Measurements of a piezoelectric contact microphone

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***Abstract*—We explored piezoelectric contact microphones and the challenges of measuring them. We measured the parameters of a VIBE 1 piezoelectric contact microphone. This was done with a Brüel & Kjær 4513-002 piezoelectric accelerometer and a Brüel & Kjær 4810 Mini-shaker as our reference point. We introduced the 2 models, that we used to measure the features of a VIBE 1 microphone. We measured it's frequency response, noise floor (self noise), sensitivity, effect on a musical instrument's frequency response and the temperature dependence of it's frequency response. We presented the challenges and constraints that came up while measuring these parameters. There are other features we wanted to measure, but did not know how as they do not translate well to contact microphones. We summed up the results and set new goals for further exploration and improvements of the Piezo Pickups VIBE 1 piezoelectric contact microphone.**

Keywords: acoustics, sensor, microphone, transducer, piezoelectric, contact, frequency response, frequency analysis, frequency spectrum, temperature dependence

I. Introduction

Piezoelectric contact microphones do not pickup vibrations from the air like other microphones. They capture the vibrations from the surface that they are attached to. That makes them very different and offer new ways of recording. This also means, that their frequency response is dependent on the surface they are attached to. The core of a piezoelectric contact microphone is a crystal or ceramic membrane that is attached to the surface. [1] This membrane takes advantage of the piezoelectric effect. Piezoelectric contact microphones are used in recording acoustic instruments and ambient sounds. They are also used to locate and measure surface vibrations. These types of microphones have a number of good qualities. This includes a wide frequency range, a high signal-to-noise ratio, small frequency distortion, small dimensions. They are also relatively cheap. Their biggest weakness is their sensitivity to temperature and humidity. It is important to measure accurately so that we can understand and optimize the performance of the microphones.

It is important to measure the parameters of a microphone, so that we know, when and why to record with it. We must also be acquaint with it's strengths and weaknesses. Knowledge of our equipment is crucial to using it's full potential. Knowing that makes our recording process much smoother and problem-free. It allows use to capture the sound we want.

Piezoelectric contact microphones are not as prominent on the market. Most popular microphones are either condenser or dynamic microphones. Contact recording is a niche and unique type of recording. There is an untapped potential in piezoelectric contact microphones. This specific piezoelectric contact microphone, the Piezo Pickups VIBE 1 has not yet been measured. I was interested in exploring it.

I am interested in measuring it's frequency response, noise floor (self noise), sensitivity, effect on a musical instrument's frequency response and most importantly the temperature dependence of it's frequency response. We are aiming to get acquainted with this microphone, address the challenges that come with it and optimize it.

II. Background and problem statement

We wanted to measure the standard parameters of a Piezo Pickups VIBE 1 piezoelectric contact microphone. Knowing that the response of a contact microphone is based on the surface that the microphone is attached to, we ran into the problem of the reproducibility of the measurement conditions. This led us down a path of discovering what else affects the recorded sound. This includes the material of the surface, the location of the microphone, what instrument or device was used to produce the sound , the piezoelectric membrane, the cable and type of it's connector, the recording device etc.

III. Measurement methodology

The microphone is supposed to be used on a guitar, yet measuring that does not provide reproducible conditions. That is why we introduced 2 models to measure the microphone.

The first method of measuring gave us better reproducible conditions. We attached a Brüel & Kjær 4513-002 piezoelectric accelerometer to a Brüel & Kjær 4810 Mini-shaker with the provided screw. [2] [3] We repeated the measurement with a Brüel & Kjær 4517-002 piezoelectric accelerometer. [4] After the initial measurements we attached a VIBE 1 microphone with 3M adhesive and repeated the measurements.

Figure 1. VIBE 1 microphone on a 4810 Mini-shaker.

The second method is attaching the Piezo Pickups VIBE 1 microphone with the 3M adhesive to the body of a guitar about 25 cm from the center of the soundhole. We also attached a

Figure 2. VIBE 1 microphone on a 4810 Mini-shaker from another angle.

Brüel & Kjær 4513 accelerometer with double-sided tape as a reference for our measurements. We also recorded the audio with a Brüel & Kjær 4189 microphone. [5]

Figure 3. VIBE 1 microphone and 4513 accelerometer on an acoustic guitar.

