Fast Transimpedance Stages for Audio Power Amplifiers

Anti-saturation Techniques for Audio Amplifier TIS/VAS Stages

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This short presentation demonstrates some techniques for ensuring fast recovery in audio amplifier transimpedance stages (TIS) aka voltage amplifier stages (VAS) when overdriven

Transistor saturation and excessive base charge storage

Excessive *base charge storage* arises when a transistor is in saturation (i.e. turned fully ON with Vce≈ 0 and the collector current has plateaued but current well in excess of that required to keep the transistor ON continues to be injected into the base.

This accumulates as base charge in the device, and will cause it to continue conducting even after the incoming base current is reduced to zero.

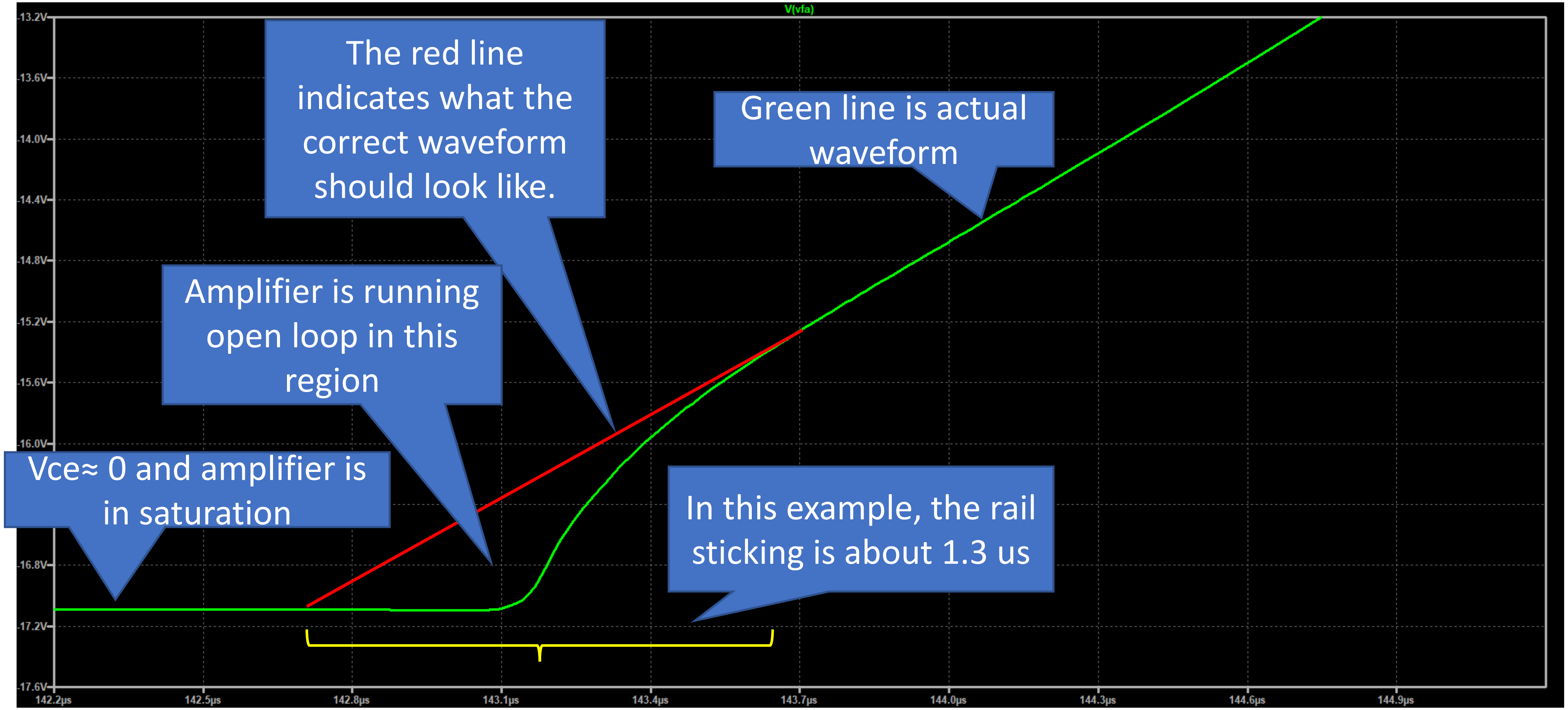
To speed up transistor switching, base current *in excess* of that required to just ensure Vce≈ 0, has to be diverted away from the device base – a circuit technique commonly referred to as a Baker clamp

There are two main types of problems that occur when an amplifier VAS (aka TIS) is driven into saturation

