9.4 Guitar Cables

Guitar pickups are usually connected to the guitar amplifier via a cable several meters long. In more rare cases an amplifier is already built into the guitar or even into the pickup - wireless connections are also used. The customary guitar cable determines the sound. Its capacitance generates - in cooperation with the capacitance and the inductance of the pickup coil - the **pickup resonance** which lends a characteristic color to the transmission.

The guitar cable holds an internal conductor (in some cases two). This is constructed as a thin, flexible stranded wire (sometimes two) outwardly insulated cylindrically e.g. by foamed polyethylene. Around the insulator there is a concentric braided shielding which sometimes holds conducting synthetics in addition. For high-quality cables double shielding is customary. Every differential little piece of cable can be described by four elements: a series resistance, a series inductance, a parallel capacitance and a parallel resistance.

The series resistance amounts to just a few Ωs - it may with very good approximation be fully neglected re. the source impedance (kΩ). The series inductance (ca. 1 µH) is so small, as well, that is will not play any role here. As a rule, the parallel resistance is large (> 100 MΩ) to the extent that it, too, will have no audible effect. On the other hand, charge displacements and corresponding very small mechanical deformations will occur in the dielectric (the insulating synthetic). This will lead to mounting energy losses with increasing frequency. Such effects cannot be captured with a normal **insulation measurement** which is normally done with direct current. For this reason, more elaborate equivalent circuits feature not just one simple (real) parallel resistor but a complicated **RC-array** modeling the complex parallel conductance. On other words: the **cable capacitance** is frequency dependent to a small degree and decreases a little with increasing frequency, while the **cable losses** are strongly frequency dependent and mount with increasing frequency.

Lossy capacitances are described in a simplified manner by an RC equivalent circuit. In the lower frequency ranges an RC parallel circuit is employed while in the higher frequency ranges an RC parallel circuit is used. The energy stored in the capacitor can be recalled, however the resistor irreversibly converts electrical energy into thermal energy – thus the term **loss**. In the complex admittance plane, the admittance real component represents the conductance due to the loss while the admittance imaginary component is the susceptance due to the capacitance. Instead of the Cartesian coordinate system with conductance and susceptance the polar coordinate system with magnitude and phase may also be used. The magnitude is the admittance while the tangent of the complementary phase angle ∂ is the dissipation factor *d*.

$d = \tan\partial = 1/R \cdot 1/(\omega C) = 1/(\omega RC)$ ∂ = dissipation angle (Fig. 9.14)

For high quality capacitors the parallel resistance *R* is very large, and consequently the parallel conductance *1/R* very small. The result is a very small value for ∂. Data sheets show e.g. values of $d = \tan\partial \approx 10^{-4}$. Inserting into the above formula a frequency-independent resistance *R* and a frequency-independent capacitance *C* should lead to reciprocal dependency of tan ∂ on frequency. However, in reality tan ∂ is more or less constant at lower frequencies, and for many insulators even an increase with frequency is found (see also Chapter 9.2, tone capacitor).

The measurements are in clear contradiction with the formula shown above. If frequency dependent components (the function of which is difficult to understand) are to be avoided, the only solution is to extend the equivalent circuit to multiple components. Depending on the desired accuracy a rather large RC array may be required. Fig. 9.14 shows one simple and two extended equivalent circuits.

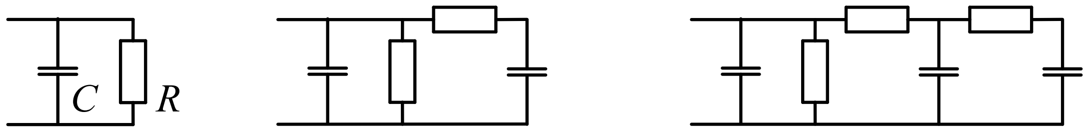

Fig. 9.14: Two-pole equivalent circuits of different complexity for a guitar cable. (see also 5.9.2).

