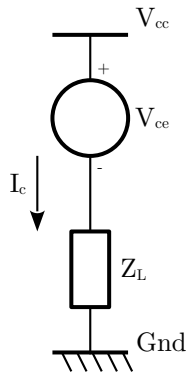
Load Lines

The output biplor transistor and speaker load are modelled with the simple circuit:



The speaker load impedance is defined as:

$$\begin{aligned} Z_L &= R(1 + j\tan\phi) \\ &= \frac{R}{\cos\phi} e^{j\phi} \end{aligned}$$

with ϕ chosen from the interval $0 \leq \phi \leq \frac{\pi}{2}$. And, the signal voltage across the load:

$$V_L = V_p e^{j\theta}$$

with $0 \leq \theta < 2\pi$ and V_p a constant selected from the interval $0 < V_p \leq V_{cc}$.

It then follows that:

$$\begin{aligned} V_{ce} &= V_{cc} - V_p e^{j\theta} \\ I_c &= \frac{V_p \cos\phi}{R} e^{j(\theta-\phi)} \end{aligned}$$

To simplify the plotting of load lines, let:

$$\gamma = \theta - \phi$$

Which after subsitution gives:

$$\begin{aligned} V_{ce} &= V_{cc} - V_p e^{j(\gamma+\phi)} \\ I_c &= \frac{V_p \cos\phi}{R} e^{j\gamma} \end{aligned}$$

The real components form a set of parametric equations:

$$\Re(V_{ce}) = V_{cc} - V_p \cos(\gamma + \phi) \quad (1)$$

$$\Re(I_c) = \frac{V_p \cos\phi \cos\gamma}{R} \quad (2)$$

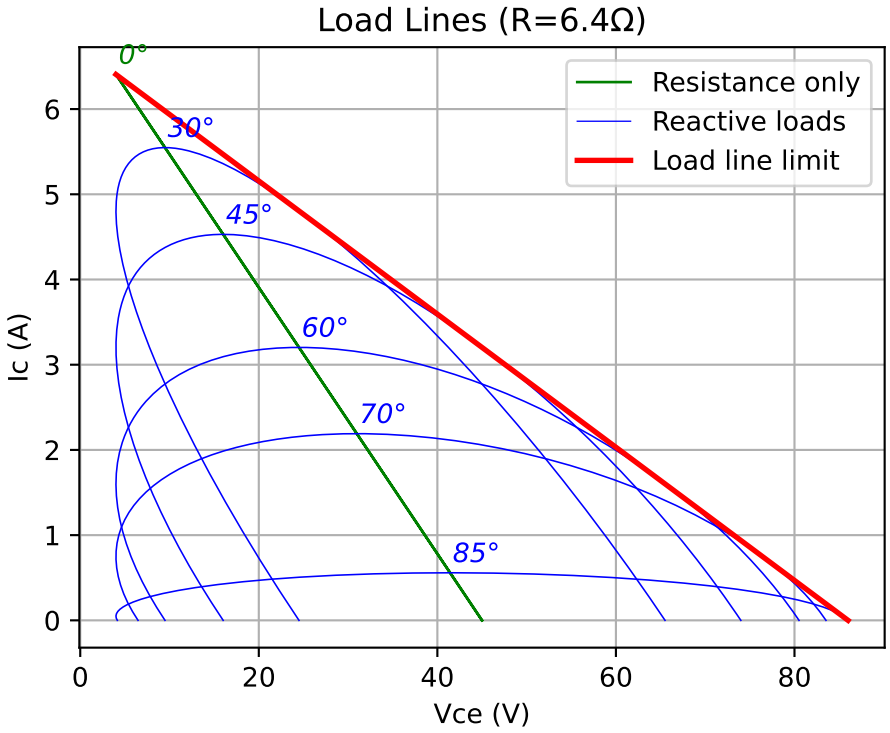
$\Re(I_c)$ will always be zero when γ is equal to $-\frac{\pi}{2}$ or $+\frac{\pi}{2}$ and has maximum positive value at γ equal to zero.

A loadline is plotted by first selecting nominal values for V_{cc}, V_p, R and ϕ. Then selecting a set of values for γ from the interval $-\frac{\pi}{2} \leq \gamma \leq \frac{\pi}{2}$. For each γ the resulting values of $\Re(V_{ce})$ and $\Re(I_c)$ are plotted on a graph.

For verification I decided to model the overlapped elliptic load lines presented by Bob Cordell in his book "Designing Audio Power Amplifiers" in Figure 15.7, page 323. These lines can be modelled using the following parameters:

$$\begin{aligned} V_{cc} &= 45\text{V} \\ V_p &= V_{cc} - 4\text{V} \\ R &= 6.4\Omega \\ \phi &\in \{0^o, 30^o, 45^o, 60^o, 70^o, 85^o\} \end{aligned}$$

Then plotting the load lines over the upper half of the ellipse, which corresponds to the interval $-\frac{\pi}{2} \leq \gamma \leq \frac{\pi}{2}$.



These load lines are a good match for the results presented in Cordell's book. The nonlinear behaviour as I_c approaches zero is not captured, but this is not relevant for load sizing. There has been no provision for an emitter resister. This could be included if necessary. I believe the results presented by Cordell are obtained by extracting values from a spice simulation of an amplifier.

The load lines were calculated using a simple python script. It will be just as easy to use Matlab or a spreadsheet to perform the same calculation.