I performed the measurements several times, and the results were consistent, showing little variation. Since calculating the average and deviation was unnecessary for the level of precision we required, I randomly selected one of the measurements for use.

IV. Course of Measurements

A. Frequency responses of Brüel & Kjær piezoelectric accelerometers

First we measured the impedance so that we can choose the optimal input device. We measured an impedance of 470 kΩ. That prompted us to use a high-impedance sound card. We used a RME Babyface pro and an E-MU 0404 USB with an impedance of 470 kΩ and 1 MΩ, respectively. [6] [7] We set the analog line inputs of the Babyface at -10 dBV gain and measured the response of a Brüel & Kjær 4513-002 piezoelectric accelerometer with a 4810 Mini-shaker as the source in an acoustically dead room. The x-axis represents the frequency in Hz and the y-axis represents the SPL in dB:

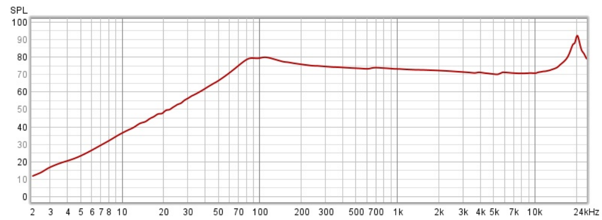

Figure 4. Frequency response of a 4513 accelerometer with -10 dB gain and 4810 Mini-shaker as the source.

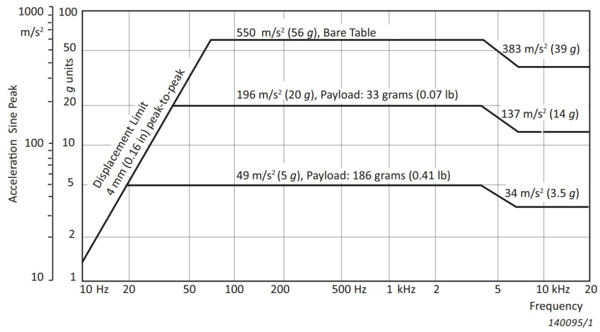

Figure 5. Sine performance curves of a 4810 Mini-shaker [3].

The response of a 4513 accelerometer is generally flat so the response is quite similar to the output of a 4810 Mini-shaker. The exception being the resonant frequency at 20 kHz. We are not sure what caused this resonance, as it is out of bounds of the frequency response provided in the product data.

We repeated the measurement, but this time we set the analog line inputs of the Babyface at +4 dBU gain:

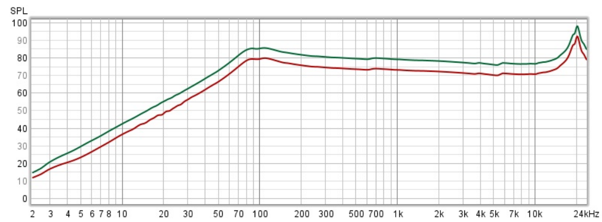

Figure 6. Frequency response of a 4513 accelerometer with +4 dB gain next to the previous measurement.

The amplitude increased at all frequencies. The distortion didn't change significantly, which is why we will continue at this input level setting.

We wanted to see, if the resonance at 20 kHz is caused by the accelerometer or some other source out of our hearing frequency spectrum. We used a Brüel & Kjær 4517-002 piezoelectric accelerometer.

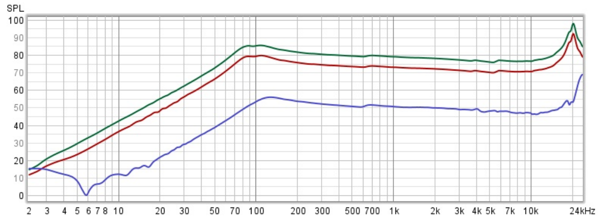

Figure 7. Frequency response of a 4517 accelerometer with +4 dB gain next to the previous measurements.

