## 7.2 The Frets

### 7.2.1 Position of Frets

The right-handed guitar player changes the length of the vibrating string by ‘fingering’ (i.e. fretting) with the left hand. (Other fretting and playing techniques are also possible.) With the finger, he or she presses the string to be sounded towards the neck so that contact is made with the **fret**♣. Frets are metal wires with a T-shaped profile (Fig. 7.3). They are set into grooves in the fretboard cut transversely to the direction of the strings. The upper part of the fret that protrudes from the fretboard is rounded, and the lower part that is set into the fretboard is designed as a barbed hook to ensure that the fret remains fixed in place. Frets make it easier for the guitar player to achieve clean intonation (achieve correct pitch). The length of the vibrating string is "fretted" at discrete intervals only rather than continuously. As a first approximation, it does not matter where between the two neighboring frets the finger is pressed. For the string, the important contact occurs on the fret. Upon closer inspection, though, we observe that, particularly in the case of tall frets (protruding more), the strength and position of the fingering can have a small effect on the pitch (see also Fig.7.5).

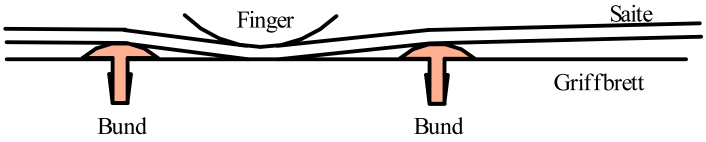

***Fig. 7.3:*** *Longitudinal cut along the neck. Usually, the finger does not press the string („Saite“) all the way down to the fretboard („Griffbrett“). „Bund“ = Fret.*

The *open string* is supported at bridge and at nut. The distance between the latter two, the **scale**, is 24” – 25.5” i.e. 61-65 cm. However, guitars with a longer scale (baritone guitar, LONG NECK GUITAR) are also in use, as are short-scale guitars (3/4-guitar). Electric guitars generally have 21-24 frets, not counting bridge and nut. The length of the fretted neck (i.e. the length of the fretboard) amounts to approximately ¾ of the scale. In some guitars, the strings do not run directly from fretboard to nut but pass over a **zero fret**. In that case the string is always in contact with the same material, regardless of whether it is played open or fretted. The resulting higher friction has noticeable disadvantages, though: for easy tuning, the string should be able to longitudinally move over the nut or the zero fret with as little friction as possible. With too much friction, undesirable hysteresis may be the result.

The difference between simple theory and reality can be found in the **distance between frets**. To simplify the calculation, the string and its supports are assumed to be ideal. The guitar is tuned in equal temperament, with the semi-tone intervals being uniformly approximately 6%.

$$I_H = \sqrt[12]{2} = 1.05946 \qquad \text{Semi-tone interval}$$

Already the choice of this approach will invite and define fundamental deviations from just intonation, amounting e.g. to -0.9% for the minor third, and +0.8% for the major third. Just intonation is not the preferred ideal (Chapter 8.1): (equally) tempered tuning is the standard used today. The reciprocity between string length and fundamental frequency results in a geometric progression for the distances between frets. If the distance between the nut and the first fret amounts to $\Delta B$, then the distance between the nth fret and (n+1)-th fret is $\Delta B \,/\, I_H^n$. The distance between frets thus diminishes from nut towards bridge, while at the same time the neck width (and thus the length of the frets) increases (**Fig. 7.4**).

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♣ Sometimes the area between two fret wires is referred to as “fret”, as well.

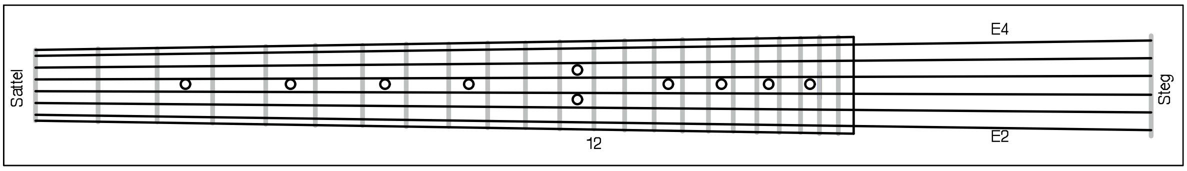

**Fig. 7.4**: Fretted neck (22 frets) with strings and bridge. $E_2$= low E string (at the thumb), $E_4$ = high E string. The octave relative to the open string is fretted at the 12th fret – at the mid-point of the string. The full length of the strings across the nut on the headstock is not shown. ("Sattel" = nut, "Steg" = bridge)

The above calculation does not take into account that the string tension is increased when the string is pressed down; this results in a further change in the pitch. For instance, if a string is fingered at the 12th fret, its fundamental frequency should actually be doubled. However, pressing down on the string causes a minimal lengthening of the string, causing a further increase in the frequency. The fact that the frequency of the lengthened string is higher rather than lower is due to the tension change that is dominant here (compared to the change in length).

