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Evaluation of an EL84/6P14P tube stage in Ultra-Linear operation

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Table of Content

SUMMARY

The original publications into the principle of Ultra – Linear operations, have been published in the light of the application in push pull amplifiers. Since then, the concept also finds frequent use in single ended amplifier concepts. It is the intend of this paper to evaluate the effects of Ultra-Linear operations in single ended amplifiers and to identify the differences of the effects regarding the two amplifier topologies.

INTRODUCTION

2 years ago, the author designed and built a compact amplifier featuring the ECL86 tube. The performance proved to be very satisfactory for such a tiny tube and he decided to create the mature version by implementing the ECC83(12AX7)/EL84(6P14P) combo. The design is a single ended, Class-A amplifier utilizing Ultra-Linear mode and over all negative feedback. It is an "honest" 2W amplifier (THD <0.6%, 30Hz - 20kHz) with a headroom of up to 3W+ before clipping sets in. A MOSFET stabilized power supply was the choice, providing a 100 Hz attenuation of more than 100dB. As a result, both S/N and stereo channel separation are better than 85dB based on 1W@8 ohms.

SYMBOLS/ABBREVIATIONS

THD	Total Harmonic Distortion
k2	Second order harmonics
k3	Third order harmonics
k4	Forth order harmonics
VAS	Voltage amplification stage
UL	Ultra – Linear
OTP	Output Transformer

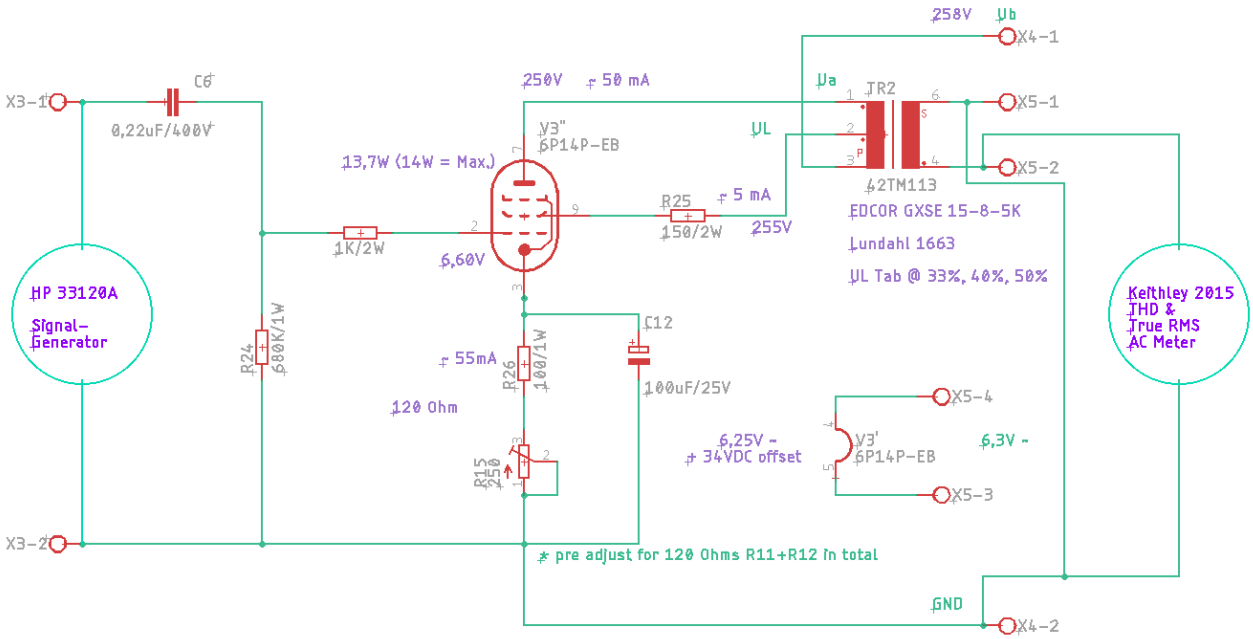
METHODS/TOOLS/APPERATUS

The EL84 output stage of the above-mentioned amplifier has been used as a test bed for this evaluation.

To exclude a feedback effect of the driver stage at the input of the power amplifier tube, the signal generator was fed directly into grid 1 of the power section by a HP33120A signal generator.

