10.3 Tone-Controls

Just to state it right upfront: the secret of a great-sounding guitar amp does not lie in its tone controls (tone-filter). Of course, these modules are necessary to adjust bass, middle and treble to the subjective desires, but modifications to the tone controls normally will not convert a bad amp into a great one.

The first guitar amps often had merely a simple treble-control. Fender's Champ even had only one solitary knob: *Volume*. If sound variations were indeed indispensable, you had to do them on the guitar. The Deluxe at least already had a treble-control, and over the years, further controls were added. In the 1950's, your standard helping of tone-control included a Bass and a Treble-knob, and later some chosen few received a middle-control in addition. Marshall copies Fender's tone-control circuit (with minor modifications), and in Jennings' VOX-amps, a comparable filter-stage is found. And there you have it: the glorious Big Three – most subjectively chosen, of course. Trying to put together even only an approximately representative selection of all tone-controls developed over the years would go WAY beyond the scope planned here, and so we will limit ourselves to a only few circuits.

Set to their middle ("neutral") position, the tone controls in a HiFi-amplifier need to give a frequency-independent reproduction. The tone controls in a guitar amplifier do not have to perform that way, because the amp is – together with the loudspeaker – still a part of the sound generator and contributes to the sound. Although the tone controls may include frequency-selective filtering of more than 20 dB, it is not the only filter-stage in a guitar amp. The input capacitances of the tubes have (in conjunction with the usually high-impedance circuitry) the effect of a treble-cut. Bridging capacitors (over-) compensate this via a treble-boost. Intentionally small coupling capacitors attenuate the lows, as do small cathode-capacitors. Frequency-selective negative feedback in the power stages yields brilliance, output transformers may contribute resonance-accentuations and/or bass-cuts, and at the end of the transmission chain we have the loudspeaker with its only weakly dampened resonances. No, this transmission is everything but frequency independent – and that is what makes it so desirable.

10.3.1 Bass-Middle-Treble

As an example for a **passive tone control** we chose a circuit that is included in many Fender-amps, but (in more or less modified versions) also has found its way into amps by Ampeg, Kitty Hawk, Marshall, Mesa Boogie, Music Man, Randall, Rickenbacker, Roland, Selmer, Solton, VOX, and many more. The term "passive tone control" indicates that the frequency-dependent filtering is done exclusively via passive components, i.e. by resistors and capacitors. The tube-stages grouped around the tone control contribute frequency-independent gain. As an approximation, we may ignore for now that this is not fully correct. In an *active* tone control, the RC-network is integrated into the feedback loop of a tube, and corresponding circuits have a significantly different structure. Fundamentally, inductances also count as passive components – but they are not liked, due to their relatively large build. At the most they are included as exotic birds, if at all.

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In **Fig. 10.3.1**, we see a good example for a simple passive tone-filter. This circuit was deployed in early Fender-amplifiers (e.g. the 5E4) but may be found in variations also in radios and similar devices. Turning down the bass control (i.e. moving the tap in the figure fully to the right) results in a readily comprehensible situation. What remains now is merely a complex-valued voltage divider that can be further simplified if we take the load resistance as infinite. The current becomes independent of the position of the center-tap, and depends on the frequency only as a 1st-order function (cutoff frequency = 653 Hz), despite the presence of *two* storage-elements. The output voltage, as multiplication of this current with the transverse impedance, also merely has a 1st-order dependency on $p = j\omega$, and an appropriate adjustment of the treble control even results in a 0-order-system with frequency independent transmission (32.2 dB attenuation). The right-hand diagram in Fig. 10.3.1 shows the transmission functions of the divider without load; the position of the center-tap is the parameter.

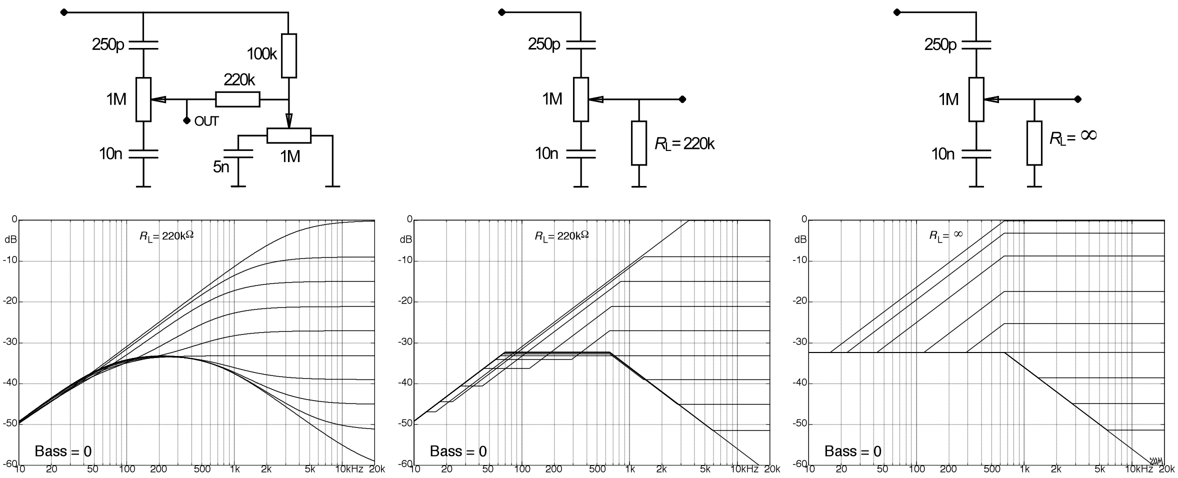

Fig. 10.3.1: Simple treble-filter. The circuit on the left was used in the 5E4 Super-Amp; the circuits to the right are simplifications for the bass-control turned down. See also Fig. 10.3.3.

Introducing a load-impedance yields a 2nd-order transmission-function that, as an approximation, can be seen as load-less divider with an additional high-pass (f_g = 70 Hz). The middle picture shows this scenario as a Bode-diagram with approximation lines. In the left-hand picture, we see the complete magnitude-frequency-response. In a real circuit, it will be necessary to consider the input capacitance of the subsequent tube; this capacitance can easily amount up to 100 pF due to the Miller-effect. The resulting minor treble-attenuation is only felt above about 10 kHz. **Fig. 10.3.2** shows a peculiarity of the Fender-circuit that sets it apart from the tone-filters usually found in audio-engineering: while the latter keep the cutoff frequency constant and fan out the curves symmetrically, the cutoff-frequency for the Fender-filter changes as the treble control is adjusted.

