9. Guitar circuitry

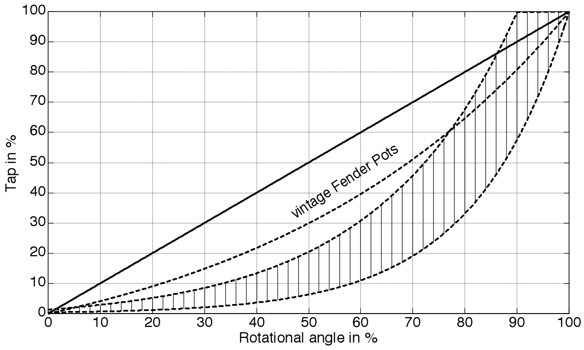
In its original form, the electric guitar was equipped with one, two or three pickups. The voltages of these could be selected or combined with switches. Guitars fitted with four pickups did surface occasionally but proved to be of little interest – apparently switching between the pickups gave too little the sonic difference. With the standard circuitry normally in use, the switch on the guitar allows for the selection of a pickup or the parallel-connected combination of two pickups. Later variations on this arrangement additionally offered series connections and phase reversal. Controlling volume and tone was usually achieved via the installation of simple RC-networks. For manipulating tone, one occasionally one finds more complex filter networks (e.g. in the Gibson ES-345) or battery-powered amplifier and filter circuits. The following descriptions relate to simple passive circuits – more extensive information can e.g. be found in the book "Electric Guitar – Sound Secrets and Technology" by Helmuth Lemme.

9.1. Potentiometers

In the guitar, potentiometers (i.e. adjustable resistors) are connected to the pickups to control volume and tone. The respective values are in most cases ca. 250 or 500 kΩ, less frequently used are 100 kΩ or 1 MΩ. The tone potentiometer allows for shunting a capacitor (typically in the order of 20 - 50 nF) in parallel to the pickup. As one turns the tone knob counter-clockwise to the end position, the potentiometer reaches 0 Ω, and the now directly connected capacitor further reduces the resonant frequency of the pickup and cable in combination to values below 1 kHz. Turning the knob to the other extreme position leaves the full resistance of the potentiometer connected to the circuit. This results in a minor dampening of the resonance with the capacitor acting like a short circuit (i.e. having no audible effect in itself). Some guitars sport a special potentiometer which completely switches the resistance out of the circuit in the clockwise end position – in this case the resonance is fully retained without any dampening. Normally, however, it is safe to assume that the volume and tone controls do have a load-effect on the pickup. To be certain, one would have to make a measurement or have access to the schematics. The latter are also advantageous if the guitar holds a battery and an amplifier the input impedance of which would be the effective load to the pickup.

Fig. 9.1: Schematics for an electric guitar
T = pickup, P = volume control, R = tone control, C = capacitor.
The figure on the right shows the effective electrical situation for clockwise position of the controls ("full up"). The clockwise end-position of the potentiometer taps in the figure on the left is at the upper end of the resistor for the volume control and on the lower end for the tone control

Fig. 9.1 shows a typical guitar circuit. By twisting the knob, the potentiometer tap (the arrow in the figure) can be moved continuously between the end points. The rotational angle usually extends over about 270°. For **linear** potentiometers, the tapped resistance is proportional to the rotational angle while for **logarithmic** potentiometers, the resistance change rises progressively (see **Fig. 9.2**). Theoretically, the potentiometer characteristic can be shown as exponential function. The *logarithm* of the exponentially growing resistance is proportional to the rotational angle: thus the designation *logarithmic potentiometer*. In practice, substantial deviations from the exponential function are likely because for cost reasons this desirable characteristic is only approximated.



Theoretical dependency on angle of rotation:

$R/R_{max} = k^{x-1}$ $x = 0 \ldots 1$ $k = 50 \ldots 300$

Fig. 9.2: Resistance characteristic for a linear potentiometer (straight line) and logarithmic potentiometers (hatched area).
The dashed line shows a typical characteristic of potentiometers used in vintage Fender guitars

Potentiometers of recent production typically have **tolerances** of about +/-20%, i.e. the actual value of a 250-kΩ-Potentiometer lies between 200 and 300 kΩ. Even 150 to 350 kΩ values can occur as outliers – especially with older guitars which appear not to have been subject to any excessive quality control. If a tone pot has a value of 350 kΩ rather than 250 kΩ the guitar sounds more brilliant. If this is not desired, turning down the pot slightly (for the purist: twist the knob counterclockwise) will compensate. Connecting a 0.9 MΩ resistor in parallel to the pot will do the same job. On the other hand, a pot having merely 150 kΩ will make the guitar sound duller. In this case the only remedy will be exchanging the pot. Still really dramatic differences are not to be expected (see **Fig. 9.3**). The most important parameter for a potentiometer are resistance and angle-over-resistance characteristic. The power rating (usually 0,1 - 0,5 Watt) is unimportant since the pickups will generate merely a few micro-Watts. All other parasitic electrical effects (capacity, inductivity) can be neglected in the audio range. Good contacts (i.e. no drop-outs across the turning range) go without saying when using brand potentiometers. The latter will cost in the order of $ 2.- to 4.-. Prices of more than $ 100.- for "vintage parts" are not justifiable from an engineering point of view.

