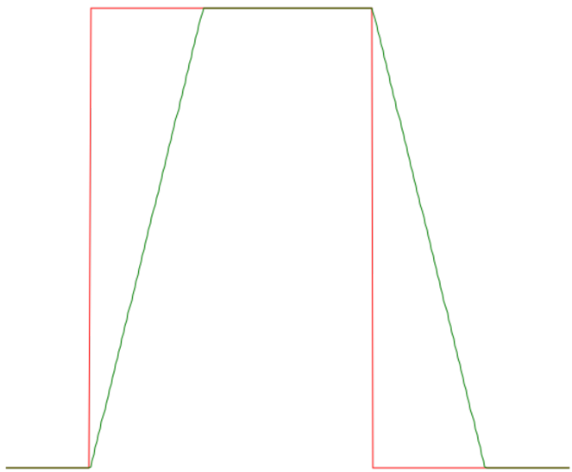
# Slew rate problems in switching audio amplifiers (class D, T)

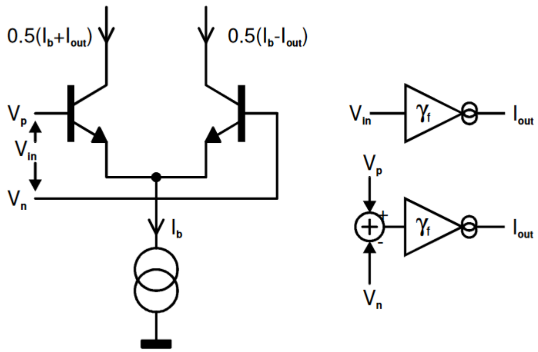
**Premise**

In electronics, slew rate is defined as the change of voltage or current, or any other electrical quantity, per unit of time. Expressed in SI units, the unit of measurement is volts/second or amperes/second or the unit being discussed, (but is usually expressed in V/µs).



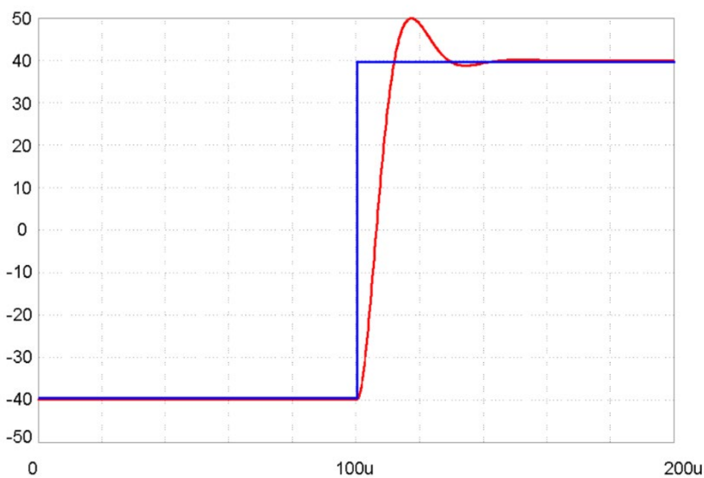
**Slew in linear amplifiers (A, B, AB, etc) vs in switching amplifiers (D, T)**

Slew-rate distortion in linear amplifiers is a cause for a further rise in THD against frequency beyond (but linked to) the decreasing loop gain. It has been identified as an important cause of bad sound in amplifiers. In linear amplifiers, slew rate distortion is caused by: total current passing through the input stage, compensation and poles, total current passing through the intermediate amplification stage and total gain of the differential itself.



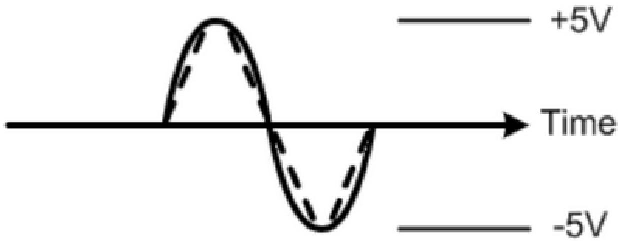

In class D amplifiers, or switching amplifiers, the slew rate is determined by the cutoff of the output filter not by the internal stages.

Let's say we pass an ideal square wave through a common LC filter (inductance - capacitor). Since an LC filter is a low pass, the passband will be limited. The bandwidth limitation is directly proportional to the slew limitation.



## Speed and power bandwidth limitations

The slew rate limitation not only limits the total speed of the circuit, but determines the distortion and the maximum deliverable power.




When insufficient current is available to accommodate the steep rising and falling slopes of a high frequency sine wave, it turns into a triangle wave adding new distortion frequencies.

Assuming the case of a simple sinusoid, to calculate the slew needed (in microseconds) for each volt of voltage, the following formula is used:

$$SR = \frac{2 \times \pi \times freq}{10^6} \; V/\mu S$$

This formula defines the slew, expressed in volts per microsecond, necessary to perfectly reproduce a given frequency, without distortion, in a sinusoidal regime.