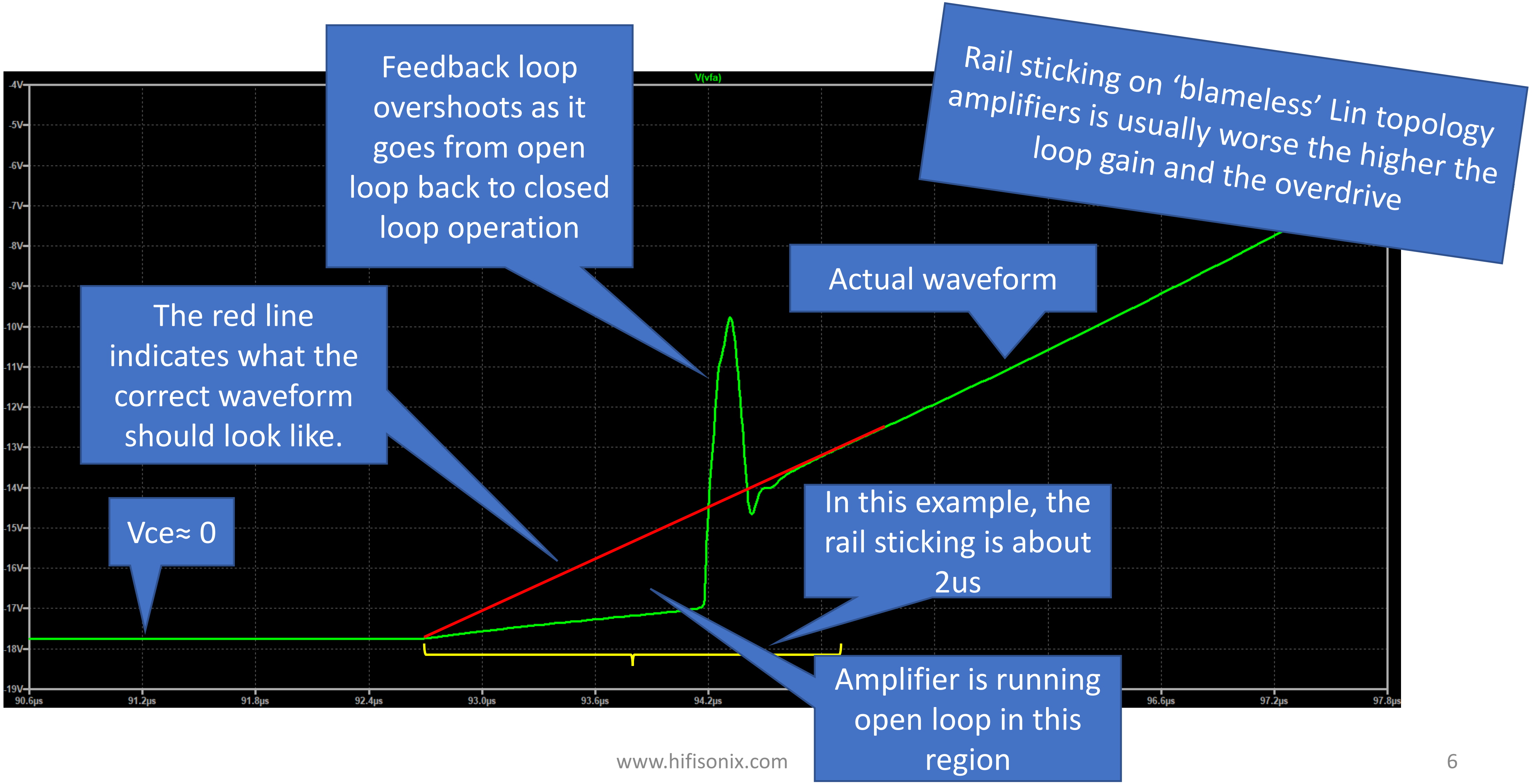
1. On single ended or ‘blameless’ amplifier types loaded with a current source, a phenomena called ‘rail sticking’ arises wherein the saturated amplifying device remains ‘stuck’ to either of the two supply rails, despite the input signal having progressed well away from its peak. This causes severe recovery problems and while the overhang is in progress, the amplifier is effectively operating open loop – *note this has nothing to do with SID/TIM – it’s a completely different mechanism*.
2. In symmetrical amplifier types overdrive also causes the VAS current to spike to very high levels. This is especially an issue in CFA topology amplifiers where the current on-demand behaviour can cause the VAS current to exceed the standing current by >10x even with no load connected to the output – i.e. the OPS drive current is negligible
3. In all cases, the problem is exacerbated by high(er) loop gains and level of overdrive

The following pages show some anti-saturation techniques which can mitigate the problem

