For the $I_2 \rightarrow v_1$-operation, a generator with a low-impedance AC-output is connected to the electrical input of the pickup. Since the pickup represents (in good approximation) a purely capacitive electric load independent of its mechanical loading, it is easy to make the connection from the electrical voltage $\underline{U}_2$ to the current $\underline{I}_2$ ($\underline{I}_2 = j\omega C\underline{U}_2$). This current→velocity transmission-coefficient T_{vI} corresponds to the force→voltage transmission-coefficient T_{UF} for the electrical open-circuit:

$$\frac{\underline{U}_2}{\underline{F}_1} = \frac{\underline{v}_1}{\underline{I}_2} = \frac{\underline{v}_1}{j\omega C \cdot \underline{U}_2} = \frac{\underline{x}_1}{C \cdot \underline{U}_2} \qquad T_{UF} \text{ for } I_2 = 0, \quad T_{vI} \text{ for } F_1 = 0$$

The oscillation-velocity v_1 can be determined e.g. with a Laser-vibrometer; due to the small values to be measured, suitable averaging is mandatory.

6.5 Operation as an actor

Piezo-electric materials convert in both directions: mechanical quantities into electrical ones (operation as sensor), and electrical quantities into mechanical ones (operation as actor). As an electric AC-voltage is connected to the electrical connectors of the pickup, the bridge piece vibrates up and down … a bit. A very small bit, actually: merely a few nanometers. We could not find out at which voltage the crystal was going to receive irreversible damage, and therefore the following measurements were carried out with a RMS-voltage of 10 V – no recognizable damage occurred there. During the measurement, the Ovation guitar was placed in its case, and the vibration velocity was measured using a **laser-vibrometer** (Polytec). Based on the equivalent circuit diagram shown in Fig. 6.8, we would expect, for a mass-free bridge piece (idealization), a frequency-independent *displacement*, if a frequency independent voltage is imprinted. However, the vibrometer – based on the Doppler effect – measures the vibration velocity as its source-quantity, and therefore the measurement grows more difficult with decreasing frequency. Nevertheless, using sufficiently narrow-band filters makes coherent results possible also in the low frequency domain (**Fig. 6.14**). Both the actor- and the sensor-measurements show, as a 1st-order approximation, a frequency-independent transmission factor, although there are smallish frequency peaks – these are mainly caused by the guitar and not by the measuring process.

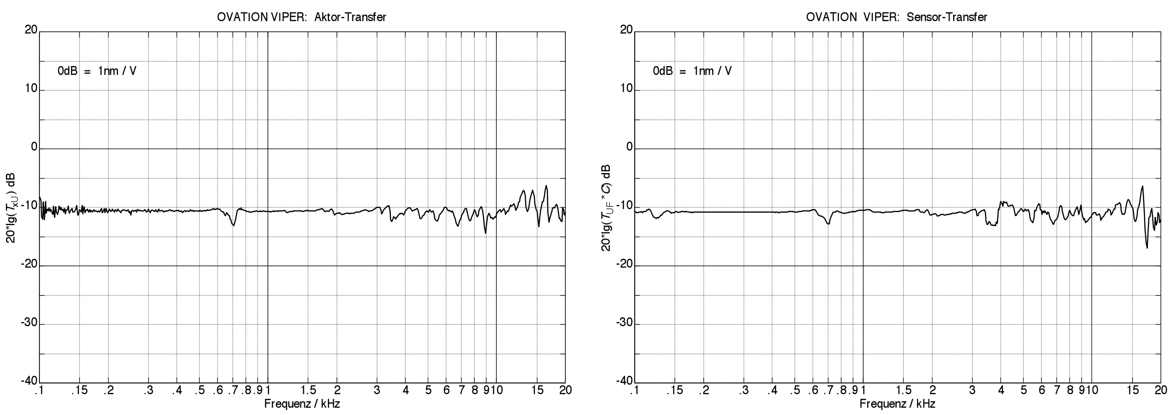

Fig. 6.14: Transmission factor G_{xU} as measured with the laser-vibrometer (left). For comparison, the corresponding sensor-measurement is shown on the right: $T_{xU} = C \cdot T_{UF}$. The correspondence is impressive. "Frequenz" = frequency; "Aktor" = actor.