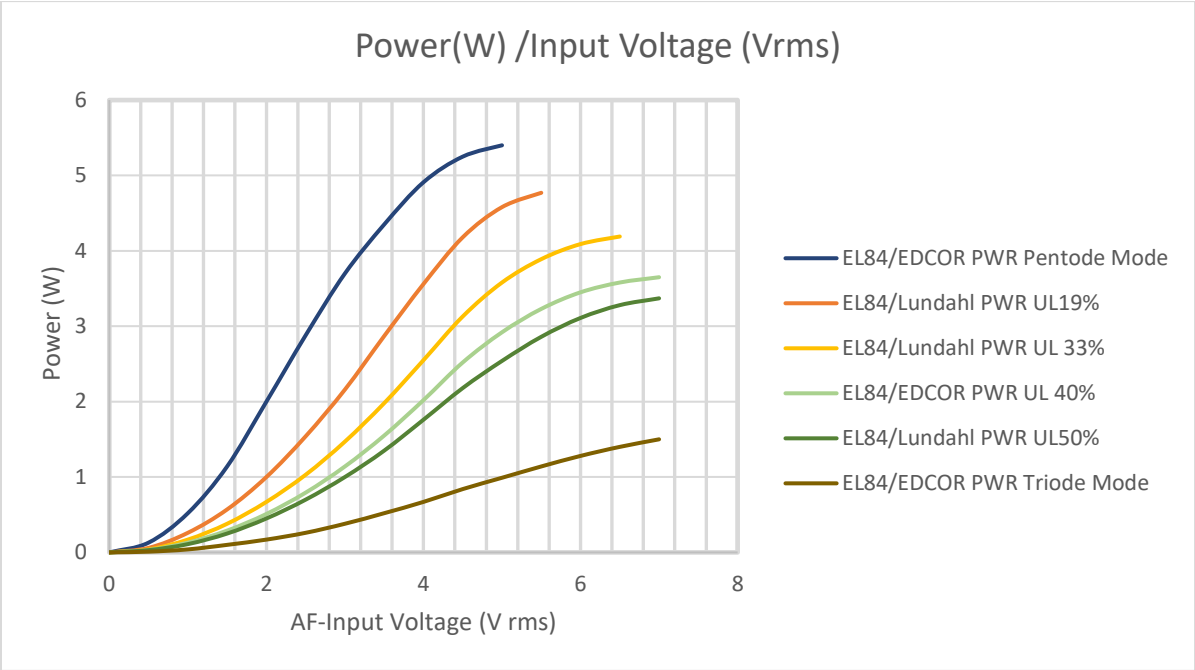
The layout of this output stage, as seen from the input of the output tube via the output transformer resembles an impedance converter with a voltage gain of unity.
4 V(rms) on grid 1 of the power tube correspond to 4 V(rms) at the 8 Ohm load. The entire voltage amplification of this amplifier takes place in the driver stage (VAS).

Two output transformers are evaluated, an EDCOR GXSE15-8-5K and alternatively a Lundahl 1663. The efficiencies of both transformers differ, the EDCOR incorporating an EI-core and set for 100mA DC tolerance was measured for an efficiency of 87%, the Lundahl, incorporating a C-core set for 50mA DC tolerance (and thus has a smaller air gap) for an efficiency of 95%. The different efficiency was not considered for the measurements, as it did not have a relevant influence on the results. The EDCOR provides a 40% UL tab, the Lundahl 19%, 33%, 50% and 66%, with only 19%,33% and 50% being used for the detailed analyses.

