Preface – by the author

The present book is the result of the lifelong practical and theoretical dealings I have had with the electric guitar. The associated practical experiments started already in the 1960's when guitar-dominated, so-called "Beat-Music" got its global breakthrough. Looking back, "Memphis Tennessee" was the initial spark that – barely ignited – found a propellant charge in the tunes of the Beatles and the Rolling Stones that still continues to burn intensely to this day. Subsequently, Eric Clapton became the big hero in terms of sound and style – and in fact he still is, at least as far as his early years are concerned. My funding situation back in the day required that amplifiers had to by built in DIY-fashion on a budget, with the ensuing insight that teachings in school were not nearly comprehensive enough. This automatically led to enrolling in the course for electrical engineering at the Technical University in Munich, with a focus on electro-acoustics. It was here where the theoretical part started.

Particularly formative were the lectures by Hans Marko (systems theory), Rudolf Saal (network theory), Eberhard Zwicker (acoustics), and Hans Meinke (radio frequency technology). It may be surprising that RF-technology plays a decisive role in acoustics – but Meinke's theory of transmission lines, in combination with the theory of electro-acoustical analogous networks, would prove to be ideal for the description of string vibrations. Founding a company that designed and manufactured instrumentation equipment for measurement of sound did temporarily lead to a banning of all guitars to the attic, but it did also make for the emergence of precision instrumentation that formed the basis for the hardware in the lab later. From 1990, more and more guitars succeeded to wander back to the basement and then up into the beletage: the newly commenced work as a university professor (acoustics, signal- & systems-theory) generated free time and aroused the curiosity how exactly these devices operated. Uh-oh … that may sound a bit unsettling … let's rephrase: the newly commenced task as university lecturer led to such an intense workload that a balance was urgently required, and that turned up in the form of various guitars. There was a curious inherent proliferation process among the latter over the years – and they all wanted to be played and analyzed. After several years of more sporadic experiments, systematic research on the electric guitar set in from 1999, including written documentation.

Initially I had hoped that a few equations on vibrations, and some formula on the magnetic field could adequately do the job of describing the topic. About 100 pages titled "How does the electric guitar function?" emerged from that assumption. I then realized my very limited understanding of just that functionality. This in fact is quite a good situation for any scientist. As a model, the simple hypothesis of a transversally oscillating string with complex-valued bearing impedances was of merely limited suitability. Considering the available literature, the engineer in me tried to make do with it, but as a guitarist I found grave deficiencies. There was, after all, an upside to having been able to study musical performance practice in the clubs in Munich's hip Schwabing quarter. That was back in the day as a student, when conservative educators warned, with a wagging finger, about the amalgamation of Apollonian and Dionysiac goings-on, and now it bore fruit. Still, the already mentioned transversal wave remained in the foreground, but the revelation that a string on an electric guitar played by a virtuoso will act out in a way entirely different from the teachings of all text books I knew – that revelation slowly worked its ways from cortical depths into consciousness. Unfortunately, 100 pages had already been written up.

From now on, the musician prevailed over the engineer, and unmistakably articulated the question why calculations were always done on the freely vibrating string, when that string constantly hits the frets (as required by other regions in the brain during daily guitar playing). Put another way: it is not entirely wrong to model the electric guitar as an LTI-system, but the "sound" cannot be described that way. About at the same time of that recognition, irregular occurrences in the spectrum of the strings showed that a non-negligible longitudinal wave (dilatational wave) needed to be preset on top of the transversal movement of the string. This longitudinal wave could at first be assumed only hypothetically but (from 2005) found comprehensive confirmation via the use of a laser-vibrometer. By that, the book that at that point had been considered to be very much on course, suddenly lost its whole structure. Chapters and figures had to be repositioned, pagination did not fit anymore, whole passages had to be completely re-written.

Today, more than 16 years have passed, and more than 1200 pages written for the book have resulted. That extent had never been envisaged – but then, how far can research be planned? Reading the first pages again after 16 years, ideas for a redesign pop up on impulse – but giving in to them would preclude any finalization. Thus: over and done – that's it!