The actor-measurement gives us a voltage→deflection transmission coefficient of 0,29 nm/V. For the selected generator voltage (10 V_{eff}), this implies a deflection of 2,9 nm, and a velocity of only 1,8 μm/s at 100 Hz, and it also means that the laser-vibrometer generates as little as 0,36 mV (for 0,2 Vs/mm). This small voltage of the signal is clearly below the **intrinsic noise** of the laser-vibrometer, and an exact measurement requires deployment of a frequency-selective tracking-filter (**Fig. 6.15**). Alternatively to the process applied here (**Hilbert-transform**, complex quotient, block-averaging), we could also calculate the complex quotient of two DFT-spectra – however, the path via the Hilbert-transform is more conducive for the logarithmic frequency axis we employ.

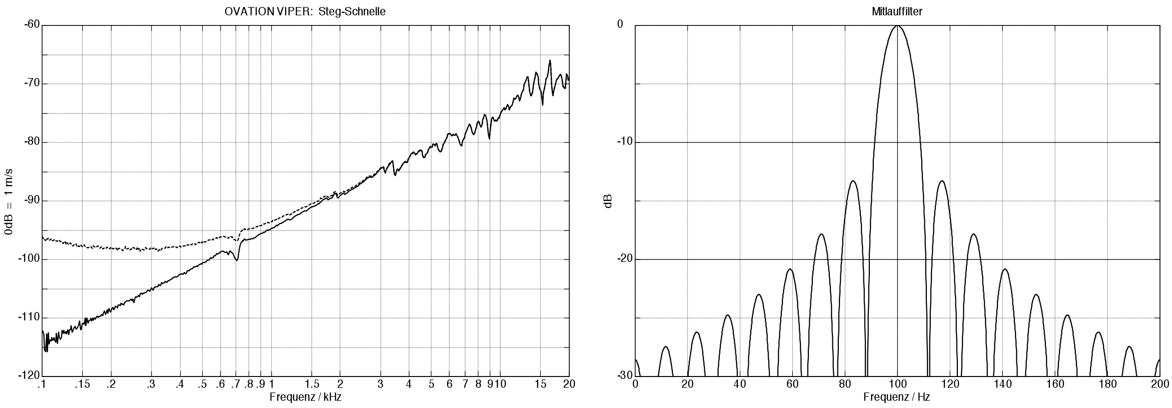

Fig. 6.15: Measured velocity w/out (---) and with tracking filter (left); filter characteristic at 100 Hz (right).

The **comparison** of operations as sensor and actor (Fig. 6.14) indicates that the mass-compensation elaborated in Chapter 6.3 delivers exact results, and that our modeling of the transducer is suitable as a first approximation. The noise-effects appearing in the low-frequency range with the laser measurement can easily by reduced by extending the averaging-window – thus we have at our disposal two equivalent processes for f < 3 kHz. In the higher frequency range, the two approaches show smallish differences that can be attributed to an imperfect mass-compensation, and to small differences in the measurement position.

Many of the high-frequency resonance peaks can be traced to structural resonances of the roof-shaped string pieces and the strings. Still, the **lower side of the pickup** merits some consideration because it forms the reference system relative to which the upper side of the piezo (oriented towards the string) vibrates. The lower side of the pickup is formed from a u-shaped aluminum rail laid on top of shims (made from Pertinax) that are placed on the routed-out guitar body. At least this is the situation with the factory-fitted instrument. For the measurements described above, strips of corrugated paper replaced the shims; any misgivings that the absorption would be unduly increased were in fact unfounded. On the contrary, the original shims resulted in a small dip in the frequency response of the transmission at around 5 kHz that could be attributed to a resonance in the u-rail. It appears the strips of corrugated paper made for a better contact and therefore a better dampening of this resonance. Note, though, that axiom "the sound is in the ear of the beholder" does always hold. In its left-hand section, **Fig. 6.16** shows the transmission factor G_{xU} for actor-operation with the original shims, and on the right the displacement of the u-rail measured for the same drive-level. We clearly see that the u-rail starts to vibrate more strongly in the range around 5 kHz. The special shape of these vibrations was not further investigated since the effort would have been unreasonable.