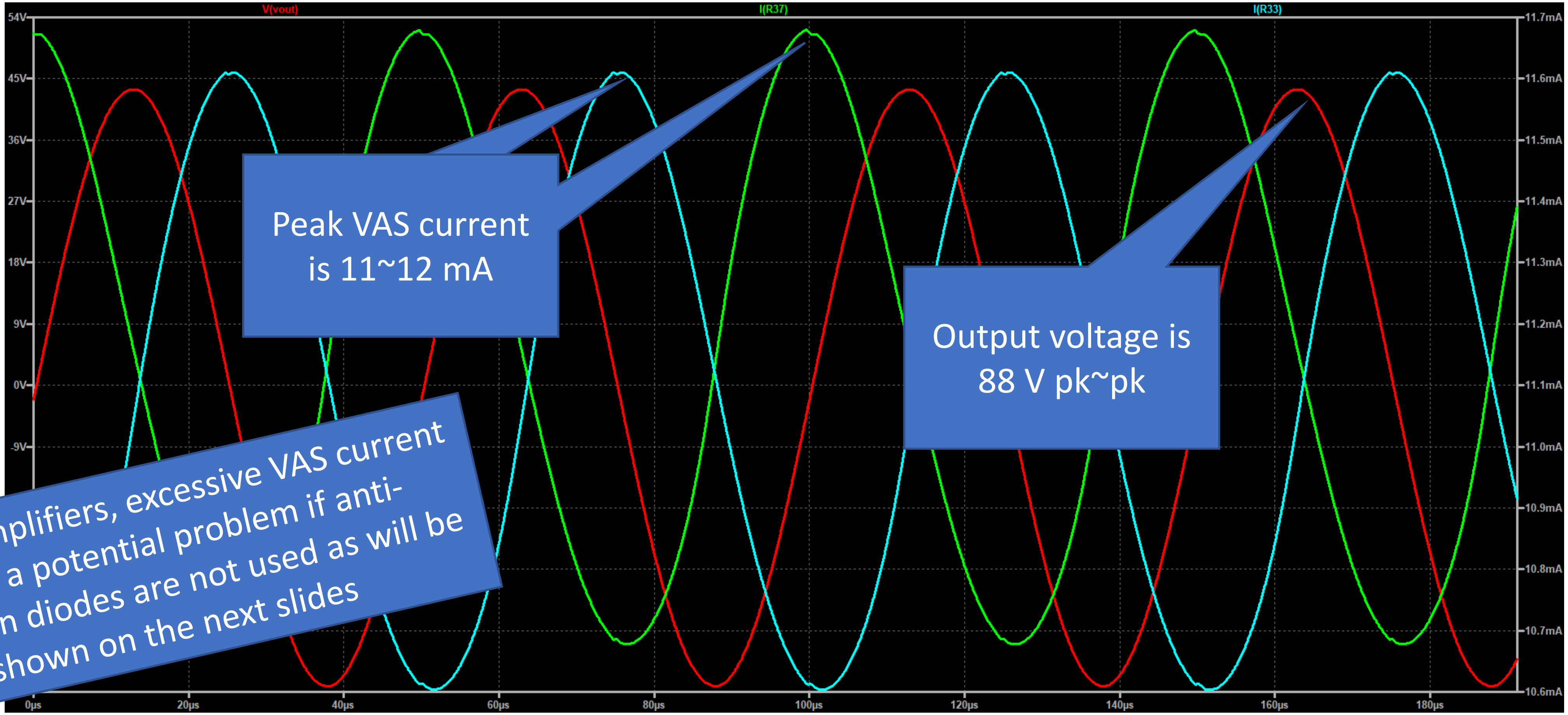
An example of a mild case of rail sticking – VAS collector voltage on an overdriven Lin topology amplifier



An example of a severe case of rail sticking – VAS collector voltage on an overdriven Lin topology amplifier