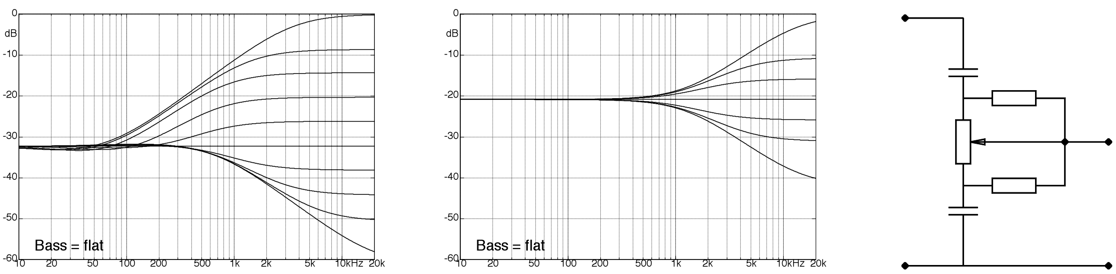

Fig. 10.3.2: Comparison of magnitude-frequency-responses: guitar amp (left), audio amplifier (middle and right).

Fig. 10.3.3 depicts the effect of the Fender tone-filter in 6 diagrams. Again, pronounced differences compared to classic audio-filters are apparent: treble- and bass-attenuation influence each other, and for bass and treble fully turned up, a rather selective mid-cut results. The latter is a specialty that will remain in almost all later Fender amplifiers.

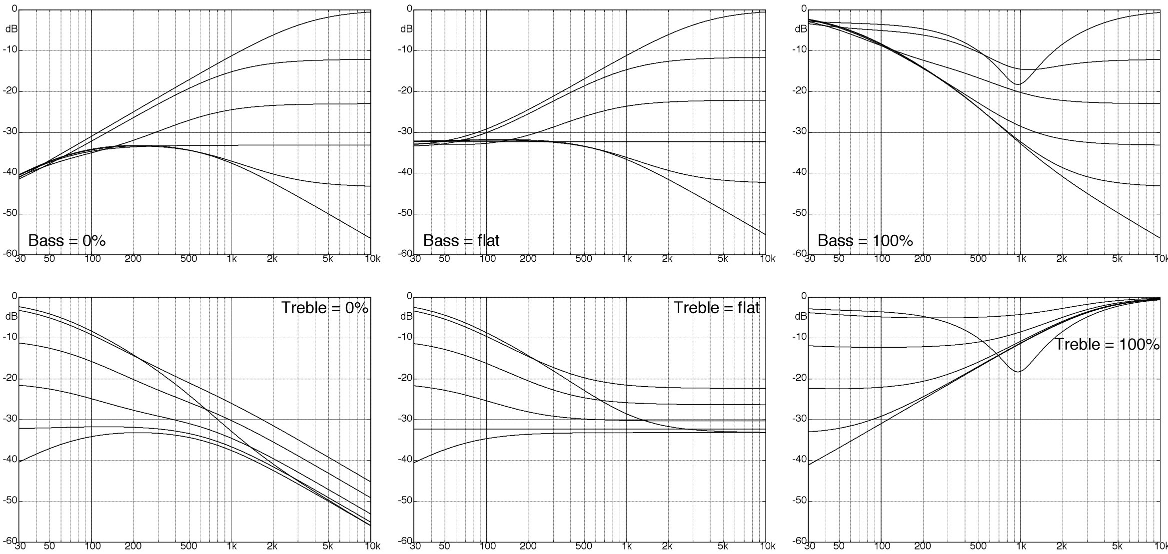

Fig. 10.3.3: Frequency-responses of the Filter circuit acc. to Fig. 10.3.1 (Fender Super-Amp 5E4, ca. 1955)

The structure of this tone-filter has some similarities to the mixing-stage discussed in Chapter 10.2.3: treble and bass are divided up into two parallel channels, then high- and low-pass filtered, respectively, and finally added up again at the output. The 5-nF-capacitor shorts high frequencies to ground; as such it has a function similar to that of the 10-nF-capacitor. Combined with a desire to cut cost, it was presumably this similarity that led to a merging of the two capacitor-branches. To keep the effect of the Treble filter when the Bass-control was turned down, a resistor was required between the 10-nF-capacitor and ground … and you got a tone-filter that makes do with **only two capacitors** (**Fig. 10.3.4**).

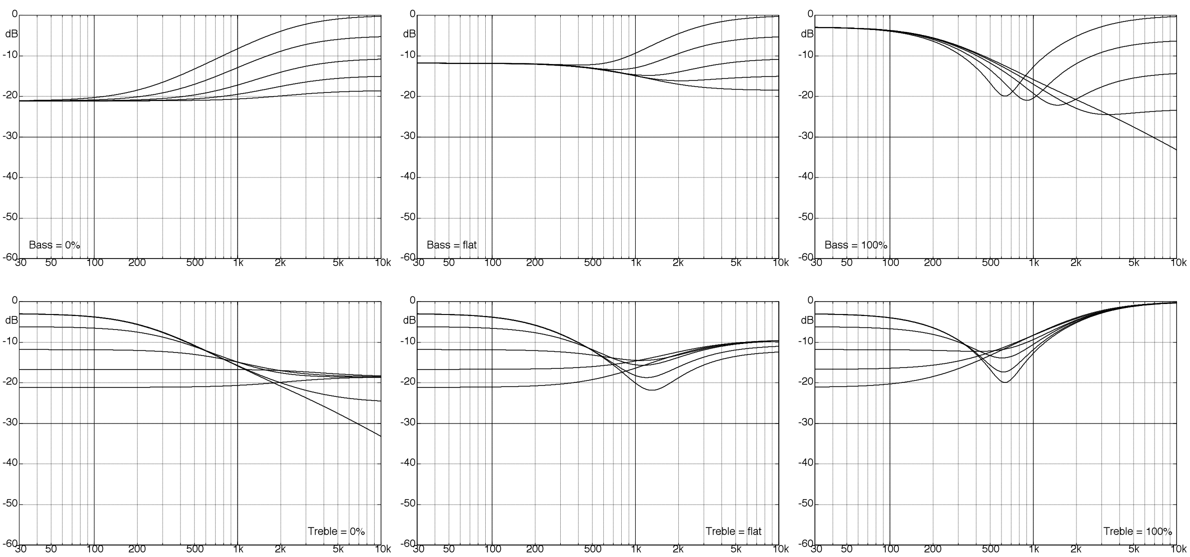

Fig. 10.3.4: Frequency-responses: tone-filter of the Super-Amp 6G4. Circuit given in Fig. 10.3.8.