In the following calculations, it is important to distinguish between the string length $L$ and the change in length $\Delta L$. The change in length $\Delta L$ is designated the **strain** $\xi$. A string that has the length $L$ in its unfretted state (scale + residual lengths[♣] to the tailpiece and to the tuners) is stretched by the tension $\Psi$ to the new length of $L+\xi$. The more the string is stretched, the higher the fundamental frequency $f_G$ (given a fixed scale M).

$$\xi = \frac{4\overline{\rho}L}{E} \cdot \left( \frac{f_G \cdot M}{\kappa} \right)^2 \qquad \text{Strain } \xi$$

$\overline{\rho}$ is the mean density (see annex), $E$ is Young's modulus, $\kappa$ is the ratio of core diameter to outer diameter for wound strings (for solid strings, $\kappa = 1$) . With the latter, the $E$-modulus of the core should be used; $\kappa$ is between 0.3 and 0.6. The $E_4$ string must be stretched by 5.3 mm (standard tuning, $L$= 77 cm), die $E_2$ string by 1.7 mm ($\kappa = 0.42$). We observe that the strain depends on the square of the fundamental frequency $f_G$, and that the fundamental frequency is proportional to the square root of the strain. The formula for the relative changes is derived from the differential quotient of the curve.

$$\frac{\Delta f_G}{f_G} = \frac{1}{2} \cdot \frac{\Delta \xi}{\xi} \qquad \text{Relative change in frequency}$$

The relative change in frequency is half the relative change in strain. **Note**: This is not about the relative changes in length! If, for example, a string fretted at the 12th fret is extended by 0.02 mm, its *length* changes by 0.026‰, but this is not what is meant here. The *strain* changes by 3.8‰ ($E_4$), or by 11.8‰ ($E_2$) – it is this difference that causes problems. Even if the $E_2$- and $E_4$-strings are pressed down an equal distance towards the fretboard, the $E_2$-string **goes out of tune** by a much greater amount. In practice, however, the $E_2$- string is given an even greater distance to the fretboard (2 – 3 mm inside width at the 12th fret) than the $E_4$-string (1 – 1.5 mm). The frequency-increase for the $E_4$-string therefore is negligible in practical terms, while for the $E_2$-string it is quite large: 0,5·11.8‰, corresponding to 10 cent.

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[♣] Here, the friction that occurs in the nut and bridge needs be considered. Given high friction, $L = M$ applies.

To correct this frequency error, it would be possible to mount the frets in a slanted fashion, but except for a few exotic constructions, this is not done. Rather, the bridge is positioned with a slight slant such that the bearing (bridge saddle) of the $E_4$-string is exactly at double the distance from the nut compared to the 12th fret, but the bearing for the $E_2$-sring is moved back a few millimeters (= longer string). The exact amount necessary for this correction depends on the strings, the bearings, and the **string action** (inner distance of string to fret). For nylon-string guitars, almost no correction is required due to the smaller Young's modulus. In steel-string acoustics we often find around 3 mm ($E_2$); a slant of up to 6 mm ($E_2$) may be necessary for typical electric guitars.

As shown above, this **shift of the bridge** does not only depend on the fundamental frequency but also on the type of string winding. The $E_2$-, A- and D-strings are of the wound type while the B- und $E_4$-Saite are plain; the G-string may or may not be wound. The individual string data require a string-specific shift in the bridge. Therefore, many electric guitars feature a bridge with individual bridge saddles that are **adjustable** via small screws. After the guitar is restrung, the natural harmonic of the respective string is played (by very lightly touching the string – as it is being picked – exactly at its half-way point), and the bridge saddle is adjusted such that fretting the string at the 12th fret generates the same pitch as that harmonic. In some cases, two adjacent strings share a common bridge saddle – requiring a compromise in terms of the intonation.

A special example will show the influence of the **overall length** of the string: on some guitars, the string runs a considerable additional length on the other side of the nut and bridge – up to 25 cm in extreme cases. Conversely, on guitars with a string-clamping system, freely moveable string length and scale are practically identical. If all other parameters are kept the same, the string-strains differ by a factor of 88/63 = 1.4 between these two conditions. However, the (absolute) *change* in strain due to pressing the string to the fretboard depends solely on the scale and on the inner distance between (open) string and fret, and not on the overall length. This means that the longer the string is run outside of nut and bridge, the smaller is the detuning due to fretting[♣]. In the example, the relative change in strain (and thus the detuning) is a factor of 1.4 in the clamped string compared to the unclamped string. This needs to be considered if a guitar is to be retrofitted with a clamping system.

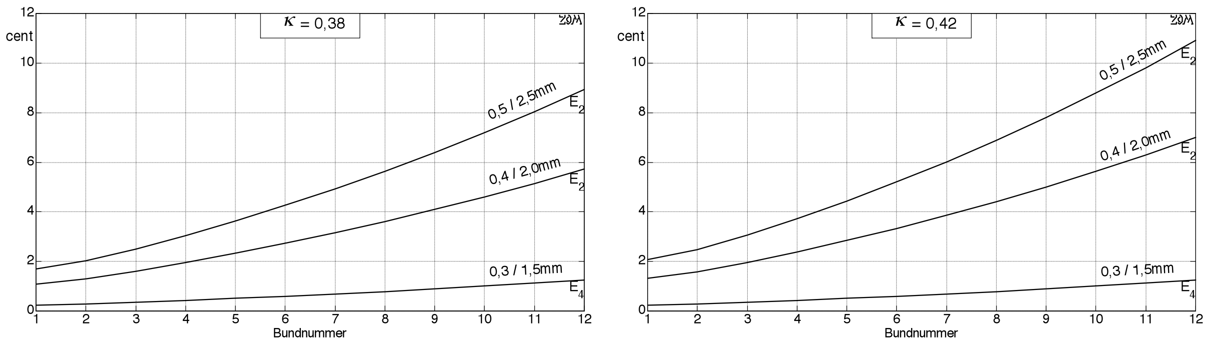

**Fig. 7.5:** Relative detuning due to pressing the string to the fret. Scale: $M$ = 0.625m; $L$ = 0.72m.
String-to-fret distance (1. fret / 12. fret) = 0.3 / 1,5mm ($E_4$); 0.4 / 2.0mm ($E_2$); 0,5 / 2,5mm ($E_2$).
Left: core-/outer diameter = $\kappa$ = 0.38. Right: $\kappa$ = 0.42. Position of bridge not compensated.
"Bundnummer" = number of fret.