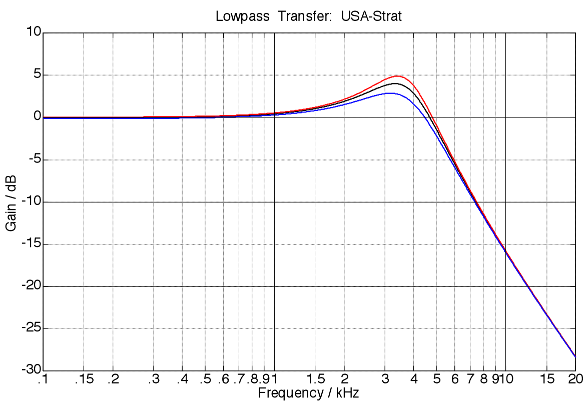


Fig. 9.3: Influence of different potentiometer values for a Fender Stratocaster. Tone and volume pots were (both!) assumed to be having a value of 300, 250 and 200 kΩ.

In **Fig. 9.4**, the effect of tone and volume control is shown for a Stratocaster. Merely turning down the **volume** slightly will already make the resonance peak disappear. The sound becomes duller. The reason for this is that a part of the resistance of the volume control is now connected between the pickup's coil inductance and the capacitance of the cable to the amplifier. This series resistance dampens the resonance. When turning down the volume further, a further resonance at a higher frequency appears but this is not really usable since the signal level is very small. Turning down the **tone** control first also reduces the resonance peak but – at fully CCW-position – then leads to a resonance at a lower frequency (typically around 350 Hz).

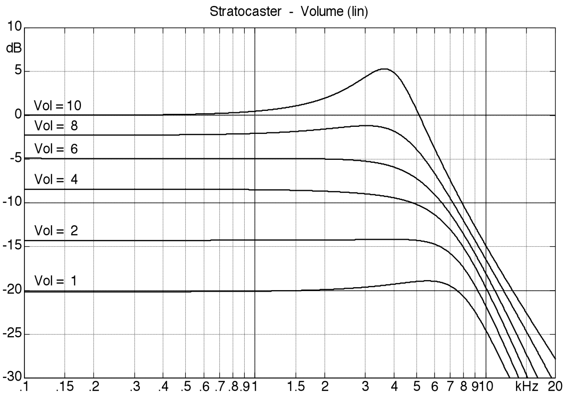


Fig. 9.4: Stratocaster: Volume control (left), tone control (right); 600-pF-cable; 1-MΩ-amplifer-input

Even more extreme is the situation with the Fender Jazzmaster (**Fig. 9.5**). Here, the high-impedance volume pot (1 MΩ) kills the treble radically already when turning down the volume just a bit. Of course, the resistance changes only have the shown effect if a high-input-impedance amp is connected to the guitar. A typical input impedance for tube amplifiers is 1 MΩ (this is indeed considered "high"). Smaller input impedances of the amp will reduce the Q-factor of the resonance circuit and therefore the resonance peak.

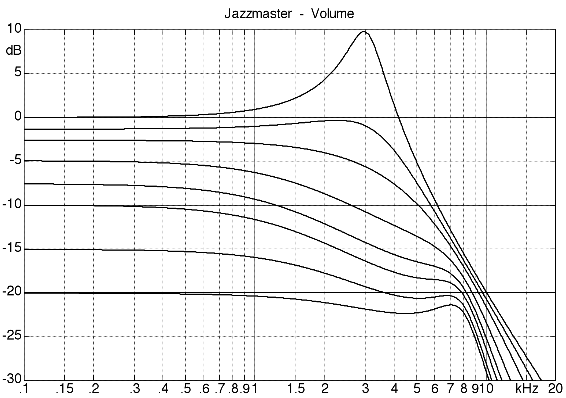


Fig. 9.5: Jazzmaster: Volume control (left), tone control (right); 600-pF-cable; 1-MΩ-amplifer-input

As a potentiometer is turned fully CW or CCW, a **resistance remains** between the tap of a potentiometer and the connection close to it. This might also deserve some consideration. High quality pots have a very small remaining resistance (< 50 Ω). Audible effects can be expected if the remaining resistance is more than ca. 500 Ω – however potentiometers showing this are very low grade and should be discarded.

The treble loss perceived with turning down the volume pot can be reduced by soldering a **bridging capacitor** between the tap and the CW end connection of the pot (**Fig. 9.6**). For low volumes (i.e. a turned-down volume pot) a stronger treble boost can be achieved. When in 1967 the Telecaster was fitted with a 1-MΩ-volume-pot, Fender evidently discovered the strong tone change this pot can result in: the guitar received a bridging capacitor (1 nF).

