More acoustic sounding timbre from guitar pickups

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Abstract

Amplified guitars with pickups tend to sound 'dry' and electric, whether the instrument is acoustic or electric. Vibration or pressure sensing pickups for acoustic guitars do not capture the body vibrations with fidelity and in the electric guitar with magnetic pickups there often is no resonating body at all. Especially with an acoustic guitar there is a need to reinforce the sound by retaining the natural acoustic timbre. In this study we have explored the use of DSP equalization to make the signal from the pickup sound more acoustic. Both acoustic and electric guitar pickups are studied. Different digital filters to simulate acoustic sound are compared, and related estimation techniques for filter parameters are discussed.

1 Introduction

It was shown experimentally in a previous study that an acoustic guitar with an under-saddle bridge pickup can be successfully equalized with a high-order digital filter to sound quite close to the same guitar's acoustic radiation [1]. A high-quality elastic electret pickup based on an electromechanical film transducer (EMFi[1]) [2], as produced in the B-Band[1] transducer, was used.

The assumption behind the equalization idea is that the body of the acoustic guitar acts as a linear and time-invariant (LTI) filter that can be approximated by a digital filter. A signal path diagram of the system under study is shown in Fig. 1. The pickup output $x(t)$ is assumed to be proportional to the bridge velocity. An estimate of the impulse response of the guitar body, i.e., signal transmission from bridge signal $x(t)$ to air radiation $p(t)$, is needed for implementing an equalization filter that simulates the body response which is not exhibited in the bridge pickup output signal $x(t)$ but should be effective in the equalizer output (EQ OUT). In [1] we discussed also the limitations of such simulation since the pickup cannot capture all signal paths.

In this paper we study the equalization of the acoustic guitar EMFi pickup output a bit further and the equalization of the magnetic pickup signal of an electric guitar in order to simulate acoustic guitar sound.

2 EQ of acoustic guitar pickup

In [1] we first estimated the EQ filter target response by an impact hammer excitation to the bridge. However, better results were achieved by using normal but spectrally rich playing of the guitar as an excitation signal. The target response of the EQ filter is computed simply by deconvolving $p(t)$ and $x(t)$ in the frequency domain

$$H_{\text{eq}}(\omega) = \frac{P(\omega)}{X(\omega)} \qquad (1)$$

The impulse response from inverse FFT of $H(\omega)$ is noisy and needs careful windowing to get a useful starting point for filter design. Figure 2 depicts the target response of the EQ filter for a flat-top guitar with metal strings, equipped with an EMFi pickup: in Fig. 2a is the impulse response and in 2b is the magnitude response. Essential factors in the response are the individual body modes at low frequencies, especially below 200 Hz, and the reverberation-like decay tail at mid and high frequencies.

In [1] we applied different digital filter design techniques to efficiently approximate the target response. In this paper we do not repeat this but rather study the EQ principles in different cases. All EQ filters discussed here can be implemented as straightforward FIR filters of order below 1000, running in real time on modern signal processors.

In the case of the acoustic guitar we noticed that the magnitude response of Fig. 2b at high frequences is primarily white noise, except for some prominent peaks. We applied notch filtering to remove some major peaks that were considered potentially harmful, but in fact it did not have much impact on the perceived equalized sound.

The most audible remaining difference between the equalized pickup sound and the original guitar sound was that left-hand effects, such as friction hiss produced by moving fingers over strings, were missing. Also the

[1] B-Band$^{\text{TM}}$ and EMFi$^{\text{TM}}$ are trademarks of EMF Acoustics Ltd and its associates.