Cable capacity and pickup inductivity cooperate to generate a **resonance** in the frequency range between 2 and 5 kHz. The cable capacity is an indispensable partner in this resonance circuit and determines the sound. Cable losses dampen the resonance – however this is negligible for good cables. As has been discussed already, it is not proper to use the (very high) insulation resistance for considering the cable loss; rather a loss simulation dependent on frequency is required. Since the pickup/cable resonant circuit has its highest impedance at resonance frequency, a dampening resistance in parallel has the biggest effect. High quality cables will yield loss resistances > 50 MΩ in the frequency range of the resonance. Compared to other losses and in particular compared to typical potentiometers used in guitars (250 kΩ), **such cable losses are consequently negligible**. This does not mean that cable losses are negligible in general. For radio-frequency transmission other criteria are valid. Guitar cables however are operated in the audio range – and here only the cable capacitance is of importance. High quality cables cost a couple of $/m – add some high quality plugs and the cost can be some $ 20.-. That should be it. "Monstrous" prices are not justifiable from a physics point of view.

The **cable capacity** usually is around 100 pF/m (+/- 30%). Normally used cable lengths thus yield capacitances of **300 - 600 pF**. For very long cables this could rise to up to about 1,5 nF. Special low-capacitance cables go as low as 70 pF/m. For comparison measurements we had access to a 40 year-old guitar cable (i.e. truly "vintage" ☺). It was 4 m long and sported a rather remarkable 1050 pF, plus a similarly noteworthy loss resistance of only 500 kΩ. Compared to the low-capacitance cable mentioned above with 4 x 70 pF = 280 pF there is a large and clearly audible difference. The effects of the low loss resistance can be (just) audible for high-impedance guitars, as well. The "vintage" cable is however not typical for modern cable production.

Next to the above elementary electrical parameters there are some other properties of importance: shielding effect, mechanical resilience, flexibility, safety against fracture, flexural strength and **low noise performance**. It may be surprising that a cable can generate noise. Bending and straining changes the mechanical tensions in the insulator which can lead to charge displacements. The latter can manifest themselves as crackling noise (tribo-electric effect) - for high quality cables this is not audible, though.

The sound of an electric guitar can audibly change when the **cable is switched**. Unless very low-quality cables are used, the reasons are **solely** found in the different cable capacitances. Relaxation phenomena (orientation polarization, inertia of dipole rotation in the frequency range f > 1GHz), dispersive signal-propagation or non-linear effects are insignificant in the audio range. Physics are neither applicable nor competent in the area of esoterism – nor are psychoacoustics.

Old **coil cords** could often be stretched to 5 m. The actual cable length was even longer – 8 m were probably not untypical. Capacitances of about 2,1 nF and loss resistances of 250 kΩ could be the result. If someone would like to reproduce specifically these old "vintage" characteristics but is shying away from laying 21 m of modern cable 21 x 100 pF = 2,1 nF) could solder an additional capacitor to the cable. The effect of the loss resistance can be reproduced by turning down the tone control to some degree. The final evaluation should be done via a listening test. To exclude prejudice and bias, a blind test with direct A/B-comparison is recommended.

A very flexible solution can be obtained by connecting different capacitors via a **rotary switch** to a short low-capacitance cable – the resonance frequency is now adjustable. The connection of a capacitor is indispensable in particular if a usual magnetic pickup is to be connected to an amplifier (e.g. an on-board pre-amp) *without* a long cable. The resonance frequency of the pickup without the loading by the cable capacitance is too high such that the sound becomes "glassy" or "too sharp". If this sound is not actually desired, a capacitor of 300 - 1000 pF needs to be connected in parallel to the pickup in lieu of the cable.

