Sound quality differences between electret film (EMFIT) and piezoelectric under-saddle guitar pickups

Miikka Tikander and Henri Penttinen

1. Laboratory of Acoustics and Signal Processing, Helsinki University of Technology, Otakaari 5, FI-02150 Espoo, Finland

Correspondence should be addressed to Miikka Tikander (miikka.tikander@hut.fi)

ABSTRACT

Two different types of under-saddle guitar pickups, piezoelectric and electret film (EMFIT) were measured and compared. The measurements included comparisons of magnitude, time, and phase responses, distortion and noise characteristics. The measurements were conducted with a custom rig that allowed accurate control of the environment. For excitation both frequency sweeps and impulsive stimuli were used. As for the magnitude response, the piezoelectric pickup has a boosted bass response and a slightly pronounced high frequency response. The results also imply nonlinear behaviour as a function of both the excitation type (sweep vs. impulsive) and the amount of excitation force (small vs. large). In addition, the piezoelectric microphone is fairly immune to tension changes, whereas the sensitivity of the EMMFIT microphone increases as the tension decreases. For time responses excited impulsively the only differences were found at the beginning of the responses. The distortion and noise characteristics of the measurements imply, that the EMMFIT microphone has slightly more distortion and a slightly higher noise floor. A linear filter model is also proposed for making either microphone sound like the other.

1. INTRODUCTION

Majority of under-saddle pickups used in acoustic guitars are made of piezoelectric material. Recently, under-saddle microphones made of electromechanical film (EMFIT) have also appeared on the market.

Both technologies transform pressure applied to the pickup to a charge change on the surface of the material. The pressure exerted on the pickup originates from the strings through the bridge, and also from the guitar sound board bending as the guitar body resonates.

Piezoelectric materials generate an electric charge
when they are deformed. This is due to changes in the internal polarization of a dielectric material. EMFIT, on the other hand, works more like a condenser microphone. The film consists of thin polymer layers separated by air bubbles. When pressure is applied, the thickness of the film changes, and also the charge on the surface changes. Both technologies are reciprocity in nature and thus can be used as sensors as well as actuators. For deeper insight of the physics of the piezoelectric and electret film transducer technologies one may see e.g., [1, 4] for EMFIT, and [7, 6] for piezoelectricity.

These two microphone types sound different. When the characteristics of both microphone types are known one could form a filter to make the other microphone sound like the other, and vice versa. This kind of instrument or sound device modeling has gained a huge popularity in recent years. There are already a huge amount of different kinds of modeling devices for instruments, amplifiers, and effects on the market. There are also guitars (electric and acoustic) with on-board signal processors to model different kinds of guitars with just a switch of a knob. However, guitar pickup modeling has mainly concentrated on making a humbucker coil microphone to sound like a single-coil pickup, and vice versa. Also some sort of acoustic guitar model (for electric guitars) is often available in many modeling devices, though these mainly concentrate on modeling the sound of the acoustics guitar, rather than the microphone of a certain type in an acoustics guitar. Very few, if any, modeling devices offer the ability to model different kinds of under-saddle pickups, especially the EMFIT type of under-saddle transducers. Some research on the capabilities and possibilities of electret film type of microphones have been done, e.g., in [2, 5]. The authors have not found any research specifically comparing piezoelectric and EMFIT type of microphones in guitars or other instruments.

In normal guitar playing, guitar microphones are exposed to different kinds of excitations and string loads. Actual plucking events can vary from very impulsive plucks to soft playing. On the other hand, after a string has been plucked and is allowed to decay freely, a more constant excitation is applied to the microphone. Also, different string thicknesses and musical tunings have an effect on how hard the strings press the bridge against the microphones. For this reason both frequency sweeps and impulsive stimuli were used as excitation signals in the measurements, and the measurements were repeated with different string loads.