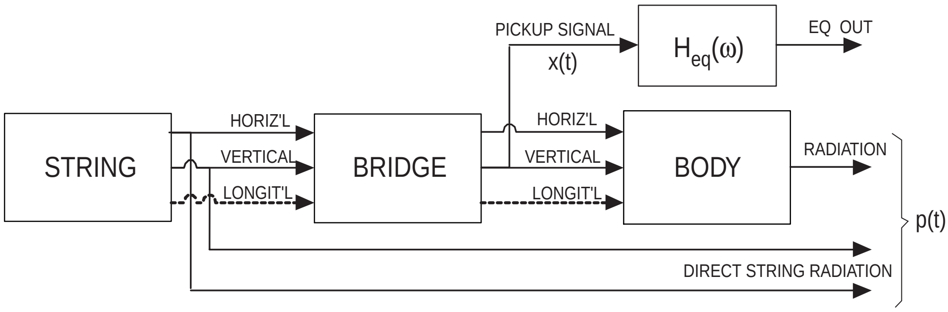

Figure 1: *Signal paths in an acoustic guitar with bridge pickup.*

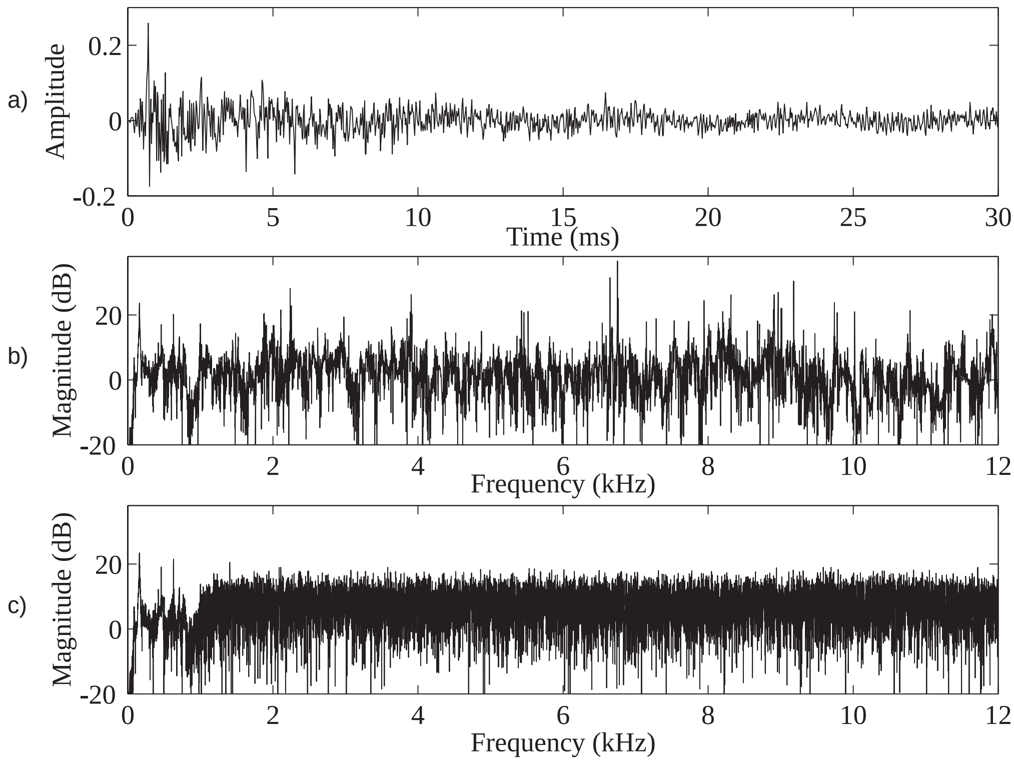

Figure 2: *Equalizer target response: (a) impulse response, (b) magnitude response, and (c) magnitude response with artificial high-frequency part from 1 kHz crossover frequency up.*

attack is a bit different.

Since the mid- to high-frequency part of the impulse response resembles exponentially decaying white noise, it is an interesting idea to replace it by artificial reverberation of such kind. In Fig. 2c we show the magnitude response where at frequencies above 1 kHz the response is replaced with white noise. The results of replacing the high frequencies, especially above 2 kHz, with white Gaussian noise were positive. Even when the crossover frequency was as low as 500 Hz, the result was useful. Some of the originality of acoustic sound was lost, however, and the sound was muffled. By more careful design the acoustic quality of such artificial body reverberation could be improved further.

3 Electric guitar EQ for acoustic sound

An interesting question is how far one can go with similar equalization techniques in order to make the magnetic pickup signal from a solid-body electric guitar sound like an acoustic guitar.