Symmetrical CFA amplifier at onset of output clipping at 120 W RMS into 8 Ohms

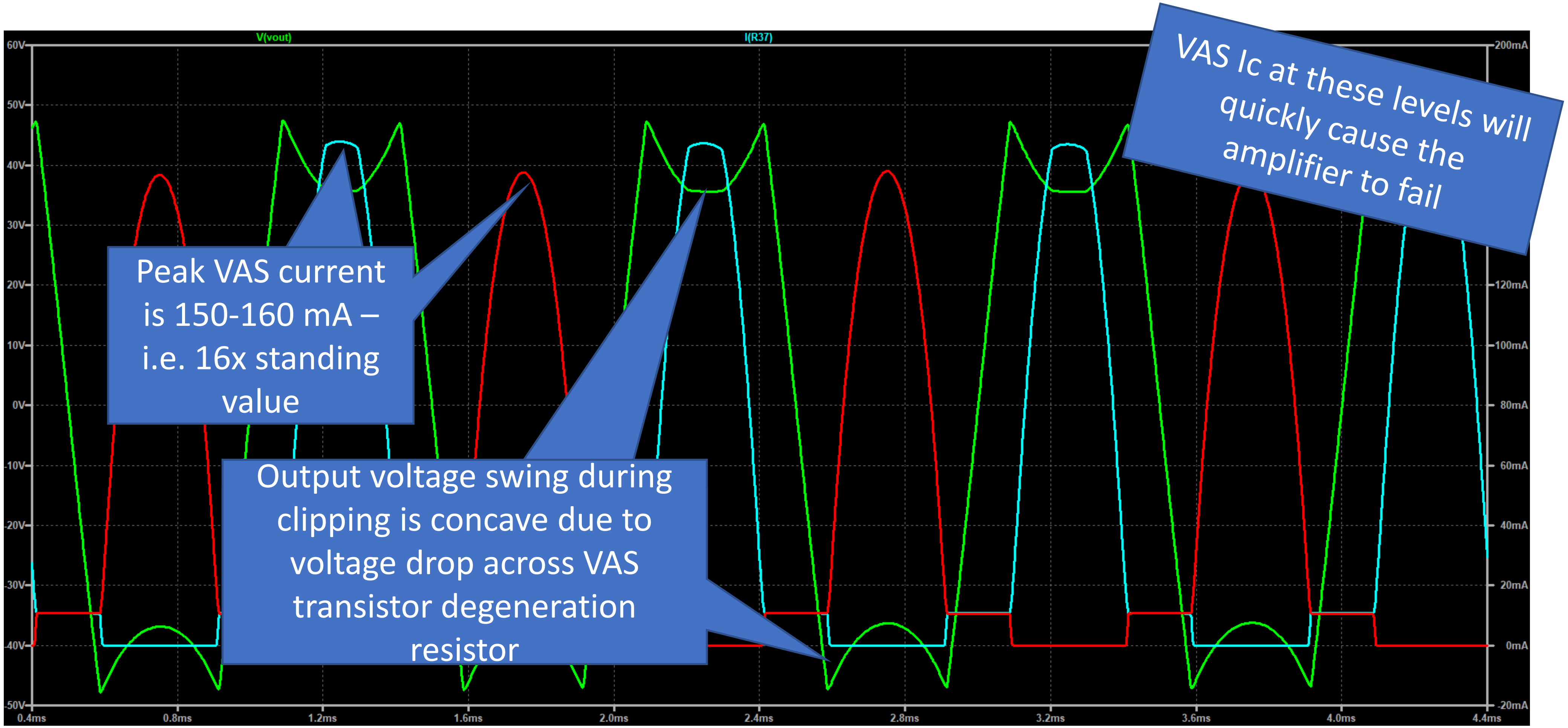


Peak VAS current is 11~12 mA

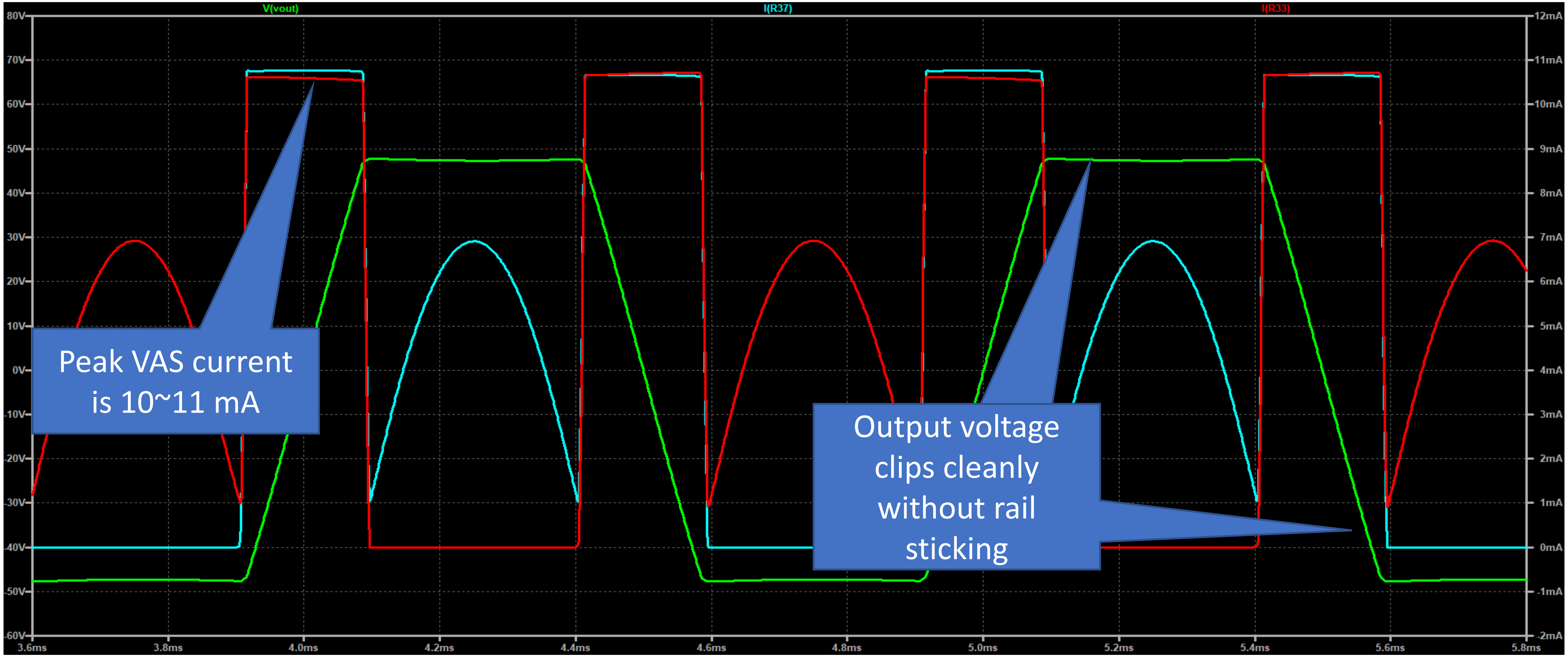
Output voltage is 88 V pk~pk

