1.5.3 String-bouncing

If a string is plucked with little force, it will approximately react as a linear system. This means that doubling the initial displacement will also double the displacement at any instant of the subsequent vibration process. Of course, any displacement is limited – at some point the string will hit the frets on the fretboard. In doing so, it generates a somewhat rattling, buzzing sound. To some degree, this is in fact a means of musical expression and thus not something generally undesired.

In the book “E-Gitarren” by Day/Waldenmaier we find the recommendation: "A slight tilt of the bridge makes it possible to adjust the action of the high E-string a little lower than that of the low E-string. The latter has a more pronounced vibration amplitude and requires more space that the high strings ". However, the transverse stiffness for all customary string sets is higher for the low E-string (E_2) than it is for the high E-string (E_4) – why then would the stiffer string require more space for its vibration? It is o.k. to concede this space to it; that decision is, however, just as individual as the choice of the string diameter and cannot be justified with a generally larger amplitude.

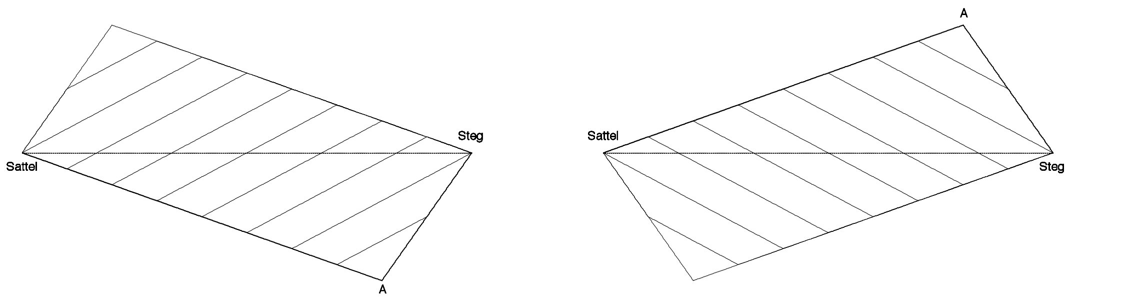

Fig. 1.31: String displaced at A (bold line), intermediate positions of the vibration (thin lines). In the left-hand figure, the string was pressed to the guitar body and then released, on the right it was pulled up and released. “Sattel” = nut; “Steg” = bridge.

The string is displaced in a triangular fashion by the plectrum (or the finger-tip, or –nail, or teeth …). After the plucking process, the string moves in a parallelogram-like fashion – given that we take a dispersion-free model as a basis (**Fig. 1.31**). However, this movement in the shape of a parallelogram can only manifest itself if the string does not encounter any obstacles. Frets are potential obstacles; their immediate vicinity has the effect that the string does not only occasionally establish contact but hits them on a regular basis … with the parallelogram-shaped movement being correspondingly changed. **Fig. 1.32** shows (seen from the side) a neck with the typical concave curvature. The axis-relations of this figure hold for the following figures, as well.

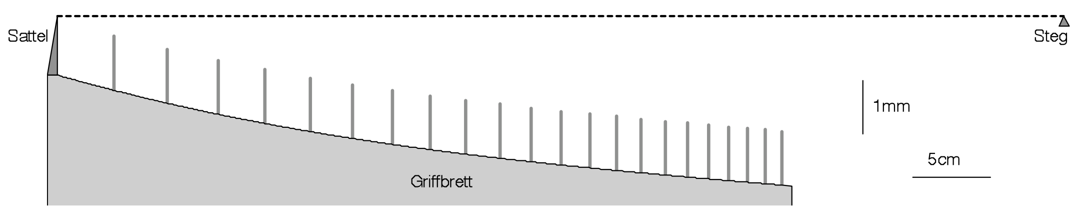

Fig. 1.32: Fretboard geometry (strongly distorted due to the scale); lower surface of the resting string (dashed). The frets are distorted into lines due to the strong magnification of the vertical dimension.
“Sattel” = nut, “Steg” = bridge; “Griffbrett” = fretboard.

If the string pressed down at point A (**Fig. 1.33**) has no contact to the frets, it can freely decay in the dispersion-free model case. The string that has been lifted up, however, hits the 10th fret already after less than half the vibration period – its vibration-shape is completely destroyed.