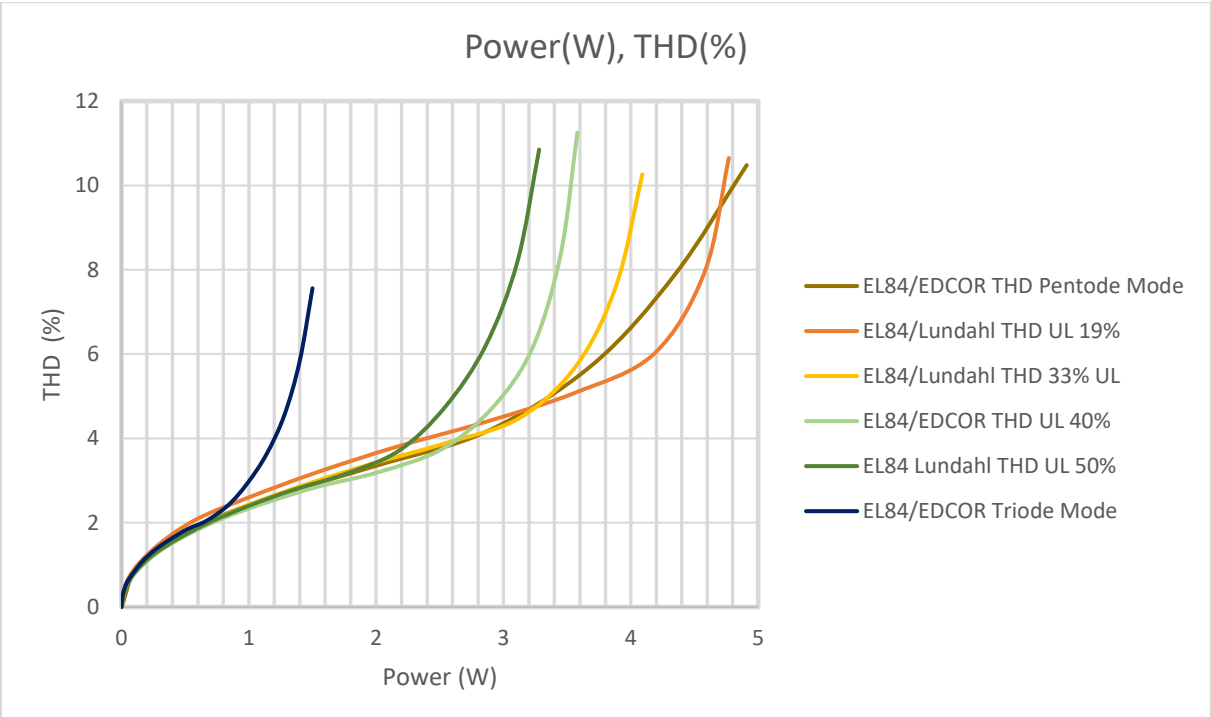


RESULTS

As a first step the output power over the input voltage for various percentages of ultra linear operation is evaluated. The pentode provides the most amplification, followed gradually by the UL-variants and finally the triode mode providing the least amplification.

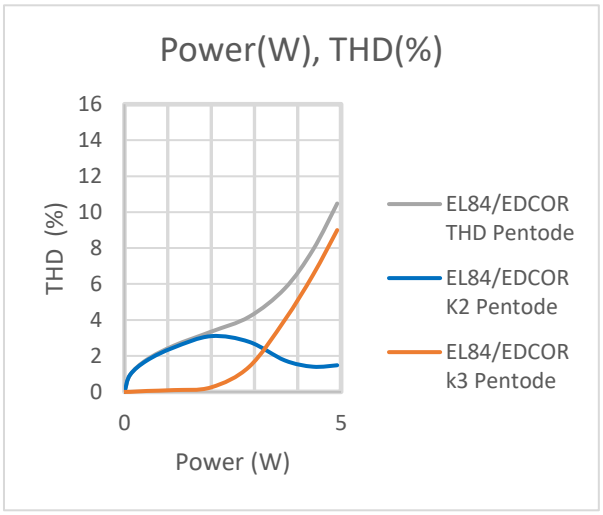


Subsequently those operation modes are evaluated in respect to total harmonic distortion (THD) (K2 - K4). As expected, the UL-traces are moving gradually from the pentode-trace towards the triode trace as the percentage of UL tab increases. The available power, limited by the onset of clipping, is continuously decreasing. Due to its low gain, the triode operation provides the least power output. According to this diagram, the pentode operation could be suspected to be superior to all others.

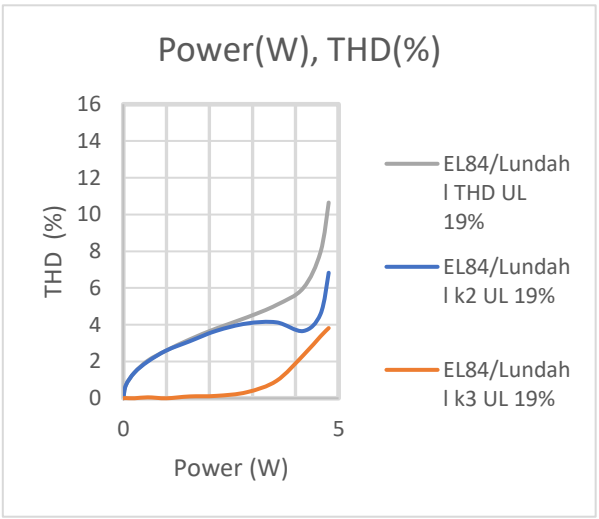


For a more detailed analyses, THD and the components k2/3 are then measured in the respective operating mode.