The physical differences between the acoustic and the electric guitar are substantial. The electric guitar used in this study has a solid body, which makes it more rigid than the acoustic guitar. The lack of a soundbox that takes some of the energy, via the bridge and the top plate from a vibrating string, makes the electric guitar less sensitive to acoustic feedback and to have a longer sustain. The guitar manufactures have innovated an extensive amount of different ways to implement the

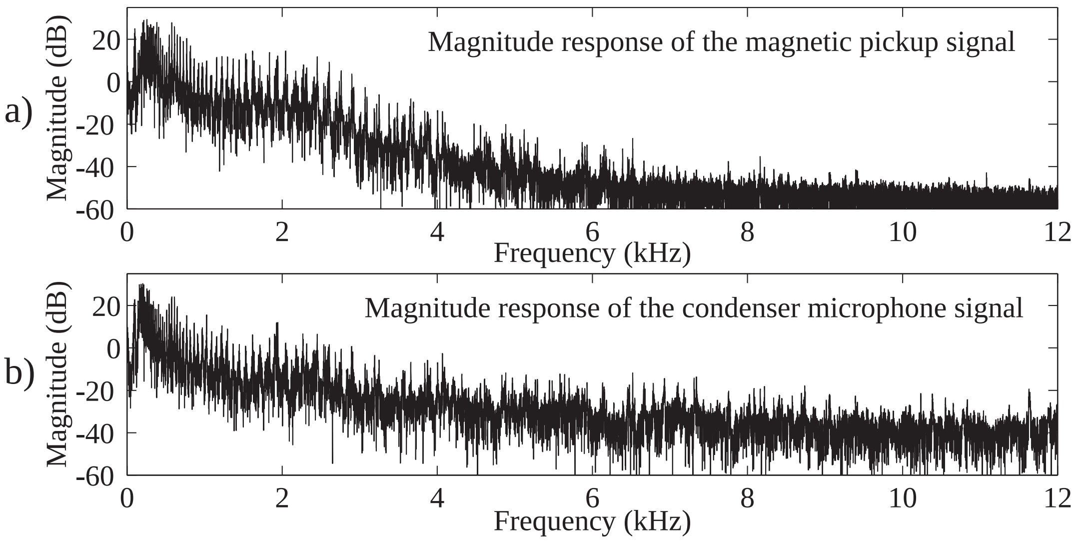

Figure 3: *Magnitude response of (a) magnetic pickup signal and (b) condenser microphone in the measurement setup where a flat-top acoustic guitar was used for electric guitar EQ estimation.*

bridge and the tuning machinery so that the electric guitar has a large number of unique implementations. The strings and their tension varies also in a wide range. Note also that a magnetic pickup reacts basically only to vertical motion, perpendicular to the top plate, and only weakly to horizontal string motion. All these and other facts affect the strings to vibrate in a slightly different manner in each electric guitar type, but definitely differently from a typical acoustic guitar. The biggest audible difference is the long sustain and the reduced amount of beats in the harmonics of an electric guitar sound.

Two fundamentally different estimation techniques were used in this study for making the electric guitar sound more acoustic. In the first method we tried to use an equalizer that was estimated for an acoustic guitar. A body impulse response was obtained by hitting the bridge of the acoustic guitar with an impulse hammer while the strings were muted with a piece of foam. This impulse response was approximated with a digital filter that was the applied to the output of an electric guitar pickup output. Since the electromagnetic pickup can roughly be modeled as a lowpass filter [3] the EQ filter was modified to compensate this by emphasizing the higher frequencies.

The second technique was based on the deconvolution approximation similar to the one used to obtain the EQ filter for the EMFi pickup. A single-coil magnetic pickup was set to the sound hole of a flat-top acoustic guitar with metal strings and a condenser microphone was placed one meter in front of the sound hole. Notice that placing the magnetic pickup in the sound hole will change its area. This lowers the Helmholtz resonance of the guitar body. This on the whole can be thought as an insignificant factor because the difference in the acoustic response is very difficult to observe.

By using the two sensors the magnitude spectra shown in Fig. 3 were obtained as responses to playing a spectrally rich sequence of notes. The lowpass characteristics of the magnetic pickup can be seen in Fig. 3a where the spectrum falls above 3 kHz more rapidly for the pickup than for the acoustic response. (Notice the flat noise floor above about 7 kHz.)

By applying Eq. (1) to the signals obtained from the sensors mentioned in the measurement installation an approximation of the transfer function from the magnetic pick-up to the radiated sound of the flat-top guitar was obtained. If this equalization filter is then applied to a solid-body electric guitar with a similar magnetic pickup there is hope to have an acoustic-like timbre. It is clear that it cannot match any acoustic guitar in detail since so many properties of the electric guitar are different.