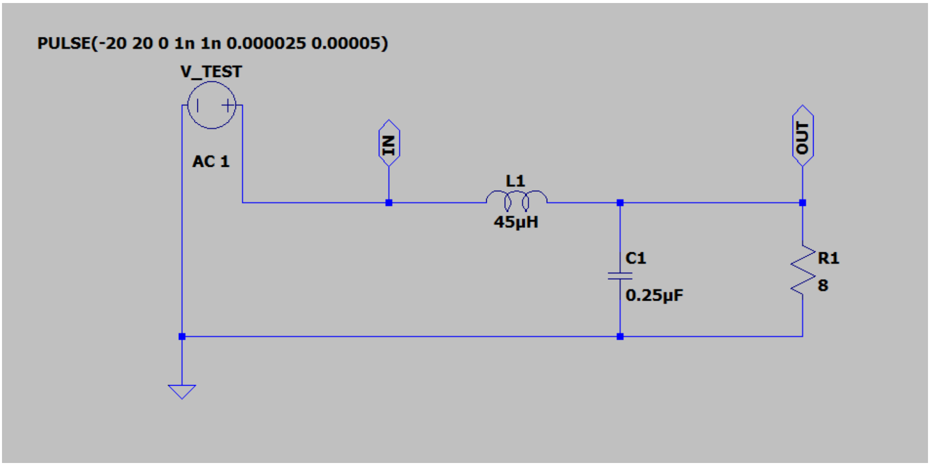
Now analyzing the fastest frequency in the audio band, we calculate how much speed is needed to perfectly reproduce a 20kHz sine wave.

$$SR\ (20kHz) = \frac{2\ \times\ \pi\ \times 20000}{10^6} = 0.125\ \ V/\mu S$$

This means that it takes 0.125V/uS of slew for each volt of output voltage to correctly reproduce a 20kHz sine wave.

If the slew is not enough, not only does the THD (total harmonic distortion) increase, but the power delivered at the specific frequency also decreases.

First, let's place a test circuit in a simulator.

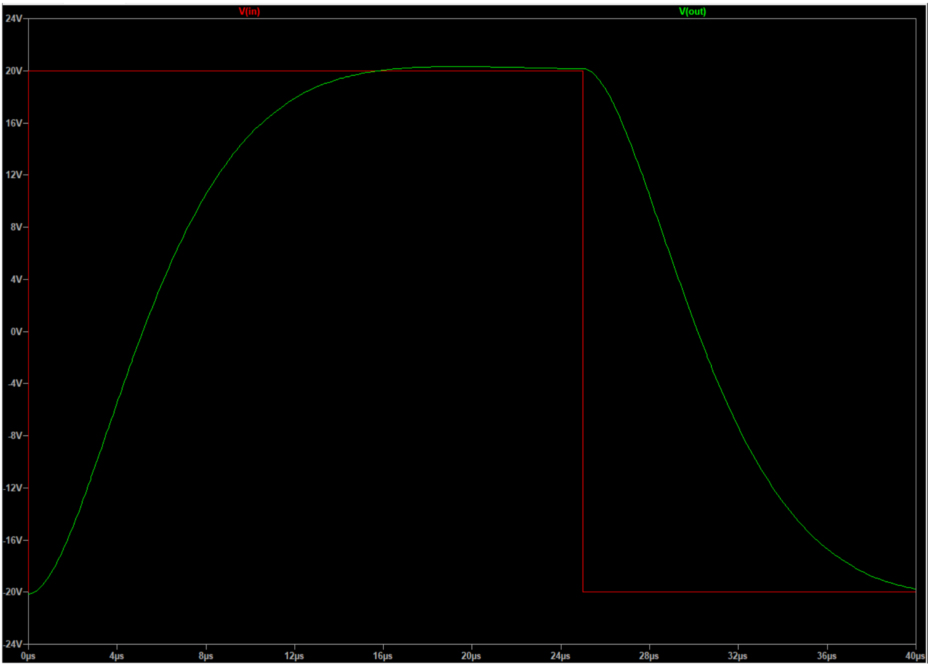



Where:

- **L1:** main inductor
- **C1:** main capacitor
- **R1:** the load which simulates a loudspeaker
- **V_TEST:** ideal voltage generator, introduces a perfect square wave with 1 nanosecond of rise and fall and a +20 to -20V voltage swing

The values are calculated according to the filter of an averaging switching amplifier. The cut is 6dB/oct, -3dB at 40kHz.

Now, let's look at the output:




As you can see, the slew is limited to **4 V/uS** by the output filter. But exactly, how much voltage can we deliver before the signal is distorted?