Supposedly, the control options of this simple filter were seen as too limited, after all, because very soon there was the revision 6G4-A (**Fig. 10.3.5**): an updated filter-circuit with no less than 4 capacitors, and with a special treble-potentiometer sporting an additional **tap**. Apparently, this development was worth the effort since the Tremolux (6G9) received it as well, and since it was also used in the Bandmaster (6G7-A) and the Vibrolux (6G11), albeit with small component modifications in the latter two.

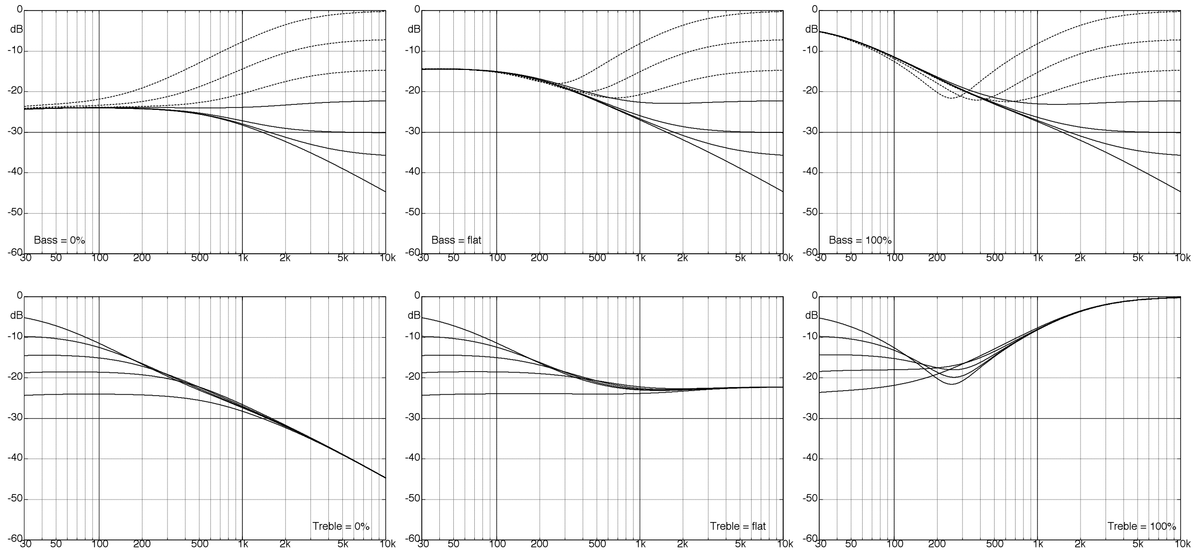

Fig. 10.3.5: Frequency-responses: tone-filter of the 6G4-A. Circuit as in Fig. 10.3.8.

Nevertheless, the pot with the special tap disappeared again already in the following amplifier generation, and around 1963 a circuit was developed that would go down in history as the mother of all tone-filters – to be found in this or very similar configurations in VOX, Marshall and many other guitar amplifiers (**Fig. 10.3.6**). In fact, the range of settings is not that big, but it apparently fits the combination Fender-guitar + Fender-amplifier perfectly. The individual component values are subject to variations at Fender as well as for the many copycats (in particular the "mid-scoop" is shifted back and forth in its frequency position), but the basic topology is now set.

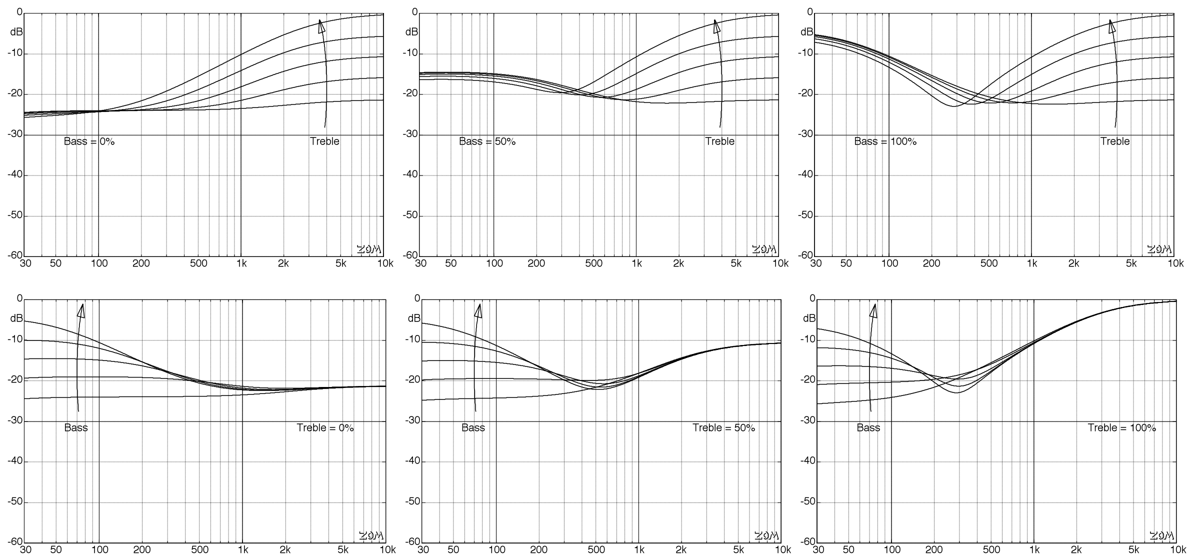

Fig. 10.3.6: Frequency-responses: tone-filter at he beginning of the 1960's. Circuit as in Fig. 10.3.8.

Also, the new filter circuit (AA763, Fig. 10.3.8) allows for the addition of a **Middle-Control** in addition to Bass- and Treble-Controls. The required effort is rather small: the fixed 6.8-kΩ-resistor of the first version is simply replaced by a 10-kΩ-potentiometer.

