Audibility of different power supplies in a guitar amplifier

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Introduction

While in most audio equipment a power supply is expected to provide smooth and stable supply voltages, this is commonly not the case for guitar amplifiers and, moreover, not even desired in principle. Historically, the expected sound of an electric guitar is in part shaped by power supplies with high internal resistances. These cause a supply voltage drop ('sagging') leading to compression of the output signal at the moment the strings are picked as well as to expansion of the sound during the fade out. In contrast, more modern power supplies operating with lower internal resistances and silicon diodes instead of rectifier tubes for rectification are ascribed a different sound by guitar players. This contribution compares power supplies in a classic guitar amplifier by measurements and in a listening test. The power supplies under study differ in terms of rectification (tube vs. silicon diodes) and size of the internal resistance. The results show that differences in the output signal of the amplifier due to different power supplies can be measured and also perceived under laboratory conditions.

Power supplies in traditional guitar amplifiers

State of the art

Treatment of vacuum diodes in power supplies can be found in older textbooks, e.g. [1], but is usually limited to a description of their basic modes of operation. An in-depth analysis of the guitar amplifier Fender Bassman 5F6-A that has also been used in the study at hand can be found in [2] where theoretic results are compared to measurements. Also focussed on the Fender Bassman 5F6-A is a project report from Technische Universität Berlin where this amplifier has been recreated and detailed measurements have been performed [3]. More analyses and measurements for all stages of guitar amplifier power supplies have been conducted by [4], who also investigated the variance of parameters of rectifying tubes. [5] focusses on a description of the compression effect caused by 'sagging' of the supply voltages. While these sources describe the physical effects of power supplies in guitar amplifiers and also formulate assumptions on the resulting consequences for the sound, a direct comparison between power supplies in the same setup is missing, neither in terms of measurements nor in a listening test.

Mode of operation of a guitar power supply

The circuit of a typical power supply in a traditional guitar amplifier with a vacuum tube for rectification is depicted in fig. 1. A double anode rectifying tube is connected to a transformer with centre tap and is rectifying each half-wave of the transformed mains voltage separately. The vacuum diodes are only conducting when the voltage at their plates is larger than the voltage V_{plate} across the filter capacitor used to power the plates of the power amplifier's tubes. During this conduction period the capacitor is charged while at other times it is discharged due to the load caused by the amplifying tubes. This leads to a DC voltage V_{plate} with a remaining ripple. The following inductance is reducing this ripple for the next stage in the power supply leading to a slightly smaller, but smoother supply voltage V_{screen} for the screen grids of the power amplifier's tubes. Following stages in a power supply are typically filtered further by RC circuits providing the voltages for preamplifier tubes.

A real-world power supply is not an ideal power supply and thus not free of an internal resistance. This leads to a voltage drop of all supply voltages depending on the load caused by amplifying tubes. For guitar signals, this means that characteristics of the amplifier change depending on the style of playing, e.g. when picking single strings versus strumming whole chords. It also means that for each picking of strings, the very high amplitudes in the attack moment of the tone are compressed because the decreased supply voltages of the tubes lead to less amplification. Conversely, the fade out of the sound is enhanced when the supply voltages recover. Moreover, the consequences of this effect are not just simple differences in amplification. The operating points of the amplifying tubes also differ and as they are typically operating nonlinearly in a guitar amplifier (even if the resulting guitar sound is described as 'clean'), this can change the sound due to different distortion products.

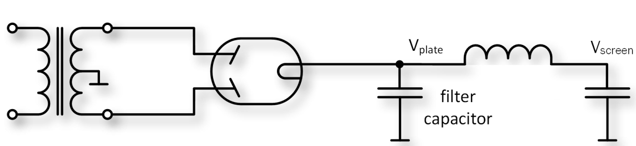

Figure 1: Typical power supply in a traditional guitar amplifier, also used in the studied Fender Bassman 5F6-A.

Essential components of the power supply

Transformer The transformer provides, among other voltages, 2 times a high voltage of a few hundred Volt to be full-wave rectified by the rectifier tube. The secondary DC resistance of these windings is a few ten Ohm each. This value yields the bulk of the transformer's source resistance; it may be augmented by 10–20% due to the transformed primary DC resistance. It is good practice to think of a power transformer as a voltage source with a real valued source resistance, although an additional inductance coexists. When taking a closer look, both resistance and inductance turn out to be nonlinear, but for a general view, the linear model is sufficient.

Rectifying component The rectifying component is also contributing to the internal resistance of the power supply. In the case of a vacuum tube, the internal resistance is nonlinear and can only roughly be approximated by an Ohmic resistance as its value is changing with the load of the power supply. Depending on the operating point and the type of tube, this resistance has the magnitude of several ten to a few hundred Ohm. Instead of a vacuum diode, silicon diodes can also be used for rectification which exhibit a close to zero resistance. This leaves the choice to the developer to either simulate the internal resistance of the tube by an Ohmic resistance or to just omit it. The latter results in a much smaller overall internal resistance of the power supply that is mainly influenced by the transformer and causes less 'sagging'.