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[♣] If the string were tensioned via a weight, the tensile force would not change at all when pressing down the string; the detuning would be negligible (merely a minimum change in length).

By slanting the bridge, the problems mentioned above can be taken care of – such that the octave (12th fret) can be played fully in tune. That does not imply, however, that all other frets offer correct intonation. **Fig. 7.5** shows the relative detuning occurring as the string is fretted – at first without slanted bridge position. The distance of string to fret (the "action") was assumed to grow linearly between the 1st and the 12th fret; for the low E-string, two different cases are calculated. In the left-hand graph, the ratio between core diameter and outer diameter equals $\kappa = 0.38$, on the right it amounts to 0.42. A smaller core diameter results in smaller detuning but also increases the danger of string-breakage.

For the left-hand section of **Fig. 7.6**, the bridge received a slant. The change for the $E_4$-string is very small (0.5mm); for the two $E_2$-cases, 2.5 and 3.9 mm are necessary, respectively. This already offers a decent solution. A detuning of 1 cent does not really require correction, anyway. Shifting not only the bridge but also the nut (in the direction towards the bridge), a further improvement is possible (right-hand graph), although a precision of 0.1 cent (0.0006%) is merely of theoretical interest. Basis for the calculation was that the string runs in a straight line from the nut to the tip of the fret, and continues to the bridge from there. Since the finger fretting the string during play does not actually provide an ideal line-contact but presses down the string behind[♣] behind the fret, an additional strain of the string results and the required shift of the bridge increases.

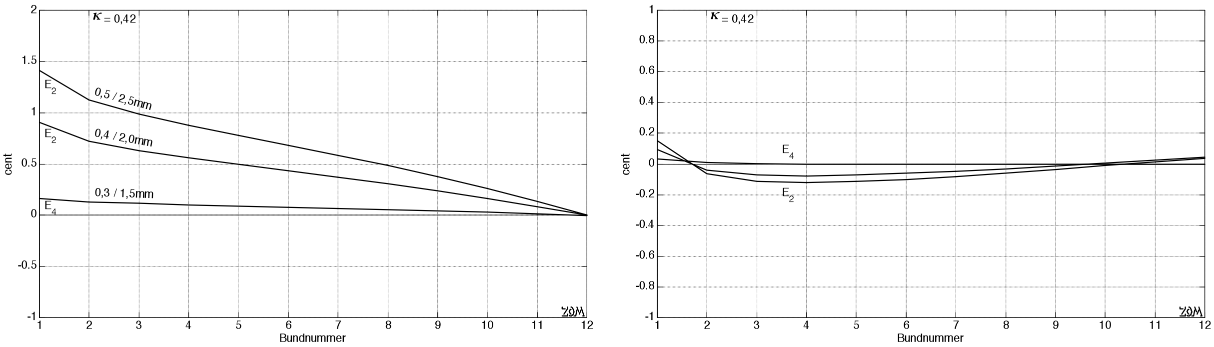

**Fig. 7.6:** Data as in Fig. 7.5 but $\kappa = 0.42$ (unchanged). In the graph on the left, only the bridge is shifted; on the right-hand graph additionally also the nut. For the $E_4$-string, the calculated shift of the bridge by 0.05 mm is not relevant, for the $E_2$-string, 0.3 and 0.5 mm, respectively, are calculated (line-contact at the tip of the fret only). "Bundnummer" = number of fret.

**In summary**, we find the following rule for guitar construction: first, the theoretical scale $M$ is set, e.g. at 625 mm. Then the calculation of the distance between nut (or zero fret) and the 1st fret results in $M \cdot \left(1 - \sqrt[12]{0.5}\right) = M / 17.817$. We obtain the distance between the $n$-th and the $n+1$-th fret by dividing the distance between $n$-th fret and bridge saddle by 17.817. <u>Alternative:</u> the $n$-th fret is at a distance of $M / 1.05946^n$ from the bridge. As a next step, the nut is slightly slanted: its position remains unchanged for the $E_4$-string, while at the $E_2$-string it is shifted in the direction of the bridge by about 1 mm. Now the bridge saddle is shifted such that we can play the exact octave at the 12th fret. Given these adjustments, every string should now be tuned with equal temperament. An additional check using a measurement device, or our hearing, is advised – possibly small modifications are necessary.

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[♣] "behind" means: in the direction of the headstock.