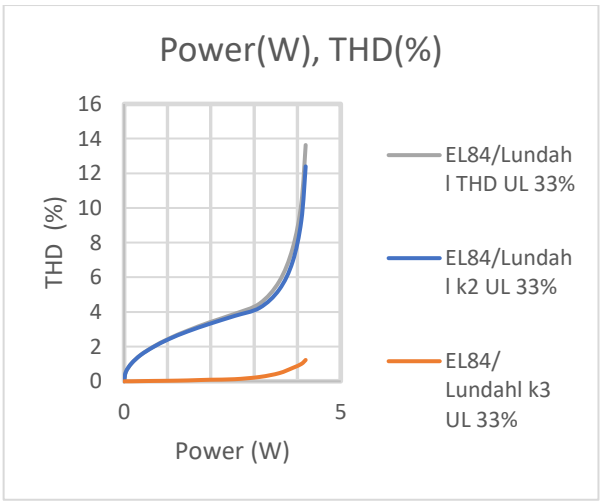
Pentode Mode:



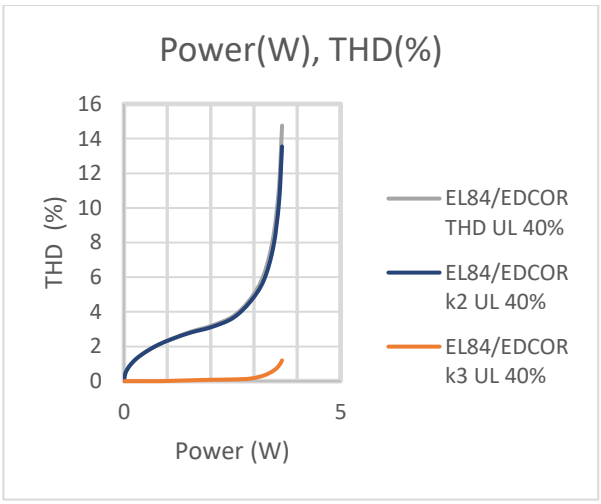
UL 19%



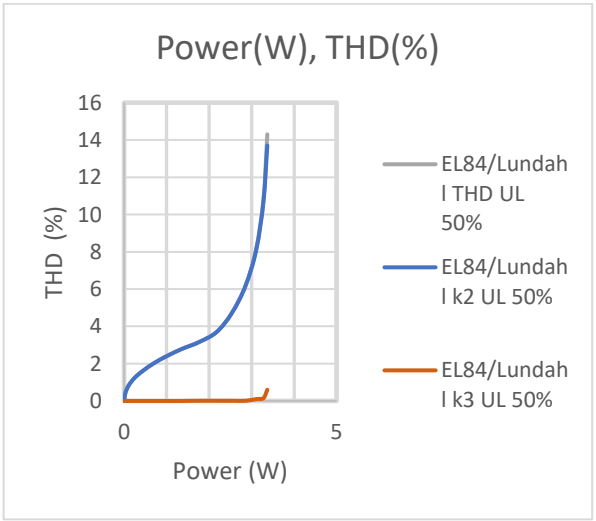
UL 33%



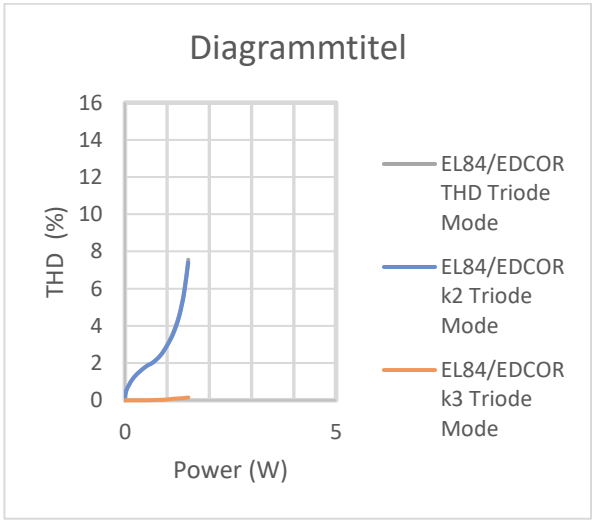
UL 40%



UL 50%



Triode Mode:



EVALUATION

The measurements confirm that the pentode operation delivers the most power. While the value of total harmonic distortion seems reasonable, the detailed analysis shows that even from medium power levels on the unpleasant sounding third order harmonic content is increasing while at the same time the even order harmonics are decreasing.