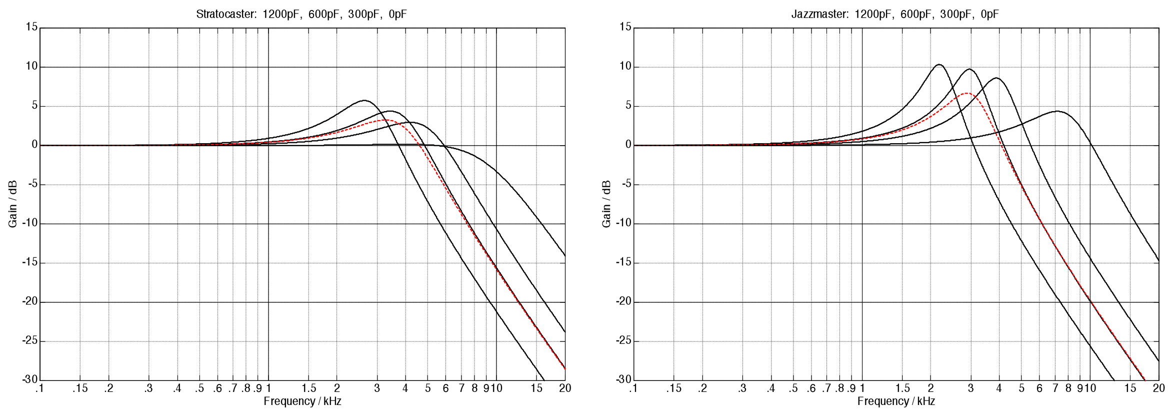

Fig. 9.15: Low-pass transmission for varying cable capacitances: 1200 pF, 600 pF, 300 pF, 0 pF. The solid lines show loss-free cables, the dotted line refers to a 500 kΩ loss resistance. For modern high quality cables the loss resistance of R>50 MΩ in the range of the resonance frequency is certainly negligible.

In **Fig. 9.15** we see the influence of the cable capacity on the H_{UV}-transmission function (low-pass model). Elongating the cable has the effect of a capacitance increase proportional to the length increase. This reduces the resonance frequency. The resonance peak at the same time becomes stronger. The figure is meant to exemplify the effect in principle. Additional data are found where the specific pickups are discussed.

Fig. 9.16 depicts the loss factors for a number of guitar cables. The five lines in the upper region of the figure are the results of guitar cables from old production, and of modern microphone (!) cables. These cables can result in an audible dampening of the resonance. The cables of the makes Horizon, Straight, Klotz LaGrange and Gibson will clearly not decrease the resonance peak, nor will the RG58-CU used in measuring and instrumentation (it would however not be flexible enough as a guitar cable). The rather thin George-L's-cable can be seen as a borderline case: the dissipation factor should not exceed 2% in the range of the resonance frequency (2 - 5 kHz).

Microphone cables are generally not suitable as guitar cables. They are usually a two-wire line and optimized for connection to a differential amplifier input; the issue of low capacitance is not much considered. The survey measurements revealed microphone cables sporting a rather sizeable 250 pF/m and dissipation factors of 10%. When operating a dynamic 200-Ω-microphone one can still get very good results with a 10-m-long-line, but for a high-impedance guitar such a cable should not be used. This does not imply that microphone cables are generally unsuitable for electric guitars – there are indeed also very good microphone cables. The suitability should therefore be checked in the specific situation.

It should be general knowledge that **loudspeaker cables** are unsuitable for guitars. Most often speaker cables are constructed as thick stranded cables, and they are not shielded. The pickup might be susceptible to noise, but at least the cable should be silent.

