TUBES VERSUS TRANSISTORS IN ELECTRIC GUITAR AMPLIFIERS

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ABSTRACT

Although transistors have replaced tubes in most applications, the tube remains the dominant force in electric guitar amplifiers, representing millions of dollars in annual sales. This is due to the musician's insistence that tubes "sound better". Advertising literature of some manufacturers claims that their solid state circuit has the tube sound, while other manufacturers insist that the tube sound can only be obtained with tubes. It is the purpose of this paper to identify the electrical parameters that define the differences in the perceived sound of tube and transistor guitar amplifiers.

INTRODUCTION

Previous papers exploring the tube versus transistor sound have dealt with high fidelity amplifiers and sound reproduction. Much debate has centered on which type of amplifier is more accurate. This paper, however, is limiting its scope to the specific case of electric guitar amplification. In this application the amplifier becomes part of the musical instrument, and is frequently used to radically alter the signal from the guitar. Thus the question of accuracy in the amplification becomes irrelevant, and the choice of one amp over another is left to purely subjective evaluations of the sound quality. Adjectives such as "thin", "hollow" or "metallic" have been used to describe transistor amps, while tube amps have been described as "warm", "rounder" or "punchier".

In order to identify the differences, it was felt that the best approach would be to perform subjective listening tests on guitar players, and ask them to describe what they heard. Bench testing could then be done to identify the electrical parameters causing the differences.

A Fender Twin Reverb tube amplifier was used throughout the test to represent the tube sound. This amp has been commercially available for nearly twenty years and is well known throughout the music industry. The Normal channel was used. The transistor amp consisted of a commercially available power amp with a custom made preamp. The power amp circuit is straightforward and has an operational amplifier front end, with a quasi-complementary bipolar output.

The circuit configuration of the preamp was similar to the Twin, but used operational amplifiers (4558's) instead of tubes.

PRELIMINARY ELECTRICAL TESTS

To obtain meaningful results, it is necessary to balance the gain and frequency response of the amps. This was done by using a spectrum analyzer. The power amplification sections were done first, with each amp operating into a four ohm resistive load. However, it was found that the response of the tube amp changed dramatically when connected to a four ohm speaker load (see Fig. 1). This did not occur with the transistor amp.

This effect is caused by the reactive speaker impedance and the output impedance of the amplifiers. The transistor amp has an output impedance of less than a tenth of an ohm, whereas the tube amp has an output impedance of above five ohms. Thus the output of the tube amp will increase as the speaker impedance increases.

A frequency response difference this large can be easily heard. Thus we have identified one audible difference. In order to find other differences it is necessary to remove this effect so that it does not mask other, more subtle, differences. This can be done by raising the output impedance of the transistor amp or by equalization preceding the power amp. It was decided to use a third octave equalizer before the transistor power amp's input. This allows for correction of the response differences, but does not alter the output impedance. Thus it is possible to determine the audibility of other effects, such as speaker damping, caused by the differences in output impedances.

With the equalizer in place it is possible to match the responses of the two amps within 0.1 dB across most of the audio band, with a few spots deviating to 0.3 dB.

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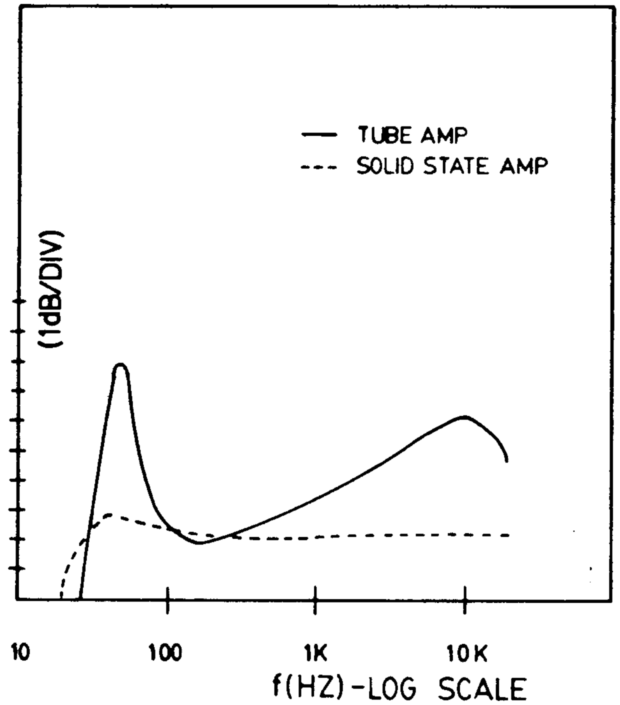