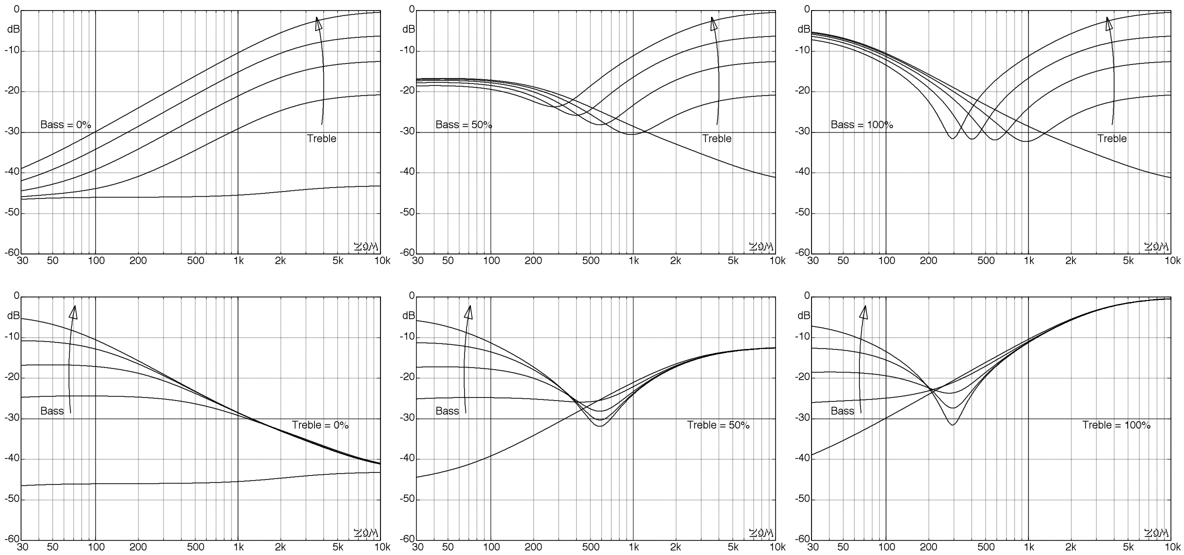

Fig. 10.3.7: Frequency-responses of the tone-filter with middle-control (R_M = 500Ω). Compare to Fig. 10.3.6.

Fig. 10.3.8 documents the development of the Fender tone-circuit. The number of capacitors changes from two to four until a simple 3-capacitor-circuit is found the topology of which to this day is seen as a standard.

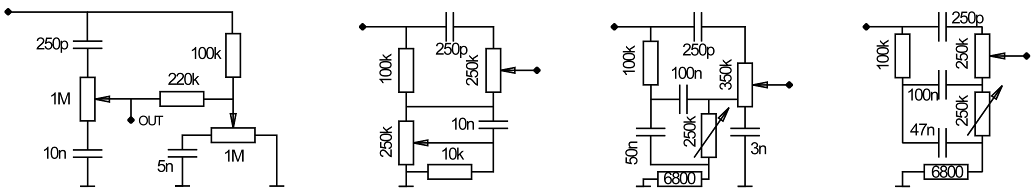

Fig. 10.3.8: Fender tone-filter circuits: 5E4, 6G4, 6G4-A, AA763 (left to right).

As mentioned, there were changes now and again in the values of the components of the AA763-tone-filter: apart from the variations on the 6800-Ω-resistor (middle-pot), the 47-nF-capcitor was subject to several modifications and varied from 22 nF to 33 nF and on to 47 nF. The effect of this change in capacitance is shown in **Fig. 10.3.9**: if the Bass control is not entirely turned down, the spectral components below 500 Hz are boosted by the reduction of the capacitance. With the bass-pot at "0" nothing changes because in the relevant frequency-range the parallel connection with the 100-nF-capacitor acts approximately as a short compared to the 100-kΩ-resistor. This holds for 22 nF as well as for 47 nF. It is difficult to find a clear criterion for the choice of this capacitor-value in Fender amps. Some amplifiers such as the **Showman** or the **Twin** start with 47 nF in 1963 and keep that value. The **Bandmaster** receives the 47-nF-capacitor in 1963 but 5 years later this is changed to 22 nF. The **Pro-Amp** sports a 33-nF-capacitor to begin with (AA763), but that is changed to 47 nF in the same year (AB763) – and 6 years later we find a 22-nF-capacitor. In the **Super-Amp**, the capacitor-history is different: it starts out with 33 nF (AA763), then in the same year sees the change to 22 nF. Yet another approach in the **Deluxe**: 33 nF in the AA763 and the change to 47 nF in the same year. Must be magic …

Fig. 10.3.9: Differences between 22 nF (fine line) and 47 nF (heavy line) in Fender tone-filters; R_M = 6800Ω.
These figures are reserved for the printed version of the book.

The frequency-responses shown so far do not consider the peripheral circuitry. The source impedance of the preceding stage and the input impedance of the subsequent stage change the curves – but not fundamentally; in fact the differences are rather marginal. In Fender amplifiers, the source impedance typically amounts to 30 – 40 kΩ, which is low enough that we approximately have a stiff voltage source. The load of the tone-circuit is either a high-impedance tube-input or the volume-potentiometer. The latter is at 1 MΩ (rarely also 500 kΩ) of sufficiently high impedance; the output of the tone circuit therefore can be seen as operating without load. For the uppermost frequency-range, however, we do need to consider the **input capacitance** of the subsequent tube. Due to the Miller-effect this has to be assumed to be 100 – 150 pF, leading – in conjunction with 250 kΩ (see below) – to a cutoff frequency of 6.4 or 4.2 kHz, respectively. The corresponding loss in brilliance makes itself felt most when the center-tap of the volume potentiometer is set mid-way, because here the internal impedance of the pot is largest (R/4 = e.g. 250 kΩ). In order to counteract the treble-loss, already the first guitar amps had a **bright-capacitor** installed that bridged the upper part of the volume pot. In its left-hand section, **Fig. 10.3.10** shows the treble-loss due to the capacitance, and in the right-hand section the effect of the bright-capacitor. The figure focuses on the transmission characteristic given by source impedance (38 kΩ), volume pot (1 MΩ), bright-capacitor (120 pF), and input capacitance (150 pF); the additional attenuation of the tone-filter is not shown to maintain a straightforward display.

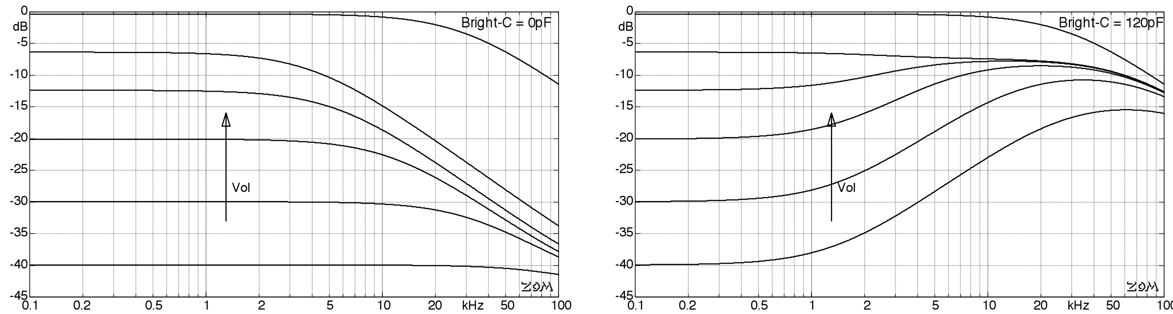

Fig. 10.3.10: Treble-loss due to capacitive loading of the volume pot (left), treble boost via bright-C (right)
Source impedance R_Q = 38kΩ, 1-MΩ-potentiometer, input capacitance of the subsequent stage: 150 pF.

