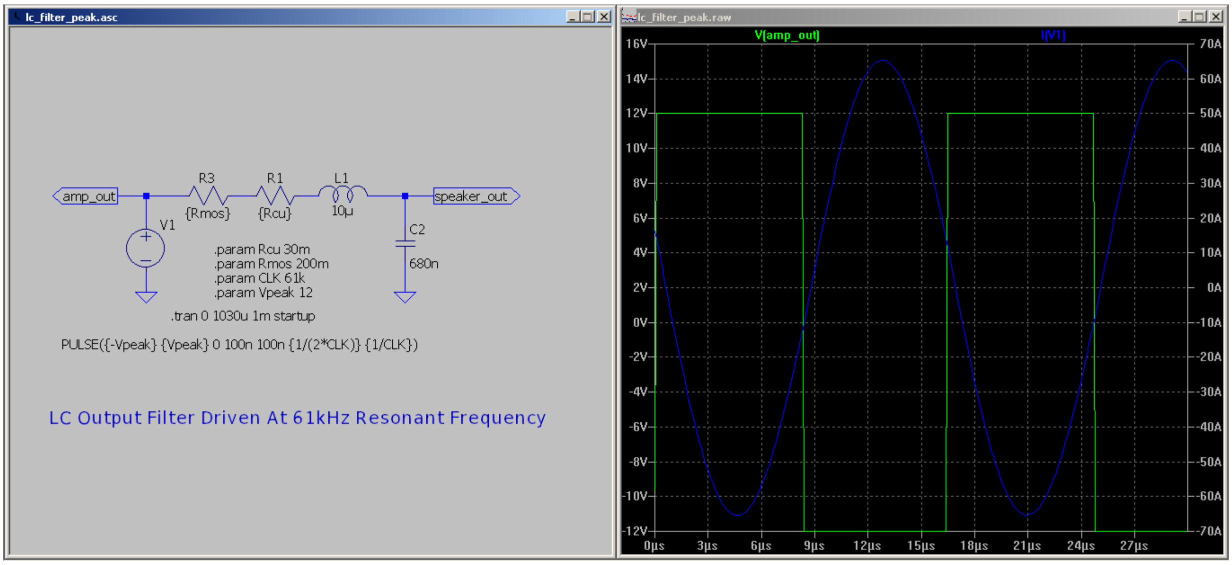
LC Output Filter and Zobel Network

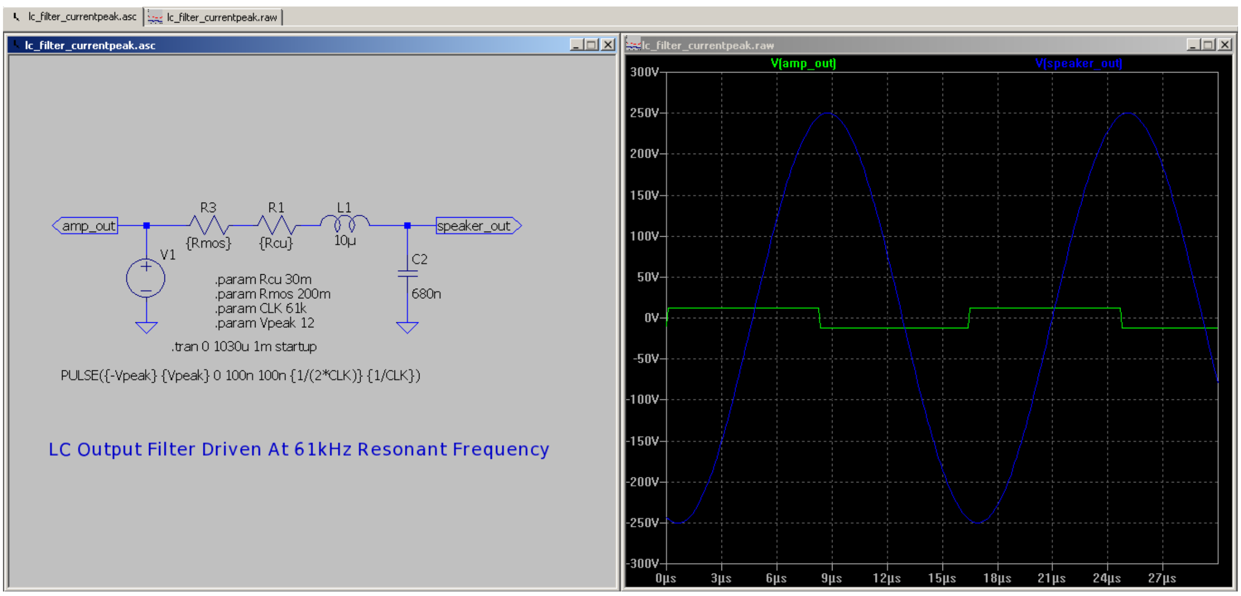
The typical LC-output filter is designed for about 50khz resonant frequency with an impedance matching to minimum load resistance. For example

