6.7 Noise

For every piezo pickup cooperating with a battery-powered preamplifier, we encounter conflicting goals between noise interference and life-time of the battery: the smaller the drain-current of the involved field-effect transistor, the longer the battery keeps – but the higher also the noise-voltage density e_n, and thus the preamp noise. However, as a rule we are not sailing in very critical waters here, and we can opt in favor of the staying power of the battery.

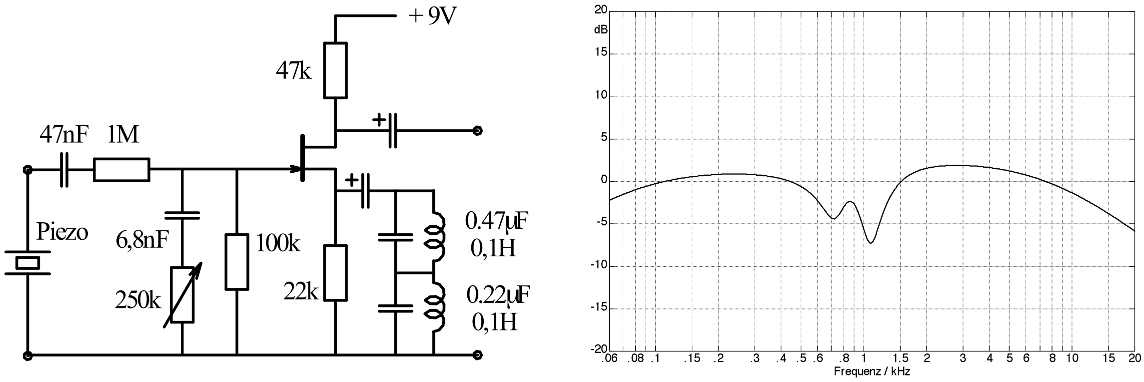
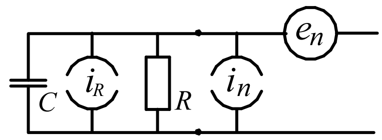


Fig. 6.21: Schematic and gain of an early Ovation-preamplifier. The adjustable 250-kΩ-resistor serves as tone control, at the output we find a volume potentiometer of 100-kΩ (not included in the drawing).

Fig. 6.21 shows the schematic of a battery-powered FET-amplifier as it was deployed in the first-generation **Ovation** guitars. Given a quiescent current of about 0,1 mA, a battery lifetime of about 4000 h may be expected (for Alkaline batteries). The two resonance circuits connected to the source cause an attenuation of the mids that – according to the manufacturer – influence the sound advantageously. Since in this configuration, the FET reaches a voltage-gain factor of about 20 and could easily be overdriven, the signal from the piezo needs to be correspondingly reduced by a voltage divider at the input. In the 2-kHz-frequency-range that is important to our hearing, we therefore find an effective resistance of 67 kΩ at the FET-input that causes – with 33 $\mathrm{nV}/\sqrt{\mathrm{Hz}}$ – so much noise that the FET-noise itself may be disregarded. The multiplication of the noise-voltage density mentioned above with the square-root of the bandwidth of the 1/3rd -octave at 2 kHz, and with the voltage gain gives us a noise voltage of 14 µV at the circuit output – that ain't really much of a low-noise design, but it's not that bad either given a maximum obtainable signal voltage of 1 – 2 V.

Later Ovation preamps distinguish themselves from the model discussed above by a somewhat lower noise, and by distinctly higher current consumption. For example, the **quiescent current** of the Ovation Viper described in the preceding chapters amounts to about 1,2 mA, and the SMT even draws as much as 4,6 mA from the 9V-battery. On the other hand, we should not be silent about the versatile equalizer built into these models that also requires power. If we want to look into the data of integrated operational amplifiers (OP), we need to direct our attention first to their voltage supply: typically, an OP is operated with ±15 V; battery-operation with ±4,5 V or even as low as ±3,5 V is often but not always possible. Moreover it needs to be noted that some OP-data deteriorate relative to the datasheets if the supply voltage is reduced.