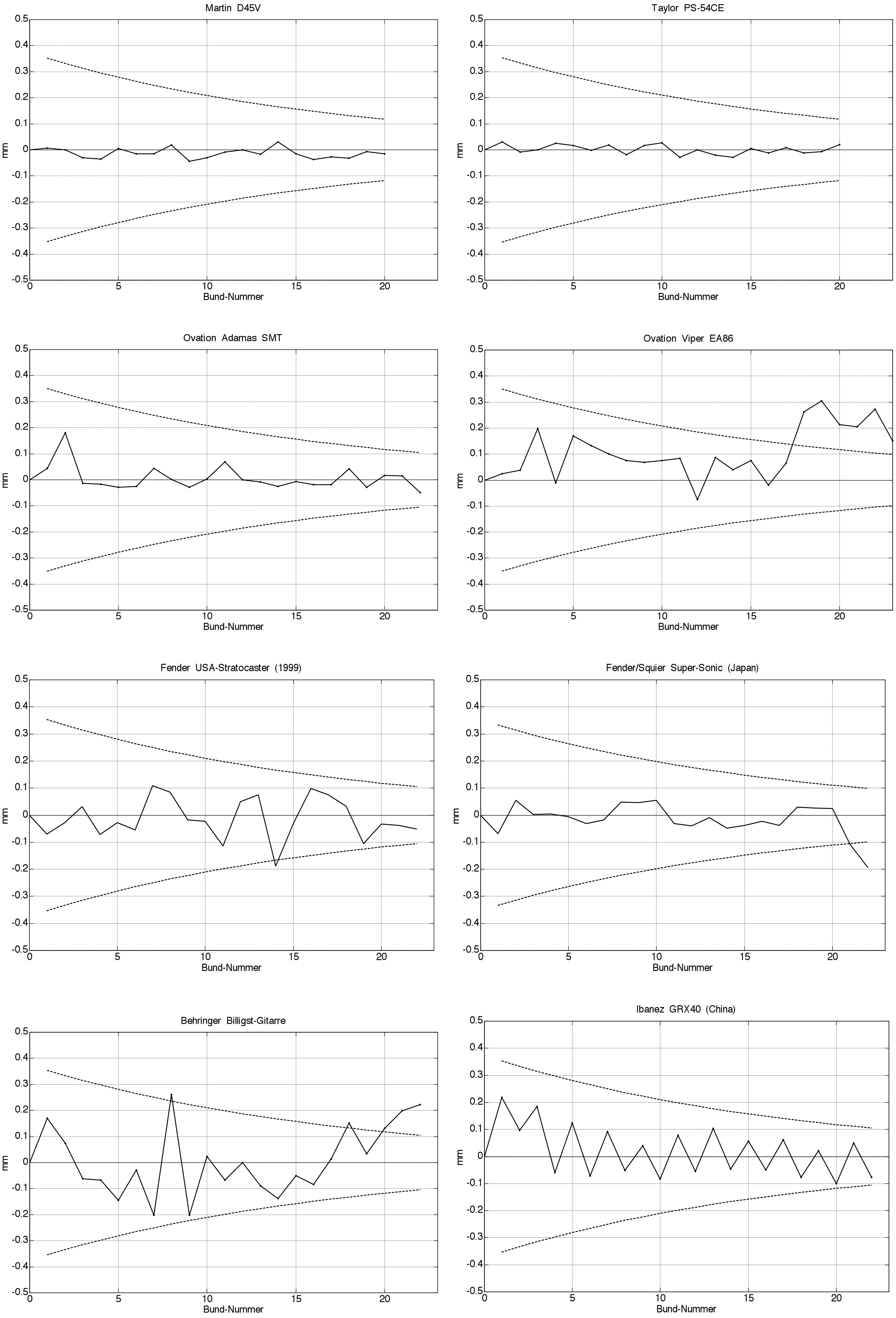

**Fig. 7.7a:** Deviation of the measured position of a fret from the theoretical position. The dashed limit lines show pitch deviations of ± 1 cent. Measurement tolerance: ± 0.05mm. “Bund-Nummer” = number of fret.

Relative to the exact equal-temperament tuning (i.e. *HT* = 1.05946, *k* = 17.817), both Gibson guitars deviate significantly from nominal value in the higher positions. With the (inaccurate) rule-of-18, however, (column on the right), the tolerances are o.k. Could it be that Gibson would still use outdated rules for manufacture even in the year 2004? Epiphone, Gibson's budget line produced in Asia, on the other hand, shows much higher precision.