L = 10uH   C = 680nF

Fres = 1 / 2*pi*sqrt(L*C) = 61kHz

The LC output filter acts as a series resonant tank loading the driving amplifier. Circulating output current increases drastically when driven at resonant frequency due to the impedance drop of series resonant tank, limited only by Rdson of PowerMOSFETs and copper resistance of inductors. At the same time voltage peaks to excessive levels far beyond supply voltage. The following simulation shows a realistic unloaded output tank, excited by 61khz square at 12V amplitude. The resulting current exceeds 60amp peak, the voltage 200V!



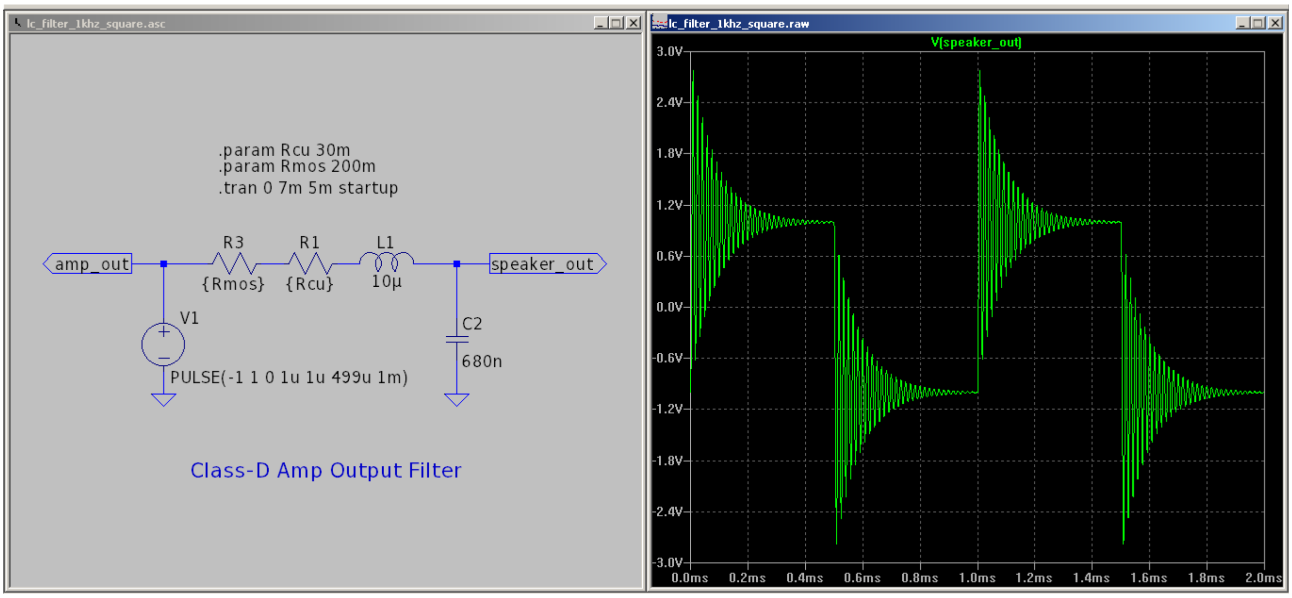


This can be avoided by damping the high Q-factor of the LC-filter. For optimum frequency response without overshoot aperiodic damping is required. The corresponding damping resistors computes to