Filter capacitor The size of the filter capacitor influences the amount of ripple that remains on the supply voltage V_{plate}. The higher the load, the larger the ripple becomes as more electric charge is moved. To reduce the ripple and get a smoother DC voltage, the capacitance can be increased. This leads to less moved electric charge percentage-wise, but also a higher peak current during the conduction period of the diodes. Therefore, this approach is limited by the maximally tolerated peak current of the diode. This is why traditional power supplies with a rectifying vacuum diode use rather small filter capacitors and exhibit a quite high ripple.

Power supplies under test

The power supplies under test include the original power supply of the Fender Bassman 5F6-A (termed 'original' in this paper) whose structure is shown in fig. 1. This circuit has been modified by replacing the rectifying vacuum tube type GZ34 by solid-state diodes 1N4007 and emulating the nonlinear internal resistance of the vacuum tube by a serially connected Ohmic resistance (termed 'solid-state + R'). To make the power supplies better comparable, the supply voltages at idle should be equal. This is achieved by using an Ohmic resistance of 70 Ω. A third variant omits this Ohmic resistance, making a reduction of the mains voltage by a variable AC transformer necessary to yield the same idle voltages (termed 'solid-state + variac'). To introduce more variance in the power supplies under test, a version with solid-state diodes but without both Ohmic resistance and variable AC transformer (termed 'solid-state') has been utilised as well, leading to higher idle voltages as an exception. The last variant depicted in fig. 2 is a circuit developed by [3] recreating the 'sagging' behaviour of the 'original' power supply while eliminating the ripple voltage (termed 'low-noise'). This is achieved by first providing a ripple-free DC voltage with a circuit with low internal resistance and then emulating the internal resistance of the rectifying tube with a double triode vacuum tube acting as a controllable resistance adjustable by the grid voltage.

Throughout the measurements, the grid bias voltage for the tubes of the power amplifier has been provided by a separate circuit and transformer to not be influenced in a different manner by the power supplies under test. Finally, to avoid problems with accurately setting the potentiometers of the tone stack to the same values for all measurements and the recording of the stimuli for the listening test, the tone stack has been bypassed. This led to an increase of amplification of about a factor of 3 which should be kept in mind when looking at the results.

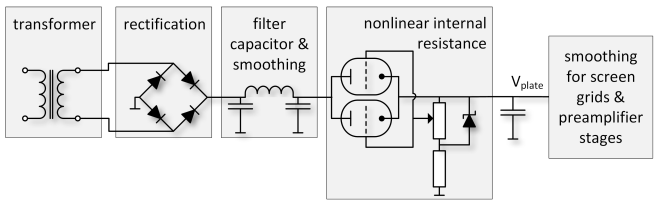

Figure 2: Schematic circuit of the 'low-noise' power supply [3].

Measurement results

Fig. 3 shows measurement results when applying a high-level sine burst to the amplifier at maximum amplification. The power supplies' full reaction of voltage drop and recovery is shown for the screen supply voltage in the

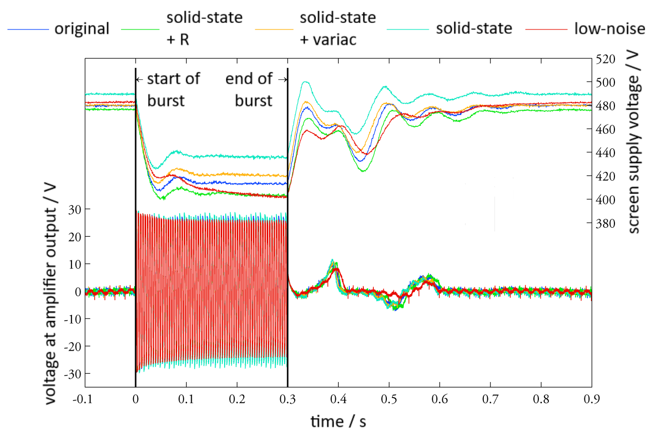

Figure 3: Screen supply and output voltages for different power supplies when applying a high-level sine burst to the amplifier input. Volume setting of amplifier: 10 out of 10.