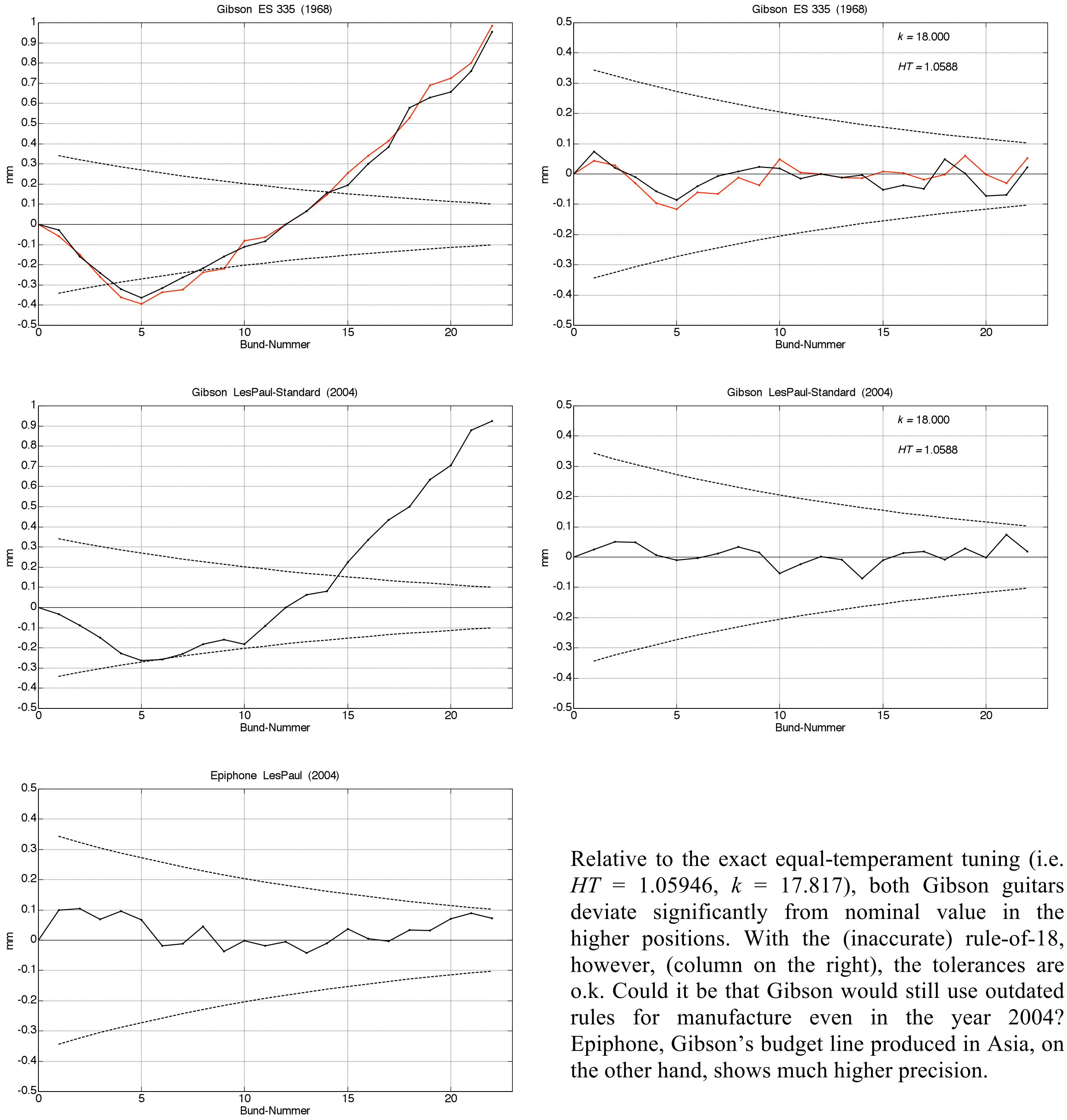

Fig. 7.7b: Deviation of the measured position of a fret from the theoretical position. The dashed limit lines show pitch deviations of ± 1 cent. Measurement tolerance: ± 0.05mm. "Bund-Nummer" = number of fret.

**Fig. 7.7** depicts the measured fret positions for a number of guitars. Since frets are rounded-off metal wires and do not provide sharp delimitations, the exact position is only available in approximation, with a measurement tolerance of about ± 0,05 mm. We can see exemplary precision for Taylor and Martin; for the other guitars the deviations are larger but still acceptable. Only Gibson shows to be the odd one out. Interesting in the two Fender guitars: Japanese "budget" production by no means shows worse results compared to fabrication in the US – rather, the contrary is the case. For all graphs, scale and position of the nut were set for an optimal curve. This is because the actual effective position of the string bearing is difficult to determine (rounding off of notches, bending stiffness of the strings).

### 7.2.2 Fret materials

The material most often used for frets is German silver (nickel silver, white copper, argentan, alpakka[§]). The precious metal silver is not contained in this material, though – or only in traces. German silver is an umbrella term for copper/nickel/zinc-alloys that could also be termed "highly nickel-alloyed special-brass". The pure copper-zinc alloy is called **brass**; it is used as material for frets, as well, albeit rarely. By itself, copper is of a reddish color, adding zinc results in yellowish hue, and nickel moves the coloring towards the greenish and on into the silver-white area – thus the name nickel-silver. The addition of nickel and zinc particularly adds to the hardness – that should be high anyway because the contact to the steel strings wears down the frets during play. Also, nickel makes the fret more resilient against tarnish and corrosion. The high nickel content of >30% required for the silver-white color is not found in guitar frets, though: customary is a nickel additive of 12% (acoustic classical guitar), or 18 % (electric guitar). More recently, steel has also become popular as a material used for frets. No problems or issues have been reported – steel seems to be well suited for this application.

Due to the direct contact to the strings, the frets have a sound-determining function, and thus we do find a wide range of materials and shapes. Besides German silver, bell brass should be mentioned – another copper alloy, but with tin as additive rather than zinc. The silver-white bell brass contains about 77 – 80% copper with the rest being constituted by tin. Relative to German silver, bell brass tends to corrode more easily but this rarely poses a problem. Despite the fact that tin is a soft metal, Cu/Sn-alloys reach a similar hardness as German silver.

The **dimensions** of the frets visible to the guitarist are width and height of the tip of the fret. Small frets (often found on vintage guitars) have a width of between 1 mm and 1.7 mm, and a height of 0.6 mm and 0.8 mm. Medium size would be $B$ = 1 – 2.6 mm, and $H$ = 0.7 – 1.1 mm, while large (jumbo-) frets would measure $B$ = 2.6 – 3 mm, and $H$ = 0,9 – 1,5 mm.