The goal of this study was to find and identify the differences between these two under-saddle pickup transducer technologies. Also, as an application a filter for modeling piezoelectric pickup with an EMFIT pickup, and vice versa, is introduced.

The structure of this paper is as follows. Section 2 introduces the custom measurement setup used in the measurements. Section 3 and 4 report the frequency and time responses of the microphones and especially the differences of the microphones. Distortion and noises analysis is considered in Section 5, and Section 6 introduces a filter model from one microphone to another. Finally, in Section 7 some discussion and conclusion are drawn.

2. THE MEASUREMENT SETUP

A custom made measurement device was built for measuring the microphones. The measurement device was designed to provide a guitar-like environment for the microphones, and also different string tensions could be simulated easily, without removing the microphones.

2.1. Measurement device

The custom made measurement device, shown in Fig. 2, consisted of two plates and a weight. The pickups were placed between the plates, on top of each other. This way both microphones were exposed to same tension and the microphones received the excitation signal exactly the same time, which is necessary for temporal inspection and comparison of the microphones. The lower plate was laminated chipboard and thus provided a flat surface for the pickups, and the top plate was birch. For the measurements the device was placed between two tables, with a 5 cm space between the tables, so that each table supported one side of the measurement device. As shown in Fig. 2, two screws go through both plates (screw diameter was smaller than the hole, thus the screws can move up and down freely). The upper ends of the screws are anchored at the top of the top plate by washers, and at the lower end the
Fig. 1: Pickups used in the measurement were B-Band UST 29L under-saddle electret film transducer and A1 preamplifier, and L.R. Baggs The Element Active System under-saddle transducer with a preamplifier. The transducer elements are shown in the figure placed on the measurement device (The L.R Baggs is placed on top, and the B-Band on bottom). Note that during the measurements the elements were placed on top of each other.

screws are attached to a vertical metal bar holding a weight. By changing the weight the tension between the plates could be varied. This way different string tensions could be simulated.

2.2 Measurement setup
The whole measurement setup is shown in Fig. 2. A laptop with WinMLS software and a Digigram VX Pocket v2 audio card was used to perform the measurements. In the measurements, a force transducer [3] was used to excite the surface of the measuring device. The force transducer consists of a tube with a coil wound around the tube at one end. A very small magnet (2 mm x 2 mm x 2 mm) was attached on the surface of the top plate with bee-wax. The force transducer tube was positioned very close to the surface of the measurement device, and the magnet was left nearly completely inside the tube. A laser vibrometer (Polytec OFV 3001 S Vibrometer Controller, and 303 Sensor Head) was used to detect the vibrations at surface that was excited with the transducer. The laser detected the surface vibration at the center position of the microphones, 7 mm from the excitation point. The laser vibrometer signal was used as the reference excitation signal in the analysis state.

The microphones were connected to preamplifiers that came bundled with the transducer elements. The preamplifier for the EMFIT pickup did not have a volume control and thus the output of the amplifier was used as such. The preamplifier of the piezoelectric pickup had a volume knob, and for the measurements the volume was set to about 90% of the full volume to leave a safety margin from possible full gain level artifacts.

3. FREQUENCY RESPONSE ANALYSIS
Frequency responses were measured with two different kinds of excitation signals, a logarithmic sweep and an impulse. This allowed to compare the responses of the microphones for different excitation

Fig. 2: Schematic view of the measurement setup.
For impulsive excitation, the surface was tapped with a drill bit. The frequency responses were computed by comparing the microphone output signal to the actual surface vibration detected by the laser vibrometer. First, the microphones were measured individually, i.e., one microphone at a time.

It should be noted that, when the measurements are performed as described above, the results include the transfer characteristics of the microphone but also the transfer function from the surface of the measurement device to the microphone. The effect of the measurement device in the measurements is hard to diminish without losing the guitar-like environment for the microphones. These measurements were performed to obtain the overall frequency response of the microphones.