Again, we can see on figure 7, that there appears to be a resonant frequency, but it is a few kHz higher. We are not sure what could be the cause of this, but we suspect the accelerometers, as they are not supposed to be used in that frequency range. The 4517 accelerometer does not have as smooth a curve as the 4513 accelerometer in the lower frequency range. We will continue to use a 4513 accelerometer as our reference measurement device.

We raised the gain to match the previous measurements:

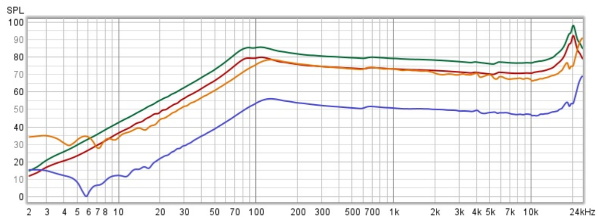

Figure 8. Frequency response of a 4517 accelerometer with gain from the ADC next to the previous measurements.

B. Noise floor of a VIBE 1 microphone

Finally it was time to measure the VIBE 1 microphone. We measured the noise floor at 0 dB and +23 dB gain:

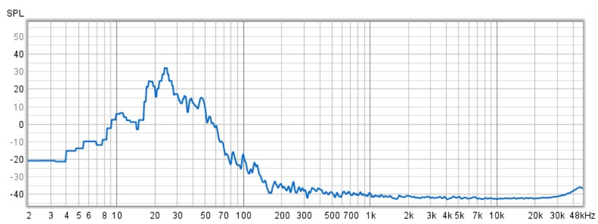

Figure 9. Noise floor of a VIBE 1 microphone with 0 dB gain.

We can see a lot of noise in the lower frequencies. A few spikes appear when gain is applied. There is not much noise after 700 Hz.

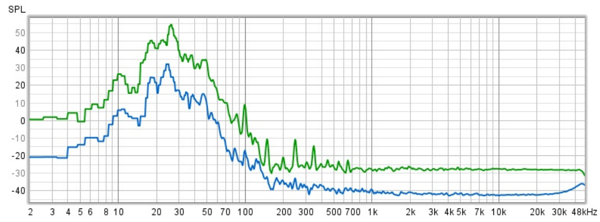

Figure 10. Noise floor of a VIBE 1 microphone with +23 dB gain next to the previous measurement.

C. Sensitivity

We measured the sensitivity of a VIBE 1 microphone and a 4513 accelerometer at 1 kHz. The accelerometer reached a value of -60.3 dB and the VIBE 1 reached a value of -50.4 dB. We used +30 dB gain on the VIBE 1 to reach this value.

D. Frequency responses of a VIBE 1 microphone

We measured the frequency response of a VIBE 1 microphone:

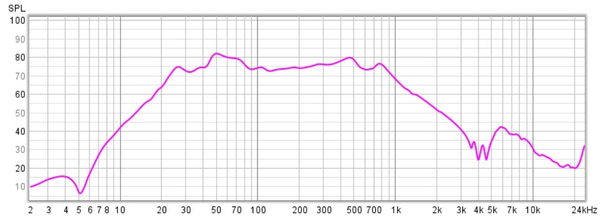

Figure 11. Frequency response of a VIBE 1 microphone.

We can see a significant drop in amplitude after 1 kHz. That is quite interesting considering the noise falls of at the same frequency. The frequency range from 20 Hz to 1 kHz is reasonably flat. Comparing it to the frequency response of a 4513 accelerometer, we can see, how much of a difference there is at high frequencies:

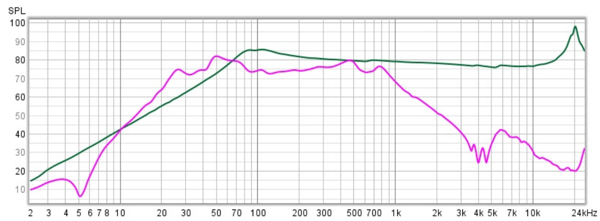

Figure 12. Frequency response of a VIBE 1 microphone and a 4513 accelerometer.

The important part of the frequency response, is the one which lies between 20 Hz and 20 kHz:

We must be aware, that this was measured with a Mini-shaker, that has it's own output spectrum. Knowing the response of a VIBE 1 microphone and a 4513 accelerometer, we can plot the output spectrum of a 4810 Mini-shaker as seen on figure 14.