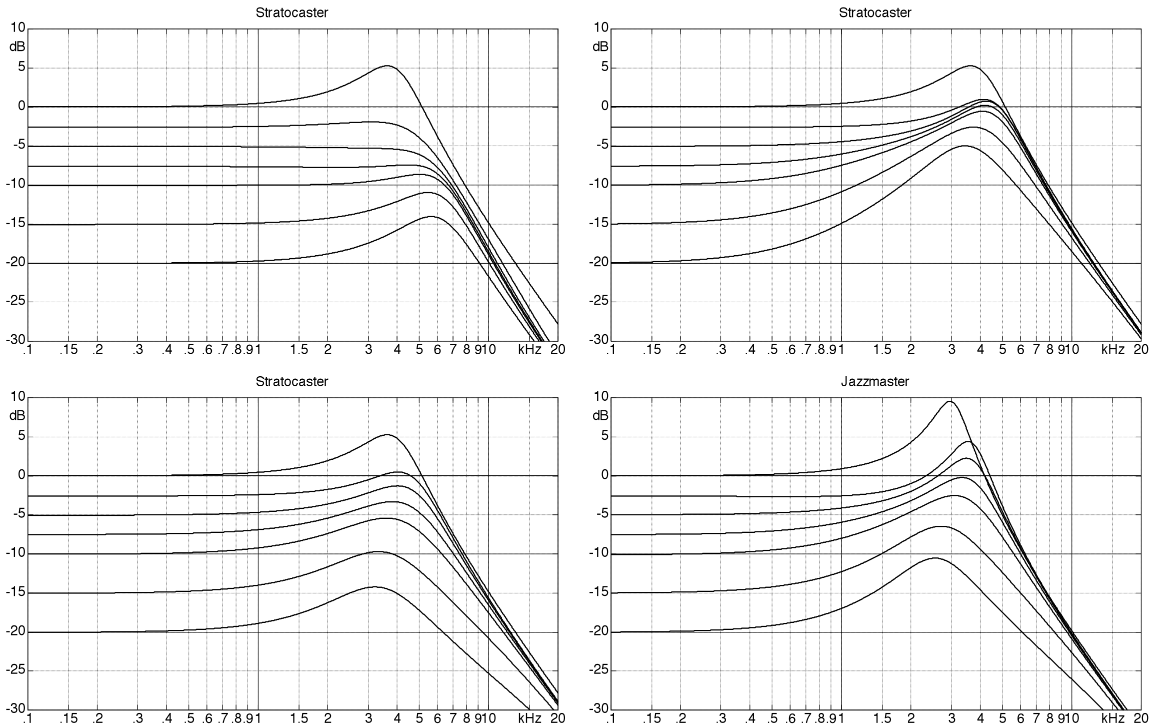


Fig. 9.6: Stratocaster: volume pot with bridging cap; 150pF (upper left), 1nF (u. r.), 1nF//100kΩ (l.l.); Jazzmaster: 1nF//150kΩ (lower right); all diagrams with 600pF-cable and 1MΩ amp input impedance

Selective tone changes are possible with **LC-filter-networks** installed in the guitar. One example is shown in **Fig. 9.7**: for some Gibson guitars a 8-H-coil is fitted. A rotary switch connects various capacitors in series with this coil creating a resonant shunt connected in parallel to the pickup. The result is an attenuation of a narrow band of frequencies. It appears that the tonal control achieved this way did not enthuse many guitar players since the demand remained rather low.

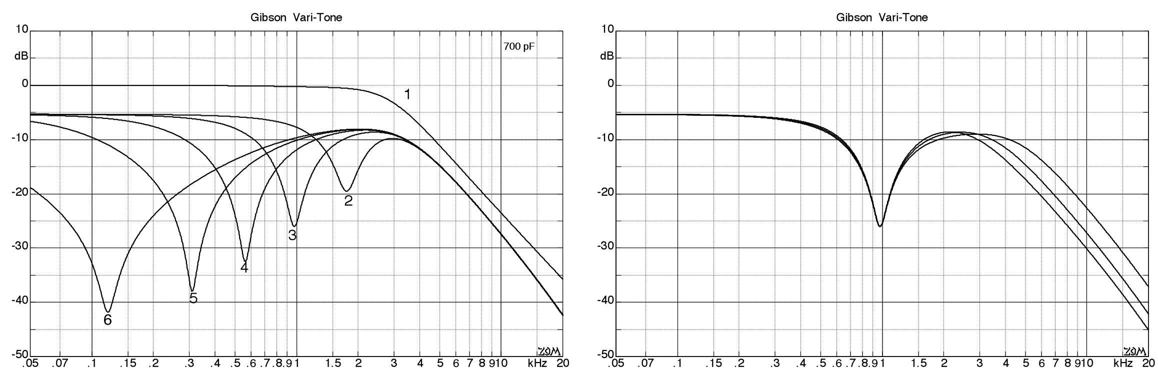


Fig. 9.7: Vari-Tone-Filter of the Gibson Lucille: 6 frequency responses selected via a rotary switch (left, cable capacity 700 pF). Right: the cable capacity is varied (330 pF, 680 pF, 1000 pF) for Vari-Tone position no. 3