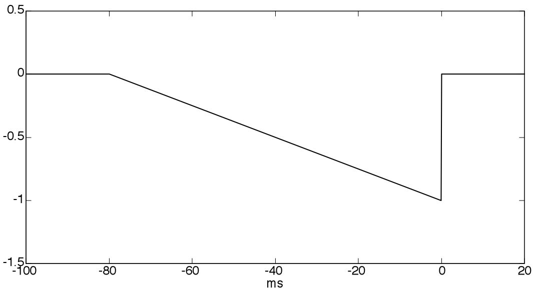
1.5.2 Influence of the plectrum

It is most purposeful to discuss the effects of the plucking process on the sound in the frequency domain (**Fig. 1.27**). The force impulse shown in the figure has an arbitrary duration of T = 80 ms; $\hat{F}$ is the maximum value (negative in the present case). F_S describes the spectrum corresponding to this sawtooth impulse, and F_δ pertains to the time-derivative of the sawtooth impulse. Within the frequency range pertinent to the guitar it makes no big difference whether the impulse starts at –80 ms (as it does in the figure) or much earlier … it is only important that the actual step occurs at t = 0. For this reason, we use the term **step excitation** despite the fact that strictly speaking we have an impulse. We obtain the mathematically correct limiting case as T moves towards ∞; the first fraction in the spectral function vanishes in this case and – with $1/j\omega$ – a pure (rectangular) step-function remains. The time-derivative of this ideal step is the **Dirac impulse** that corresponds to a constant (white) spectrum F_δ. In systems theory, (Dirac-) impulse excitation and impulse response are most commonly used; step excitation and step response are somewhat closer to the practical application. Disregarding the frequency f = 0 that does not actually exist, both descriptions are equivalent and may be converted from one to the other.



$$F_S(j\omega) = \hat{F}\left(\frac{1-\exp(j\omega T)}{\omega^2 T} - \frac{1}{j\omega}\right)$$

$$F_\delta(j\omega) = \hat{F}\left(j\frac{1-\exp(j\omega T)}{\omega T} - 1\right)$$

Fig. 1.27: Sawtooth impulse: time- and spectral-function

Because in reality the force process occurring upon plucking does not correspond to the depiction in Fig. 1.27, we define a **plectrum-filter** that shapes the actual force process from the theoretical rectangular step. The magnitude of the frequency response this plectrum-filter has describes the impact of the plucking process onto the sound.

The following figures show the analyses for the already mentioned Ovation guitar. The low E-string was plucked with a thin nylon-pick (Meazzi 19), while the piezo-signal was fed directly into a high-impedance measuring amplifier – and cleared of the dispersion via de-convolution with an inverse all-pass (Chapter 1.3.2) **Fig. 1.28** shows two time functions obtained that way. Compared to Fig. 1.27, there are several striking differences: the force increase (in terms of its amount) is not linear but progressive; during the last few milliseconds several peaks appear (slip-stick); after the step, reflections are visible that presumably are caused by longitudinal resonances.

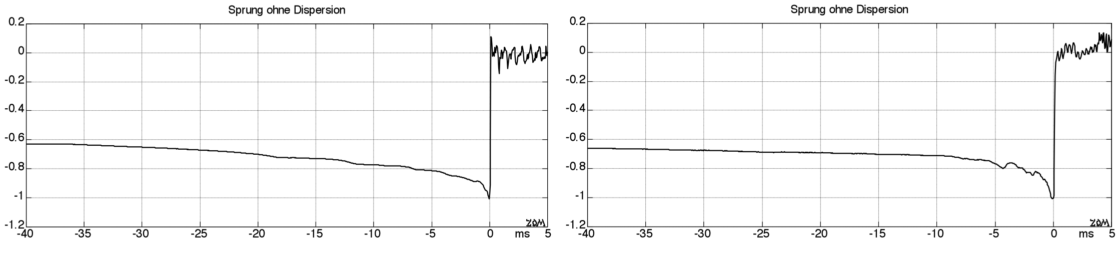


Fig. 1.28: De-convolved piezo-signal; two different plucking processes.
"Sprung ohne Dispersion" = step without dispersion.

In **Fig. 1.29** we see different plucking processes in comparison. The left-hand column shows the dispersion-free, de-convolved piezo-signal while the right-hand column shows the magnitude spectrum belonging to the differentiated piezo-signal. The derivative makes for an easier evaluation: the ideal rectangular step is linked to a constant (white) spectral function.

The first line a) depicts an almost perfect step. Only from about 3 kHz, a treble loss occurs; it is connected to the rounding off of the step. There may be several reasons for this: the tip of the plectrum is rounded off, and therefore the string is not displaced in an exactly triangular manner. This effect is probably further increased by the bending stiffness of the string. The high frequencies are consequently attenuated already in the excitation signal. In addition, dispersion effects in the string need to be considered that also manifest themselves in the high frequency range.

In the case of b), the force rises to its magnitude maximum only during the very last milliseconds. This will occur if the plectrum has a high angle of attack and moves in parallel to the guitar top. The shape is more impulse-like, and in the spectrum the bass is attenuated.

