Supply Pumping

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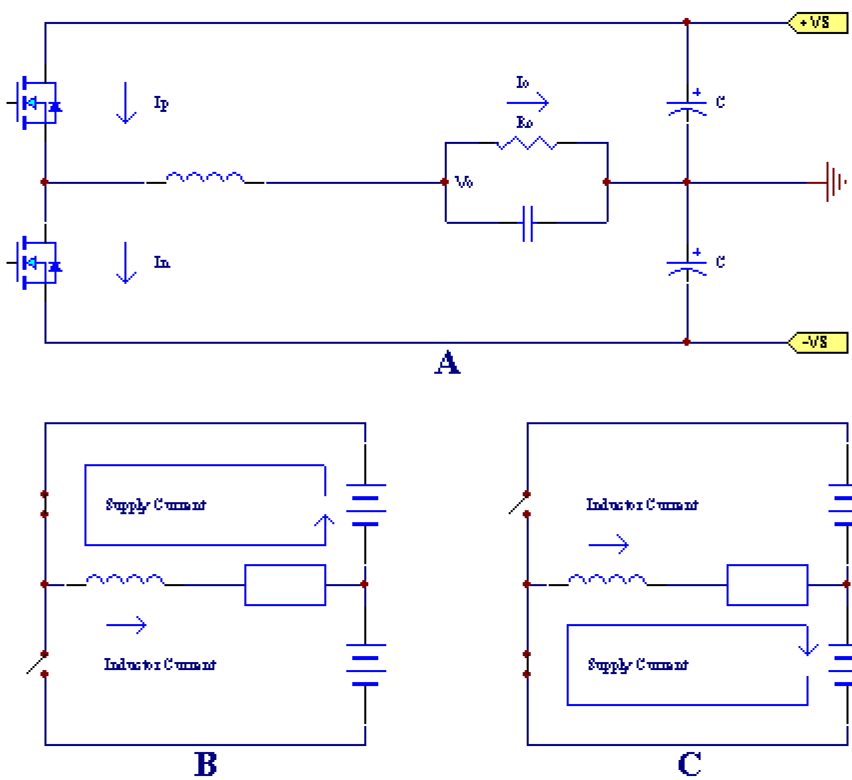
Supply pumping is an issue in single-ended class-D amplifiers which use power supplies that cannot effectively sink current (e.g. a typical transformer/rectifier/capacitor supply). It is greatest when driving low impedance loads at low frequencies. The primary means to alleviate this is to use adequately sized storage capacitors, as the following analysis will show.



A Typical class-D half-bridge output stage detailing some of the parameters used in the following analysis.

B The upper MOSFET is turned on and current flows in the forward direction through the channel. Current is *drawn* from the upper supply.

C The lower MOSFET is turned on and current flows in the reverse direction through the channel. Current is *delivered* to the negative supply.

$$V_O = (2D-1)V_S \qquad I_P = \frac{V_S}{R_O}(2D-1)D \qquad I_N = \frac{V_S}{R_O}(2D-1)(D-1)$$

For the case of a sinusoidal output:

$$D = \alpha \sin(\omega t) + \frac{1}{2}$$ where $0 \le \alpha \le \frac{1}{2}$

$$I_P = \frac{V_S}{R_O}(2\alpha \sin(\omega t))\left(\alpha \sin(\omega t) + \frac{1}{2}\right)$$ positive rail current

$$I_N = \frac{V_S}{R_O}(2\alpha \sin(\omega t))\left(\alpha \sin(\omega t) - \frac{1}{2}\right)$$ negative rail current

Charge *drawn* from positive supply during positive half cycle:

$$Q_P = \int_0^{\pi/\omega} I_P dt = \frac{\pi V_S}{\omega R_O}\alpha\left(\alpha + \frac{2}{\pi}\right)$$

Charge *delivered* to negative supply during positive half cycle:

$$Q_N = \int_0^{\pi/\omega} I_N dt = \frac{\pi V_S}{\omega R_O}\alpha\left(\alpha - \frac{2}{\pi}\right)$$

Taking into account the capacitance on the supply rails:

$$V = \frac{Q}{C} \qquad \Delta V_P = \frac{\pi V_S}{\omega R_O C}\alpha\left(\alpha + \frac{2}{\pi}\right) \qquad \Delta V_N = \frac{\pi V_S}{\omega R_O C}\alpha\left(\alpha - \frac{2}{\pi}\right)$$

Determining the condition for maximum change in voltage:

$$\frac{d}{d\alpha}Q_N = \frac{V_S}{\omega R_O}\frac{d}{d\alpha}\left(\pi\alpha^2 - 2\alpha\right) = 0 \Rightarrow \alpha_{\max} = \frac{1}{\pi}$$

Inserting this into the voltage change expression:

$$\Delta V_{N(\max)} = -\frac{V_S}{\pi\omega R_O C}$$

Example:

$$V_S = 40V; \omega = 2\pi \cdot 20Hz; R_O = 4\Omega; C = 2200\mu F$$

$$\Rightarrow \Delta V_{N(\max)} = -11.5V$$

For the case of a square wave output:

$$D = \alpha + \frac{1}{2}$$ for $0 \le \omega t \le \pi$

$$I_P = \frac{V_S}{R_O} 2\alpha\left(\alpha + \frac{1}{2}\right)$$ positive rail current

$$I_N = \frac{V_S}{R_O} 2\alpha\left(\alpha - \frac{1}{2}\right)$$ negative rail current

Charge *drawn* from positive supply during positive half cycle:

$$Q_P = \int_0^{\pi/\omega} I_P dt = \frac{2\pi V_S}{\omega R_O}\alpha\left(\alpha + \frac{1}{2}\right)$$

Charge *delivered* to negative supply during positive half cycle:

$$Q_N = \int_0^{\pi/\omega} I_P dt = \frac{2\pi V_S}{\omega R_O}\alpha\left(\alpha - \frac{1}{2}\right)$$

The maxima occurs for $\alpha_{\max} = \frac{1}{4}$

$$\Delta V_{N(\max)} = -\frac{\pi V_S}{8\omega R_O C}$$ this is $\pi^2/8$ times more than for a sinusoid