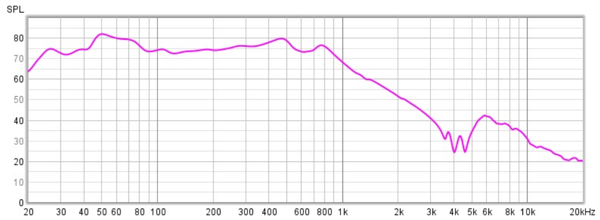

Figure 13. Frequency response of a VIBE 1 microphone in the hearing range.

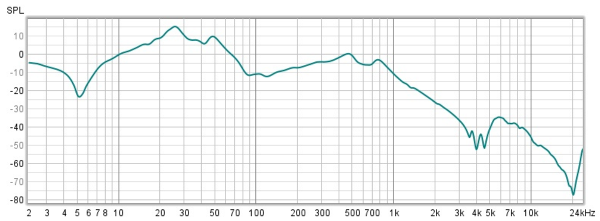

Figure 14. Output spectrum of a 4810 Mini-shaker.

E. Effect on the Frequency Response

These frequency responses were quite reproducible, but they might not be the same as the frequency response, when using a musical instrument. But before we measured the frequency response with a musical instrument, we measured just how much does the frequency response change, when a VIBE 1 microphone is attached to the instrument. First we measured the frequency response of an acoustic guitar. We used a calibrated speaker to send a frequency sweep, which the guitar body captured. On the body of the guitar was a 4513 accelerometer which captured the frequency response of the guitar:

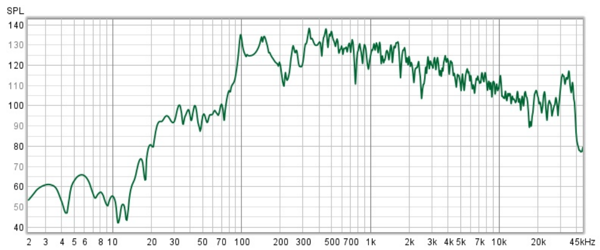

Figure 15. Frequency response of an acoustic guitar without a VIBE 1 microphone.

We added a VIBE 1 microphone and repeated the measurement:

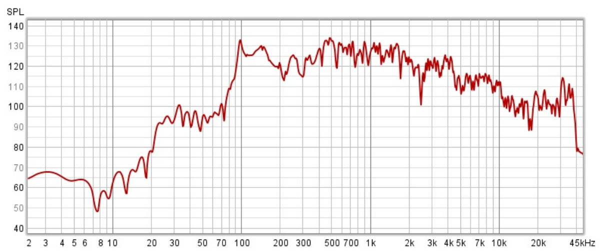

Figure 16. Frequency response of an acoustic guitar with a VIBE 1 microphone.

We plotted the difference on figure 17.

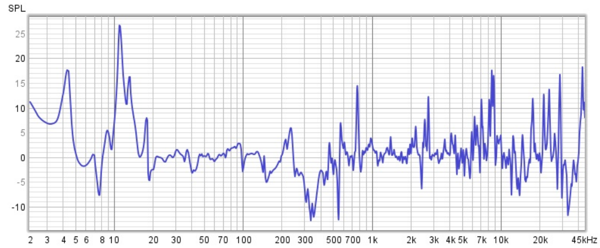

Figure 17. Effect of a VIBE 1 microphone on the frequency response.

There is a spike of 27 dB at 11 Hz. The change seems random, but the general outline stays the same. Again we adjusted the scale to the hearing range:

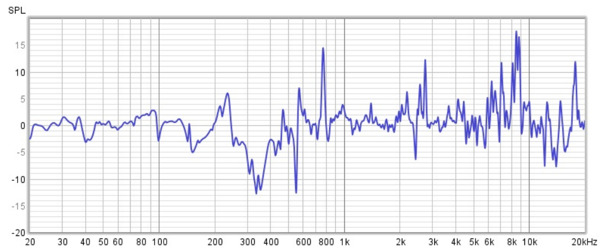

Figure 18. Effect of a VIBE 1 microphone on the frequency response in the hearing range.