In order to get a clean transfer function (no artifacts from the measurement device) from one microphone to another, a comparison measurement was performed. The measurements were performed with the same excitation signals as the above frequency response measurements, but now the transfer function was computed by comparing the output signal of one microphone to another. A major advantage in this method over the frequency response measurement is that the measurement device does not affect the results. The excitation signal detected by the microphones is modified by the measurement device the same way for both microphones and the effect of the measuring device is automatically canceled when computing the transfer function from one microphone to another.

In the following all transfer function measurements are computed by using the EMFIT microphone as reference. In other words, the transfer functions tell how the EMFIT microphone should be equalized to make it sound like the piezoelectric microphone.

3.1. Frequency responses

Figs. 3 and 4 show the power spectral densities of the piezoelectric and EMFIT microphones used in this study. Measurements were performed with 9 kg, 16 kg, 25 kg, 34 kg, and 40 kg loadings, and a logarithmic sweep was used as excitation. Octave smoothing has been applied to the responses. Notches at around 1.4 kHz and around 5 kHz are most probably caused by the measurement device. Fig. 6 shows the differences in the magnitude spectra of the microphones. When computing the difference the EMFIT microphone has been used as reference. The results show that the piezoelectric microphone has a boosted bass response, and also slightly pronounced high frequency response.

The magnitude difference in Fig. 5 was computed by
Fig. 5: Power spectral density differences between the microphones for 16 kg, 25 kg, 34 kg, and 40 kg loads. EMFIT microphone has been used as reference.

using individual frequency response measurements of both microphones. Fig. 6 shows the results for a direct transfer function measurement, i.e., the outputs of both microphones was recorded, and the piezoelectric microphone signal was compared to the EMFIT microphone signal. A logarithmic sweep was used as excitation signal. Top panel shows the magnitude spectra differences for different loads, and the lower panel show the phase differences of corresponding measurements. The magnitude responses reveal the same observations as mentioned above, the piezoelectric microphone has a boosted bass response up to about 1 kHz, and also a boosted high frequency response starting at around 4 kHz. The peaks close to 4 kHz are most probably artifact’s due to measuring device. There is also quite deep notch at 1 kHz. The notch is consistent with different loads and therefore it could be a real difference between the microphones. By looking back at Figs. 3 and 4 deeper notches at this frequency are seen in piezoelectric microphone’s responses. However, this could also be due to a resonance in the measuring device.

The same comparison measurement was also performed with a transient excitation. A drill bit was used to knock the surface of the top plate at the same place where the force transducer was applied to, and the piezoelectric microphone signal was compared with the EMFIT microphone signal. Measurements were performed only with 25 kg and 43 kg loads. Fig. 7 shows the results of the measurement. The low frequency behavior is similar as seen in the results above, but now there is no boost at higher frequencies. This would imply that the microphones behave differently depending on the excitation type.

It was also found out that the frequency responses for transient excitation varied quite a lot depending on the force of the excitation. Figs. 8 and 9 show the frequency responses of both microphones for a group of drill bit knocks. Fig. 8 shows the responses of the piezoelectric microphone with 34 kg and 43 kg loads, and Fig. 9 the same results for the EMFIT
microphone. The microphone signals were recorded simultaneously, thus both microphones received the same excitation signal. The magnitude responses are normalized to 0 dB, though the magnitude of the excitation varied between knocks. It can be clearly seen that the level of the low frequency (below 700 Hz) changes a lot between responses.

3.2. Sensitivity
By looking at Figs. 3 and 4, one can see that the piezoelectric microphone is fairly immune to the amount of loading, whereas the sensitivity of the EMFIT microphone increases as the load decreases. This phenomena is also clearly seen in comparison measurements shown in Fig. 6.

The piezoelectric microphone response for a 9 kg load is slightly different compared to other loads. It could be that 9 kg does not provide enough tension for a proper coupling of the microphone to the measurement device. For the EMFIT microphone the 9 kg is still working normally. Because of improper coupling with piezoelectric microphone comparison measurements were not performed for 9 kg loads.

