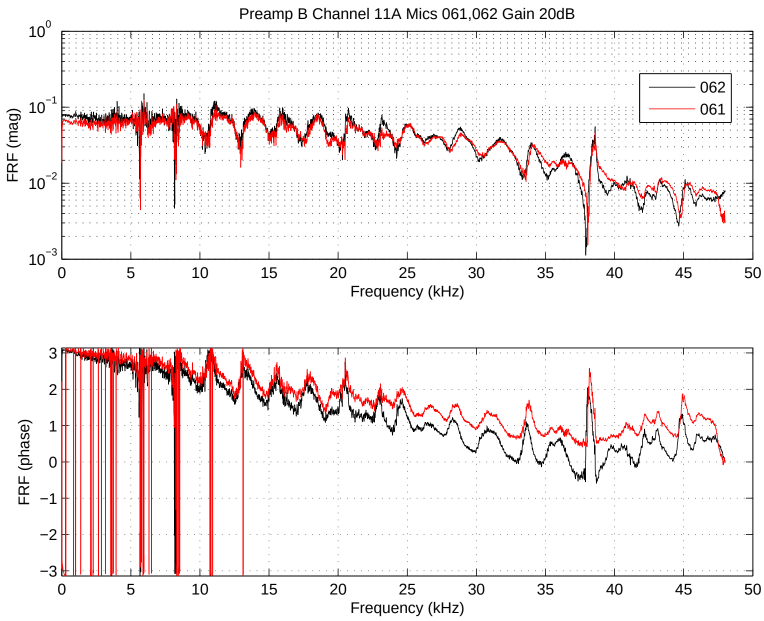

Figure 17: Frequency response of two different microphone capsule connected to the same ISVR preamp circuit; gain setting (20dB). Linear frequency scale.

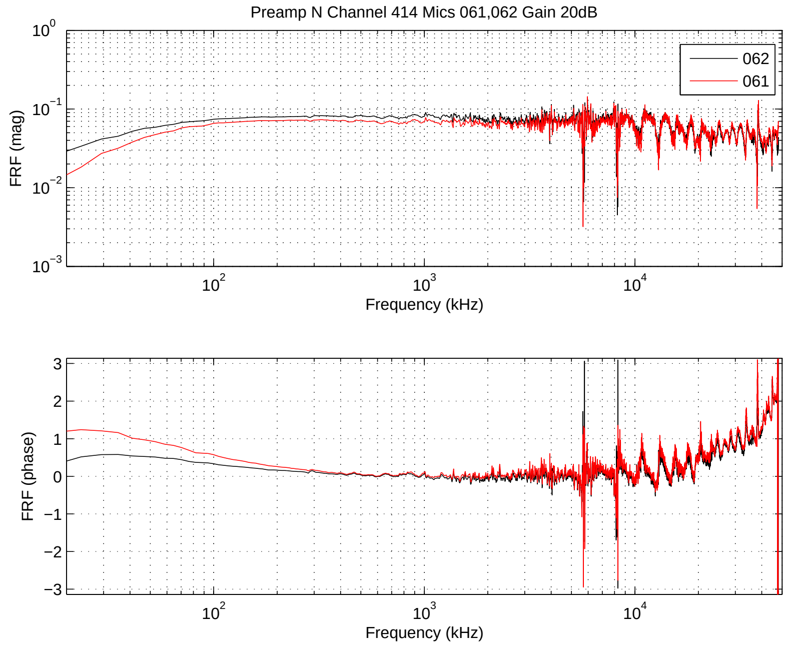

Figure 18: Frequency response of two different microphone capsule connected to the same SES preamp circuit; gain setting (20dB). Logarithmic frequency scale.

a larger deviation in the phase of the two microphones at the higher frequencies; this can be attributed to larger errors due to weaker signals recorded from this preamp.

In light of the small deviation between the two microphone capsules, especially with the SES preamps, one can be inclined to ignore the calibration step completely, and assume that all microphone array channels have roughly the same response. However it is useful to note that capsules 61 and 62 were chosen from the same batch of microphones, most likely manufactured on the same product line minutes or seconds within each other. Larger deviations might well be present between the same type of capsules bought on a different day or from a different retailer.