It is worth mentioning the drops in amplitude at 350 Hz and 550 Hz, which amount to about -13 dB. It is also worth mentioning the peaks at 750 Hz, 2.8 kHz, 7.1 kHz, 8.1 kHz, 8.5 kHz, 8.9 kHz, 17.8 kHz, which can reach up to 17 dB.

F. Frequency Response From a Recording

Using the second measuring method we recorded the audio of an acoustic guitar. We recorded a strum of an A major chord with a 4513 accelerometer, a VIBE 1 microphone and a 4189 microphone, which was 33 cm away from the acoustic guitar:

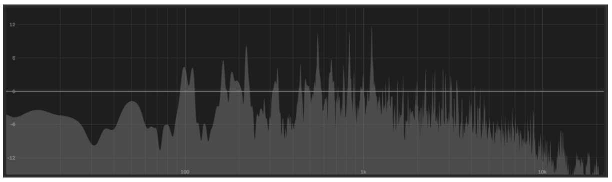

Figure 19. Graphic EQ plot from Ableton Live of an A major chord recorded with a 4513 accelerometer.

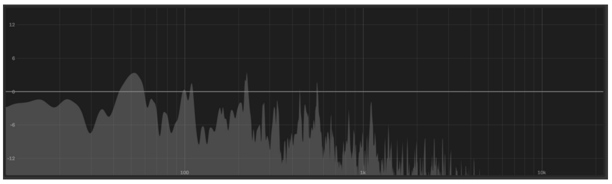

Figure 20. Graphic EQ plot from Ableton Live of an A major chord recorded with a VIBE 1 microphone.

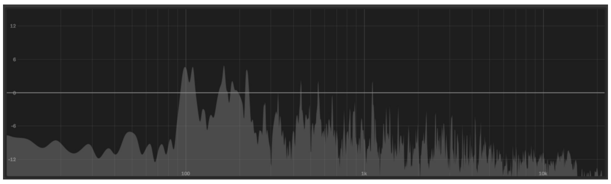

Figure 21. Graphic EQ plot from Ableton Live of an A major chord recorded with a 4189 microphone.

We can see the cut off at the high frequencies on figure 20. The VIBE 1 microphone has a much lower output signal than the 4513 accelerometer and the 4189 microphone. The 4513 accelerometer reached a peak value of -0.06 dB, the VIBE 1 reached -19.4 dB and the 4189 microphone reached -16.2 dB. Their noise floors were -75.0 dB, -83.8 dB and -55.9 dB respectively.

G. *Temperature Dependence of Frequency Response*

Another question that came up was, how does the frequency response change with the temperature. Musicians often perform outside, where temperatures can vary from negative tens to positive forties. We did not want to damage any of musical instruments or measuring equipment. That is why, we measured with a 4810 Mini-shaker in it's operating temperature range (5 to 40 °C). We quickly noticed this is not an acoustically dead room and heard a lot of noise. We measured the noise in an open and closed temperature chamber:

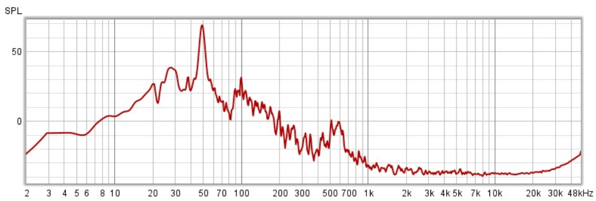

Figure 22. Noise in an open temperature chamber.

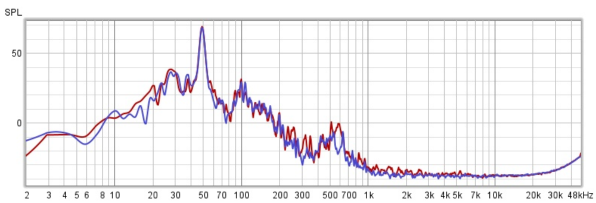

Figure 23. Noise in a closed temperature chamber with the previous measurement.

Closing the chamber provided little to no noise reduction. Turning the chamber on provided even more noise and vibrations. To dampen this effect, we decided to put different types of sound insulation between the 4810 Mini-shaker and the temperature chamber grilles.

