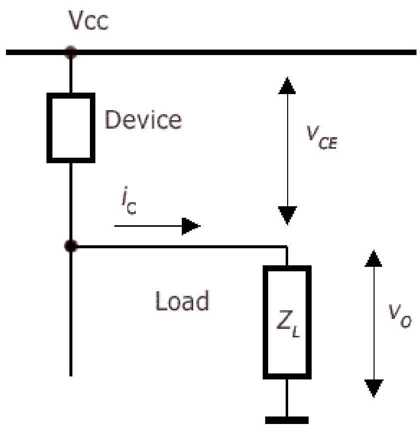
Safe Operating Area and reactive loads.

Ing. Rodolfo Astrada for DIY audio. **June/2005**



With reference to the actual operating condition for non resistive loads, with an eye to its impact on SOA, looking at the simplified schematic above we may write for the positive going quadrant:

$$i_C = \frac{V_O}{Z_L} \quad \text{and} \quad V_{CE} = V_{CC} - V_O \qquad [1]$$

Where V_{CE} is the collector – emitter (drain - source) voltage, i_C the collector (drain) and load current, and $Z_L = R_L + sX_L$ the load impedance.

Taking $i_C = I_0 e^{st}$ and for a sinusoidal excitation $s = j\omega$, factoring from [1]:

$$V_{CE} = V_{CC} - I_0 e^{j\omega t} Z_L = V_{CC} - I_0 e^{j\omega t} |Z_L(\omega)| e^{j\varphi(\omega)} = V_{CC} - I_0 |Z_L(\omega)| e^{j(\omega t + \varphi(\omega))} \qquad [2]$$

Where $|Z_L(\omega)|$ and $\varphi(\omega)$ are alternative vector expressions for the load impedance.

Equation [2] is the load line expression $V_{CE} = f(i_C)$ in complex form, actual voltages and currents are given by the real part:

$$R_E(V_{CE}) = V_{CC} - I_O |Z_L(\omega)| [\cos(\omega t)\cos(\varphi(\omega)) - \sin(\omega t)\sin(\varphi(\omega))] \qquad [3]$$

Since the load impedance is frequency-dependent, we cannot have a truly $V_{CE} = f(i_C)$ expression in the sense of being valid for any value of i_C, but parametric on ω.

For $\varphi(\omega) \equiv 0$, i.e. for a purely resistive load, [3] simplifies to the straight load line.

$$R_E(V_{CE}) = V_{CC} - I_O |Z_L| \cos(\omega t) = V_{CC} - R_E(i_C) R_L \qquad [4]$$

The consequences of [3] are that to explore the implications of reactive loads with regard to SOA, one must plot $V_{CE} = f(i_C)$ for different values of ω, making t vary so as to make $-\frac{\pi}{2} \le \omega t \le \frac{\pi}{2}$, replacing $\varphi(\omega)$ for its value for each plot. Note [3] is general in the sense any arbitrary complex load is covered as long as we can determine both $\varphi(\omega)$ and $|Z_L(\omega)|$.

A plot from [3] leads to the case of current mode driving, in the sense we set I_0.

Alternatively we can solve for $i_C = f(V_{CE})$ leading to the voltage mode drive.

$V_{CE} = V_{CC} - i_C Z_L$ so $i_C = \frac{1}{Z_L}(V_{CC} - V_{CE})$ and for $V_{CE} = V_0 e^{j\omega t}$ we have as in [2]:

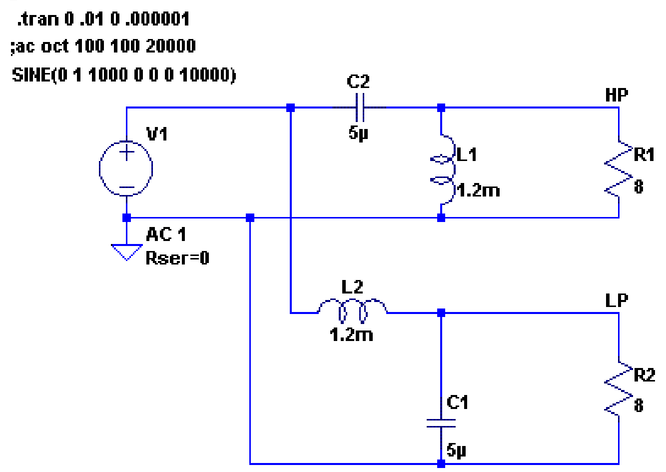
$$i_C = \frac{1}{|Z_L(\omega)| e^{j\varphi(\omega)}}(V_{CC} - V_0 e^{j\omega t}) = \frac{V_{CC}}{|Z_L(\omega)|} e^{-j\varphi(\omega)} - \frac{V_0}{|Z_L(\omega)|} e^{j(\omega t - \varphi(\omega))}$$

[5]