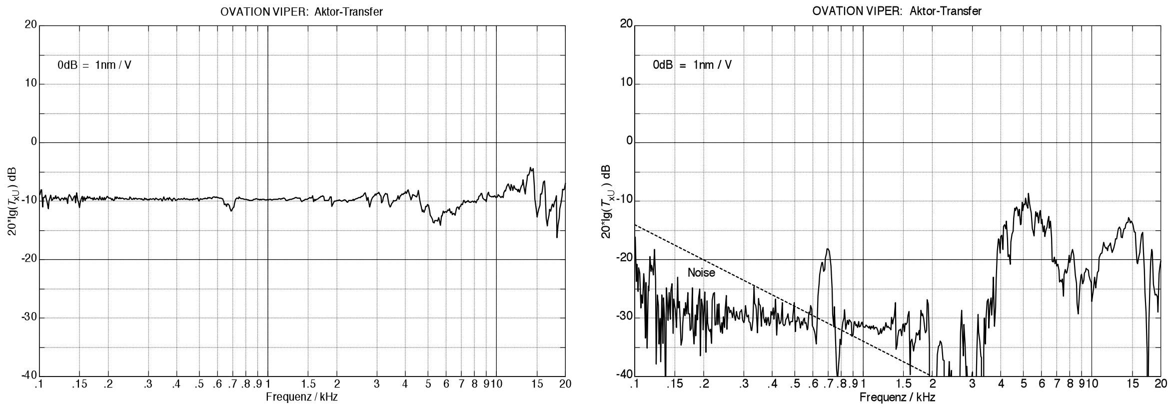

Fig. 6.16: Transmission factor incl. the Pertinax-shims: bridge pieces (left), u-rail (right). The piezo-pickup was driven from a low-impedance source for both measurements. We see a resonance of the guitar top around 700 Hz,; around 5 kHz and 15 kHz, a resonance of the u-rail carrying the piezo crystal occurs.
"Frequenz" = frequency; "Aktor" = actor.

Besides the solid-body Viper (EA-68, a rather uncommon design for an Ovation guitar), a more typical steel string acoustic (**Adamas SMT**) was also analyzed. The "mid-depth bowl"-designated Lyrachord-body carries a laminated top of birch and carbon-fiber layers; a piezo-pickup is built into the bridge. **Fig. 6.17** shows the comparison between sensor- and actor-operation; again there is good correspondence. Measuring in the actor-operation proved to be somewhat more difficult than for the Ovation EA-68, because the vibration-happy top was excited by ambient noise – especially in the range of the 160-Hz-resonance.

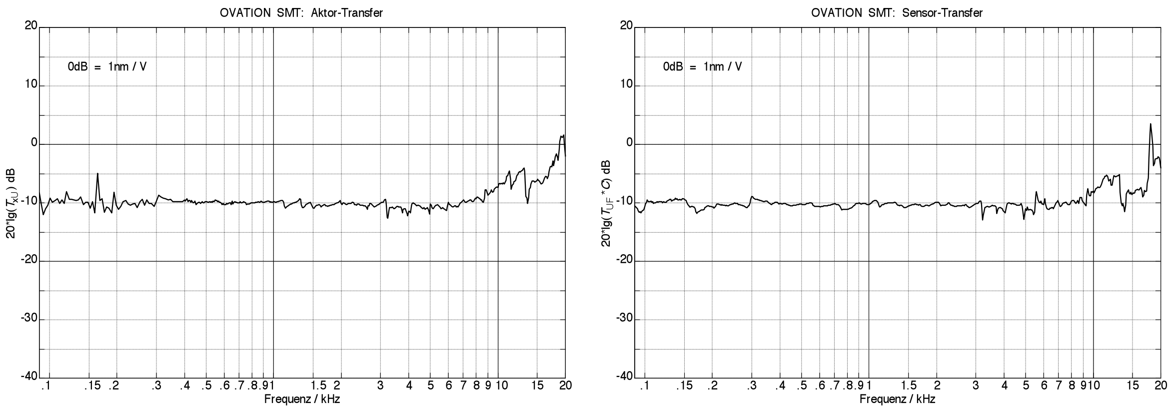

Fig. 6.17: Transmission factor of the Adamas SMT. Actor-measurement (left), sensor-measurement (right).
C = 450pF. "Frequenz" = frequency; "Aktor" = actor

Compared to the Viper, two significant differences show up: the capacitance of the SMT-pickup only amounts to 450 pF (re. 1,45 nF for the Viper), and the transmission behavior of the SMT includes a boost in the range of the highest octave. Operating the pickup in conjunction with the FET-preamp built into the respective guitar, a small difference is also revealed in the low-frequency range: the Viper-piezo sees a load of 500 kΩ resulting in a high-pass with a cutoff-frequency of 220 Hz. Conversely, the SMT-piezo is connected to a preamp with an input-impedance of 2 MΩ, yielding a lower cutoff-frequency of 177 Hz. The above measurements do, however, not show any high-pass behavior: this does not occur in the actor-operation as a matter of principle, and it was computed out for the sensor-operation.

 Translated by Tilmann Zwicker