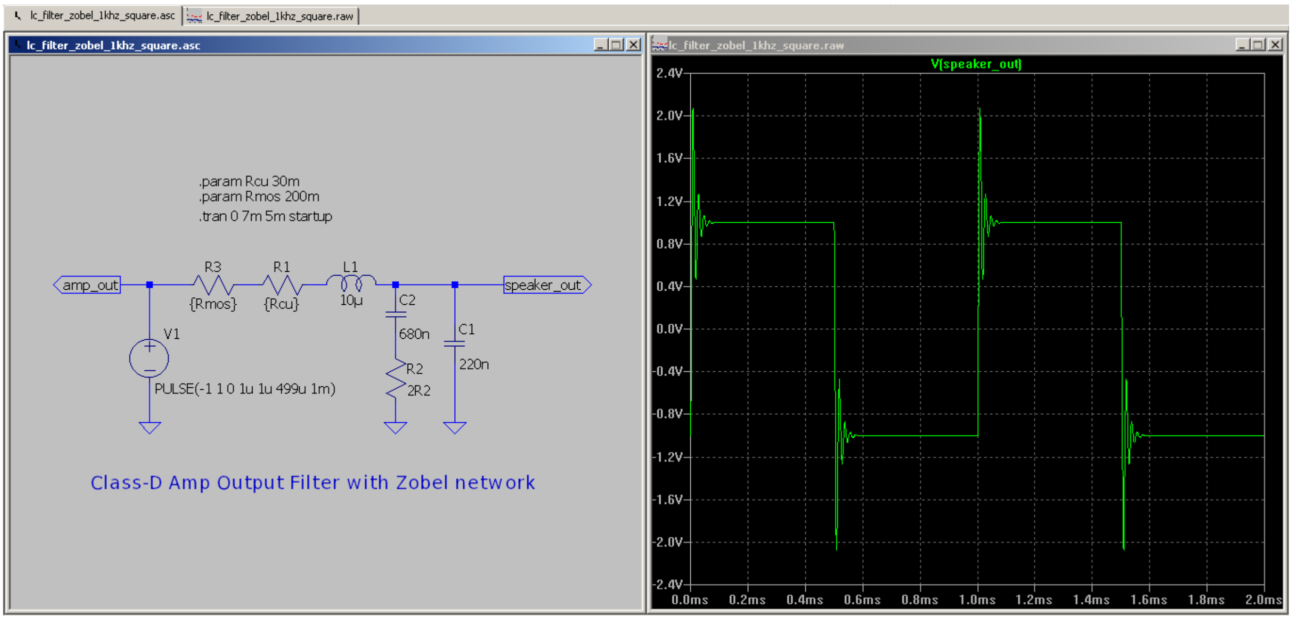
Z = sqrt(L/C) =3.8 Ohms

Thus loading the amp with a 4 Ohm dummy yields perfect smooth frequency response. That is what you find in the datasheets published by manufacturers measuring their devices with low inductance dummies. Sadly this is not the hole truth. A real loudspeaker always exhibits some inductance that leads to a rising impedance with increasing frequency. Impedance of a 4 Ohm speakers measured at 60kHz will give results far beyond 3.8 Ohm thus damping will not work in real life.