The **nut** is fabricated from bone, or from a special low-friction plastic, or in some cases from metal. There is no limit to the imagination of the manufacturers when coming up with designations: Vintage Bone, Bonoid, Ebonol, Graphite, Graph Tech, TUSQ, to name but a few. Much attention is paid to the low-friction aspect because the strings need to slip through the nut free of any hysteresis while they are tuned or bent. Static friction prohibits this slip to some degree and creates a zone of lacking discrimination. Roller-nuts promise a particularly low friction; however, they are wider than regular nuts and not necessarily easy to install. The string should find a firm but still almost frictionless bearing in the notch (or groove) of the nut. Well suited are v-shaped nut-notches that offer a small seating towards the headstock and end abruptly towards the side of the fretboard. Shape and depth of the groove of the nut are carved into a blank nut-piece using a **nut-file**. Also worth mentioning is the clamping nut that however requires fine tuners at the other end of the string.

Frets and nut are rounded off at their sides so as not to hurt the hands and fingers of the guitarist – a fact that is less relevant to guitar-physics but more to accident-prevention regulations, practices of law, and pathology. Still, a connection to physics may be made: the dimensions of wood are humidity-dependent while the dimensions of fret-material are not (i.e. not fretted by it …☺). If in winter you suddenly feel the ends of the frets on your guitar: file them off, or see to a higher humidity of the air!

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[§] inconsistent spelling. N.B.: Alpaka = Lama.

### 7.2.3 The Buzz-Feiten-system

In his US-patent no. 6642442 (uspto.gov), Howard B. Feiten describes a system for a tempered tuning of fretted musical instruments. Supposedly, an *extraordinarily pleasing intonation* is achieved by applying small deviations from the traditional tuning. *"One very important aspect of acoustic guitars that has been overlooked is proper intonation"* – i.e. according to Mr. Feiten, luthiers have – until the year 2002 – studiously overlooked that guitars indeed need to be correctly tuned. Without a doubt, old-world luthiers will beg to differ, insisting that correct tuning was an objective since long before building guitars became fashionable west of the Canary Islands. Anyway, not every guitarist is always happy with the result of his strive for balanced tuning. Enter Howard "Buzz" Feiten.

In the description of his patent, Mr. Feiten explains that guitars have their frets positioned according to the *Pythagorean Scale*. One is tempted to object with a "well in that case …" and to add – depending on ones disposition – a sarcastic "yeah, maybe the axes made stateside"; but let's hold our horses for a minute. To begin with, and in order to avoid misunderstandings, the term "Pythagorean" is explained: "*The Pythagorean Scale is based upon the fourth, the fifth, and the octave interval ratios*." Without a doubt: that's Pythagorean. However, what's that got to do with the guitar? In Europe, especially in Old Europe[♣], tuning is accomplished since the 1700's using equal temperament, not Pythagorean. But let us allow Mr. F. to continue his explanation: "*To determine fret positions, guitar builders use a mathematical formula based on the work of Pythagoras, called the rule of 18 (the number used is actually 17.817). This is the distance from the nut to the first fret.*" May the present work be charmed against that many errors in a single paragraph – that's what one instinctively thinks as the author of the book you are reading … Anyway: the rule of 18 generates a geometric sequence for fret positions: equal temperament; but he latter does not trace back to Pythagoras whose intonation is based on fifths, fourths and octaves, as Mr. F. elucidates himself. What Mr. F. seeks to express with "*this is the distance*" remains shrouded in Greek history, too. The subsequent explanations in the patent (not cited here) then do reasonably and correctly clarify what the rule of 18 purports. Let's note: H. B. F. sees the reason for the inadequate precision of tuning in the use of the Pythagorean (fifths-) tuning as it is contained in the rule of 18. That is incorrect but apparently did not phase the patent examiner (the one at the *US Patent Office*).

To cite Mr. F. some more: *"Prior to the mid 1600's, pianos had evolved from a 'just' intonation to 'equal temperment'; i.e., tuning the instrument so that all the notes were mathematically equidistant from each other. ... It was only partially successful and resulted in the entire keyboard sounding slightly out of tune, especially in the upper and lower registers. In the mid-1600's, an enormous breakthrough occurred in piano technology. The 'well tempered' keyboard was conceived*." Let us ask J. M. Barbour to comment about just intonation: *"There is no such thing as just intonation, but rather many different just intonations; of these, the best is that which comes closest to the Pythagorean tuning"*. So indeed: in the Middle Ages there was need for action, and "equal temperament", i.e. an intonation causing equal beats within the scale and allowing for modulations across the whole circle of fifths was considerable progress. However, "equal temperament" must not be confused with the "well tempered intonation" proposed by H. B. Feiten! The latter in fact distinguishes between "equal temperament" and "well tempered". "Well tempered" is a specially modified tuning derived from the uniformly-beating equal temperament.