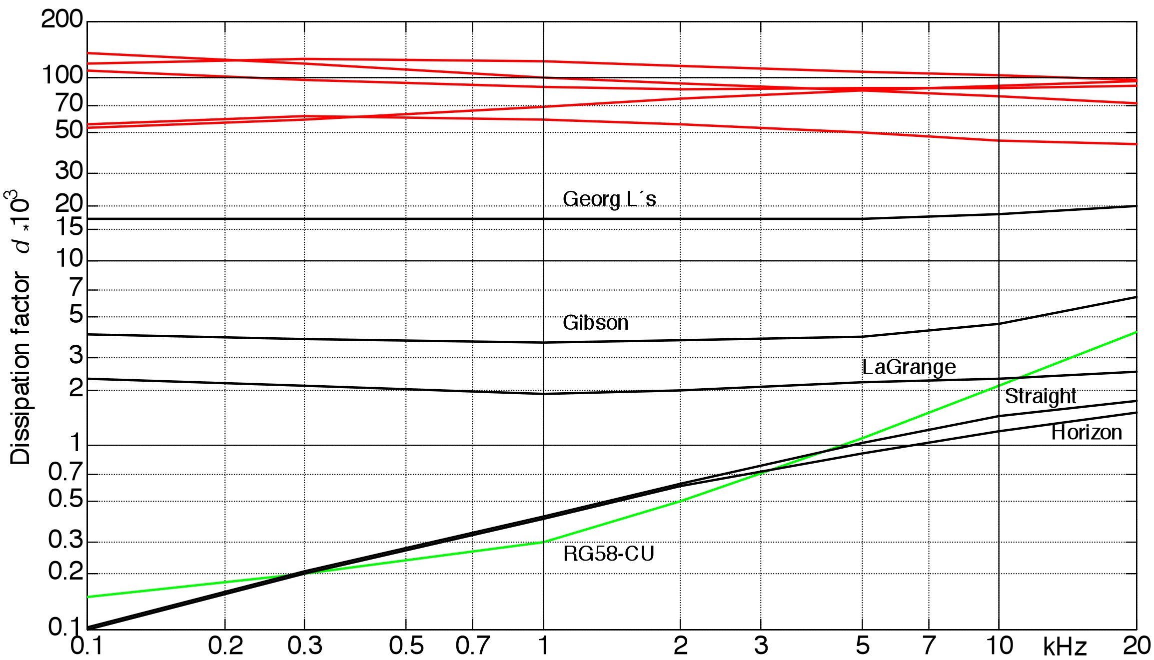

Fig. 9.16: Dissipation factors of guitar cables. The sample shows just a few examples, there are many more manufacturers.

It is no surprise that inconceivable nonsense is sometimes found in advertisements – rather this appears almost to be part of the specific charm of the genre. In contrast, editorial test reports published regularly in musician's magazines carry a high weight since one assumes an independent expert author to be behind it. To illustrate here an excerpt from a well-respected guitar and bass magazine: in an issue in spring 2000, the well-known author notes, in the framework of a test of instrument cables, with some prudence: *"According to the manufacturer, the Monster-Cable Performer 500 Rock supposedly is distinguished by an aggressive sound, while the Bass Instrument Cable (Performer 500 Bass) supposedly has a particular strength in the low frequency range and achieves an extended-dynamic performance.*" Supposedly! This wording leaves room for interpretation of the kind we know to be smart when dealing with the tourist industry: "given that the hotel is located in the immediate vicinity of the airport, it supposedly is relatively quiet." If you still go there, it's your own fault. In the next issue of the same magazine the same author writes: *"While the cables for bass and Rock distinguish themselves through emphasizing the cutoff frequencies and aggressive presence, respectively, the Performer 500 Jazz establishes itself audibly more succinct in the lower mid frequencies and presents the character-defining timbre-range with extensive emphasis but remains pleasant and round .... compared to other Monster Cables, the Studio Pro 1000 appears a tad softer - this can be traced to a particularly balanced transmission without any emphasis or peculiarities."*
So much for diplomatic restraint: here is the opinion of the man carrying out the test. Of course, he is entitled to it and may publish it. However, he will then have to put up with the question whether he indeed has any clue at all of the electric function of a cable. "Without any emphasis"? Does that mean the cable has no capacitance? That would probably not work, and it is not desirable, either. What actually is the capacitance of these wonder-cables? One could easily and cost-effectively measure them and publish the result - the reader would take away much more than he will profit from speculations about cutoff frequencies. In any case the price of these wondrous cables does not remain in the dark (remember, this is in 2000, and below we are using a conversion rate of slightly more than 1 $ to the EUR):

- Performer 500 Monster Bass Guitar Cable 6,4 m: ca. $ 70.-
- Performer 500 Monster Rock Guitar Cable 6,4 m: ca. $ 70.-
- Performer 500 Monster Jazz Guitar Cable 6,4 m: ca. $ 85.-
- Studio Pro 1000 6,4 m: ca. $ 180.- No typing error: **onehundredandeighty bucks!**

It is of course understood that a Jazz-cable will be more expensive than a Rock-cable. If that weren't the case, the marketing manager should be laid off without notice. The step size is o.k., as well: one quarter more expensive. You do see it the same way, dear Jazz guitarists, don't you? But what about the actual level of these prices?? The very high-grade Klotz LaGrange cost at the time about $30.-. Same length of 6,4 m, and a capacitance of 67 pF/m, with two Neutrik plugs. And that cable, as well, will not have been sold without profit ....
It may be that the special capacitance of the Monstercables generated a special sound during the test which led to the mentioned description. Of course nobody will will imply that the Author may have simply copied the advertisement texts provided by the manufacturer and then signed with his name. However the special capacitive load could have been achieved at less expense: for $180.- one could buy 1000 capacitors and as many resistors to go with them. That would have been sufficient for a whole lot of set-ups to emulate ANY cable, even the Monster-ones. And a loc-cap cable with two Neutriks would have been thrown in ...

To cite an author/tester from another magazine: "The idea of an instrinsic sound of cables as propagated by the industry is, in my opinion, a load of total BS." Stated by a well-respected studio owner and regular author with this other magazine.