

## Some thoughts about resonant peaking of class-d amps

There are some discussions going on about resonant peaking of LC output filter in class D-amps and how to avoid these using snubbers. To enlighten the DIYer it is worth to delve into theory to get some basic understanding of what is going on.

The LC output filter forms a second order low pass filter that cuts off most of the clock signal while maintaining audio bandwidth. These were the good news, now the bad ones: If excited close to its resonant frequency this filter acts as series resonant tank. To understand this it is helpful to explore its equivalent circuit diagram. Starting with a pure pre-filter feedback configuration the amp acts as voltage source with an impedance of  $R_{dson}$ . The inductor is characterized by inductance  $L$  and coil resistance  $R_{dc}$ , the capacitor by its capacitance  $C$ .

Driven with an input signal equal to the resonant frequency the output of the amp is loaded with an impedance that drops far below 1 Ohm. Output current draw soon reaches the limits and overcurrent protection will trip (hopefully!). At the same time the output voltage rises excessively to the resonant peak and soon surpasses the supply rails. There is a good chance that output caps release their magic smoke. To illustrate this here is a typical example of one bridge leg

$L=10\mu H$        $C=680nF$        $R_{dc}=0.023R$     $R_{dson}=0.12R$

resonant frequency:       $f_{res} = 1 / (2\pi \sqrt{L \cdot C}) = 61kHz$

min impedance:       $Z_{res} = R_{dc} + R_{dson} = 0.143R$

aperiodic damping res:       $R_{res} = \sqrt{L/C} = 3.8R$

Loading this resonant tank with a resistor of  $3.8R$  tames that resonant peak aperiodically, impedance drop no longer exists. This can easily be expanded to a full bridge configuration. Loaded with  $7.6R$  the full bridge output filter is aperiodically damped. So an 8 Ohm speaker should work perfect here. At least that is what datasheets let expect you – and where they miserably fail. Laboratory measurements of frequency response are carried out using non-inductive dummy resistors thus confirming theoretical expectations of a stable circuit. So the only remaining problem was using the amp without speaker load. Ok, we learned not to switch on without the speaker connected, now every thing is fine?! Not really...

The assumption behind is that the speaker has a non-inductive impedance of 8 Ohms measured at LC resonant frequency, i.e. in the range of 50kHz. And this assumption is not valid for 99,9% of real existing speaker drivers. Consequently the real speaker lets the output unloaded in the critical frequency region and does not make a difference at all.

So, what's the hack? There is some risk of resonant peaking at frequencies around 50kHz, i.e. beyond the audible band. But this requires some excitation at the input – normally not available from our band-limited audio sources. And if this appears in some rare occasions – overcurrent protection trips and shuts down the chip. No real danger inside. I built several guitar amps based on TPA3116 without any resonant damping and did not have any related trouble using them live over the years. All in all this is a typical drawback of pre-filter feedback class D-amps with little effect in real life application, not really important, but UGLY!

## Taming the beast: Output LC-filter controlled snubberless

The goal is to dampen the output LC-filter in the worst case scenario of unloaded output. One option is to use a snubber, i.e. a RC-combination loading the output terminals. Ideally  $R$  equals the optimal damping resistor of LC-filter ( $3.8R$  in our example) and  $C$  is infinite. The dilemma is evident: With infinite  $C_{snub}$  the amp is loaded permanently over the entire audio band with  $3.8$  Ohms creating excessive loss. As a rule of thumb  $C_{snub}$  is chosen twice the value  $C_{filter}$  which yields acceptable resonant overshoot. But when driven with a high pitched audio signal (on stage micro feedback) the snubber resistor will dissipate excessive heat and burn. Snubbers are always a compromise between achievable damping effect and additional power dissipation. In other words: Using the snubber limits power bandwidth of the amp far below  $20\text{kHz}$  – and that is why I disregard this approach here.

A better solution are clamping diodes. These clamp the output terminals in case of excessive ringing (not the driving bridge legs!) to the supply rails. By clamping the output voltage the input current is clamped as well so there is a good chance that the OCP does not trip. I never applied this to a class-d-amp, but can confirm this works fine in LLC applications.

But my favourite idea is damping the resonant peak lossless, and that is snubberless. This can be achieved by some amount of post-filter feedback. Without a valid spice model of real class-d-amps I did the experimental approach and discovered a solution that flattens the frequency response above  $20\text{kHz}$  independent of load. A prototype TPA3118 mono-PBTL amp has been modified accordingly and measured.

The improvements with this approach are obvious.

And this will work with other chips as well.

The test circuit depicts a first implementation with additional components  $R_{fb1}$ ,  $R_{fb2}$ ,  $C_{fb1}$ ,  $C_{fb2}$