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[♣] The ethnologist Donald Rumsfeld specified this term (otherwise to be understood more as a geographic distinction) via his subjective, differential diagnostic observations that were complemented by the philosopher Joschka Fischer by an evaluation of the origin of European and US-American culture (*translator's note: you better read this observing a STRONG twinkle in the author's eye ...*)

Mr. F. continues: *"the universally accepted method for intonating guitars represents a form of "equal temperment" ... a method that was abandoned in the 1600's by piano tuners"*. Hold it, Buzz, didn't you say a moment ago that guitars are tuned pythagoreically? *"Based upon the fourth, the fifth, and the octave interval ratios."* Ye gods and little fishes! Hopefully we all still know after reading the patent how in the end any tuning and intonation is achieved. At this point, why don't we digress a little into contemporary literature, to show what kind of wide appeal a topical – if error-prone – patent can have:

**Musik Produktiv**, one of the giants in German music commerce, state regarding the matter: *with this modification of the scale, Buzz Feiten achieves a "well-tempered" tuning for the guitar*. Um … the term "well-tempered" is a bit misleading here because Mr. Feiten expressly seeks to avoid this piano-tuning. Musik Produktiv continue: *a piano tuner explained to Buzz Feiten that an electronic tuner cannot generate a well-tempered tuning*. We may disregard the nitpicky rationale that – as a measuring instrument – an electronic tuner can never by itself generate a tuning, but we cannot help recognize another considerable discrepancy: the piano tuner sought to achieve a stretched tuning (according to the Railsback curve). That is – at least according to conventional terminology – something rather different than a well-tempered tuning that is directly connected to Bach/Werckmeister (supposedly equally beating).

**Musik-Thomann**, the huge mail-order shop, writes: *For calculating the scale and adjusting the intonation, people relied on old, traditional formula. These heirlooms were based on a method that piano tuners developed already in the 16th century: the equal-temperament tuning. The commonly used formula to position the frets had already been developed by Pythagoras. There is, however, an error due to the stiffness of the string that generates too strong a disturbance.* In this comment in its German language form, "equal temperment" has been translated into the German expression for "equal temperament" – not as intended, but with some good will we can arrive at the intended interpretation. Again, Pythagoras is brought in. And finally: *All over the world, more and more guitarists have their darlings modified by authorized retrofitters.* Right, a lot of offers are said to exist across the Internet. Guitar players may need that kind of thing. Cave inflammtio!

Here's what **Proguitar** (not yet a giant) contributes: *The formula for positioning the frets was already developed by Pythagoras.* Mr. P. must have been a very early fan of the Strat.

Maybe we can clarify this jumble a bit: Pythagoras is readily cited with his insight that given constant string tension, frequency and length of the string are reciprocal (monochord = single string instrument). Still: already before Pythagoras, the Egyptians, Sumerians, Chinese, Indians, and presumably many other peoples in the ancient world knew about physical and mathematical interrelations. However, the Pythagorean school had the greater impact onto Western civilization, and in particular it left written documents early on (Euklid, Didymos, Ptolemäus, and many more). This Pythagorean school spawned a tonal system based on fifths and octaves that to this day is designated the **Pythagorean tonal system** (Chapter 8.1). It is applied, in its pure form, by the canons regular up to the 16th century, and in a modified form by the harmonists [Simbriger/Zehelein, Barbour]. When, from the 16th century, keys with more and more chromatic signs appeared, the subjectively perceived dissonances of the Pythagorean system were increasingly felt (or rather heard). Two improvements were devised as a remedy:

1. Increasing of the number of steps within an octave, and
2. Tempering, i.e. the fine-tuning of individual notes.

The temperament may feature equal or different beating between notes. Simbringer/Zehelein date the first introduction of temperament back to 1482: *Bartolomeo de Ramis demands that the difference between the third (5:4 = 1,2500) and the fifth no. 4 (81:64 = 1,2656) be balanced out by temperament.* Barbour assumes the date to be 1496, and lists 17 different temperaments, designating them “meantone temperament” and “comma temperament”. Around 1533, Lanfranco lays the foundation for the equal-beating intonation (equal temperament), and subsequently Vincenzo Galilei and Marine Mersenne (1636) concern themselves with the question how to calculate the 12th-order-root of 2 (or an approximation as precise as possible, at least), without having a pocket calculator at hand. Then, the works of Neidhardt and **Werckmeister** – carried out around 1700 – become very popular. Almost 200 years later, Alexander Ellis reports that even “the best British piano tuners” could not produce an acceptable tuning with equal beating, and in 1948 and 1943, **Railsback** and Schuck/Young publish in the Journal of the Acoustical Society of America (JASA) the **stretched** intonation found in pianos: high notes are tuned slightly sharp, and low notes slightly flat.

At this point, the Feiten-patent picks up: *"In the mid-1600's, an enormous breakthrough occurred in piano technology. The 'well tempered' keyboard was conceived, and with it a new standard for piano keyboard intonation <u>which we still use today</u>."* In the mid-1600's, i.e. in the 17th century, Mersenne & Co. were working on that root-calculation and developed the equal temperament. Does therefore, in Mr. F.’s book, equal temperament mean “*well tempered*”? No, that can’t be because he has (correctly) termed the equal temperament with “*equal tempered*". But why would he (with the apparent support of the patent examiner) then write: *"The inventors believe that the reason that guitars still sound out of tune, in spite of 'perfect' intonation, is that the universally accepted method for intonating guitars represents a form of 'equal temperment' ... a method that was abandoned in the 1600's by piano tuners!"*? Quite enigmatic, these Americans! The patent continues: *"When a piano tuner intonates a piano, he uses one string as his 'reference' note, typically, A-440 (or Middle "C"). He then 'stretches' the intonation of the octaves, plus or minus a very small amount of pitch. These units are called cents"*. Ah – here’s the crux of the Buzz-ing matter. Even without further historic ado (already the ancient Greeks …) we could formulate the idea behind the patent application as follows: *similarly to pianos, guitars should be tuned using a stretched intonation.*