4. TIME RESPONSE ANALYSIS

The previous section showed that the frequency responses of the microphones varied depending on excitation signal. Figs. 10 and 11 show first few milliseconds of temporal responses to a transient excitations for 34 kg and 43 kg loads. The data is from the transient frequency response measurements described above. Because the microphones originally had opposite phasing the phase of the other microphone was switched to enable direct comparison.

The most notable difference in the transient time responses is the difference of the magnitude of the first upward slope of the response. This could explain the difference in the low frequency responses shown in Fig. 7, and in Figs. 3 and 4. Some preliminary simulations were made that gave some confirmation to this assumptions. However, the effect of the first slope was left for later work.
Fig. 9: Frequency responses of the EMFIT microphone for transient excitation. Responses are normalized to 0 dB. For clarity responses for 34 kg load are shifted upward 40 dB, and the responses for 43 kg below.

5. DISTORTION AND NOISE ANALYSIS

The harmonic distortion of the microphones was measured at three different point frequencies (80 Hz, 110 Hz, and 220 Hz) while using a 34kg. The force transducer was used to excite the surface of the custom measurement device at one frequency at time and the microphone signals were recorded simultaneously from both microphones. A thirty seconds long continuous sinusoid was used as excitation signal. For reference, the excitation signal was also directly routed to the third input channel of the sound card.

5.1 Harmonic distortion

The harmonic distortion was computed by inspecting the fourier transform of the recorded sinusoids.

Fig. 10: Response to an impulsive excitation. Dashed line piezo, and solid line EMFI. The loading for the microphones was 34 kg.

Fig. 11: Response to an impulsive excitation. Dashed line piezo, and solid line EMFI. The loading for the microphones was 43 kg.
Table 1: Total harmonic distortion (THD) measured with 34 kg load.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>EMFIT</th>
<th>piezo</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 Hz</td>
<td>0.32 %</td>
<td>0.13 %</td>
</tr>
<tr>
<td>110 Hz</td>
<td>0.43 %</td>
<td>0.25 %</td>
</tr>
<tr>
<td>210 Hz</td>
<td>0.22 %</td>
<td>0.13 %</td>
</tr>
</tbody>
</table>

After transforming the recorded signals into the frequency domain, all signals were normalized to have unity gain at the measurement frequency (80 Hz, 110 Hz, or 210 Hz). Then the levels of the harmonic components were measured. All the harmonic components above the noise floor were used for the computations. However, only few components were eventually found. Table 1 lists the total harmonic distortion of both microphones at the measured frequencies. The EMFIT microphone has slightly more harmonic distortion at each measured frequency.

Fig. 12 shows all orders of the harmonic distortion components that were found in the measurements. The level of the measurement frequency was normalized to 0 dB. The overall characteristics of harmonic distortion for both microphones is similar, at 80 and 110 Hz the second order harmonic is dominant, and at 210 Hz the third order harmonic is dominating. The fifth order harmonic distortion component was the highest order component that was still reliably found that was not at the noise floor level.

The harmonic distortion of the reference channel (the sound card) was also measured. However, all orders of the distortion components were below -100 dB, and all harmonic components were well below the noise floor of the microphones. Thus it was assumed that the sound card had no effect on the distortion measurements.

5.2. Noise floor

The noise performance of the microphones were also measured. Figure 13 shows the noise floor of the microphones, and also the noise floor of the sound card used in the measurements. The noise floor was measured by recording the microphone outputs for thirty second without any excitation. The setup and the levels were exactly the same as were with the
Fig. 13: Noise floor of the microphones and sound card used in the measurements. Dashed line is the EMFIT, and solid line is the piezoelectric. The solid line at the bottom is the noise floor of the sound card.

Fig. 14: Difference in noise floors between the microphones. Piezoelectric has been used as reference, i.e., this tells how much noisier EMFI-microphone is.

and the relative difference in the results remains unaffected.

