ISCE

The Institute of Sound and
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Engineering Note 22.2

Capacitors in series with loudspeakers

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A well-known technique to prevent high-power low frequency signals overloading small loudspeakers and horn drivers is to add a capacitor in series. It sounds straightforward but, like many other things in audio, it's not quite a simple as it seems.

To begin with, we consider a low-impedance loudspeaker, either a bare driver or a sealed box. A line transformer adds too much mathematical excitement for the initial treatment. Suppose we think that, in order to protect the loudspeaker from excessive cone excursion at low frequencies, we want to reduce the frequency response of an 8 ohm loudspeaker by 3 dB at 250 Hz. Around that frequency, the impedance is likely to be a minimum, and that minimum should not be less than 6.4 ohms (IEC/EN 60268-5). The formula for the capacitance *C* is:

$$C = 1/(2\pi fZ),$$

where

f is the frequency for -3 dB response,

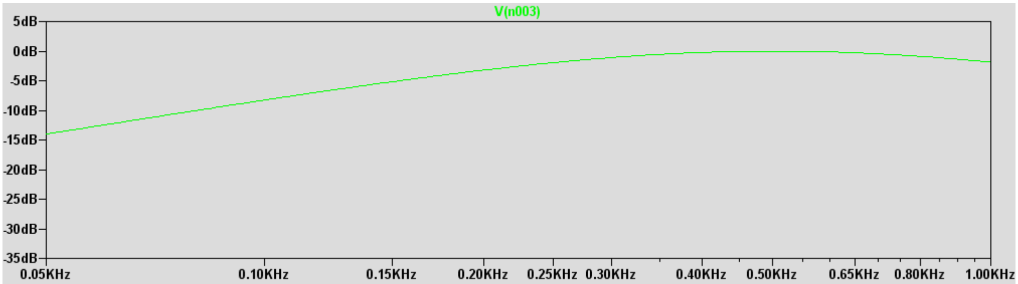
Z is the impedance (a pure resistance when a minimum).

This gives:

$$C = 1/(2\pi*250*6.4) = 100\ \mu\text{F near enough .}$$

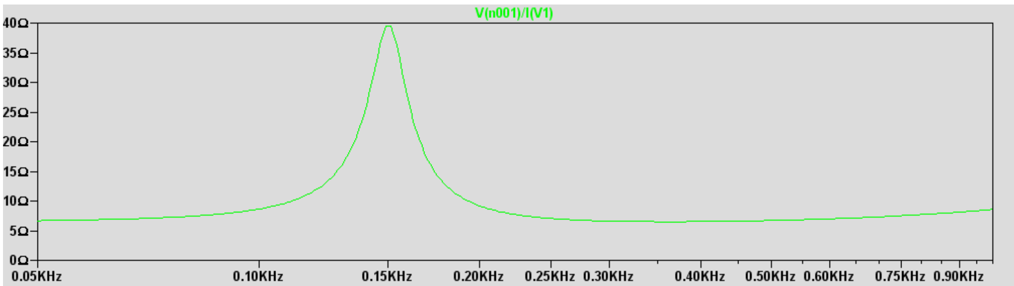
The FREE LTSpice (or SwCAD III) circuit analysis application (available from http://www.linear.com) allows us to plot the frequency response of the voltage across the 6.4 ohms (representing the ideal loudspeaker with1 mH voice-coil inductance) when it is connected via the 100 µF capacitor to a constant voltage signal generator, which is just as we should expect.

When we add the series 100 uF capacitor, we get no surprises:

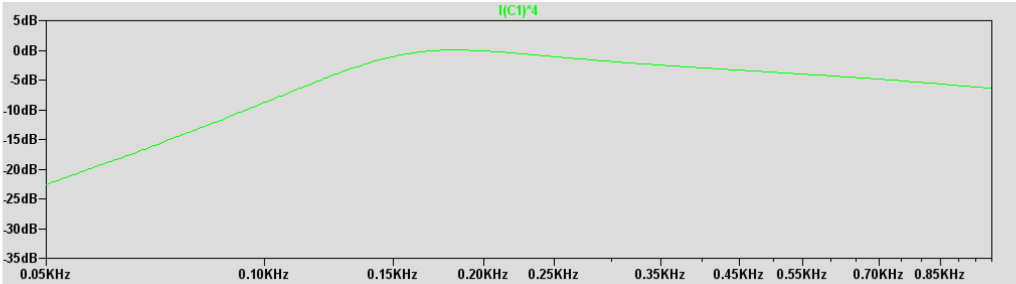


The frequency response just drops at low frequencies, eventually at 6 dB/octave.