FIGURE 1.
FREQUENCY RESPONSE INTO SPEAKER LOAD

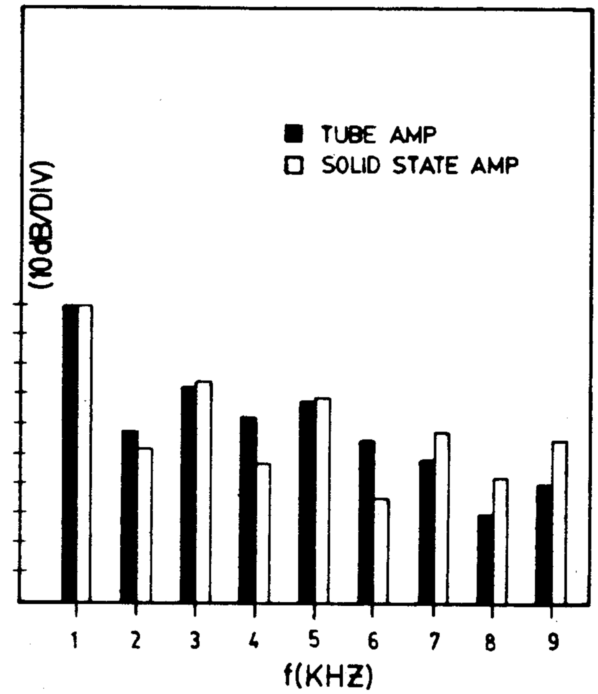

FIGURE 2.
HARMONIC DISTORTION SPECTRUM

It is also necessary to match the maximum output voltages that each amp can deliver under dynamic conditions. This was done by playing a guitar through the tube amp and observing the output clipping level on an oscilloscope. The power supply rails on the solid state amp were then adjusted to give identical output clipping levels for each amp.

The tube preamp is capable of delivering unclipped signals of approximately 96 volts peak to peak. The solid state preamp can only deliver about 27 volts. Thus it is necessary to lower the gain of the solid state preamp so that both preamps will require the same input level to be driven into clipping. The gain of the solid state power amp can be increased to make up the loss.

It is well known that the harmonic distortion of transistor amps is predominantly odd harmonics, whereas tube amps produce even, as well as odd, harmonics. This is illustrated in Fig. 2, with both amps overloaded to 5% total harmonic distortion. No attempt was made to enrich the transistor amp with even harmonics. Listening tests will reveal whether this is audible.

SUBJECTIVE LISTENING TESTS

General Test Procedure

All of the listening tests were conducted as double-blind A/B tests. A specially designed A/B box allowed the test subject to select either amp A or amp B via a footswitch. An LED indicated that either A or B was playing, but neither subject nor test administrator knew whether A or B was tube or solid state. The test subject was allowed to switch between A and B as much as he liked, until convinced whether or not a difference was present. If a difference was detected, the subject was asked to explain what he heard, and any preference. At this point the subject and administrator left the room and a third person reassigned A and B and recorded the results. This process was repeated until meaningful results were obtained. It is important to note that either amp could be assigned to A or B, or A and B could be the same amp.

All of the test subjects were guitar players with professional or semi-professional experience. Several different guitars were available, and the subjects were allowed to use more than one guitar.

The preamps and power amps were tested separately at first. Concluding the testing was a comparison of a totally tube system versus a totally solid state system.

Power Amp Comparison

The first set of listening tests involved comparison of the tube and transistor power amplifiers with both driven from a tube type preamplifier. The test subjects were allowed to adjust the preamplifier tone controls to their preference, but the volume level was set so that the power amplifiers did not reach clipping. A total of 12 subjects participated, resulting in a total of 54 trials. Four subjects did not report a difference in any trial. While eight of the remaining subjects reported hearing differences, seven were unable to identify the difference reliably. Reliable detection requires that the subject correctly identify the difference in amplifiers more than 50% of the time and not indicate a false difference. A false difference is reporting a difference even though A and B are assigned to the same amplifier. The remaining subject (subject #1) correctly identified the difference on two of three trials with no false differences.

In the second set of tests the equipment configuration was the same as the first test, except that the power amplifiers were driven into clipping. A total of six subjects participated, resulting in 23 trials. Three subjects did not report a difference on any trial. One of the remaining three subjects reported only false differences. The other two subjects were able to reliably detect a difference in sound. One of them was able to identify a "buzzing" sound which was more pronounced in the tube amplifier. He was able to detect this difference 100% of the time. It is interesting to note that this was subject #1 that detected a difference in test one. The other subject (#2) described the tube amp as sounding "fuller" two out of three times.

This phase of the testing was then halted so that the buzz could be studied. The results of this investigation are discussed later.

Preamp Comparison

The third set of tests involved comparison of the tube and solid state preamplifiers using the tube power amplifier. The tone controls of the two preamplifiers were adjusted to provide matched frequency response and the volume was adjusted to provide linear operation in the preamplifier. Five subjects participated, resulting in 24 trials. Two of the subjects did not report a difference on any trial. One subject reported only a false difference. The other two subjects could not reliably detect a difference.