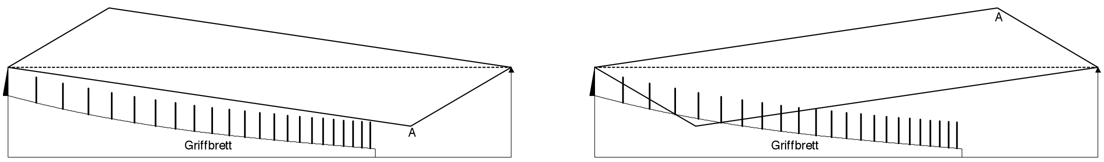

Fig. 1.33: String-parallelogram. On the left, the string was pressed down and then released (uninhibited vibration); on the right it was lifted up and then released (fret-bounce at the 10th fret). “Griffbrett” = fretboard.

The well-versed guitarist will vary his/her “attack” as required and shape the sound of the respective picked note via change of the picking-strength and –direction: both pressing-down and lifting-up of a string happen. However, in particular when using light string sets, a further vibration pattern occurs. It is generated as the string contacts the last fret (towards the bridge) when being pressed down during plucking (**Fig. 1.34**). As soon as the string is released, a transverse wave propagates in both directions and is first reflected at the last fret and then at the bridge. Consequently, a peak running towards the nut is generated – it is reflected there and bounces onto the first fret (right-hand part of the figure).

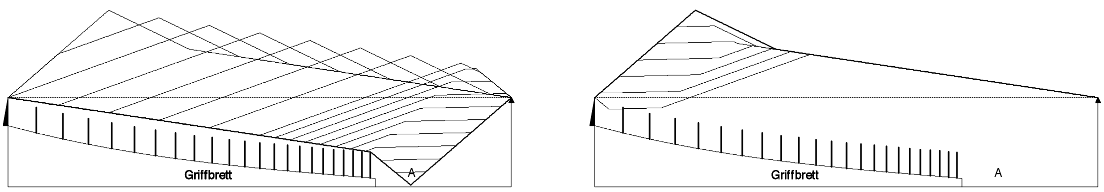

Fig. 1.34: String displacement at different points in time. On the left, the first half-period is shown, on the right we see the subsequent process including bouncing off the first fret. Plucking happens at point A with contact to the fretboard. The time-intervals are chosen such that the resolution is improved at first and after $t = T/2$. Without dispersion. “Griffbrett” = fretboard.

Immediately the question pops up: how often does this case happen? Contact-measurement at the last fret tells us: a lot. For better understanding, **Fig. 1.35** depicts the connection between plucking force (transverse force) and initial string displacement (at A). Since the transverse forces often reach 5 N (or even 10 N occasionally), contact to the last fret often occurs.

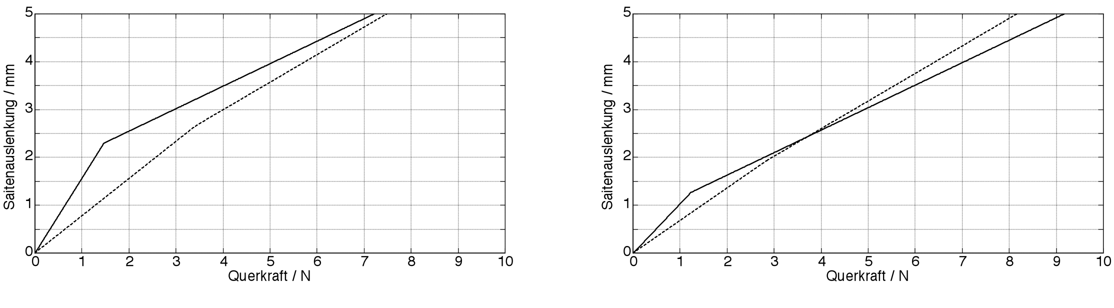

Fig. 1.35: Connection between transverse force and string displacement, open string (left), string fretted at the 14th fret (right), plucking point 14 cm (——) and 6 cm (---) from the bridge. 2,1 mm clearance between the string and the last fret (= 22nd fret). B-string, 13 mil, calculations.
“Saitenauslenkung” = string displacement; “Querkraft” = transverse force.