3.3 Effectiveness of High-Frequency Cut-on

The last feature to be analysed is the high-frequency cut-on function on the new preamps. This feature was included to offer the possibility to reduce the influence of the turbulent boundary layer in contact with the microphones, which often causes the preamps to overload. This type of noise is highest at frequencies lower than 1 kHz, which are not of interest for beamforming

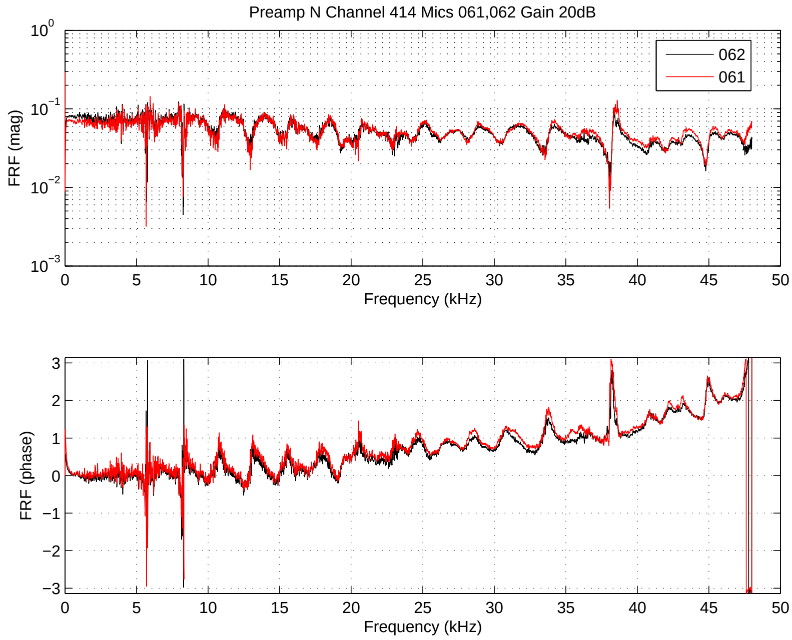

Figure 19: Frequency response of two different microphone capsule connected to the same SES preamp circuit; gain setting (20dB). Linear frequency scale.

measurements.

Figure 20 shows the frequency response of the new preamp corresponding to the three cut-on settings: OFF (no cut-on filter), 300 Hz and 800 Hz. The microphone capsule and preamp channel are different from the ones used in the previous tests; the gain was set to 20 dB. The cut-on does make a noticeable influence on the frequency response, although it differs from the specified criteria. With the switch in the "OFF" position, the response is linear from approximately 100 Hz. The "300 Hz" correctly denotes a linear curve from 300 Hz, however the 800 Hz setting exhibits linear behaviour already at 400 Hz, with a drop-off gradient very similar to the "300 Hz" setting.

The cut-on is thus effective in blocking part of the low-frequency energy, however this comes at a price, which is most evident in figure 21. The extra circuitry used as a high-pass filter has an influence on the overall gain of the preamp, effectively reducing the gain the higher the cut-on setting. There is no change in the phase of the response, except at the intentionally-addressed lower frequencies.

