Class-E design process

This design process is based on the assumption of a “perfect” transistor switch and an output network Q-factor greater than about 5-7 (10% or so error) and a perfect inductive choke between the drain and power supply. Output circuit blocks all harmonics allowing only fundamental frequency power to load. This is not completely valid for low Q. As output Q factor rises to 10 or more, the assumption of fundamental signal transmission to the load with negligible harmonic content becomes more valid.

<table>
<thead>
<tr>
<th>Component</th>
<th>Name/Function</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>RFC</td>
<td>Bias choke</td>
<td>Impedance at least 10-15 times $R_{load}$</td>
</tr>
<tr>
<td>$C_p$</td>
<td>Drain shunt capacitance</td>
<td>Combination of intrinsic drain source capacitance and externally applied capacitance</td>
</tr>
<tr>
<td>$C_l$</td>
<td>Series capacitance</td>
<td>Needed to achieve Q-factor</td>
</tr>
<tr>
<td>$L$</td>
<td>Series inductor</td>
<td>Combination of “series resonant” LC network inductance $L_{res}$ plus excess inductance $L_{exc}$ to achieve proper fundamental drain current/voltage phasing. $L=L_{res}+L_{exc}$</td>
</tr>
<tr>
<td>$L_0$</td>
<td>Matching inductor</td>
<td>Part of L-match to 50 ohm load. This is absorbed into $L$.</td>
</tr>
<tr>
<td>$C_m$</td>
<td>Matching capacitor</td>
<td>Part of L-match to 50 ohms</td>
</tr>
<tr>
<td>$R_l$</td>
<td>Load resistor</td>
<td>50 ohms (usually, but not necessarily).</td>
</tr>
<tr>
<td>$R_{load}$</td>
<td>Resistive part of load seen by switch at fundamental frequency</td>
<td>This is transformed by the L-match network to $R_l$ (50 ohms, etc.)</td>
</tr>
</tbody>
</table>

For the design, we need to specify:
1. Output power $P_{\text{load}}$
2. The load impedance $R_l$ (usually 50Ω).
3. Supply voltage $V_{cc}$. (Note: this needs to be based on max transistor breakdown voltage, which should be more than 3.6 times the supply voltage.)
4. Operating center frequency $\omega = 2\pi \cdot f$.
5. Desired output circuit Q (Determines bandwidth, choose > 5 or so, otherwise component values shift as a result of the simplifying assumptions used in the analysis. Q=10 or more gives very little error).

- Step 1: If switching device shunt capacitance is known, specify the desired output power $P_{\text{load}}$ and the DC supply voltage $V_{cc}$. This yields a relationship between $I_0$ and the load resistance from

$$P_{\text{load}} = \frac{8 \cdot V_{cc}^2}{\pi^2 + 4 R_{\text{load}}} = V_{cc} I_0.$$  

- From the expected supply voltage and currents needed to provide the desired power, the drain-source shunt capacitance is yielded by

$$I_0 = \frac{\omega \pi}{C_p V_{cc}}.$$  

- Compute the required “excess inductance” $L_{\text{exc}}$:

$$L_{\text{exc}} = \frac{1.153 \cdot R_{\text{load}}}{\omega}.$$  

- Compute the resonant inductance $L_{\text{res}}$ and the series capacitance based on chosen Q factor and resonant frequency $\omega$:

$$C_{\text{f}} = \frac{1}{Q \cdot R_{\text{load}} \cdot \omega},$$

$$L_{\text{res}} = \frac{Q \cdot R_{\text{load}}}{\omega}.$$  

- Compute the L-match parallel capacitance based on the values for $R_l$ and $R_{\text{load}}$:

$$C_{\text{m}} = \frac{1}{\omega \cdot R_l \sqrt{R_{\text{load}} - 1}}.$$  

- Calculate L-match series inductance:

$$L_0 = C_{\text{m}} \cdot R_l \cdot R_{\text{load}}.$$  

We now have the full design. Looking at a specific example, let us choose a set of specifications.
1. $V_{cc}$=12V
2. $P_{\text{load}}$=5W
3. Q=10
4. $\omega$=2$\pi$6.9x10$^6$rad/sec

Following the design procedure, we compute

- $R_{\text{load}} = \frac{8 \cdot V_{cc}^2}{\pi^2 + 4 R_{\text{load}}} = \frac{(8)(12)(12)}{(13.869)(5)} = 16.6\Omega$

- $I_0 = \frac{P_{\text{load}}}{V_{cc}} = \frac{5}{12} = 0.4167 A$

The needed shunt drain-source capacitance.

- $C_p = \frac{I_0}{\omega \cdot \pi \cdot V_{cc}} = \frac{0.4167}{(6.283)(6.9\times10^6)(3.1415)(12)} = 255 pF$
The excess inductance needed to have Class-E operation.

\[ L_{exc} = \frac{1.153 \cdot R_{load}}{\omega} = \frac{(1.153)(16.6)}{(6.283)(6.9 \times 10^6)} = 441nH \]

The resonant part at 6.9MHz with a Q of 10.

\[ C_t = \frac{1}{(10)(16.67)(6.283)(6.9 \times 10^6)} = 139pF \]

\[ L_{res} = \frac{Q \cdot R_{load}}{\omega} = \frac{(10)(16.67)}{(6.28)(6.9 \times 10^6)} = 3.829uH \]

L-match to 50 ohm load.

\[ C_m = \frac{1}{(6.283)(6.9 \times 10^6)(50) \sqrt{\frac{50}{16.67}}} - 1 = 652pF \]

\[ L_0 = (6.52 \times 10^{-10})(50)(16.67) = 544nH \]

This yields the following circuit.

This circuit yields the drain waveforms that clearly exhibit class e characteristics.