The analyses c) to e) indicate a progressive treble damping as it is typical for a round, hard plectrum.

For the remaining analyses, the force increases first (in its magnitude) and then moves through a magnitude minimum (the force acts in the negative direction). Presumably, this includes a sliding along the string of the plectrum, the latter getting stuck on the string for a short time and then finally separating from the string.

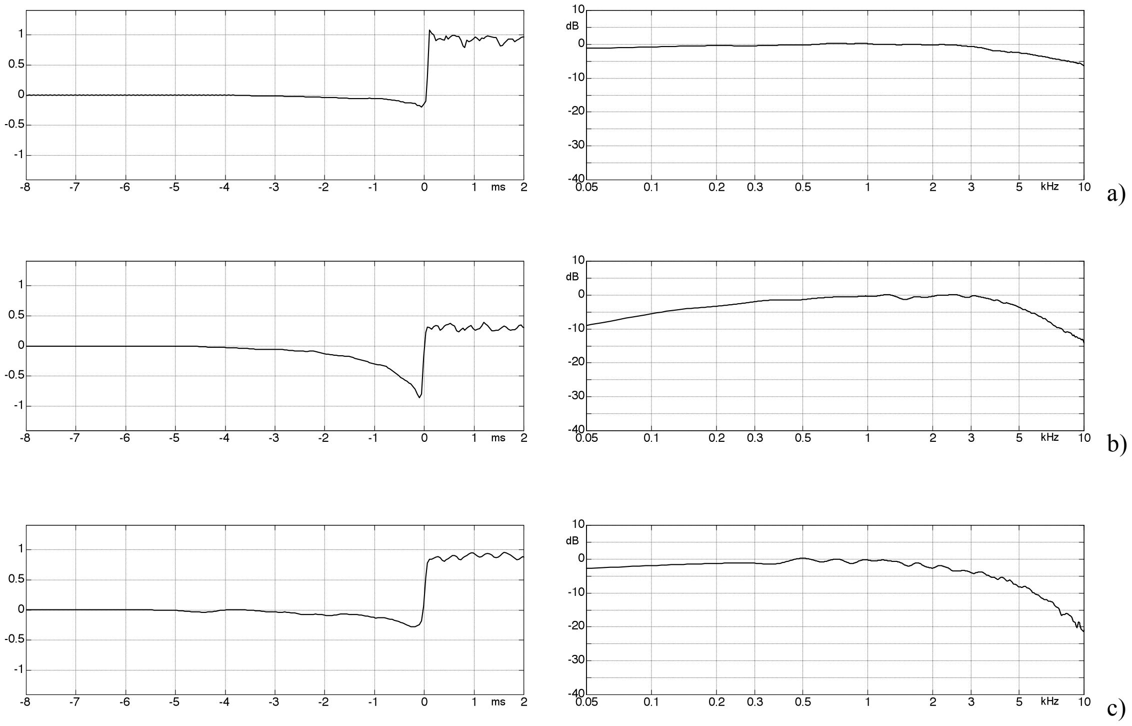


Fig. 1.29: Excitation step, and spectrum of the differentiated step for various plectrum movements.