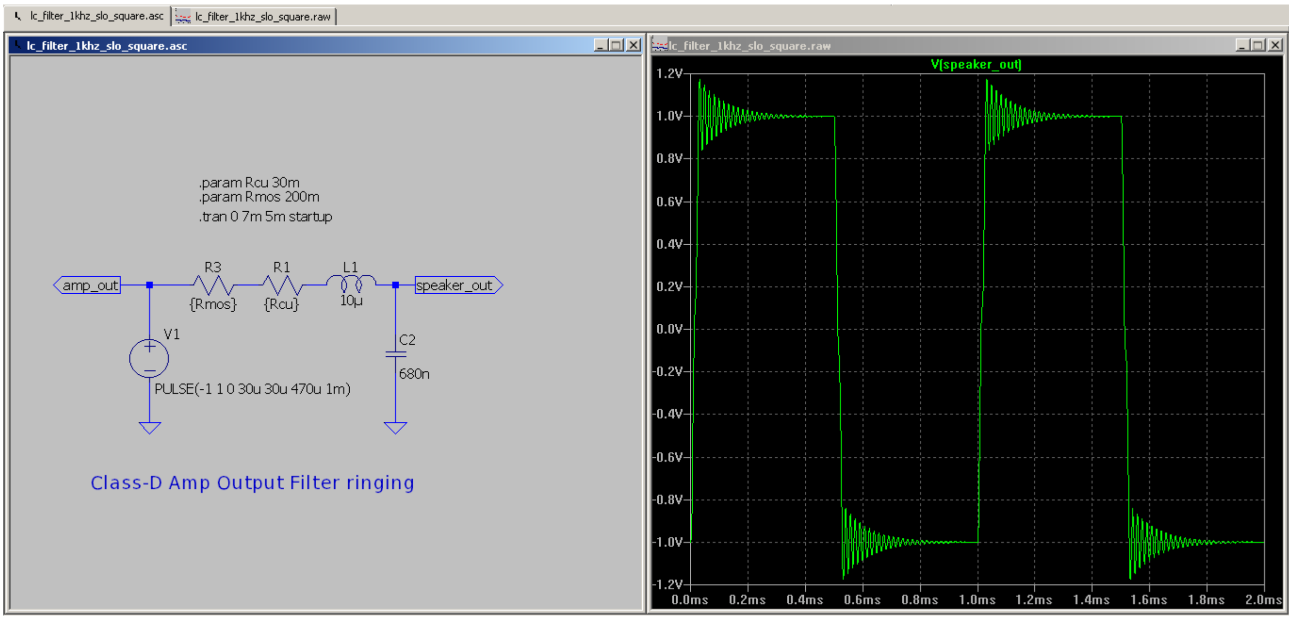
All in all the worst case scenario is an unloaded output where damping is at its minimum. It is no surprise that frequency plots of unloaded amps are not published in these data sheets. You may expect something similar to this simulation when driven with 1kHz square wave with 1us rise time:



Here the Zobel network comes in. It replaces the 4 Ohm dummy by a RC-network. The usual approach is a resistor twice the value of speaker impedance in series with a cap rated a fraction of output filter cap connected parallel to the filter cap. This will reduce possible ringing to acceptable levels keeping losses in the resistor low at normal operation, similar to this simulation:



You might have noticed that in mainstream applications Zobel networks are omitted most of the time. Their drawbacks are obvious: In case of heavy resonant ringing, the Zobel resistor will burn and release that magic smoke, being useful only once in a lifetime. Otherwise an appropriate rated resistor could be quite bulky and unacceptable. Consider the LC filter excited by 1 Khz square wave with a more realistic rise and fall time of 30us instead of 1us - this looks much mor friendly:



So, what's the hack? Nobody needs the Zobel provided the amp will never be driven with a signal of some level close to filter resonant frequency. And in these rare events of some significant high frequency resonant voltage you may say goodbye to your tweeters.

Obviously there are some good reasons to consider the Zobel network. An alternative approach to the described parallel network is a resistor half the value of speaker impedance in Series with the filter cap, parallelled by another cap with a fraction of the filter cap. This yields a slower phase lag in the resonant region thus simplyfying the feedback design of post-filter feedback.

To avoid the magic smoke in case of high signal levels close to LC self-resonant frequency a NTC used as damping resistor does the trick: Normally working at its cold resistance of 2.2 Ohms for instance, in case of significant resonant current the NTC heats up, reduces its resistance and limits power loss. Due to the lack of damping now ringing takes place, circulating current may increase to several amps until overcurrent fault trips and shuts down the hole thing. After restart and cooling down everything works again, no damage at all.

This may or may not protect your tweeters.