That justifies a quick look into JASA: Schuck/Young cite in their publication (JASA 1943) the stretched intonation found by **Railsback**. Below $E_2$ and above approximately $E_6$, a considerable effect is indeed recognizable, with the piano tuning deviating by up to as much as 30 cent. That is not a wonder: the investigated pianoforte will be challenged to conjure a whopping bass of 25,6 Hz out of a mere approx. 1 m string-length, and at the top there’s about 4 kHz tickling out of some tiny 5 cm string-length – in this scenario, dispersion-induced inharmonicity will definitely play a role. In the guitar … how shall we put this without being transatlantic-ally un-accommodating … well: it’s not directly possible to coax 27.5 Hz out of your regularly tuned guitar, and 4.2 kHz on an open string is more of an un-feasible wish, to put it mildly. That’s not even considering that in the piano, for the medium pitch range, the different frequencies come from strings of almost equal in gauge but of different lengths, while on the guitar we have strings of the same length but differing thickness. Schuck/Young explicitly say: *"The sharpening is least in the two octaves below middle C"*. “Sharpening” relates to the partials and can be taken to be synonymous with “stretching”. Middle C is on the $E_4$-string at the 8th fret. The string-pitches of the guitar therefore fall exactly into the range where the effect is minimal on the piano. Nevertheless: 2 cent per octave may occur according to Schuck/Young and Railsback, i.e. about 0,12%. For the <u>piano</u>, that is – with its $E_4$-string being about 1 mm thick. That is about 4 times the thickness of the corresponding guitar string! And thus on the piano the build of the partials includes much more inharmonicity.

Nevertheless, there must be something to this patent by Mr. Feiten. Doesn’t Californian guitar-god **Larry Carlton** say about the Feiten-tuning: “*I’ve been playing the guitar since I was six years old, and finally it is in tune.*” One could of course find a number of reasons for this[♣]. How about: Larry C.’s nickname is Mr. 335 due to his penchant for Gibson’s thin-line guitars. If, on the necks of his noble vintage pieces, the frets were placed as inaccurately as on all Gibson necks this author checked, then reworking of the necks might indeed have made for audible added value. Whether the application of the Buzz-Feiten-offsets alone really involves significant advantages … every guitarist needs to find that out for him/herself. Here are the Feiten-tuning-offsets proposed for electric guitars, to be adjusted after the nut- and bridge repositioning has been done:

| | | |
|---|---|---|
| E: | 0 / 0 | 0 / 0 |
| H: | +1 / 0 | 0 / –1 |
| G: | –2 / 1 | 0 / +1 |
| D: | –2 / 1 | 0 / +1 |
| A: | –2 / 0 | 0 / +1 |
| E: | –2 / 0 | –1 / 0 |

**Patent USA-6642442 (Feiten), uspto.gov:**
Tuning-offset in cents relative the equal-temperament intonation. The first number holds for the open string, the second number is for the octave fretted at the 12th fret. Column on the left to be applied to electric guitars; the column on the right is for acoustic guitars.

In terms of the tuning offset, the Feiten-patent only distinguishes between electric guitar, steel string acoustic, and nylon string acoustic. It ignores the fact that, in wound stings, the ratio of core- to winding-diameter influences the inharmonicity of the partials. On the other hand, rather extreme precision is required, as the table for the acoustic guitar shows. The high E-string is to be tuned exactly to the (pure) octave for the 12th fret: for all other strings, the octave is detuned by **1 cent**. Just as a side-remark: if a string is heated up by a mere **1° C**, the string frequency diminishes (for unchanged mounting) by 9 cent. Therefore, the string may change its temperature by no more than 0.1 °C in order to maintain the Feiten-tuning! *That fearful sport, father attempt not too oft!* [Schiller]. And from the same author and the same poem (“The Diver”): *Let not man to tempt the immortals e'er try, Let him never desire the thing to see, That with terror and night they veil graciously.* And since there is still some room here: the unforgotten K.-H. Hansen tells us: *Easily does the lad talk big about the mil – he will be an old man by the time he achieves the hundredth part.*

In conclusion of this chapter a bit of an anecdote: a much-lauded Californian guitar god (we shall omit the name … for legal reasons) visits Germany to play a concert. Just before the gig, he takes his el-cheapo[♥] six-string to the local shop for a quickie-bridge-adjustment. The latter, however, runs into a substantial snag because the bridge is attached so firmly with double-sided adhesive that to forcedly move the thing is deemed dangerous and inviting real damage. The guys in the shop don’t dare to do anything, cause *let not man to tempt the immortals e'er try* (see above), especially with the gig looming that same night: with that god visiting Old Europe once every blue moon, you don’t want to botch up his guitar – here in Germany, of all places. So: bring back the guitar unrepaired. That evening: the god plays god-like, in spite of the “displaced” bridge. Or was it because of the resulting special intonation? Who knows how exactly a god ticks?

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[♣] Larry C. is not really a spring chicken anymore; it’s been a while since he passed the age of 6.
On impulse, also the thought pops up: what further heights might Jimi H. have climbed, had he in time ...

[♥] The real (precious) stuff will probably and preferably stay safely at home in CA ...