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CAN TRANSISTORS SOUND LIKE VALVES?

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ABSTRACT

An objective comparison is made between a referenced high-voltage solid state preamplifier with acclaims of large signal capabilities comparable to a valve amplifier, and an ECC83 based preamplifier topology. By analyzing the interaction of individual harmonic amplitudes throughout the amplifiers overload regions it is shown that there is little correlation between the two systems signal outputs. The paper describes the properties of the valve sound as having a dominant second order harmonic with an array of higher order harmonics producing the popular warmth of distortion often used for guitar amplification. The resulting dominance of 2nd and 4th harmonic components in the solid state system suggests that the sound could well be appealing to the listener, however the presence of prevalent higher order harmonics in contrast to the attenuated higher harmonics of the valve stage demonstrate that the two systems may sound different.

Keywords – Audio, amplification, valves, thermionic, tubes, guitar, harmonics.

1 – THE VALVE SOUND

Monteith and Flowers [1] have designed “a low-noise microphone preamplifier transistor circuit which has the same large signal capability as tube designs.” Fig. 1. They specifically mention that “this design exhibits the desirable overload characteristics of tubes” in accordance with the investigations of Hamm [2]. Hamm ultimately denotes that tube amplifiers react differently to transistor amplifiers in their regions of overload, particularly in the output signals interchanging dominance of odd and even harmonics when pushed up to 12dB into overload.

The pretension of the Montieth/Flowers paper demonstrates the harmonic content of their systems performance approaching and passing through the point of output clipping showing the dominance of a 2nd order harmonic. It states that the circuit “produces harmonic distortion components which are comparable to, and perhaps more pleasing than, tube preamplifiers.’” [1]

Hamms developed measurement technique [2] using Fourier analysis to study the percentages of ensuing harmonics in relation to the fundamental showed conclusively, Fig. 2, that triode preamplifiers “outstanding characteristic” was a particularly dominant 2nd harmonic in tandem with an initially dominant 3rd harmonic and an increasing 4th harmonic further in to overload.

A comparison with the resulting plot of the Monteith/Flowers circuit, Fig. 3, shows that although there are some “harmonic distortion components which are comparable to” [1] Hamms plots, there are also some apparent differences; An ultimately more dominant 3rd harmonic increasing over 20% of the fundamental approaching maximum overload; A diminishing 4th harmonic falling to less than 5% of the fundamental as opposed to Hamms steadily increasing one; And a prominent 5th harmonic peaking at approximately 11% of the fundamental in contrast to Hamms where the 5th, 6th and 7th harmonics all remain under the 5% line throughout clipping.

Hamms conclusion that ”inaudible harmonics in the early overload condition might very well be causing the difference in sound coloration between tubes and transistors” [2] would suggest that these differences in harmonic content could well belie the fact that the Monteith/Flowers circuit can indeed sound better than a tube amplifier.

The other main characteristic identified by Montieth/Flowers as “tubelike” is an output waveform that displays asymmetrical clipping. This too was documented by Hamm, as is demonstrated by comparing the oscilloscope shots within each paper. It is also well documented [4] that using Fourier analysis on complex signals can demonstrate that any waveform with a strong presence of 2^{nd} harmonic will result in an asymmetric output, and as Mintz [5] implies, ”a particular ‘sound’ may be incurred or avoided at the designer’s pleasure no matter what active devices he uses.’” [5]

It is the authors’ belief that no conclusions should be made as to whether an amplifier system sounds “tubelike” or not by noting an asymmetrical waveform on an oscilloscope.

2 – GUITAR AMPLIFICATION VERSUS HIGH FIDELITY AMPLIFICATION

The aforementioned papers were fundamentally focused towards high fidelity reproduction of sounds where accurate reproduction of signals is of utmost importance. This paper however is concentrated particularly on the use of valves in guitar amplification. Bussey and Haiglers paper [6] identifies the crucial difference between audio reproduction and guitar amplification in that, ”In this application the amplifier becomes part of the musical instrument, and is frequently used to radically alter the signal from the guitar.” [6]

Rutt [7] further studied into the use of valves for guitar amplification, paying particular attention to the preamplifier stage, almost exclusively triode nonlinearity, suggesting that the common ECC83 triode stage was perhaps the most commonly used stage in guitar preamplifier design. In concert with the usual test methods using single frequency test sources Rutt also based his research on the more complex guitar waveform constructed of many frequencies of sinusoidal wave.