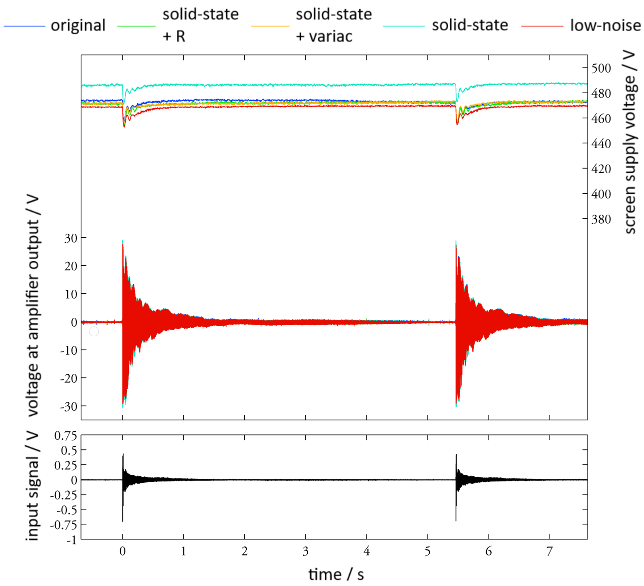

Figure 4: Screen supply and output voltages for different power supplies when applying a pre-recorded guitar signal to the amplifier input. Volume setting of amplifier: 2 out of 10.

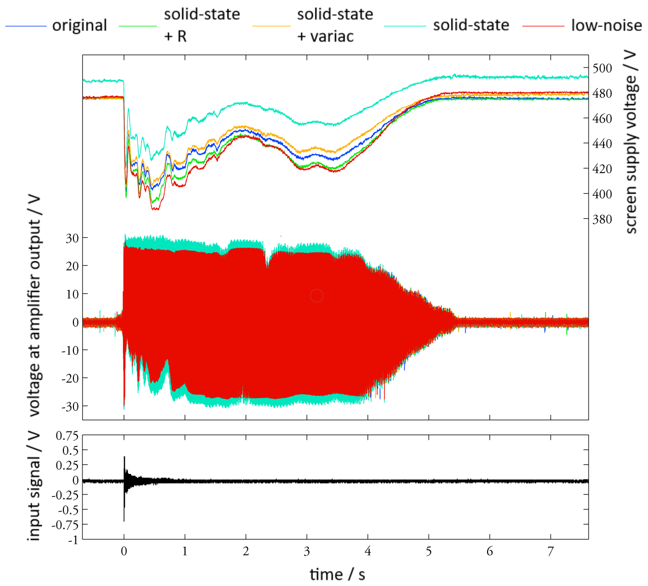

Figure 5: Screen supply and output voltages for different power supplies when applying a pre-recorded guitar signal to the amplifier input. Volume setting of amplifier: 10 out of 10.

upper half of the figure. The screen voltage more than the plate voltage of the power amplifier's tubes is determining their operating points and thus the amplification and distortion of the amplifier. The measured voltages drop by about 60 V with a slight delay and are superimposed by a damped oscillation that is caused by the inductance and capacitors in the power supplies. After the burst has ended the supply voltages recover to their former levels. Differences between the power supplies under test can be observed both for the screen supply voltage as well as for the output voltage of the amplifier measured at a resistive dummy load (lower half of fig. 3): Different amounts and slightly different shapes of the voltage drop also lead to variations in the output signal.

Fig. 4 and 5 show measurement results when using a pre-recorded guitar signal as a more realistic input signal where only a single string of a Stratocaster guitar has been picked. Even with a low amplification setting of the amplifier (volume potentiometer set to a value of 2 on a scale going to 10) in fig. 4 the supply voltage drop still occurs with slight differences between the power supplies under test. For higher amplification settings of the amplifier as shown in fig. 5, the supply voltage drop increases as expected. Fig. 5 also demonstrates the compression effect of the output signal, where the peak of the guitar input signal is reduced while the fade-out is greatly enhanced.

Listening test

To determine whether the measured differences between the power supplies are audible when playing guitar over the amplifier, a listening test has been conducted.

Preparation of the stimuli

To allow for instant comparison of the conditions, the output of the amplifier has been recorded while feeding pre-recorded pieces of electric guitar into the amplifier. The pre-recording makes an impedance converter circuit[1] between guitar and audio input device necessary so that the guitar is connected to a high impedance. This ensures similar conditions as when plugging the guitar directly into the amplifier. Elsewise, the low input impedance of typical audio input devices would dampen the resonance frequency of the guitar pickups resulting in an atypical guitar sound.

To record the output of the amplifier, a simple studio recording was performed. The amplifier was connected to a loudspeaker (12″, 8 Ω) and recorded with microphones in 0,4 m and 1 m distance inside the large Electronic Studio of the Audio Communication Group at Technische Universität Berlin (room volume: 220 m^3, $RT_{30\,@\,1\,kHz} = 0.4$ s). The microphone tracks have been mixed together to form mono-channel stimuli that have been used diotically over headphones. During the recording, the volume potentiometer of the amplifier was set constant to a value of 2 (out of 10). For more details on the recording setup see [6].

