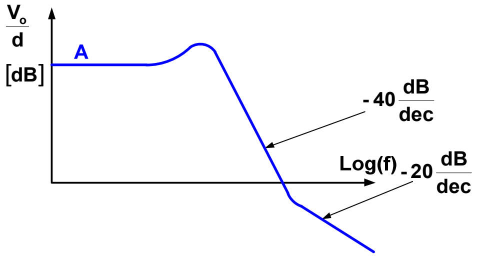
Control of switch-mode converters

Current Programmed Mode control
CPM

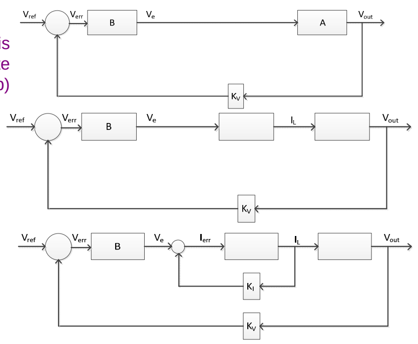
Problem of voltage mode control



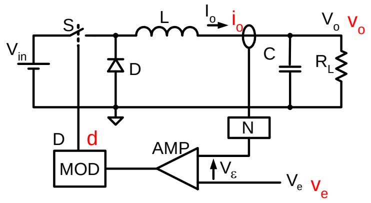
Second order transfer function = complex compensator

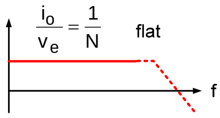
Additional feedback
System order reduction

System order is reduced for each state variable (inner loop) feedback



Current feedback loop



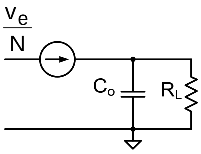


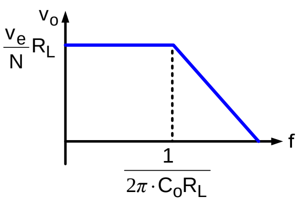
For 'strong' feedback

$$\mathbf{LG} \gg \mathbf{1} \quad \mathbf{v_\varepsilon \to 0}$$

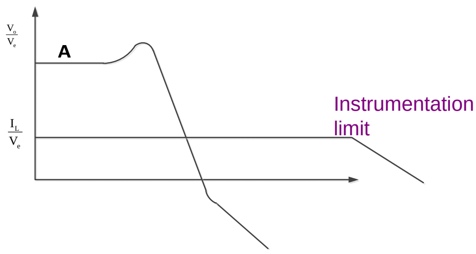
$$\mathbf{i_o = \frac{1}{N} v_e}$$

System representation in CPM



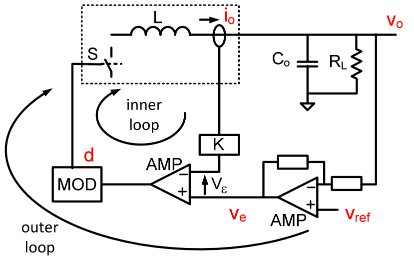


Design of the feedback loops

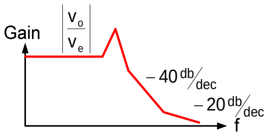


BW of the inner loop must be well above the outer loop BW

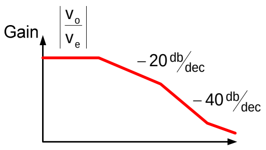
Design of the feedback loops



The advantages of current feedback

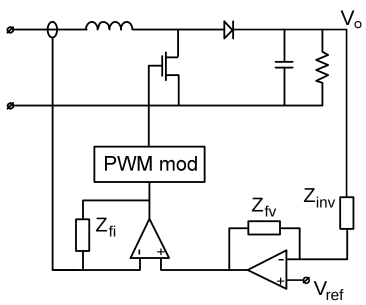


Typical power stage VM

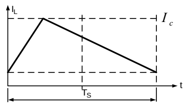


Same power stage (outer loop) with CM

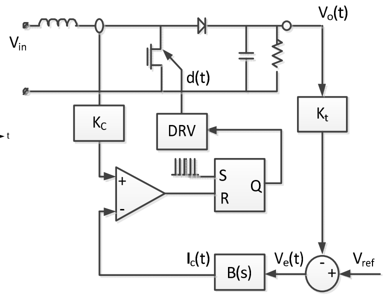
Average current mode



Peak current mode



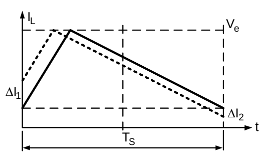
Cycle-by-cycle protection



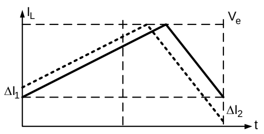
PCM and ACM

- Current feedbacks - reduce the order of system
- The difference is in BW of the current feedback loop
- Increase the output impedance