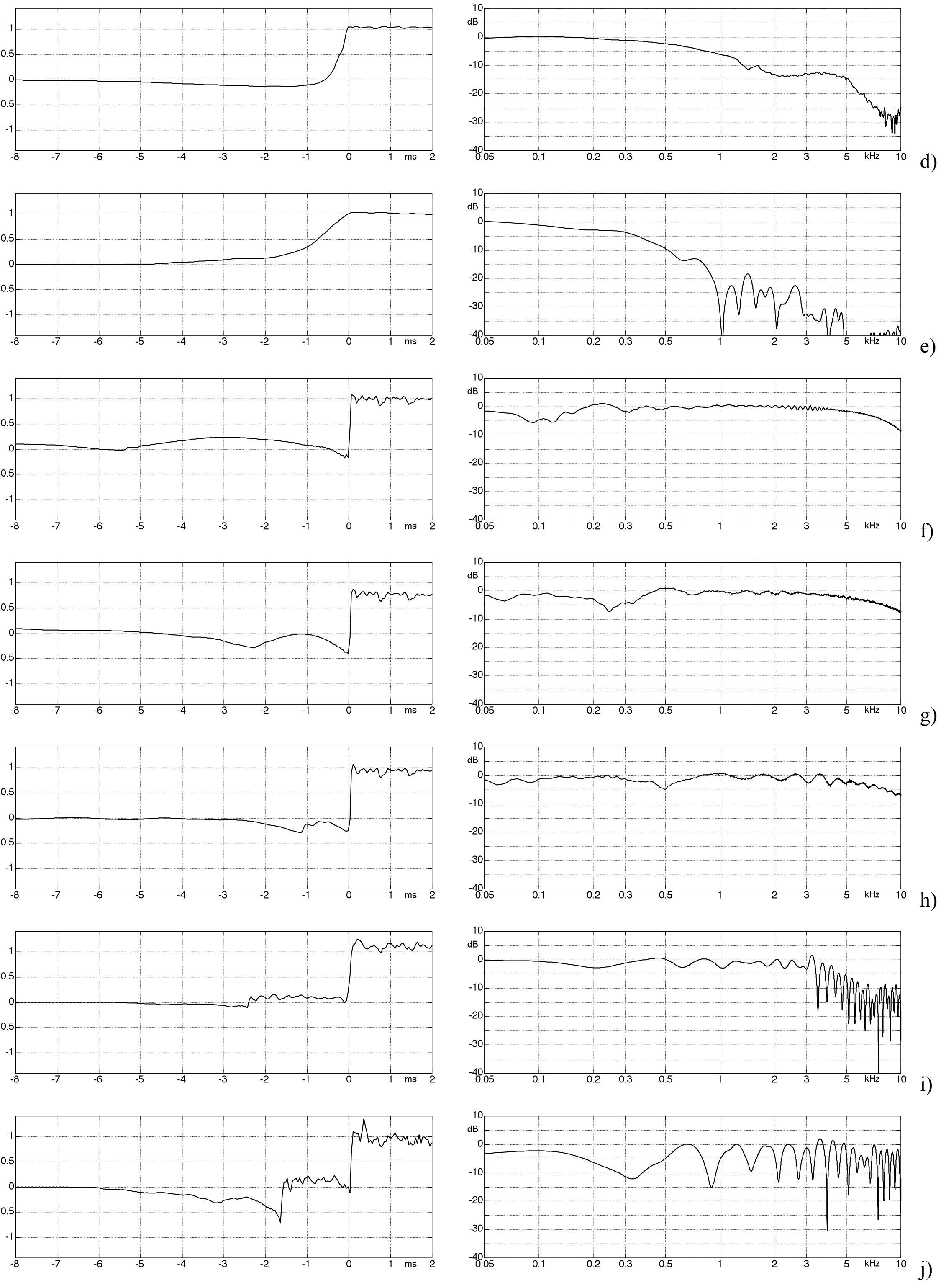


Fig. 1.29: Continuation from the previous page.

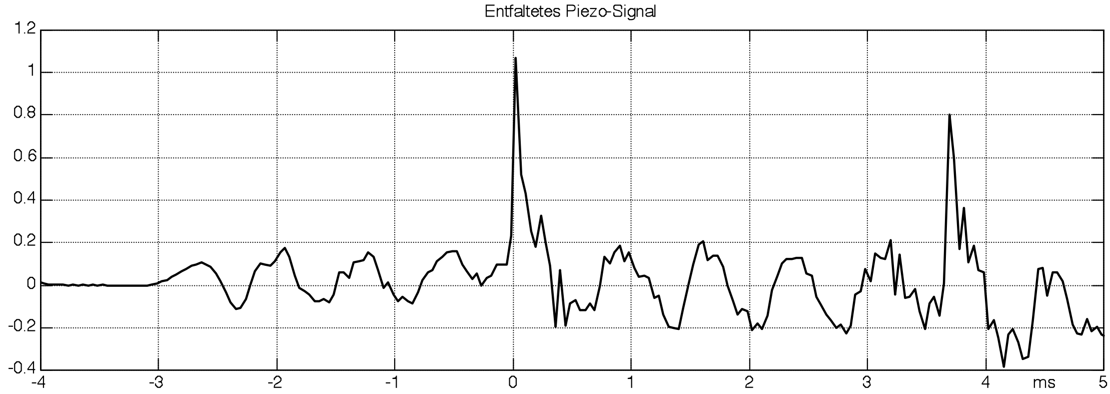


Fig. 1.30: De-convolved piezo-signal for the string excited in its longitudinal direction (scratched string). “Entfaltet” = de-convolved.

Fig. 1.30 documents an interesting detail: here, the low E-string was excited using a sharp-edged metal plectrum at mid-string in the **longitudinal direction**, i.e. the plectrum scratches along the string, jumping from one winding to the next. The signal transmitted by the piezo was again de-convolved i.e. cleared of the dispersion. As the plectrum jumps across the winding, a flexural wave is generated. The first (de-convolved) impulse of this wave is shown at 0 ms (the second impulse appears at 3,7 ms). However, in addition a **dilatational wave** of about 1,4 kHz occurs (Chapter 1.4). This (non-dispersive) dilatational wave propagates with a considerably higher speed than the transversal wave; its start is shifted by 3 ms towards the past due to the de-convolution. In fact, the de-convolution algorithm does separate according to wave-type but it corrects the phase delay of any 1,4-kHz-signal by -3 ms. Further details of the dilatational wave (in particular regarding its coupling to the transversal wave) have already been described in Chapter 1.4.

The plucking processes shown in Figs. 1.29 and 1.30 are typical for guitars but represent merely a relatively arbitrary selection. There is also a multitude of other possibilities to excite the string – and we need to particularly consider that the tip of the thumb or the first finger may also come into contact with the string. It is therefore not necessarily an indication of excessive vanity if the well-known professional guitarist, after an extensive narrative highlighting his wonderful custom-built paraphernalia, concludes the interview about his equipment with a confident: “90% of the sound is in the fingers, though”.