If **0.125 V/uS** of slew is needed for each volt of voltage at 20kHz, then it means:

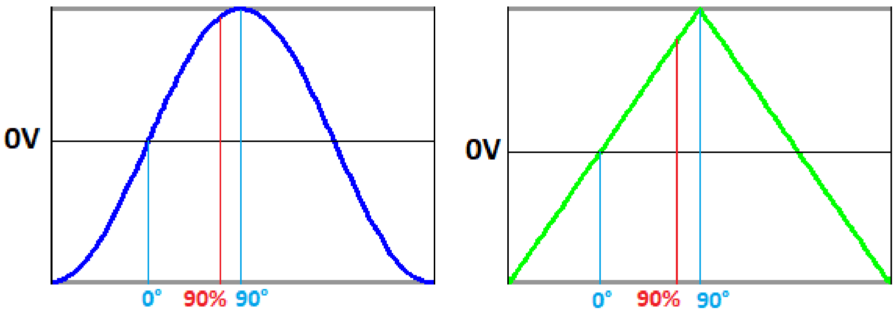
$$\boldsymbol{V = 4 \div 0.125 = 32\,Vpp = 16\,Vp}$$

Peak voltage of 16V means 32W delivered to a 8 Ohm load. So what happens to the power transferred to the load when the sinusoid voltage exceeds the maximum slew?

By keeping the slew constant, the sine function increases its harmonic distortion as the voltage increases adding odd harmonics and transforming itself into a triangular function.

Then, what is the power dissipated by a sine wave and a triangle wave? To study this effect, we need to see what happens in the point of slowest change of rate of the wave.

The slowest change of rate point of the signal is 90% of the period between 0° and 90°, this will be 81°.




To calculate the power dissipated, the frequency is not relevant. Assuming that the load resistance and the maximum peak voltage are known, and that both the voltage and the current are in perfect phase, the power at the moment is calculated with Ohm's simple law:

$$\boldsymbol{P(W) = V(V) \times I(A)}$$

The voltage point is calculated respectively:

For the sinusoid: $\boldsymbol{y = \sin \alpha}$

For the triangle wave: $\boldsymbol{y = x}$

For simplicity of calculation, we assume that the resistance of the calculation is **1 Ohm**, and that the peak voltage is **1Vp**.

Then, for the sine wave, $\boldsymbol{\alpha = 81° \rightarrow y = 0.98\ V}$. For the triangle wave $\boldsymbol{x = 90\%\ of\ 1V \rightarrow 0.90\ V}$.

The result is clear, lower output voltage also means lower dissipated power, keeping the load constant: **0.98V** with **1 Ohm** means **0.98A**, **0.90V** with **1 Ohm** means **0.90A**.

$$\boldsymbol{W(sine) = 0.98\ V\ \times 0.98\ A = 0.96\ W}$$

$$\boldsymbol{W\ (triangle) = 0.90\ V\ \times 0.90\ A = 0.81\ W}$$

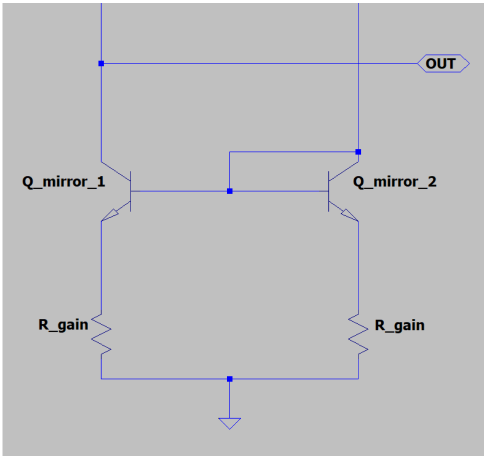
This means that, with a too low slew, and therefore with too high a distortion, the power supplied by an amplifier is about **22.24%** less.

**The effects of slew rate on acoustic perception**

In conclusion, the psychoacoustic effects of the slew rate variation on different groups of people were observed.

In linear amplifiers, it is possible to vary the slew rate, without changing the other amplifier performances. Without changing the levels of distortion, compensation, of currents passing through the stages, this is possible simply by varying the resistances at the base of the differential, after the emitters of the current mirrors.

The higher the resistances at the base of the differential, the greater the gain of the same. In this way, the differential tends to function for the VAS as a generator of current, rather than voltage. Which strongly penalizes the total speed of the circuit.




It was possible to hear a big difference with genres that used particularly fast signals such as Austrian Dubstep. The difference, of course, is perceived at a high volume, as a general timbre and distinction of sounds. In addition, the high frequencies were much more attenuated, although the frequency response did not vary.

In the general report, a high slew makes a noticeable difference in the accuracy of high frequencies.

**Sources**

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*Bruno Putzeys - Hypex Electronics - UcD and IMD, DIM, Slew Rate Application Note*

*Jung, W.G. – Slewing induced distortion (1977)*

*Douglas Self – Audio amplifier design handbook 6th ed (2013)*