In order to calculate the amplifier-noise it is conducive to transform all noise sources to the input of the amplifier and to indicate them as so-called equivalent input-noise sources. In this respect, datasheets for OPs specify the **noise voltage density** e_n and the **noise current density** i_n. A straightforward equivalent-circuit for noise (**Fig. 6.22**) considers the piezo-capacitance C (1,5 nF), the input impedance R (1 MΩ) of the amplifier, the noise voltage density e_n (42 $\mathrm{nV}/\sqrt{\mathrm{Hz}}$) of the amplifier, and the noise current density i_n ($10\,\mathrm{fA}/\sqrt{\mathrm{Hz}}$) of the amplifier. For this first example, the noise densities were taken from the datasheet of a FET-OP (TL061) that is suitable for battery operation (current drain: 0,25 mA).



$$i_R = \sqrt{4kT/R}$$

$$\sqrt{4kT} = 1{,}3 \cdot 10^{-10}\,\sqrt{\mathrm{W/Hz}}$$

Fig. 6.22: Equivalent circuit for noise of a piezo pickup with connected amplifier.

As an approximation, all noise processes are statistically independent, and their effects need to by added using a Pythagorean summation. Relative to the noise current density i_R caused by a resistor R, the noise current density i_n of a typical FET-OP is insignificant. In conjunction with R and i_R, the capacitance C forms a low-pass with a cutoff frequency at around 150 Hz. Therefore, the capacitance of the piezo pickup increasingly shorts the resistor noise toward higher frequencies. The noise generated in the kHz-range that is significant for our hearing is predominantly caused by e_n. For the TL071, the resistor noise (i_R) dominates in the low-frequency range, while for the TL061, the OP itself makes a considerable contribution, as well (flicker noise).

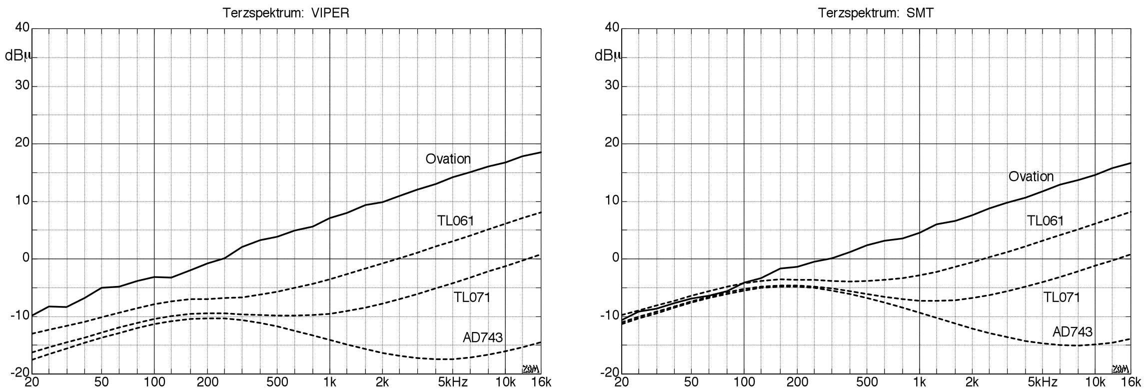


Fig. 6.23: 1/3rd-octave spectrum (= "Terzspektrum") of the piezo-preamp output. 0 dBµ ⇒ 1 µV. Ovation-Viper (left), Ovation-SMT (right). Voltage gain factor = 0,5. Ovation: measurement; FET-OP: calculation.

Fig. 6.23 depicts measurement and calculation in comparison: the **TL061** is well suitable, and with 0,25 mA supply current, a battery life of 1600 h should be possible. Even at only 7 V supply voltage, the output can deliver 1,7 V_{eff}. The **TL071** requires, at 2 mA, clearly more current, but it is less noisy in the high-frequency range. Significantly less noise if generated by the **AD743**, but this OP draws 10 mA and should be operated from a mains power supply. The degree of suffering that we encounter here, however, is not that terrible that it would push us too much towards using especially low-noise amps: when playing loudly, the pickup delivers about 1 V, and therefore an adequate signal-to-noise ration is reachable even with the Ovation preamp – in particular since the guitar itself generates interference noise, too.