On CFA amplifiers, excessive VAS current is also a potential problem if anti-saturation diodes are not used as will be shown on the next slides

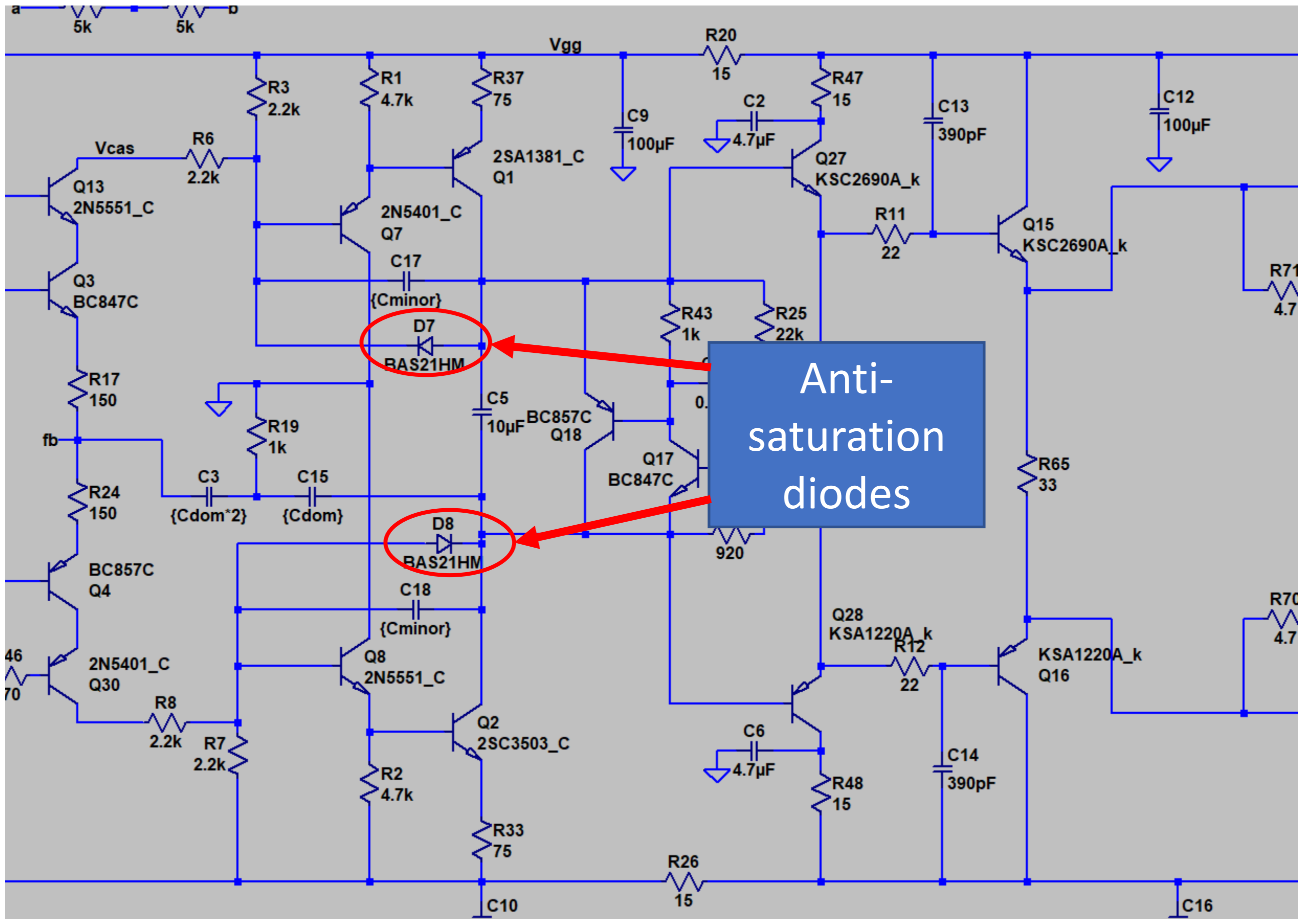
Symmetrical amplifier driven into heavy clipping without VAS anti-saturation diodes