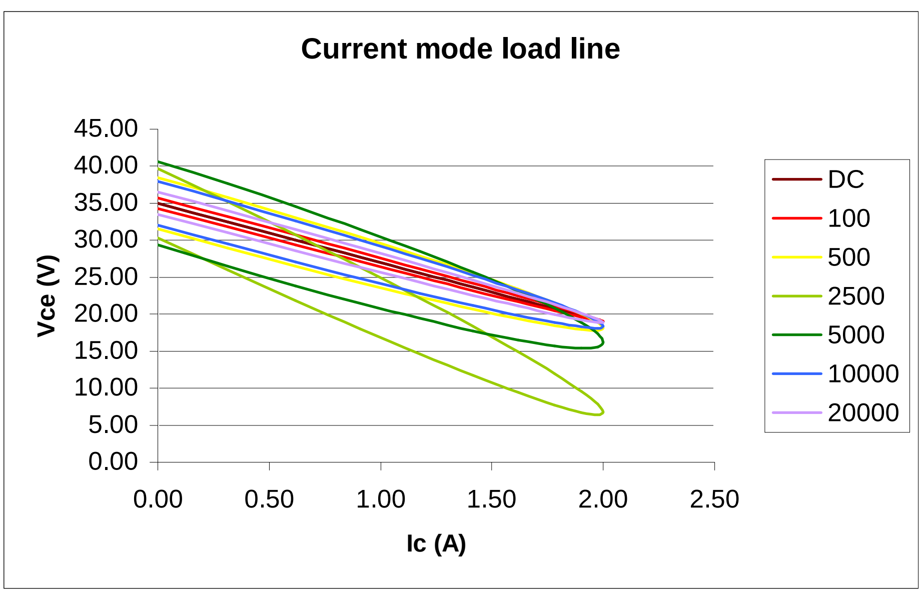
And again taking real part for actual currents and voltages:

$$R_E(i_C) = \frac{V_{CC}}{Z_L(\omega)} \cos(\varphi(\omega) - \frac{V_0}{Z_L(\omega)} [\cos(\omega t)\cos(\varphi(\omega)) - \sin(\omega t)\sin(\varphi(\omega)] \qquad [6]$$

As for appropriate tools, any math package can do as well as a simulator, but it can be done also with a basic spreadsheet. To illustrate this, an example passive crossover with ideal speaker loads is shown below.

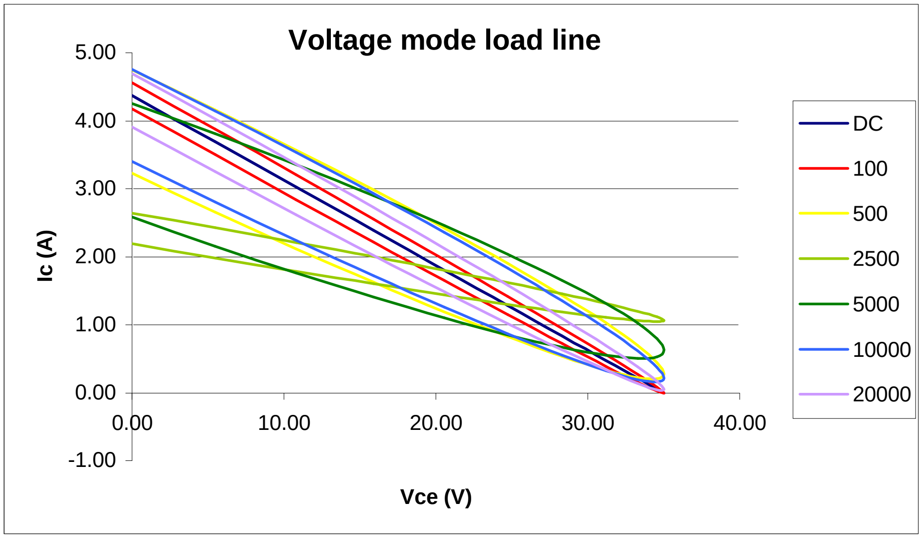


This is a highly simplified 2-way second order passive 2 kHz crossover network, where the drivers themselves are replaced by ideal resistive loads, something that is not true, yet the reactive frequency dependent load impedance nature is present. In an actual situation, load impedance frequency dependence is more complex but not very different qualitatively.



Though load modulus and phase angle may be computed solving the circuit, it is more handy to draw and simulate it and read out values for the selected frequencies.

At left is the load line variation for current mode drive as given by [3]. Note how for the zero crossing of load current, V_{CE} departs from the resistive V_{CC} value, being higher or lower depending on the combination of current slope and load phase angle sign.



At left is the corresponding plot for voltage mode as given by [4]. Again note the dependency on combination of voltage slope and phase angle sign. To read this plot in reference to SOA verification, it must be rotated and mirrored so as to present voltage and current axis in the same position as above.

If anything, this analysis highlights reactive loads are no good both in terms of SOA and in terms of power transfer frequency response. Not that passive crossovers are as bad as it may look, but good matching is tricky at best, and given the current cost of active elements there is no economic sense in sticking with single full range amplifiers except for the fact of wiring simplicity. Biamp or triamp schemes with electronic crossover are far better and provide larger power headroom.