Bussey and Haigler pointed out the difference in the way an amplifier responds to single plucked strings and chords specifically mentioning, ”one subject felt that the difference between amps was an order of magnitude below the difference in striking the strings.” [6] Rutt determines that a valves pleasing soft-limiting of signals is due to ‘an induced voltage drop across the grid circuit source resistance’ as a result of grid current, and that it is this soft/grid limiting that allows the small transient nuances produced by the higher frequency guitar strings to still be present at the output, giving greater harmonic detail to the sound.

With the emphasis of all the researched papers being on the harmonic content of signals it was proposed to investigate into the differing harmonics incited by both the Montieth/Flowers and an ECC83 based preamplifier, Fig. 1. Particular interest was to be paid to the region most exploited by guitarists in search of the fabled “warmth” of valve amplification, the overload region.

2 – METHODOLOGY

In keeping with the original paper [1] testing of the Montieth/Flowers preamp was carried out at a HT of $200V_{DC}$. The primary indicator that the circuit was performing as recorded by the original paper was to monitor its output waveforms in the overload region, Figure 4.

Once satisfied that the circuit reacted to an input signal as expected, a systematic approach to increasing the input voltages from 10mV to 3.00V of a 1kHz sine wave was undertaken. At each incremental increase of 10mV the output was monitored and recorded both for its waveform shape and for its harmonic content using an Agilent 35670A signal analyser with its internal signal generator, thus reducing error and containing all testing within one piece of equipment. At each increment the HT supply was switched to the valve stage and adjusted using a variac at source to maintain $200V_{DC}$ and the same measurements were taken.

All files were converted from .DAT to .csv and placed in to Excel for analysis. Readings of output voltage and total harmonic distortion were also taken giving a wealth of data from which to derive plots.

It was decided that the only fair way to ascertain if there were indeed similarities between the two preamplifiers was to focus upon their region of overload. As such further measurements were taken to marry up THD% readings for both stages, culminating in a further set of data as to what input voltage produces what percentage of THD at the output, Fig. 5.

3 – EXPERIMENTAL RESULTS

Taking into consideration purely FFT analysis of the two systems at maximum overload, with a 3.00V input, Fig. 6, the similarities between the two output signal characteristics are visible.

The majority of the differences are noticeable during the lower input voltages. For the Monteith /Flowers stage the 2^{nd} harmonic remains below 1% of the fundamental amplitude up until a 90mV input signal is applied. In stark contrast to this the valve stage 2^{nd} harmonic reads at 7% of the fundamental at 10mV input, with prominent 3^{rd}, 4^{th} and 5^{th} harmonics from the outset.

Initial plots of harmonic amplitude in dBm (reference to 1mW into 600Ω) against output level in dBu (reference to $0.775V_{RMS}$) over the same scale provide evidence that the Monteith/Flowers has a much sharper knee than the valve stage, resulting in a smaller range of overload and producing different distortion and transfer characteristics. These plots also clearly demonstrate the soft clip properties of a valve. However, as expected, it is the THD% against harmonic amplitude plots that provide the best insight to the differing systems characteristics, Fig. 7.

Both systems produce dominant levels of 2nd order harmonic, however unexpectedly it is the valve stage whose 3rd harmonic is most prevalent between 25-35% THD. This appears to contradict Hamms [2] results. Likewise the Monteith/Flowers plot contradicts their findings, Fig. 3, in that the 3rd harmonic apparently attenuates as the THD levels at output increase. The other notable difference for this stage is that of the 4th harmonic which actually ends being the second most dominant harmonic at maximum clip.

4 – CONCLUSIONS

This paper concludes that despite the even order harmonic dominance of the output of the Monteith/Flowers design, the overall harmonic component density, particularly in the upper octave ranges, differs quite significantly to that produced by the valve pre-amplifier under test.

There is therefore a marked difference between the two preamplifier topologies with particular respect to THD% vs. higher order harmonic amplitudes.

If Hamms theory that the valve sound lies in the subtle differences of upper order harmonics is correct then the over crowded higher order harmonics of the Monteith/Flowers in comparison to the valve stage may well prove detrimental to its sound as perceived by the listener.

5 – FURTHER WORK

It must be noted that many other properties of amplifier stages such as their frequency response, transient response, and phase response all play key roles in shaping the sound of any system. Hamms comments [3] on the Monteith/Flowers paper produces probably the most valid point of all research related to the area of audio, “they present no phychoacoustic data from real-live people that says, conclusively, that their amplifier lives up to the title of their paper.” [3] With this in mind, the immediate further work to allow more conclusive evidence as to which system sounds better is to enforce the objective measurements of this paper with subjective measurements from a series of listening tests.