We can see from Fig. 1.35 that the string operates as a linear system only for soft plucking. As soon as the string gets into contact with the last fret, the force/displacement characteristic experiences a knee – a jump in the stiffness of the string occurs. This degressive characteristic tends to correspond to the **behavior of a compressor**: despite stronger plucking force, the string-displacement grows only moderately. However, here we also find a source of potential misunderstanding, for displacement does not equal loudness! With the string establishing contact to the last fret, the shape of the vibration deviates from the mentioned parallelogram, and changes result in the spectrum, and thus in the sound.

For the following graphs, the E_4-string of an **Ovation** guitar (EA-68) was plucked using a plectrum; the electrical voltage of the piezo pickup built into the bridge was analyzed (i.e. the force at the bridge). The location of plucking was at a distance of 125 mm from the bridge, and the plectrum was pressed towards the guitar body such that a fretboard-normal vibration was generated. **Fig. 1.36** shows time function and spectrum for the linear case (no contract between string and last fret). The voltage of the piezo jumps back and forth between 0 V and 0,4 V, with a duty cycle resulting from the division of the string (517:125, scale = 642 mm). Given the transfer coefficient of 0,2 V/N (Chapter 6), the corresponding force at the bridge calculates as 2 N, this representing good correspondence to Fig. 1.35. In this example, 2 N forms the limit of linear operation – using a larger force makes the string bounce off the frets.

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Fig. 1.36: Time-function and spectrum of the piezo-signal. The upper half of the left-hand graph shows the measured time function, below is the result of the calculation. On the right is the measured spectrum and the (idealized) envelope. Open E_4-string, fretboard-normal vibration. "Frequenz" = frequency.

The analyses shown in the following graphs (**Fig. 1.37**) correspond to Fig. 1.36 but are based on (fretboard-normal) string excitations of different strengths. For the upper two pairs of graphs we can see proportionality in the time domain and in the spectral domain: the level spectrum is simply shifted upwards for stronger plucking. As soon as the plucking force exceeds 2 N (in the lower two pairs of graphs), the string touches the last fret and bounces off it. Time function and spectrum become irregular. The strong peak in the time function finds its counterpart in the location function (Fig. 1.34); it may be interpreted as the interaction between two excitations:

a) string displacement, force step at $t = 0$ (idealized), and

b) opposite-phase force step at the last fret; occurring at the instant as the string leaves the last fret ($t \approx 0,2$ ms).