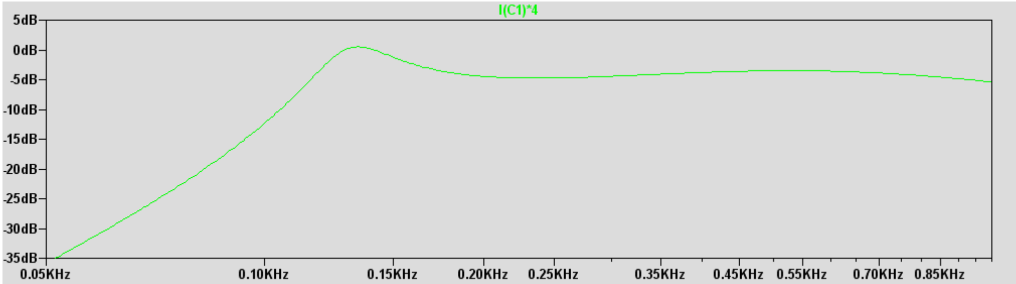
However, the impedance of a moving-coil loudspeaker is anything but a constant resistance and this makes a LOT of difference. A typical example of electrical model of a low-cost loudspeaker driver unit has an impedance curve, courtesy of LTSpice, like this, where we can see the low-frequency resonance:



The frequency response of this ideal model (which doesn't have cone-break-up above about 200 Hz, so the voice-coil inductance causes a falling response towards the higher frequencies) is:

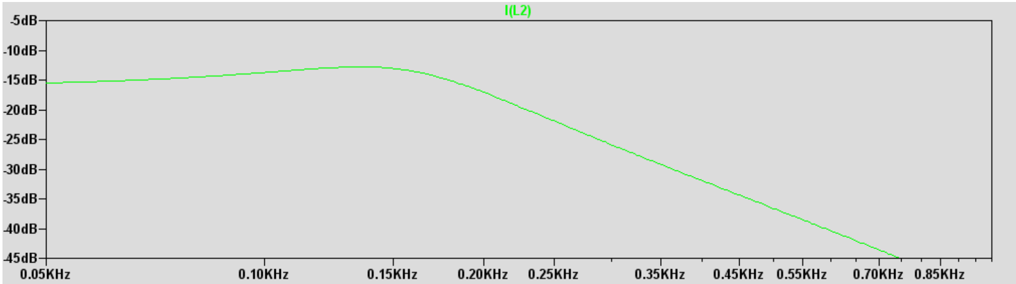


When we add the 100 µF in series, the frequency response of the modelled loudspeaker does this. It waves about a bit above 200 Hz as the capacitor and voice-coil inductance have their own private battle:

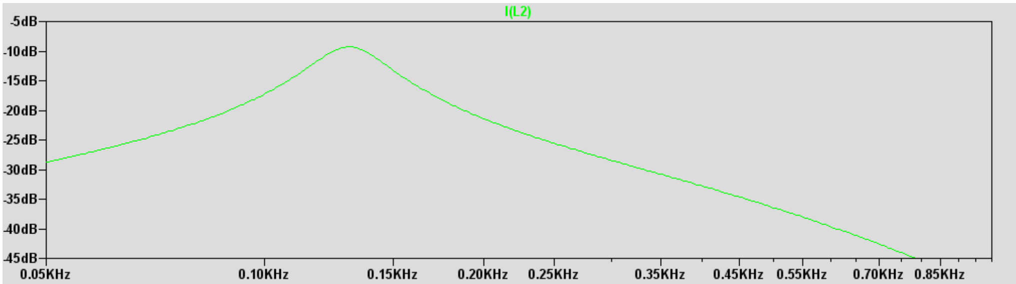


You can see that the response peak has moved LOWER in frequency, which is certainly unexpected, but more significantly, the response doesn't drop 3 dB at 250 Hz, because the impedance of the loudspeaker is rising as the frequency goes down. It doesn't drop away until the frequency is below the response peak, where it plunges twice as rapidly as it does in the absence of the capacitor.

So this 100 uF capacitor doesn't reduce the response below 250 Hz but below about 120 Hz, and that frequency depends much more on the resonance frequency of the loudspeaker than it does on the capacitor value. Furthermore, we wanted to reduce the *cone excursion* without, if possible, degrading the frequency response too much. With a bit of trickery, LTSpice will plot cone excursion as well, assuming that the loudspeaker isn't overloaded. Without the 100 µF, we get:



where the dB scale is purely relative. Adding the capacitor doesn't do what we expected:



The 0 dB scale reference here is the same as in the graph above, so we can see that in a frequency range around 130 Hz the cone excursion has gone UP, not DOWN, as we wanted, although it has gone down by about 18 dB at 50 Hz.

The series capacitor trick works for *pressure units*, because their impedance curves are quite different when mounted on a horn. Now, the interesting question is how REALLY to protect the loudspeaker against low frequency overload, and the most obvious answer is to do it with a high-pass filter in the amplifier. There isn't anything simple you can do at the loudspeaker to overcome this effect, short of putting it in a really small, nominally sealed box. By 'nominally sealed', I mean that any leaks are TINY.

Similar curious effects occur with passive crossover networks; you can get, for example, a frequency response curve with a right-angle bend in it, both in theory and in practice. It's much better and cheaper to do the filtering at low level, even though that costs you a second power output stage.