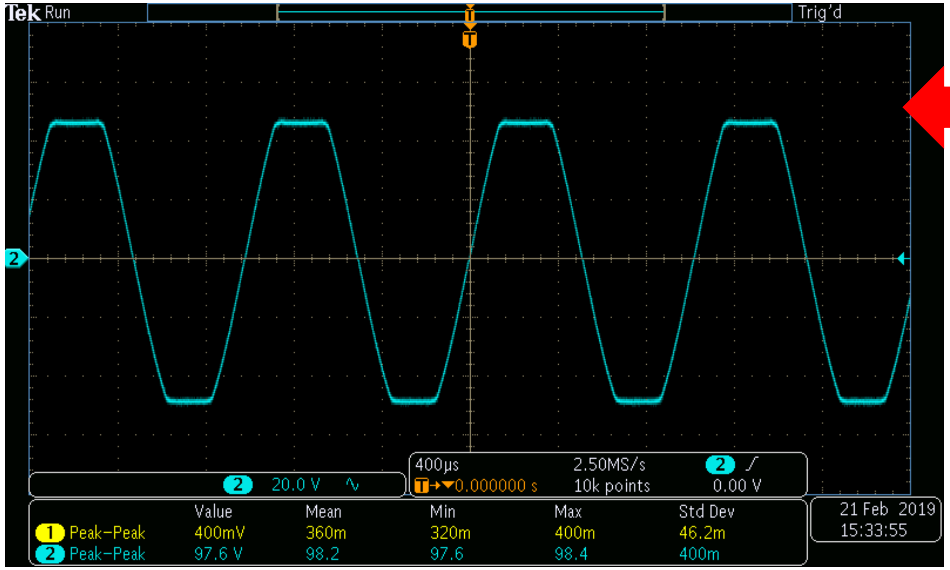
Balanced symmetrical amplifier driven into clipping with VAS anti-saturation diodes



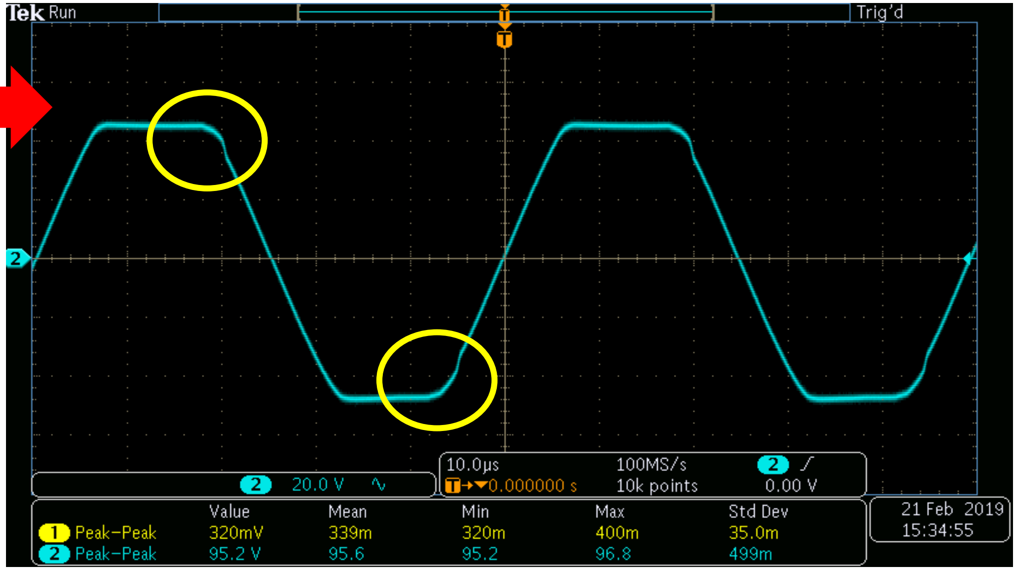
Anti-Saturation diode circuit detail on 110 Watt CFA amplifier