The biggest noise reduction was with just the foam and when the chamber being closed as it is shown in figure 28. The only unwanted effect was the noise from 3 to 10 Hz. But that does not bother us, since that is not in the hearing range.

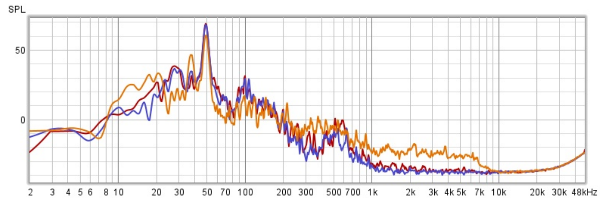

Figure 24. Noise in an open temperature chamber with a wood block and foam as insulation with the previous measurements.

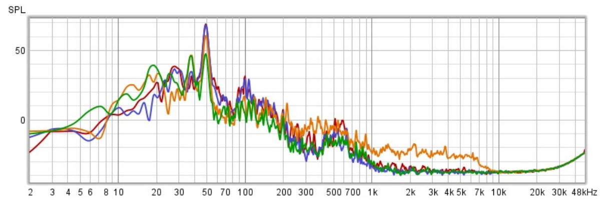

Figure 25. Noise in a closed temperature chamber with a wood block and foam as insulation with the previous measurements.

This also reduced the noise of the electrical network at 50 Hz by 24 dB. We decided to keep just the foam.

Turning the chamber on resulted in even more noise. It is presented in figure 29.

We measured the frequency response of a VIBE 1 microphone with a 4810 Mini-shaker at room temperature (21.3 °C) and plotted it in figure 30.

It is quite similar to the frequency response we measured in the acoustically dead room. We set the temperature to 5 °C, repeated the measurement and plotted the frequency response in figure 31.

There is noise present, especially around 25 Hz. We turned off the temperature chamber to remove it's noise and made a plot of the frequency response in figure 32.

The general shape is quite similar. It does, however, capture more of the higher frequencies and a small resonance frequency at 1 kHz.

We repeated the measurements from 10 to 40 °C with a step of 10 °C and plotted them out in figures 33, 34, 35, 36, 37.

It appears some noise was present while performing the measurement at 20 °C. Unfortunately we can not avoid this in a noisy environment.

The higher frequencies are captured worse with higher temperatures. A dip of 15 dB appears at 3 kHz in figure 36. That is probably because of the adhesive heating up, which lead to the microphone losing contact.

To confirm the repetability of the measurements we did the same with a 4513 accelerometer as shown in figures 38 and 39.

V. Challenges and Constraints in Measurement

We would also like to discern, if there is any directional sensitivity. For now, we do not know how to repeatably measure this, since we need a homogeneous acoustic surface and the same level of amplitude. There is also the challenge of measuring it's maximum SPL. What is considered as SPL with a contact microphone? What is it's max value? When the

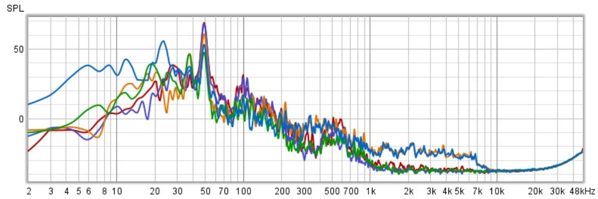

Figure 26. Noise in an open temperature chamber with just foam as insulation with the previous measurements.

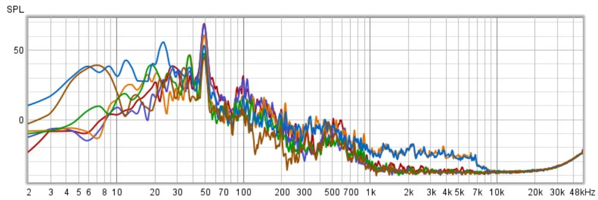

Figure 27. Noise in a closed temperature chamber with just foam as insulation with the previous measurements.