Sub-harmonic oscillations

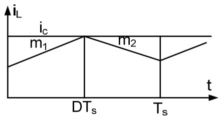


D<0.5 $\Delta I_2 < \Delta I_1$



D>0.5 $\Delta I_2 > \Delta I_1$

Stability analysis of Sub-harmonic oscillations

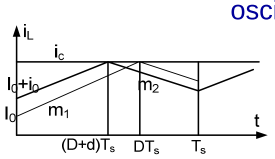


$$I_L(t_{on}) = I_L(0) + m_1 t_{on}$$
$$I_L(T_s) = I_L(t_{on}) - m_2 t_{off}$$
$$I_L(T_s) = I_L(0) + m_1 t_{on} - m_2 t_{off}$$

Steady-state: $I_L(T_s) = I_L(0)$

$$m_1 t_{on} = m_2 t_{off}$$
$$\frac{t_{on}}{t_{off}} = \frac{m_2}{m_1} = \frac{D_{on}}{D_{off}}$$

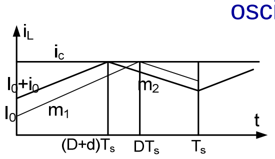
Stability analysis of Sub-harmonic oscillations



$$I_L((D+d)T_s) = I_L(0) + i_L(0) + m_1(D+d)T_s$$
$$DC: I_L(DT_s) = I_L(0) + m_1 DT_s$$
$$AC: I_L(dT_s) = i_L(0) + m_1 dT_s$$
$$i_L(0) = -m_1 dT_s$$

$$i_L(T_s) = m_2 dT_s$$
$$i_L(T_s) = i_L(0)\left(-\frac{m_2}{m_1}\right) = i_L(0)\left(-\frac{D_{on}}{D_{off}}\right)$$

Stability analysis of Sub-harmonic oscillations

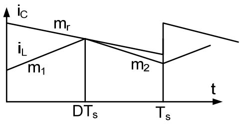


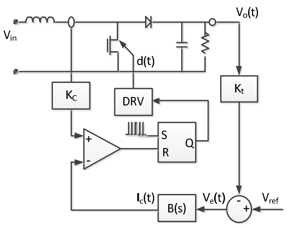
$$i_L(T_s) = i_L(0)\left(-\frac{D_{on}}{D_{off}}\right)$$
$$i_L(2T_s) = i_L(T_s)\left(-\frac{D_{on}}{D_{off}}\right) = i_L(0)\left(-\frac{D_{on}}{D_{off}}\right)^2$$
$$i_L(nT_s) = i_L((n-1)T_s)\left(-\frac{D_{on}}{D_{off}}\right) = i_L(0)\left(-\frac{D_{on}}{D_{off}}\right)^n$$

$$i_L(nT_s) = i_L(0)\left(-\frac{D_{on}}{D_{off}}\right)^n \qquad i_L(nT_s) = \begin{cases} 0, & \left|\frac{D_{on}}{D_{off}}\right| < 1 \\ \infty, & \left|\frac{D_{on}}{D_{off}}\right| > 1 \end{cases} \rightarrow \textit{Stable when } D_{on} < 0.5$$

Mor M. Peretz, Switch-Mode Power Supplies [9-16]

Slope compensation



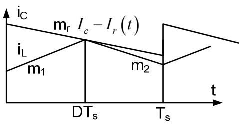


$$I_L(t) + I_r(t) = I_c$$

$$I_L(t) = I_c - I_r(t)$$

Mor M. Peretz, Switch-Mode Power Supplies [9-17]

Slope compensation



$$i_L(0) = -(m_1 + m_r)dT_s$$

$$i_L(T) = -(m_r - m_2)dT_s$$

$$i_L(T_s) = i_L(0)\left(-\frac{m_2 - m_r}{m_1 + m_r}\right)$$

$$i_L(nT_s) = i_L(0)\left(-\frac{m_2 - m_r}{m_1 + m_r}\right)^n \equiv i_L(0)\alpha^n$$

$$i_L(nT_s) = \begin{cases} 0, |\alpha| < 1 \\ \infty, |\alpha| > 1 \end{cases}$$

$$\alpha = -\frac{m_2 - m_r}{m_1 + m_r} = -\frac{1 - \frac{m_r}{m_2}}{\frac{m_1}{m_2} + \frac{m_r}{m_2}} = -\frac{1 - \frac{m_r}{m_2}}{\frac{D_{on}}{D_{off}} + \frac{m_r}{m_2}} \rightarrow \frac{m_r}{m_2} \geq 0.5$$

Mor M. Peretz, Switch-Mode Power Supplies [9-18]

Mor M. Peretz, Switch-Mode Power Supplies [9-19]

Mor M. Peretz, Switch-Mode Power Supplies [5-20]