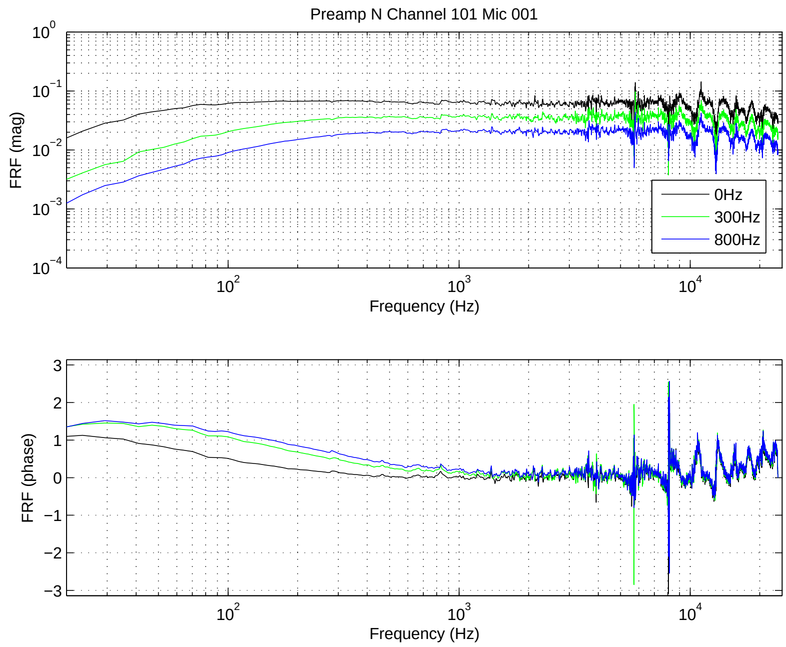

Figure 20: Frequency response of an SES preamp channel with the three different cut-on options; gain setting (20dB). Logarithmic frequency scale.

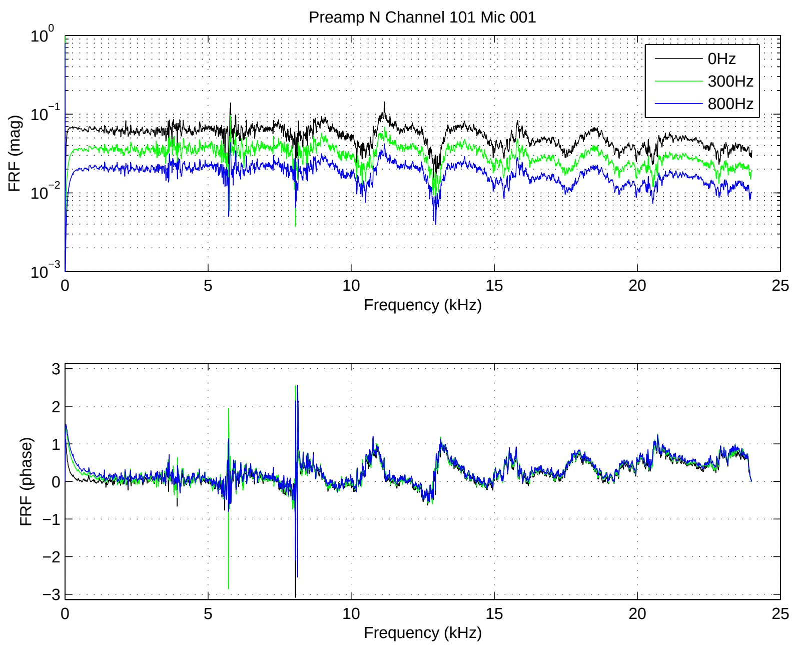

Figure 21: Frequency response of an SES preamp channel with the three different cut-on options; gain setting (20dB). Linear frequency scale.

4 Conclusion

This report gives an overview of the differences in frequency response of the ISVR (old) and SES (new) preamps which are frequently used for microphone array measurements. The two major differences between the two preamps are a wider frequency range specified in the design stage of the new preamps, and the inclusion of an adjustable high-pass filter in the latter.

From the results we have seen that the SES preamps do exhibit a flatter frequency response up to 48 kHz, with no noticeable degradation in performance. The good coherence in the measurements at the higher frequencies also shows that the Panasonic electret microphones can yield useful information beyond their specified range from 20 Hz to 20 kHz. The channels within the new preamps are also more consistent between each other within the entire frequency range (up to 48 kHz). In fact it is possible to perform a microphone array calibration using the same preamp channel for all microphone capsules – this would simplify the calibration requirements considerably.

Finally, the high-pass filter is effective at blocking low-frequency energy, at the cost of a modified gain factor. The 800 Hz setting provides a cut-on from 400 Hz.

4.1 Recommendations

It is recommended to do a similar analysis using a reference microphone which is rated up to 80 kHz to validate the data in this report, and analyse the performance of the Panasonic electret microphones and SES preamps at frequencies above 48 kHz.

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