The Fender tone-filter designated AA763 is again shown in **Fig. 10.3.11**, this time in comparison to two competitors that originated at approximately the same time: the VOX AC-30TB and the Marshall JTM-45. The basic structure is identical but there are characteristic variations in the details. For example, the Fender filter shuts the signal off completely with all controls turned down fully – the other filters avoid this awkward property. The individual component values differ substantially so that three distinct circuits emerged, after all – despite all similarities.

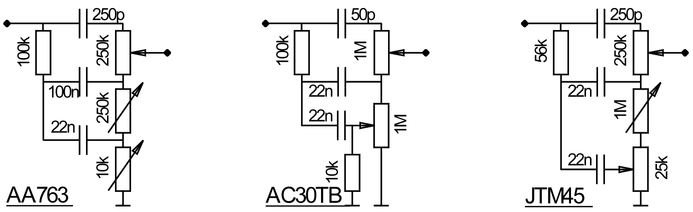

Fig. 10.3.11: Comparison of tone-filter circuits: Fender, VOX, Marshall. The filters are loaded differently: high impedance for Fender and MARSHALL, 360 kΩ for VOX (Miller capacitance to be added to each).

In **Fig. 10.3.12** we see the transmission characteristics of the **VOX**-Filter (AC-30TB). The low-cut is particularly conspicuous; it is due to an RC high-pass not shown in the figure. The Marshall-filter (**Fig. 10.3.13**) is different, again: the aim here apparently was a small attenuation of the filter stage. *(Translator's note: incidentally, this Marshall-tone-circuit is a direct copy of the circuit found in the last tweed Fender Bassman 5F6-A that had – in the tone-control-department – similar advantages and disadvantages.)* This attenuation is further reduced in the subsequent versions of the amplifier (JTM-50, **Fig. 10.3.14**) by replacing the 56-kΩ-resistor by 33 kΩ and the 250-pF-capacitor by 500 pF.

Fig. 10.3.12: Frequency-responses: the tone-filter of the VOX AC-30TB (incl. 580-Hz-high-pass).
These figures are reserved for the printed version of this book.

The **differences in tone** of the three amplifiers under scrutiny here are, however, not principally based on the different filter circuits. Only several stages cooperating make for the individual sound. For example, the high-impedance power-amp output of the AC-30TB results in a strong bass-boost (Chapter 10.5.7) that is found in Fenders only to a much smaller degree. Marshall amps, on the other hand, offer the presence filter integrated into the power amplifier stage; it brings a special treble-boost that the VOX lacks. We find further differences in the overdrive-behavior and in the loudspeakers used: the latter typically work in an open combo-cabinet in the Fender and VOX amps – for the Marshall, however, the bass-heavy 4x12-enclosure is employed. While the tone-filter is a substantial part of the overall system, its respective special realization should not be credited with any exaggerated importance.

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Fig. 10.3.13: Marshall JTM-45. The Treble-boost from preceding stages is not considered.
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Fig. 10.3.14: Marshall JTM-50. The Treble-boost from preceding stages is not considered.
These figures are reserved for the printed version of this book.

The following examples show that, in tone-filters, "more" is not necessarily "better": in the Fender circuit we find two to four capacitors but the Sound-City-filter has six of them! Or even 10, as shown in **Fig. 10.3.15**. Not bad, but short lived. If this filter structure were superior, it would have asserted itself in products by the competition, as well – but that didn't happen, and the circuits disappeared again from the market.

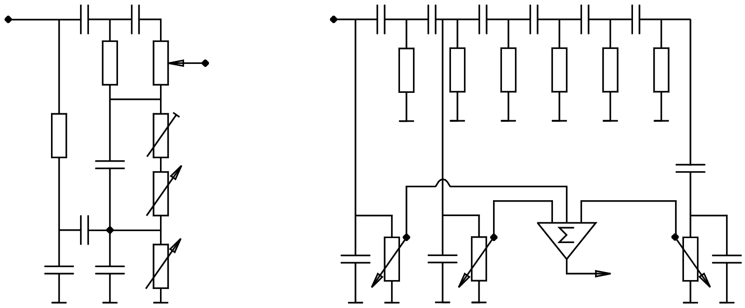

Fig. 10.3.15: tone-filters in Sound-City amps:
Left: CS100B.
Right: L/B 120 Mark IV.

Simple tone-filters do not stand in the way of creating a convincing amplifier, as the **Marshall 18-Watt-amp** (examined in the following) proves. This amplifier was produced from 1965 – 1967 and has a lot of fans despite its rather spartan filter-network. In the "Normal"-channel we find a single tone control: cut either treble, or bass – that's it. Similarly, there is only one simple Tone-knob in the "Tremolo"-channel: more treble or less treble, interactively coupled to the volume-pot.

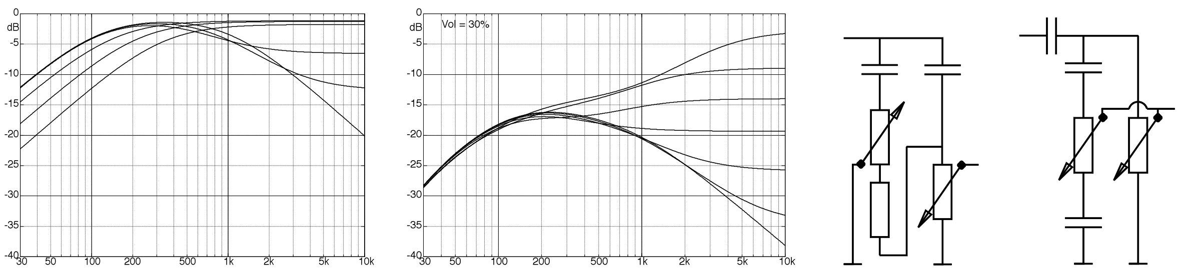

Fig.10.3.16: Frequency-response of the Marshall 18-W-amp; left: "Normal" channel; right: "Tremolo" channel.