Anti-Sat diodes in action - 110 W CFA Amplifier

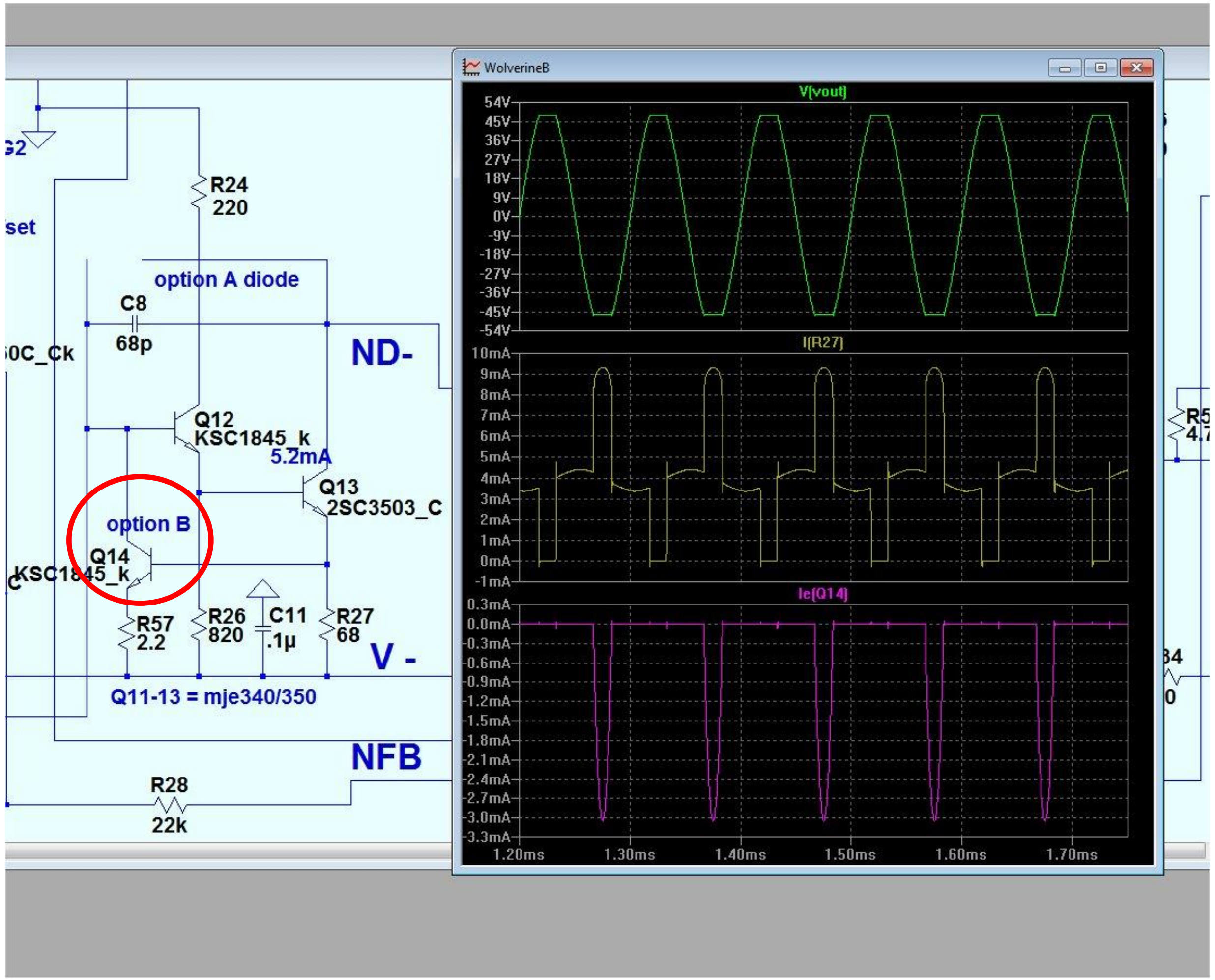


Peak to peak output is 97 volts. Load is 1k Ohms



In the left hand graphic, clipping is clean and shows no rail sticking. The input signal is ~1 kHz. On the right hand graphic, the input stimulus signal is 20 kHz, and the rail sticking problem is easier to discern. This is an extreme case and unlikely to be encountered in practice (there is very little music energy at 20 kHz), but it serves to illustrate that to detect this issue you need to drive the amplifier hard into clipping at HF. This particular amplifier features moderately high loop gains, EF3 and a beta enhanced VAS stage.