System Comparison

The fourth set of tests involved switching between the complete tube system and the complete solid state system. The system frequency response was matched, and enough gain was present in the amplifier chain to allow overdriving of the power amplifiers. A total of 9 subjects participated, resulting in 49 trials. Three subjects did not report a difference on any trial. The remaining six subjects were unable to reliably detect a difference, including test subject #2 from the previous test. However, test subject #1 from the previous trials was unavailable.

DISCUSSION OF TEST RESULTS

Ripple Intermodulation Distortion

One subject was able to reliably detect an audible difference between the tube and transistor power amplifiers. The difference was characterized as a buzzing sound in the tube amplifier, most noticeable on single notes above about 500 Hz (first string, 7th fret). It should be pointed out that the noise was not detected by 16 other subjects. However, the noise is easily recognizable when the subject is trained in how and what to play and what to listen for.

A detailed spectrum analysis using a sinusoidal input signal showed that the tube power amplifier produced spurious signals 120 Hz on each side of the input frequency. Figure 3 indicates these sideband components.

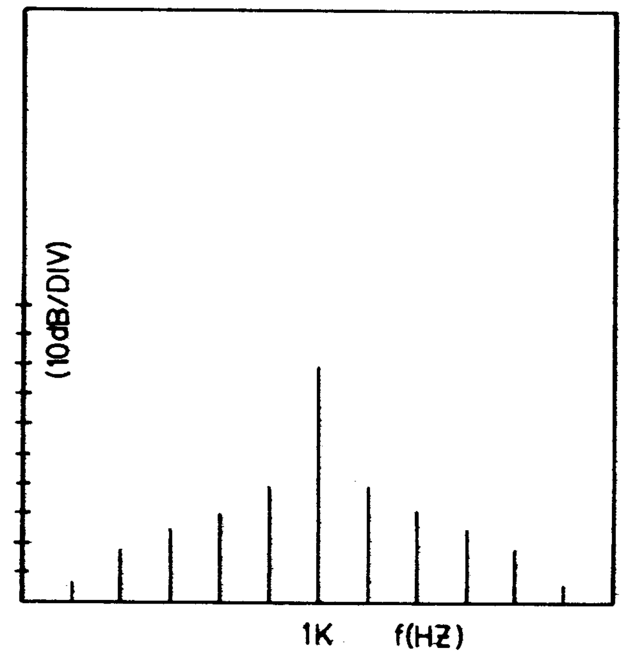

FIGURE 3.
RIPPLE INTERMODULATION DISTORTION

The relative level of the sidebands varied only about 3 dB over the output range of the amplifier. Further investigation indicated that the tube preamplifier also produced these sidebands but at a much lower level relative to the signal level.

Since the sidebands were 120 Hz from the fundamental it was felt that the AC ripple on the tube amplifier power supply was probably the cause. To verify this hypothesis, the filter capacitors were doubled in value. This resulted in a 6 dB reduction in the relative amplitude of the sidebands. While we as yet have not determined the mechanism by which the signal is modulated in the tube amplifier (probably a combination of several causes), the ripple does appear to be the cause of the distortion.

A brief attempt was made to produce this problem in the transistor amplifier by reducing the size of the filter capacitors. However, the transistor amplifier would only exhibit the problem when driven into clipping. A more detailed examination of the mechanism producing the ripple intermodulation in the tube amplifier must be left for further study.

Test Limitations

During the course of the listening tests it became apparent that variations in playing could affect the test results. It is difficult to play a note or chord precisely the same every single time. One subject felt that the difference between amps was an order of magnitude below the difference in striking the strings.

Some subjects had a tendency to hit the strings harder when the footswitch was depressed. However, since the subjects were allowed to switch between A and B as much as they desired, most of these differences should balance out.

The subject style and what they played could also affect the results. Differences that might be noticed on playing a single note might not be noticed by a subject who played mostly chords. Or a subject who played mostly high notes might not notice any difference occuring on lower notes.

Unfortunately, it would be difficult, if not impossible, to develop a standard program source. Even with the above limitations it is felt that the procedure used is acceptable, and yields valid real world results.

In recent years it has become popular to severely overload the preamp, and play the power amp at low volumes. Time did not permit investigation in this area. This subject will be the topic of a future paper.

CONCLUSION

Listening tests indicate two causes for differences in perceived sound of tube and transistor guitar amplifiers. These are ripple intermodulation distortion and frequency response differences caused by the reactive speaker load interaction with the output impedance of the amplifier. Although ripple intermodulation distortion is easily detected by trained listeners, only one of seventeen test subjects was able to detect it without training. The change in frequency response caused by the high output impedance of the tube amp is by far the predominant cause for differences.

The differences in speaker damping were not detected by the listeners. Also not detected were the differences in the harmonic content of an overloaded signal in the power amplifiers.

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