Conduct of the listening test

Informal listening of the recorded stimuli suggested that the differences caused by different power supplies are quite small. Therefore, an ABX test as a highly sensitive test design was chosen [7]. In the listening test, only two power supplies have been compared to the 'original' power supply serving as a reference to avoid fatigue of the test subjects. The 'low-noise' power supply and the 'solid-state' power supply were chosen as they exhibited

[1]SB-1P-C3 by Ulf Schaedla, `http://www.guitar-letter.de`

the largest differences to the 'original' power supply in the measurements. Two ABX tests for each comparison have been performed with two pieces of guitar, differing in style of playing and guitar output level (termed 'high' and 'medium' output here). Both guitar pieces led to a considerably higher voltage drop in contrast to just playing single notes as in fig. 4. Especially the guitar piece with 'high' output level yielded a heavily distorted sound and caused voltage drops of the screen supply voltage of up to 60 V.

The hypotheses for the listening test are:

- H_0: There exists *no* audible difference between two different power supplies.
- H_1: There *exists* an audible difference between two different power supplies.

Assuming a small effect size of 0.625, targeting the probabilities for both types of error to be 0.05 and correcting for multiple testing with two guitar pieces according to Bonferoni yields that 144 of 255 answers for each of the two ABX tests have to be correct to reject H_0 in favour of H_1. This led to a probability for the type 1 error of $\alpha = 2 \cdot 0.0224$ and a test power of 0.9793. To make so many trials manageable in one listening test, they had to be distributed across 17 test subjects who performed 15 trials each. It has to be kept in mind, though, that the answers are not completely independent of each other. All test subjects had prior audio experiences either as guitarists, in music production or by working or studying in the field of audio.

Results of the listening test

Tab. 1 shows that the number of correct answers for the ABX tests are significant in 3 out of 4 cases. So for both power supply comparisons, H_0 can be rejected in favour of H_1, giving rise to the interpretation that the differences between the power supplies are audible in both cases.

Table 1: Number of correct answers out of 255 trials for each of the four conditions in the listening test. Numbers in bold red designate significant results (i.e. ≥ 144).

	'original' vs. 'low-noise'	'original' vs. 'solid-state'
guitar piece 1 (high output)	**158**	**147**
guitar piece 2 (medium output)	**172**	140

Discussion

During the measurements and the recording the fluctuation of the mains voltage proved to be challenging because it directly influences the magnitude of the supply voltages in these simple power supplies. This made repetitions of measurements necessary whenever unusual values occurred. To reduce this effect for the listening test, the recordings have been made in the evening when the mains voltage in the University area seemed to fluctuate less. Another difficulty with the recordings is the inherent noise of the amplifier which might possibly create additional cues for the test subjects to distinguish the stimuli. Discussion with the test subjects after the listening test revealed that there was a disturbing tone in the stimulus with the 'low-noise' power supply which, although quite low, could serve as a reliable cue once it got noticed. Therefore, the results for comparison with the 'low-noise' power supply seem doubtful.

Conclusions

The effect of different power supplies in a guitar amplifier type Fender Bassman has been studied. Power supplies differed in terms of internal resistance and rectification component. Differences in the supply voltages concerning the amount and shape of the voltage drop can be measured, which also leads to changes in the output signal of the amplifier. In an ABX listening test it could be shown that those differences can be perceived under laboratory conditions, but the effect is very small and probably of little relevance in practice.

Acknowledgements

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References

[1] Schröder, H.: Elektrische Nachrichtentechnik. II. Band. Verlag für Radio-Foto-Kinotechnik, Berlin-Borsigwalde, 1968

[2] Kuehnel, R.: Circuit Analysis of a Legendary Tube Amplifier: The Fender Bassman 5F6-A. Pentode Press, Seattle, 2005

[3] Westphal, H., et al.: Abschlußbericht Projekt „Gitarrenverstärker WILDCAT". Technische Universität Berlin, 2007. URL: `http://www.emsp.tu-berlin.de/menue/studium_und_lehre/mixed_signal_baugruppen_alt/das_projekt_wildcat`

[4] Zollner, M.: Physik der Elektrogitarre. Self-published by the author, Regensburg, 2014. URL: `http://gitec-forum.de/wp/gitec-community/buch/`

[5] Lemme, H.: Der Kompressionseffekt oder das Geheimnis des Schirmgitters. Röhren-Sonderheft 8, Elektor, 2012

[6] Leontopoulos, M.: Die klanglichen Auswirkungen verschiedener Netzteile auf einen Gitarrenverstärker. Bachelor thesis, Technische Universität Berlin, 2016

[7] Leventhal, L.: Type 1 and Type 2 Errors in the Statistical Analysis of Listening Tests. J. Audio Eng. Soc. 34 (1986), 437–572