6. MODELING THE MICROPHONES

The transfer function from the EMFIT microphone to the piezo microphone was modeled with a parametric digital filter. Fig. 15 shows magnitude responses of the target response (solid) and model filter. The target response is the average of the responses shown in Fig. 6. The model filter is a parametric EQ filter that constitutes of cascaded second order peak and shelving filters discussed in [8] (on pp. 117 - 125). A linear prediction model was also designed but more accurate and computationally cheaper results were obtained with the manually tuned parametric EQ filters. The parameter values; corner frequency ($f_c$), gain ($G$), and $Q$-value; for the filters are presented in Table 2. The parametric EQ filter can model the main characteristics of the target response. The details can be modeled either by increasing the number of parametric filters or by using a long FIR filter obtained by properly windowing the time response of the target response.

7. DISCUSSION AND CONCLUSIONS

When measuring microphones like these it is important that the measurement conditions (for the
Fig. 15: Magnitude responses of the target response (solid) and parametric EQ filter (dashed) that approximate the transfer function from the piezo to the EMFIT microphone.

<table>
<thead>
<tr>
<th>Type</th>
<th>$f_c$ (Hz)</th>
<th>$G$ (dB)</th>
<th>$Q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bass boost</td>
<td>75</td>
<td>9</td>
<td>1.5</td>
</tr>
<tr>
<td>Middle cut</td>
<td>1000</td>
<td>-5</td>
<td>2.5</td>
</tr>
<tr>
<td>Middle cut</td>
<td>2500</td>
<td>-5</td>
<td>2.5</td>
</tr>
<tr>
<td>High boost</td>
<td>16000</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>High shelving</td>
<td>10000</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Parameter values of the second order cascaded EQ filters.

microphones) are close to the real world situation when they are attached to a guitar. This way the results would estimate the behavior of the microphone as an under-saddle guitar microphone at its best. However, the more realistic measurement environment, the more the measurement setup affects the results, and it is harder to determine the effect of the microphone in the results. The custom measurement device used in these measurements was build to mimic the under-saddle environment in an acoustic guitar, without the strong resonances present in acoustic guitars. However, the transfer characteristics of the measurement device (from surface to the microphone) was left unknown and therefore the results shown here, strictly speaking, corresponds only to this kind of a setup.

Also, the microphone systems used in this study consisted of a combination of the transducer itself and a separate preamplifier unit. The preamplifiers were not measured in this work and the effect of the preamplifier was left unknown, rather the microphone systems were measured as whole. For this reason these result do not necessary reveal the characteristics of specific transducer technologies (in our case, EMFIT and piezoelectric) but only the characteristics of these microphone systems.

As conclusions we sum up the results obtained from the conducted measurements. The magnitude response measurements imply that the piezoelectric pickup has a boosted bass response and a slightly pronounced high frequency response compared to the EMFIT microphone. Phase responses for both microphones are very similar. The magnitude responses are slightly different for sweep and impulsive type of excitation signals. The pronounced high frequency response for piezoelectric microphone reported above is not present in the results obtained using impulsive excitation signals.

The EMFIT microphone is more sensitive to string tension changes, whereas the piezoelectric microphone is fairly immune to changes in string tension (within the string tension range used in the measurements). The sensitivity of both microphones varied below 1 kHz depending on the amount of excitation force. A change in the excitation force caused a change in the tilt of the bass response. Also, a difference in the level of the first incoming pulse was found. So that, the level of the pulse in the piezoelectric microphone was larger than in the EMFIT microphone.

In addition to the results, a linear filter model is proposed for making either microphone sound like the other. This filter approximates the transfer function from one microphone to the other and acts as a high-order equalizer. The filter can be used for modeling purposes or as an effect. Naturally this filter model cannot approximate any nonlinear differences present in the microphones.

8. REFERENCES