The first two chapters deal with string vibrations. Much space is dedicated to dispersion, because its effects on the harmonicity are considerable already in the middle frequency range (see e.g. Fig. 1.11). The combination of the theory of electrical transmission lines and electro-mechanical network-analogies facilitates a presentation of wave-propagation and -reflection (Fig. 1.20) that is easy to grasp for the telecommunications engineer. Effects of the strings hitting the frets or buzzing are discussed in Chapters 1.5.3 and 1.5.4 only in short – the supplement is delivered in Chapter 7.12. The purpose of Chapter 2 is predominantly to elucidate the real shape of the string vibration – sine-shaped partial-modes are of little help here. By using a special presentation of the differential string-stiffness (Fig. 2.13), a way could be found to visualized transversal movements without involving too much math.

Chapter 3 discusses the magnetic string parameters. It turned out shorter than originally planned because the investigated strings barely differed in their magnetic parameters.

Chapters 4 and 5 describe magnetic pickups. Extensive and varied measurements demonstrated a relatively simple correspondence between string velocity and pickup voltage. This is a result that is well supported by theoretical considerations. The aperture-window (Chapter 5.4) is merely 1 cm long and independent of the coil geometry; the latter, however, influences the frequency response and the absolute sensitivity.

Relatively short, **Chapter 6** is dedicated to piezo pickups. Combining quadripole-theory, digital signal processing, and electro-acoustics (reciprocity, Chapters 6.4 and 6.5) transpired to be particularly interesting.

The investigations into vibrations of guitar neck and guitar body (**Chapter 7**) started from the premise that the resistive part of the string bearing (the so-called conductance) would deliver the main contribution to the string damping, and thus the wood of the body would be essential to the sound of the electric guitar (an assumption flogged to death by trivial "specialist" literature month by month). Extensive investigations regarding the decay behavior of the plucked string show, however, an entirely different result: for the solid-body guitar, the bridge is yielding only at few frequencies to such an extent that the bridge-absorption gains importance relative to the string-internal absorption. Moreover, this absorption can be mostly traced to the bridge-design itself, and practically not at all to the wood used for the body.

Neck resonances are of a bit more significance; of particular relevance, however, is the upper surface of the frets, because it determines whether and where the string bounces off the frets (attack, snap).

Chapter 8 outlines the physical basics of prevailing tonal systems (tunings) and explains some music-relevant essentials of psychoacoustics (e.g. spectral and virtual pitch, grouping of partials, consonance/dissonance, timing and rhythm, timbre and loudness).

Chapter 9 is dedicated to the electric circuitry within the electric guitar. It was not planned to be very extensive, because sufficient literature is already available on this topic [H. Lemme].

Chapter 10 (guitar amplifiers) and **Chapter 11** (guitar loudspeakers) give information on the electro-acoustic equipment. That in fact is a never-ending story – a topic that cannot be comprehensively presented even with 440 pages. Even so, there is now an extensive metrological analysis – supplementary listening experiments are desirable.

To make things somewhat less prosaic, **Chapter 0** rises a bit beyond the world of physics. Corresponding feedback has generally been very positive, it's only Ms. Growse-Glowsock who causes some agro.

As a last point, thanks should be given to the government of the State of Bavaria – with its steady donations, it has provided a though small yet still important contribution to this research project. My little acoustics lab and I were always full of joy when the dean declared that, despite unavoidable funding cuts, another € 1200.- would be at our disposal. Not per month, no, of course not. We do not see ourselves as an elite-cluster, my lab and I. We do understand that € 1200.- per year can only be mustered because an elite-cabinet in the state of Bavaria's capital Munich spares neither trouble nor expenditures. And we understand that for 16 years we have been practically alone because permanent staff for the lab cannot be financed. Having said that: my lab did have some trouble comprehending, and repeatedly asked back, why another vice-president for the university had to be added to the first one if there is as good as no money available. The additional VP requires (and gets!) staff, rooms, and – again as my lab has found out – a new computer. To be honest, the thing with the computer was difficult to communicate (to the lab) because we still have old NT-computers hanging around. Some empathy could be created, after all, by the wisdom passed down from generation to generation: that only that can grow that is present. What is not present (e.g. sufficient permanent staff posts) does not grow. And so, dear acoustics lab, it is only too reasonable that our university has by now received its third vice-president. L'enfer, c'est les autres (Sartre)…

Regensburg, in autumn 2014

Manfred Zollner