References

[1] Monteith, D.O.; Flowers, R.R.: *Transistors Can Sound Better Than Tubes*, JAES Volume 25 Issue 3 pp. 116-119; March 1977.
[2] Hamm, R.O.: *Tubes Versus Transistors – Is there an Audible Difference?*, JAES Volume 21 Number 4 pp.. 267-273, May 1973.
[3] Hamm, R.O.: *Comments on "Transistors Can Sound Better Than Tubes"*, JAES Volume 25 Issue 3 pp.119-120; March 1977.
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[6] Bussey, S.W.; Haigler, R.M.: *Tubes Versus Transistors in Electric Guitar Amplifiers*, IEEE, 1981 May 10th.
[6] Rutt, T.E.: *Vacuum Tube Triode Nonlinearity as Part of the Electric Guitar Sound*, AES 76th Convention, New York, USA, 1984 October 8-11.

Figures

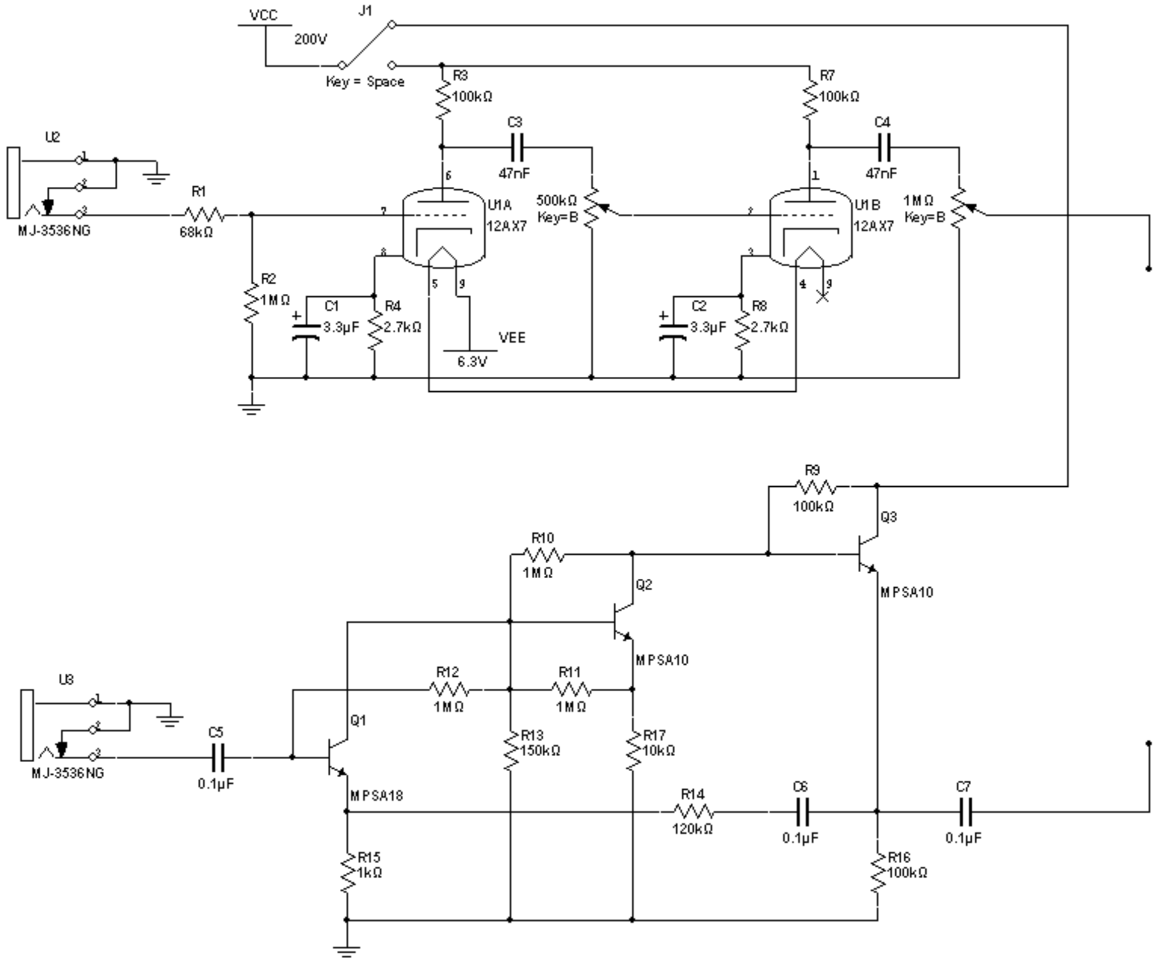

Figure 1. Circuit diagrams for the DUT. [1]