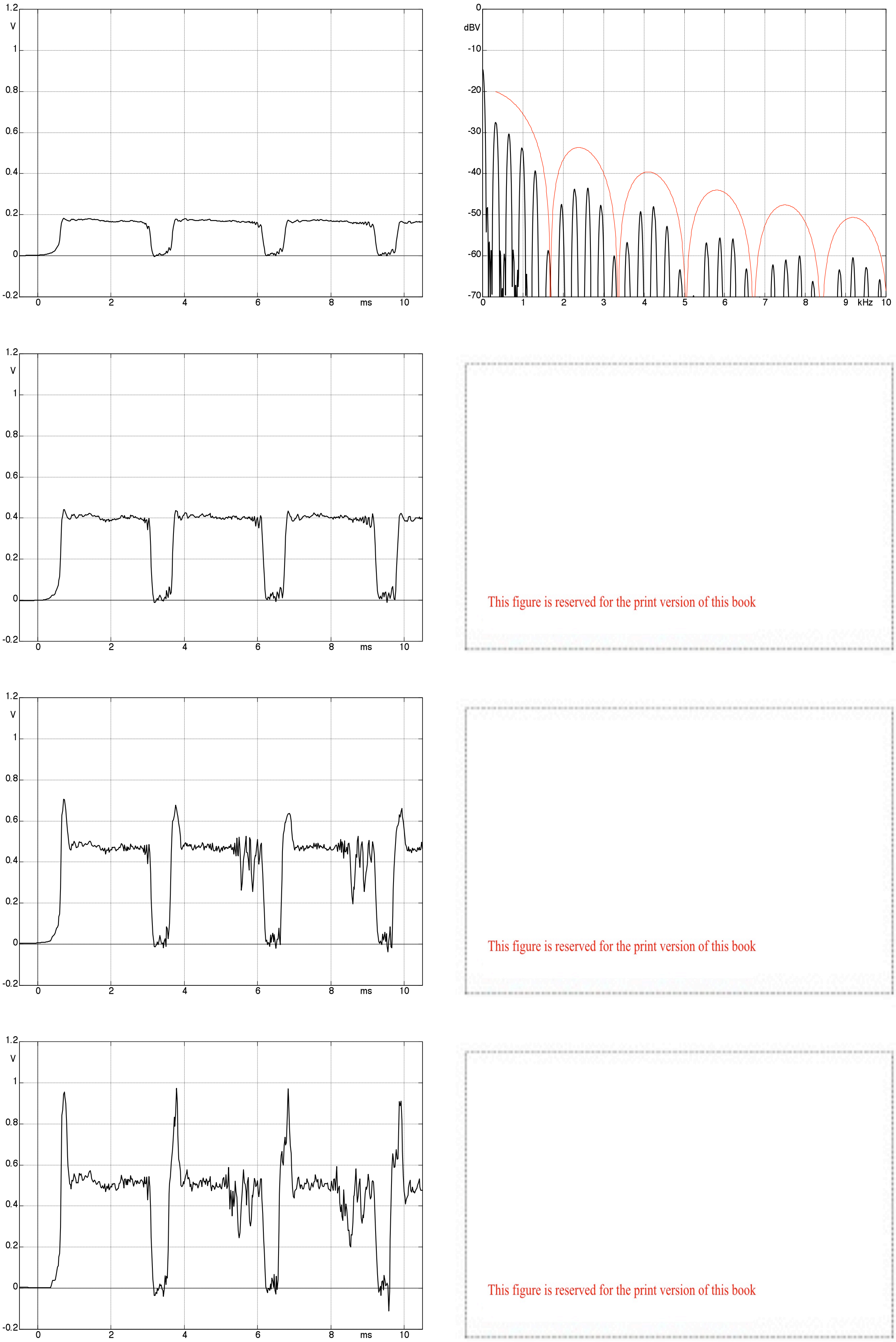

Fig. 1.37: Time-function and spectrum of the piezo-voltage. String plucked with different force. See text.

A spectral analysis encompassing the whole of the auditory range is conducive for the acoustic guitar, and the same holds for a piezo-pickup (Chapter 6). In **Fig. 1.38**, three of the sounds from Fig. 1.37 are shown as third-octave spectra. On the left, we see the spectra of strings plucked lightly and with medium strength, respectively – the system is still linear and the spectra merely experience a parallel shift. Strong plucking (right figure) leads to a level-increase merely in the middle and upper frequency range; below 1 kHz, there is even a decrease in level. As other strings are played, or as the E_4-string is fretted at other frets, this effect tends to remain, but the spectral differences are specific to the individual case.

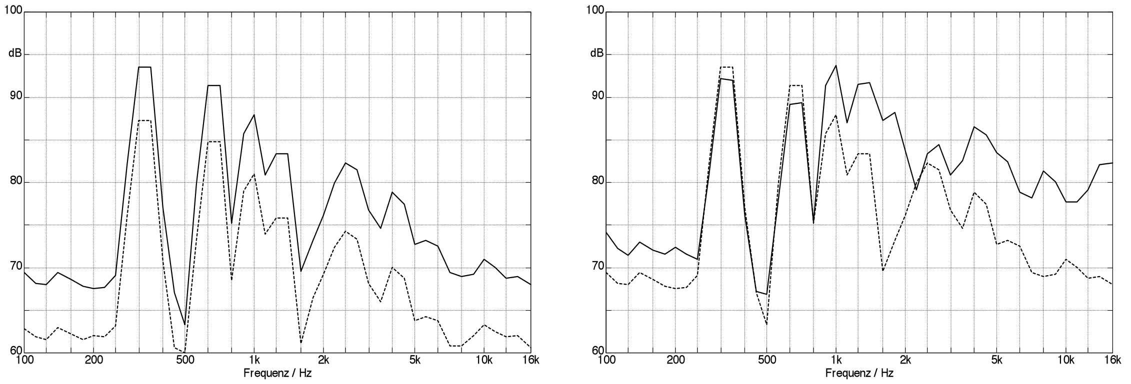

Fig. 1.38: Third-octave spectra, open E_4-string, overlapping analysis of main- and auxiliary third-octave. On the left, and for the dashed curve on the right, there is not yet any bouncing off the frets. Strong plucking (solid line of the right) causes the string to touch the last fret and bounce off it. 1^{st} and 2^{nd} harmonic actually decrease in this process, while there is a strong increase in level at middle and high frequencies.