The consecutive diagrams then show the effect that is implied by utilizing Ultra-Linear operation.

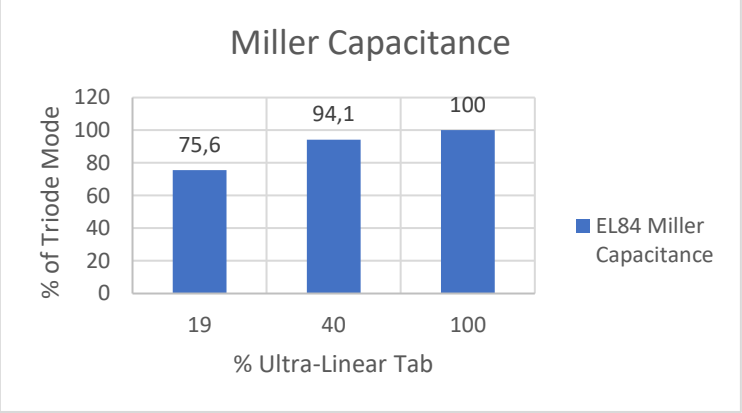
This reduces the proportions of k3, meanwhile a higher k2 contend than before can be observed. The THD (Total Harmonic Distortion) remains almost constant. The effect increases the further the UL tab is located into the direction of the anode tab at the output transformers primary winding. In other words, the higher the specified percentage of UL is applied to grid 2 of the pentode.

The available gain of the pentode is reduced more and more, finally reaching the minimum power if the tab is moved fully to the anode position. The tube is then operating as a triode.

Ultra-Linear mode of operation transforms the output impedance of the pentode almost completely to the lower values of the triode, even at tabs with low percentages. (1)

A similar behavior has been observed regarding the Miller capacitance that increases almost to the value of the triode mode. This poses a much higher frequency dependent load than the pentode mode would on the driver stage. (see diagram below)

No further research into that subject has been made, however it is assumed that the wiring of grid 2 to the Ultra-Linear tab obviously results in compromising the shielding effect of the screen grid from the anode. This happens even with small percentages of UL operation.



The best compromise regarding the reduction of k3 and the minimal loss of power can be identified for the Lundahl OPT at 33% UL, for the EDCOR OPT at 40% UL.

A very detailed data sheet for the EL84 is the edition of Mullard (2). Diagrams of pentode, triode and UL modes with different tabs were published, but the latter only for push-pull operation. The depictions of the pentode and triode operation show a high degree of agreement with the measurements carried out.

CONCLUSIONS

Single Ended Application

- In the case of single-ended amplifiers, UL operation does not reduce overall distortion (THD) but may offer sonic advantages due to trading third order harmonics into more pleasant sounding second order harmonics.
- Although, this comes at the cost of a proportional power loss, typical percentages of UL operations offer substantially more output power then the triode operation.
- The local feedback via grid 2 lowers the output impedance of the tube, thus increasing the damping factor of the amplifier (1).
- The Miller capacitance of the tube increases accordingly and must be considered when designing the driver circuit.

Push Pull Application

- All statements that have been made for the single tube of the Single ended amplifier also apply to the individual tubes of the push pull concept.
- The push-pull amplifier cancels out even order harmonics in the output transformer. Odd-order harmonics are added up. The transformation of odd order harmonics into even order harmonics is extremely advantageous here.
- In combination with moderate over all negative feedback, the remaining third order harmonics can be effectively minimized at the output signal.
- As Push Pull amplifiers develop more power than the single-ended amplifier, the reduction in available power can be accepted much easier.

REFERENCES

(1) Hafler, David; Keroes, Herbert.I “An Ultra-Linear Amplifier “, AUDIO ENGINEERING, November 1951

APPENDICIES

(2) EL84 datasheet edition of Mullard (1961-64)