Very similar circuit concepts are found already 10 years earlier in the Fender "Deluxe-Amp" amplifier; the volume-pot is merely connected "in reverse" to facilitate the connection of a second channel. Even today, these very simple old amps are not at all "out" but enjoy cult-status in the use for club-gigs or in the studio. Very obviously, a complicated tone-filter is not necessary to amplify an electric guitar. Question to Lenny Kravitz♣: *"How do you get this tone?"* Answer: *"Well, you just plug an Epiphone into a Tweed Deluxe, crank it to 10 ... and that's it."*

On the other end of the spectrum of complexity we find amplifiers that offer almost infinite variability using multi-band graphical and/or parametric equalizers (Chapter 10.3.2). They are predestinated for the creation of very "different" sounds, but the majority of guitar players seem to be able to do without them.

♣ Gitarre&Bass 06/04

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10.3.2 Equalizer (EQ)

A filter that allows for narrow-band changes in the spectrum (or in the transmission function) is called an equalizer. Besides a basic gain that we assume to be 1 ($\hat{=}$ 0dB) in the following, there are 3 parameters that define the transmission behavior of an equalizer: center-frequency, boost and Q-factor (**Fig. 10.3.17**) The center-frequency f_x is the **frequency** at which the gain assumes it maximum (or minimum) value, the **boost** β specifies the gain at f_x, and **Q-factor** Q determines the bandwidth. For a so-called parametric equalizer (EQ), all three parameters are adjustable while for a so-called graphic EQ, only β is variable, with f_x and Q fixed at predetermined values.

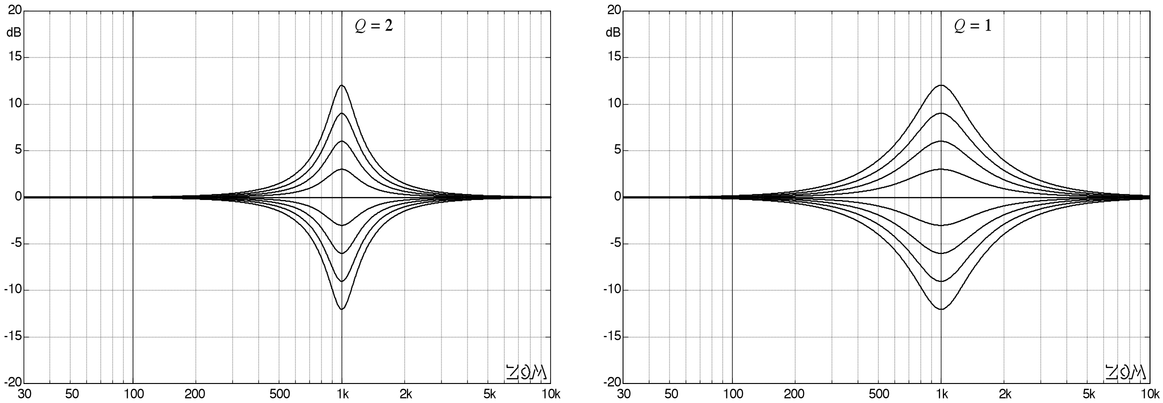

Fig. 10.3.17: Equalizer characteristic. $B = 20 \cdot \lg(\beta) = [-12\ \ -9\ \ -6\ \ -3\ \ 0\ \ 3\ \ 6\ \ 9\ \ 12]$dB, $f_x = 1$ kHz.

In Fig. 10.3.17 we see two different groups of curves. f_x and B are self-explanatory, but the Q-factor requires some supplementary comments. Often, the Q-factor is determined from the relative bandwidth measured as the distance of the -3-dB-points on the graph. This definition is, however, useless for an EQ e.g. because for a 2 dB-boost no -3-dB-points can be defined at all. The correct definition results from the transmission function $\underline{H}$:

$$\underline{H} = \frac{\omega_x^2 + p \cdot \omega_x / Q_Z + p^2}{\omega_x^2 + p \cdot \omega_x / Q_N + p^2} \qquad p = j \cdot 2\pi f \qquad \omega_x = 2\pi f_x$$

As can be seen, this filter has a pole-Q-factor Q_N and a zero-Q-factor Q_Z. For $f = f_x$, we get $b = Q_N / Q_Z$. In order to define *one single* Q-factor for an equalizer, an infinite number of possibilities present themselves; customary are two (different!) definitions. Either we keep the denominator-Q-factor constant and vary the boost-factor via the numerator-Q-factor; this filter-type is called **constant-*Q*-equalizer**, and the denominator-Q-factor is specified as the Q-factor of the equalizer. Or we link numerator- and denominator-Q-factors via $Q_Z = Q/\sqrt{\beta}$ and $Q_N = Q \cdot \sqrt{\beta}$; in this case we specify as Q-factor of the equalizer: $Q = \sqrt{Q_N \cdot Q_Z}$. Connecting two equalizer of the second variety in series with f_x and Q correspondingly identical in both EQs, and the boost-factors set reciprocally ($\beta_1 = 1/\beta_2$), the effects of these two equalizers compensate each other completely. They are inverse to each other, and therefore this EQ-type is also called **inverse EQ** (the filter shown in Fig. 10.3.17 is of this type). For the constant-*Q*-equalizer, however, a corresponding series-connection does not lead to a complete compensation: the attenuation is of a smaller bandwidth than the amplification (**Fig.10.3.18**). These differences (if they are of any importance at all) play a role only for graphic EQs, because all parameters can be freely adjusted in the parametric EQ, anyway.

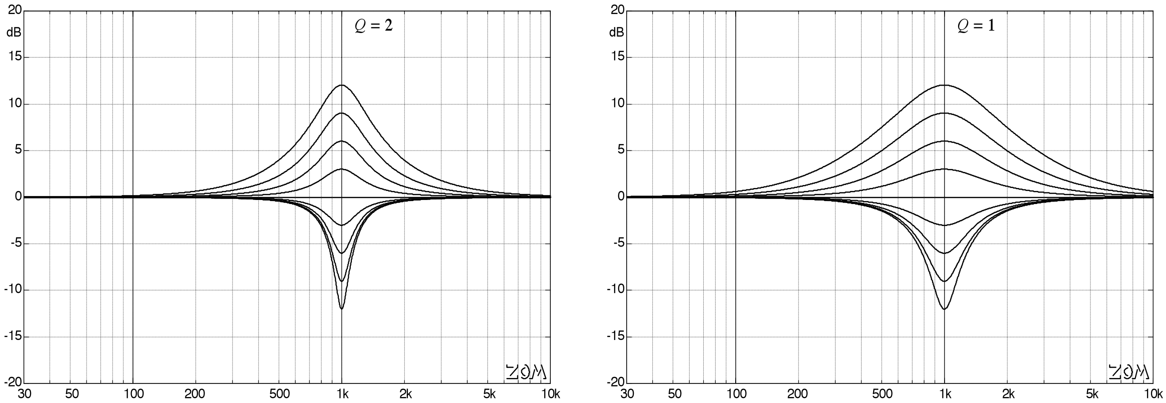

Fig. 10.3.18: Characteristic of a Constant-*Q*-Equalizer. The specified Q is the denominator-Q.