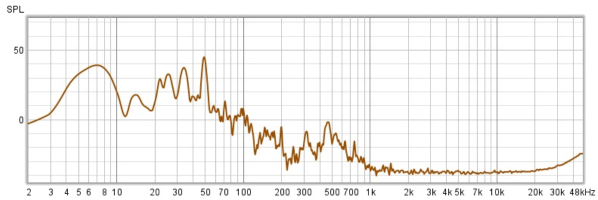

Figure 28. Noise in a closed temperature chamber with just the foam as insulation.

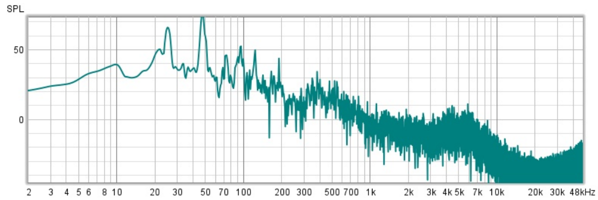

Figure 29. Noise in a tunning chamber

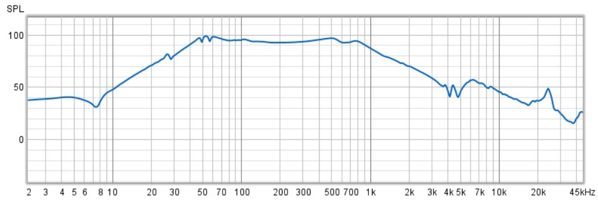

Figure 30. Frequency response of a VIBE 1 microphone at room temperature.

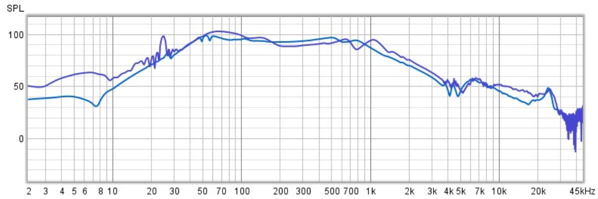

Figure 31. Frequency response of a VIBE 1 microphone at 5 °C and at room temperature with the running temperature chamber.

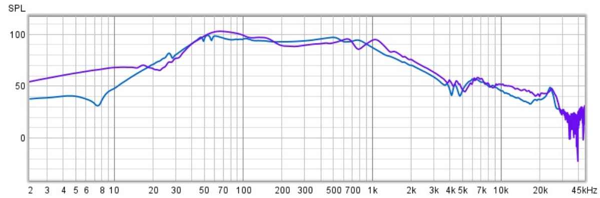

Figure 32. Frequency response of a VIBE 1 microphone at 5 °C and at room temperature with the temperature chamber turned off.

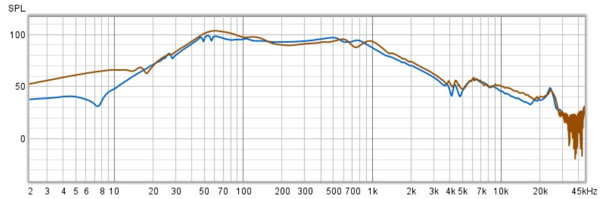

Figure 33. Frequency response of a VIBE 1 microphone at 10 °C.

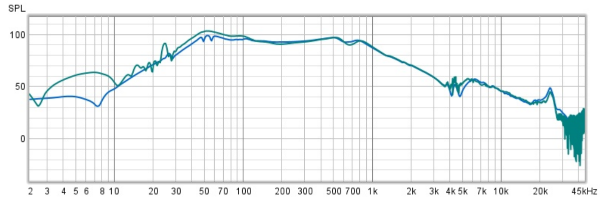

Figure 34. Frequency response of a VIBE 1 microphone at 20 °C.

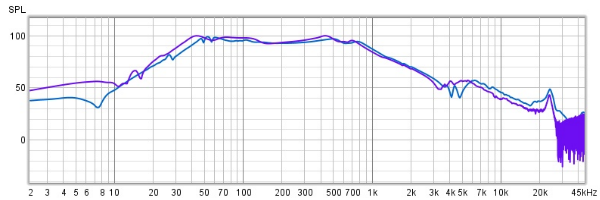

Figure 35. Frequency response of a VIBE 1 microphone at 30 °C.