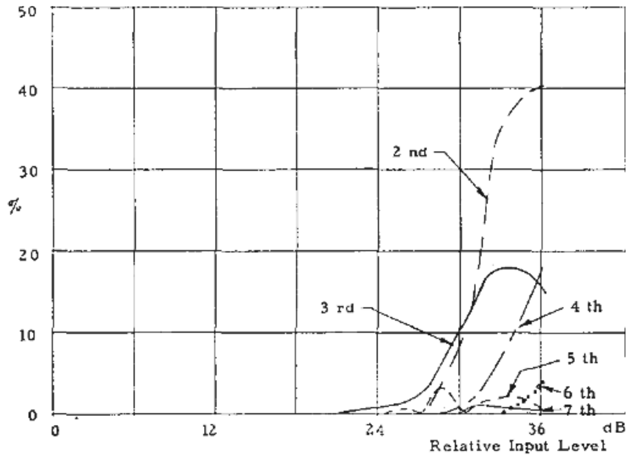

Figure 2.

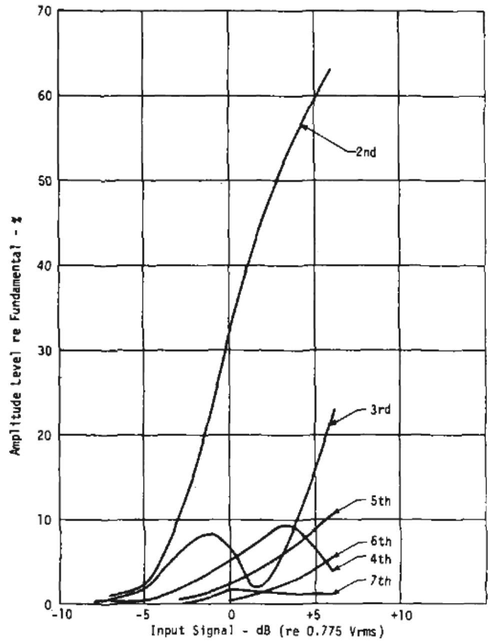

Figure 3.

Figure 2. Distortion components for two-stage triode amplifier. [2]
Figure 3. Distortion components as a function of input level for high-voltage preamplifier. [1]

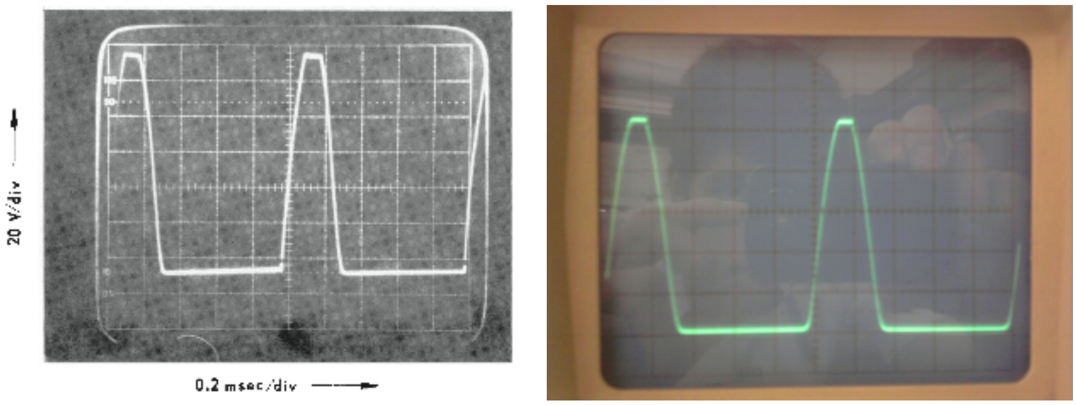

Figure 4. Oscilloscope shots taken from original paper and my experiments.