The constant-*Q*-equalizer is held in high esteem because the Q-factor does not increase as the boost-factor grows but remains constant independent of the boost. It should be added that it is the denominator-Q-factor that remains constant because the numerator-Q-factor of course does change. It is not entirely far-fetched to give priority to the denominator-Q over the numerator-Q because the **decay-coefficient** determining the time-envelope of a step- or an impulse-response indeed does depend only on the denominator-Q. However, whether it is in fact desirable that abutting EQ-bands show a boost-dependent, more or less pronounced overlap as depicted in Fig. 10.3.18, needs to be determined on a case-by-case basis according to individual preferences.

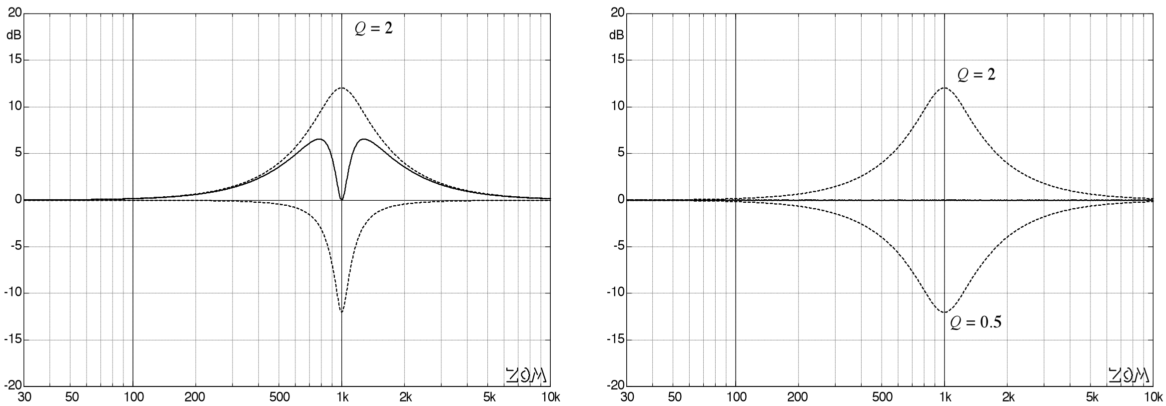

Fig. 10.3.19: Series-connection of two constant-*Q*-equalizers. Single filter (----) and series connection (——).
For the gain to add up to 0, both Q-factors need to be reciprocal (right-hand picture).

Fig. 10.3.20 shows a circuit often utilized for designing graphic EQs. The frequency-dependent impedance *Z* of the resonant circuit may be realized in a passive (RLC) or an active manner; the latter via adding an additional amplifier. The boost-factor can be controlled with the potentiometer *P*, the center-frequency and the Q-factor are pre-set by the circuit design.

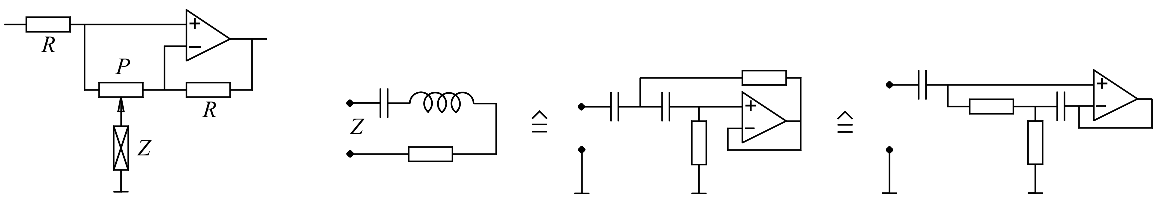

Fig. 10.3.20: Active EQ-circuit. The series-resonance-circuit (*Z*) may be realized via either active circuit.
The active resonant circuits are approximations of an ideal series-resonance circuit

The circuit presented in Fig. 10.3.20 offers the possibility to vary Q (within certain limits) depending on the boost-factor (**Fig. 10.3.21**). As can be seen, we obtain inverse behavior with a bandwidth varying in detail. Relatively high impedance in the potentiometers results in the characteristic as show on the right, and low-impedance pots give the curves on the left. For linear potentiometers, the boost-value changes predominantly towards the end to the control path – therefore special pots with an S-shaped characteristic are required.

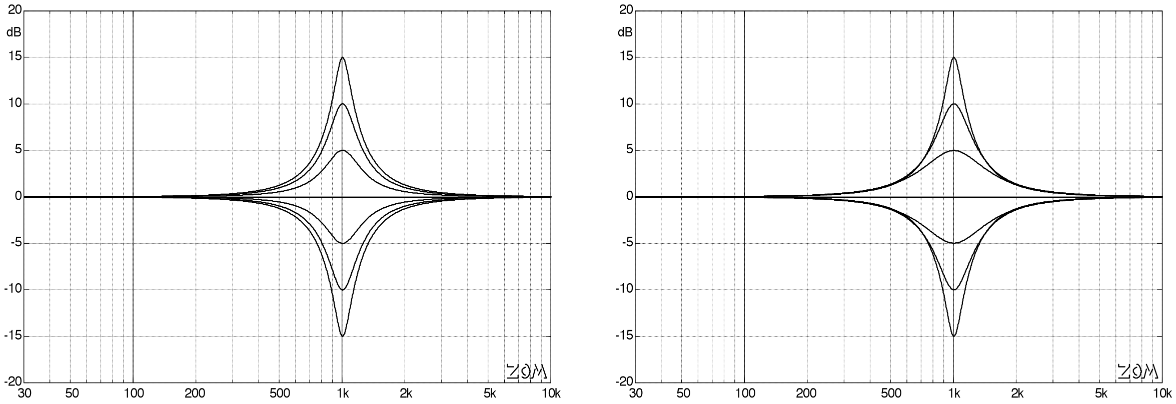

Fig. 10.3.21: Transmission characteristics of the EQ-circuit according to Fig. 10.3.20.

A multi-band graphic EQ may be designed with little effort by adding into the circuit according to Fig. 10.3.20 further potentiometers with corresponding different resonant circuits. **Fig. 10.3.22** has the corresponding diagrams for various settings.