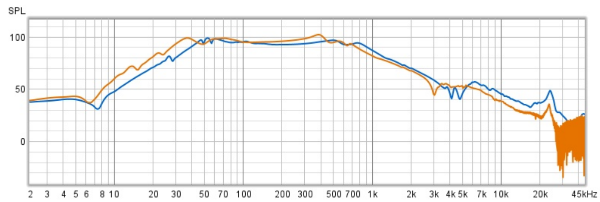

Figure 36. Frequency response of a VIBE 1 microphone at 40 °C.

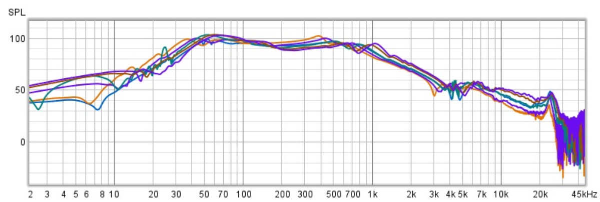

Figure 37. Frequency responses of a VIBE 1 microphone from 5 to 40 °C.

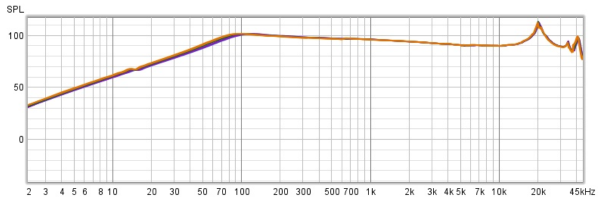

Figure 38. Frequency responses of a 4513 accelerometer from 5 to 40 °C.

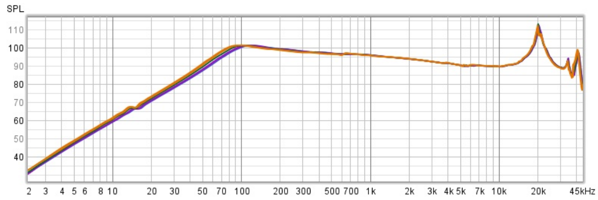

Figure 39. Frequency responses of a 4513 accelerometer from 5 to 40 °C with an adjusted scale.

microphone falls of the surface? When there is a certain level of distortion?

We would also like to see the change in a VIBE 1 microphone's frequency response, when it is placed somewhere else on an instrument. There is one way of measuring it with many VIBE 1 microphones attached to the body of the instrument, but that would change the frequency response of the instrument and the frequency responses of other microphones. We could move the same microphone along the body of the instrument, but since we can not guarantee the same playing of the instrument, we would be dealing with different input signals and therefore with different frequency responses.

The physical features are an important aspect to measure and maybe improve. With this we mean the size and mass of the contact microphone. Yet there is an important factor of aesthetics that comes with the VIBE 1 microphone. Changing it's size, mass and design would probably also change it's frequency response.

VI. Conclusions and Further Research

We measured the parameters of a VIBE 1 contact microphone. There are a lot of uncertainties with a contact microphone. We are keen on finding out, what we can guarantee and what we can't.

It's frequency response is quite flat up to 1 kHz. There is a drop in high frequencies. We tested it next to some of the best measuring devices. This was not meant as a comparison, but to see what was the actual input signal of the microphone. This was also done to prove the repeatability of the measurement conditions.

We are interested in other measurements with different models and techniques. We are keen on using different instruments and various ways of recording with a contact microphone. It would also be interesting to compare it to other microphones of the same price range, some standard studio recording or live concert microphones or other piezoelectric contact microphones. We would also like to measure different VIBE 1 microphones and the deviation between their production.

We tested the VIBE 1 microphone's temperature dependence, but we haven't measured it's resilience to humidity or any other environmental effects. The impedance of the microphone is an important propriety, but we would also like to measure it's capacitance. Future measurements will probably include measuring it's signal-to-noise ratio and nominal power.

The first step to improving the microphone itself, would be to wrap the casing in a metal foil or graphite spray, which would provide noise reduction. Another improvement would be to make a preamp that would serve as an impedance transformer. A safety improvement could be achieved with 2 diodes to limit the maximal amplitude.

VII. Acknowledgments

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