THD%	Input to M/F mVrms	Input to Valve mVrms
0.500	306.000	10.000
1.000	315.000	18.500
2.000	380.000	22.700
4.000	466.500	28.800
6.000	493.000	36.300
8.000	513.000	46.700
10.000	531.000	62.800
12.000	548.000	89.700
14.000	568.000	134.400
16.000	587.000	199.600

Figure 5. Equivalent input voltages for required THD% at output.

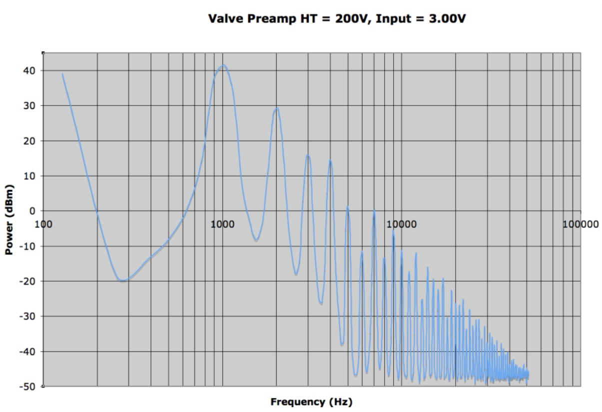

Figure 6. Signal output FFT analysis of a 3.00V Input to both preamps.

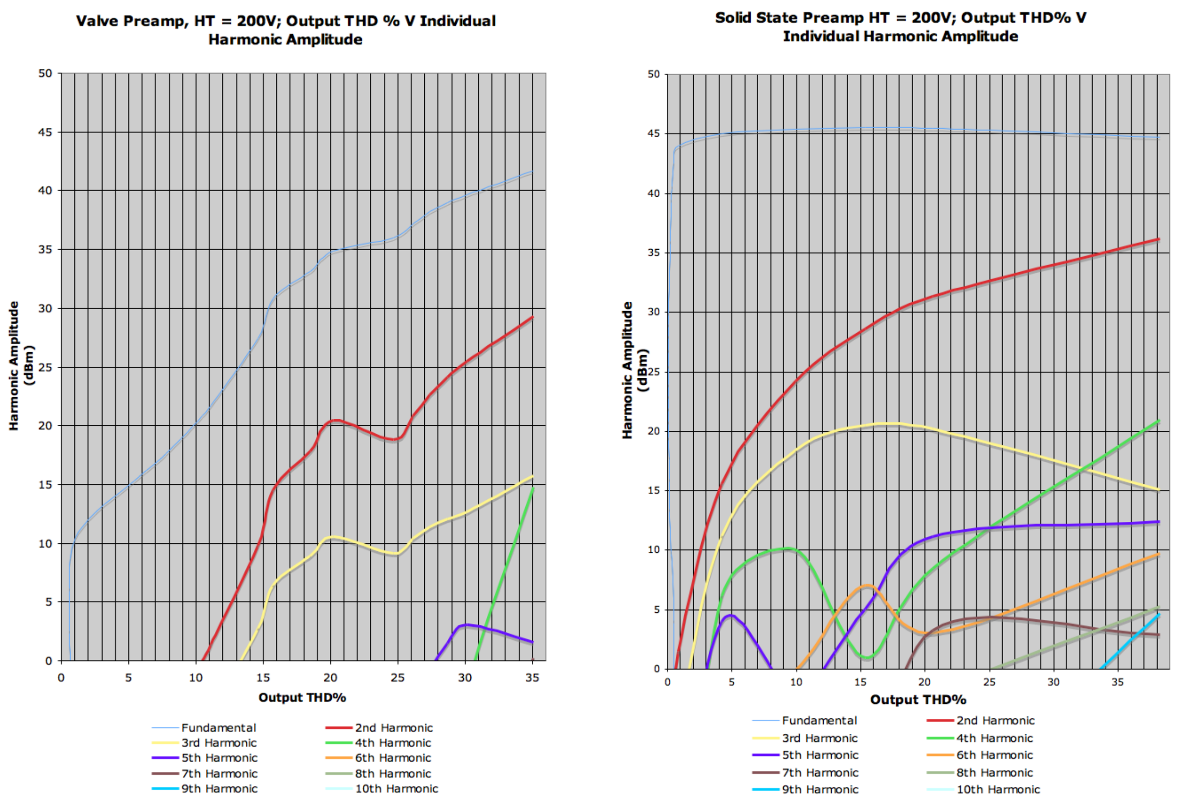

Figure 7. Individual Harmonic Amplitude V Total THD% of each system.