Using a transistor to limit VAS current and sticky rail by shunting the beta-enhance transistor base drive



Courtesy ‘Ostripper’ – DIY Audio

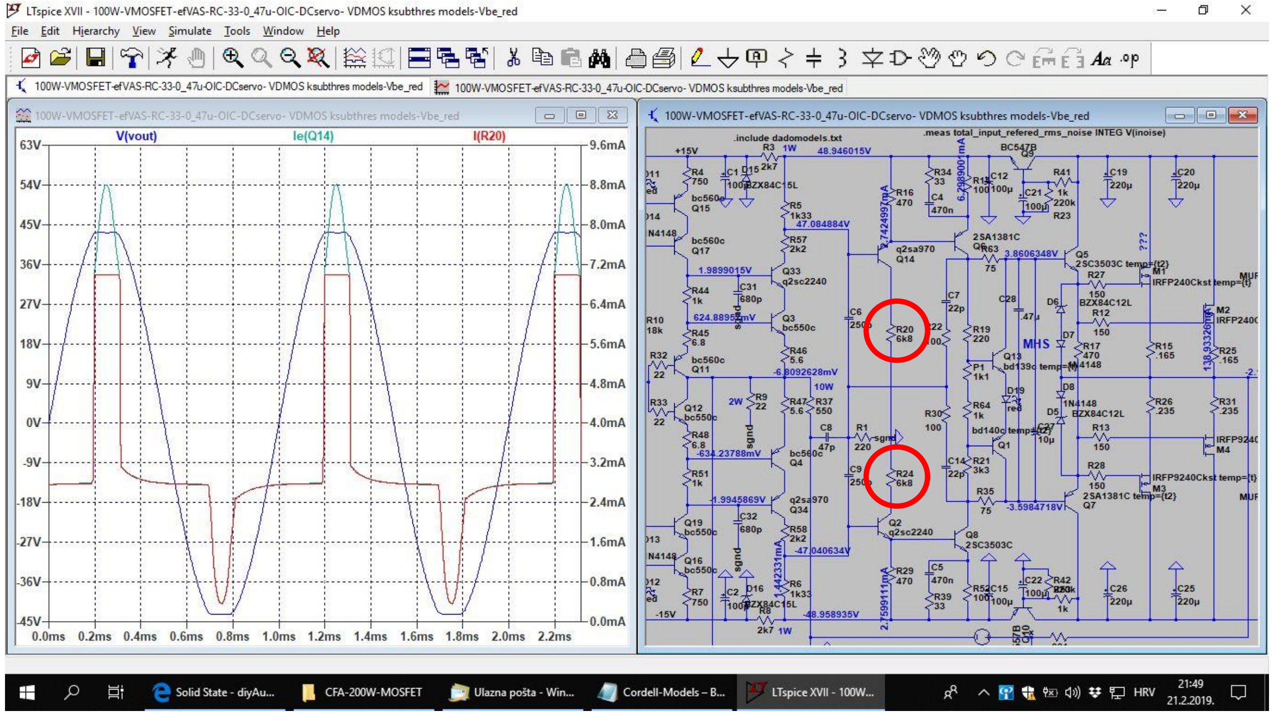
In this technique, transistor Q14 serves a dual purpose by both

1. limiting the maximum VAS current (in this case Vbe/68 = ~9mA) and,
2. when Q14 is active, shunting base drive current away from Q12

Overdrive recovery is therefore fast with no overhang or rail sticking.

The standing current in this design is c. 4mA, so the limiting action at 9mA is well away from the linear operating region, but within the bounds required for safe protection both in terms of current and thermal dissipation of the VAS transistor Q13.

Using a resistor in the collector current of the beta-enhancer transistor to limit VAS current and sticky rail



Courtesy 'dadod' – DIY Audio

In this technique, R20 and R24 limit the maximum amount of current that can be injected to the base of the main VAS transistors Q6 and Q8 by causing the beta-enhancer stage Vce≈ 0 when overdriven.

This forms a voltage divider with R16 and R29, setting the VAS peak current to

$$[Vcc*R16/(R16+R20)]/R11$$

where R11 is the VAS Q6 emitter degeneration resistor. The same applies to the –ve VAS circuit around Q8 .

Since the base charge storage is low in the small signal beta-enhance transistors Q2 and Q14, and the main VAS transistor currents are limited, the VAS recovers very quickly after overdrive with no rail sticking.

The peak VAS current can tweaked by adjusting the value of R20 and R24

Recommended anti-saturation diodes for audio amplifier VAS stages

- BAS21J – SMD SOD323F (SC90) – very fast, very low reverse capacitance (c. 0.3 pF typical) SMD diode Vrrm = 300 Volts peak

- BAV21 – Leaded SOD27 (D-05) – very fast, low reverse capacitance (C. 1.1 pF) through hole diode Vrrm = 250 Volts peak

Note: the Nexperia and Vishay types offer the best performance specifications