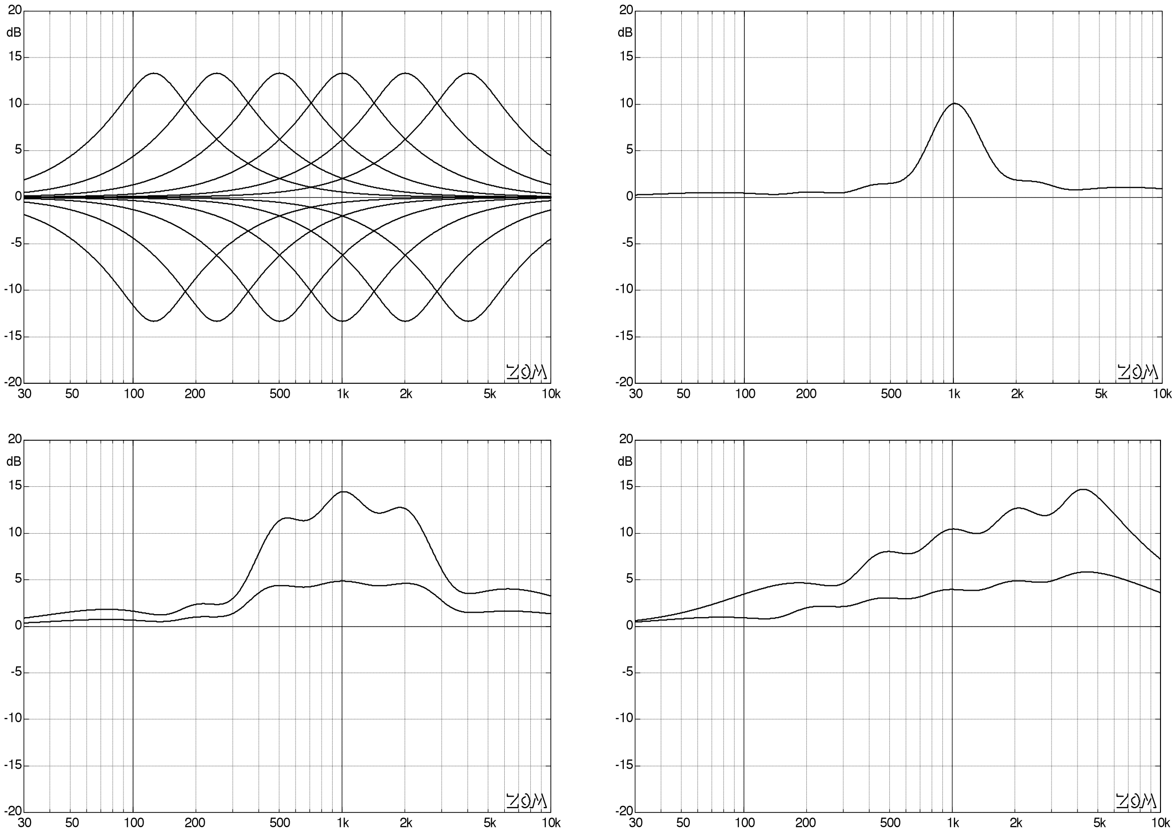

Fig. 10.3.22: Octave-equalizer: single filter (upper left). Six-band EQ, boost only in the 1-kHz-channel (u. right). Boost only in 3 bands (lower left). Boost increasing with frequency (l. right).

10.3.3 Presence-Control

In studio-electronics, the term “presence” often characterizes the frequency-range between about 1 kHz and 4 kHz, and a “**presence filter**” designates an equalizer operating in this range. In guitar amplifiers, however, the presence-control represents an alternative to the treble-control. An early variant of the presence-control is found in Leo Fender’s Bassman: already the early versions (e.g. 5B6) include negative feedback in the power amplifier, and this becomes frequency-dependent in the model 5D6. Presumably an additional treble boost was desirable. There already was a treble-control so a different designation had to be found: presence-control.

Having picked the Bassman as a model for his JTM-45, Jim Marshall (or rather Jim’s tech Ken Bran) adopts this presence-filter, as well. Only VOX takes the opposite approach: since the AC-30 already boosts the treble almost too much, the power amp here receives a treble-attenuator designated with “Cut”. In the Fender- and Marshall-amps, the presence-filter operates on the basis of a simple **principle**: a low-pass integrated into the negative-feedback-loop diminishes the loop-gain for high frequencies, and boosts the treble that way. However, despite their simple function, the circuit includes two special aspects. First, the **loudspeaker** needs to be considered as part of the negative-feedback-loop: its impedance contributes to the effect of the presence-filter. Second, the power-amplifier of a guitar amp is often subject to **overdrive**. The presence filter becomes part of a non-linear system the tonal effects of which are different from those of the treble-control.

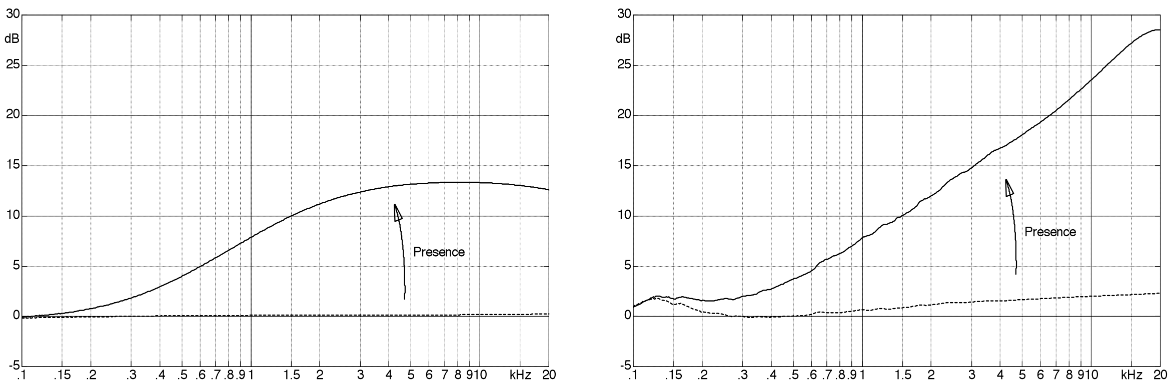

Fig. 10.3.23: Effect of the presence filter in the Marshall JTM-45. In the measurement on the left, the 16-Ω-output was loaded with a 16-Ω-resistor whereas on the right the load was a 4x12 speaker box (1960 AX).

In **Fig. 10.3.23** we see measurements on the JTM-45. The generator-signal was fed to the input of the differential amplifier; measurements were taken at the output of the power-stage. In one case the load was a 16-Ω-resistor; in the other case a loudspeaker-box was used. The latter is specified at 16 Ω, as well, but does not have constant impedance; rather, its impedance is frequency dependent.