From this, we can deduce a **compressor-like behavior** in any guitar: for light plucking, the string operates as a linear system, and slight changes in the picking strength lead (with good approximation) to similar level changes in the whole frequency range. However, already at medium picking strength, the string bounces off the frets – the lower the action and the lighter the strings, the lower is the threshold to this occurring. Now, if filtering (due to magnetic pickups) accentuates a specific frequency range, this compression is perceived with different strength. Fender-typical single-coil pickups emphasize the range around 3 – 5 kHz. This will lead to less perception of compression compared to humbuckers sporting resonance frequencies around 2,5 kHz. This may not happen for all played notes, but it does happen in the example shown in Fig. 1.38. So does a humbucker compress more strongly than a single-coil? “Somehow”, yes – but not causally. The source of the compression is the string (in conjunction wit the frets) that compresses in different ways in various frequency ranges. Pickups and amplifiers make this different compression audible in different ways.

Here’s an opinion voiced in the Gitarre & Bass magazine (02/2000): "What happens when I, for example, pick the low E-string first softly and then more and more strongly via a slightly distorted amp? The Strat behaves much more dynamically and you can open the throttle ever more until, purely theoretically, the string throws in the towel and breaks. The Les Paul shows an entirely different character: first, the increasingly harder picking also generates more loudness, but then the whole thing topples over: the notes don’t get louder anymore but more dense – almost as if there were a compressor/limiter switched in. Say what?! Indeed, the information of the string vibrations resulting from the behavior of the wood determines the tonal characteristic of the Les Paul, but not the fatter sounding humbuckers.”

The G&B-author was careful (?) enough not to throw in something like “and that shows that mahogany compresses more strongly than alder”. Still, he infers: “*now we understand, why a Strat even with Humbuckers can never turn into a Les Paul. You can at most make the tone warmer and fatter, but the typical compression is out of reach.*” Unfortunately, the author does not report which experiments or models were the basis for his last conjecture.

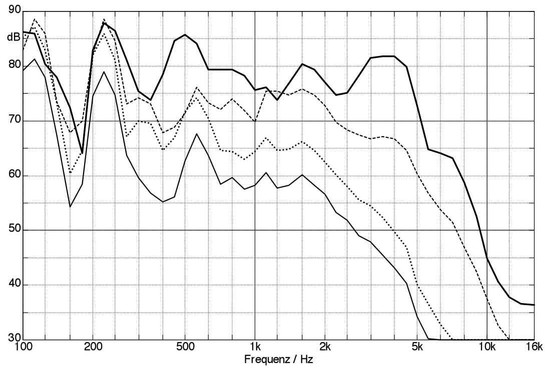

Fig. 1.39: Third-octave spectrum, Stratocaster, neck-pickup, E_2-string (42mil) fretted at the 5th fret. Plucked from lightly to strongly. Distance between plectrum and bridge: 13 cm. Clearance of the open E_2-string to the last fret: 2,3 mm.

As we can see from **Fig. 1.39**, a **Stratocaster**, too, compresses in the range of the low partials. While the level-difference between light and very strong plucking is no less than 39 dB at 4 kHz, the fundamental changes only by 7 dB. Your typical Gibson Humbucker will only transmit the spectrum of the low E-string up to about 2 kHz and therefore misses the dynamic happening in the 4-kHz-range that a Fender pickup will still capture. However, in the experiment reported in G&B, it is likely that behavior of the amplifiers was almost more important: *“via a slightly distorted amp”*. There you go! The Gibson Humbucker will have generated approximately double the voltage of the Fender single-coil. That makes the **amplifier** participate in the signal compression: it will compress (or limit) the louder signal (that of the Les Paul).

However, that does not mean that the compression is determined merely by the action on the guitar, and by the amplifier. As the string bounces off the fret, a metal hits metal (at least on the electric guitar). The result is a broad-band bouncing noise that extends to the upper limit of the audible frequency range. String- and fret-materials are of particular significance in this bouncing noise: pure-steel wound strings generate a more aggressive, treble-laden noise compared to pure-nickel wound strings. Old string with their winding filled up by rust, grease, etc, will sound duller than fresh strings. And the **fret-wire** that the string hits (that may in fact be any fret in the course of the vibration) contributes, with its mechanical impedance, to the bouncing noise, as well. A detailed analysis of the mechanical neck- and body- impedances follows in Chapter 7; string/fret-contacts are analyzed in detail in Chapter 7.12.2.