The impulse and magnitude response of the transfer function computed using Eq. (1) are illustrated in Fig 4a and 4b, respectively. The spectrum envelope level grows steadily from 2 kHz to about 4 kHz where it reaches a level that is maintained up to the end of the examined spectrum. This high-frequency boost in the EQ filter reverses the lowpass filtering influence of the pickup. The lowest body resonance of the acoustic guitar that the EQ filter will add to the signal of a magnetic pickup can also be seen clearly in Fig 4b.

3.1 EQ performance

The EQ filter obtained from the impact hammer experiment changes the timbre of the electric guitar to the direction of an acoustic guitar. The effect of an acoustic sound box appears which makes the sound fuller and more reverberant compared to the signal coming directly from the magnetic pick up. The emphasis of

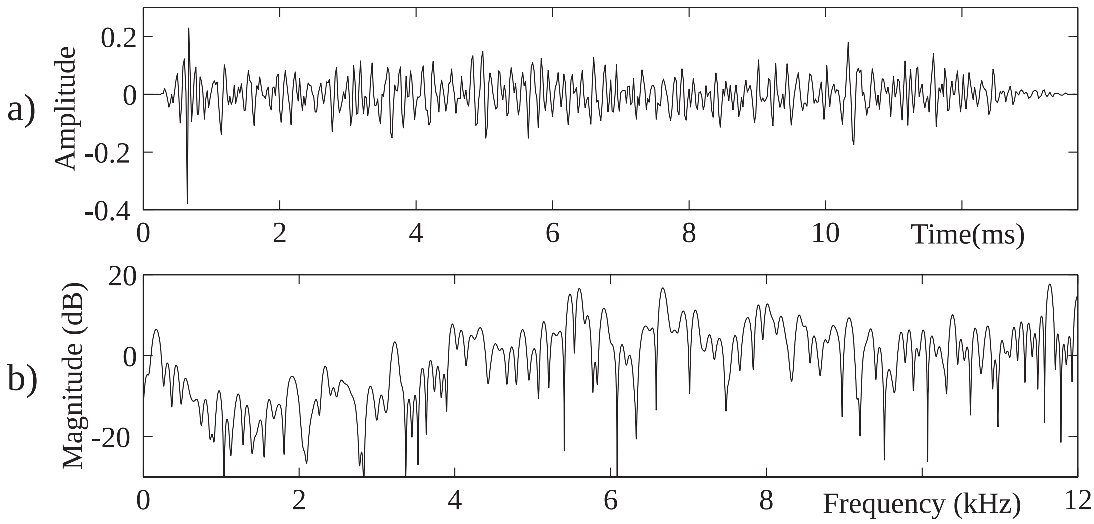

Figure 4: *Result of electric guitar pickup equalizer estimation using the deconvolution method: (a) impulse response and (b) magnitude response.*

higher frequencies also improves slightly the tone but the overall sound is 'nasal' and lacks clarity. A full accuracy FIR filter implementation is in the order of 5000 taps and above, which is very demanding for real-time implementation on the DSP processors available today.

The results achieved with the second method, the deconvolution filter, are much better. The observed sound is much richer and clearer and it does not have the 'nasal' characteristic. The best results for this EQ filter were achieved with an FIR filter of order 750. When using a higher order the perceived equalized sound has an undesired impression of a room reverberation included.

The filter computed by using Eq. (1) approximates the transfer function from the magnetic pickup to the perceived sound of the acoustic guitar. But because several physical differences are present, this filter only very roughly imitates the transfer function from the radiated response of an acoustic guitar to the audible tone from a true electric guitar's magnetic pickup played through an amplifier. Regardless of these factors the perceived response of a clean signal from the magnetic pickup changes distinguishably to a more acoustic guitar-like sound. Some of the clarity of an acoustic guitar in the tone is still absent and the attack is also different. Especially, the long sustain of the electric guitar makes the sound approach a pure electric guitar sound when playing long notes. This can be improved by muting the strings with the palm of the right hand or using damping material below strings close to the bridge.

4 Summary

In this study we have developed techniques to make sound from guitar pickups more acoustic-like. The novelties are to use noise-like reverberation tail for acoustic guitar body simulation at mid to high frequencies and method to estimate and realize an equalization filter for the electric guitar with a magnetic pickup. All these techniques were found successful to create more acoustic-like timbre.

5 Acknowledgements

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