NON − IDEAL BUCK CONVERTER

Voltage mode control Transfer functions

PLANT TRANSFER FUNCTION CALCULATIONS

Circuit Equations: (***Small − Signal Approximation***)

$\langle \mathbf{D_{on}} \rangle$ **:**

$$V_L = V_{in} - I_L \cdot R_{DSon\_HS} - I_L \cdot R_L - V_{out}$$
$$I_c = I_L - I_{out}$$

$\langle \mathbf{D_{\mathit{off}}} \rangle$ **:**

$$V_L = -\left(V_{out} + I_L \cdot \left(R_{DSon\_LS} + R_L \right) \right) = - V_{out} - I_L \cdot R_{DSon\_LS} - I_L \cdot R_L$$
$$I_c = I_L - I_{out}$$

Transfer Function Analysis

$$\langle V_L \rangle = \left(\mathrm{D}_{on} \right) \cdot \left(V_{in} - I_L \cdot R_{DSon\_HS} - I_L \cdot R_L - V_{out} \right) + \left(\mathrm{D}_{off} \right) \cdot \left(- V_{out} - I_L \cdot R_{DSon\_LS} - I_L \cdot R_L \right)$$

$$\langle I_C \rangle = \left(\mathrm{D}_{on} \right) \cdot \left(I_L - I_{out} \right) + \left(\mathrm{D}_{off} \right) \cdot \left(I_L - I_{out} \right)$$

$$\langle I_{\mathbf{in}} \rangle = \left(\mathrm{D}_{on} \right) \cdot \left(I_L \right)$$

DC versions: ($\langle \boldsymbol{x} \rangle = 0$)

$$\langle V_L \rangle = 0 = \mathrm{D}_{on} \cdot V_{\mathbf{in}} - \mathrm{D}_{on} \cdot I_L \cdot R_{DSon\_HS} - \mathrm{D}_{on} \cdot I_L \cdot R_L - \mathrm{D}_{on} \cdot V_{out} - \mathrm{D}_{off} \cdot V_{out} - \mathrm{D}_{off} \cdot I_L \cdot R_{DSon\_LS} - \mathrm{D}_{off} \cdot I_L \cdot R_L \cdot$$

$$0 = \mathrm{D}_{on} \cdot V_{\mathbf{in}} - \mathrm{D}_{on} \cdot I_L \cdot R_{DSon\_HS} - I_L \cdot R_L - V_{out} - \mathrm{D}_{off} \cdot I_L \cdot R_{DSon\_LS}$$

$$V_{out} = \mathrm{D}_{on} \cdot V_{\mathbf{in}} - \mathrm{D}_{on} \cdot I_L \cdot R_{DSon\_HS} - I_L \cdot R_L - \left(1 - \mathrm{D}_{on}\right) \cdot I_L \cdot R_{DSon\_LS} = \mathrm{D}_{on} \cdot V_{\mathbf{in}} - \mathrm{D}_{on} \cdot I_L \cdot R_{DSon\_HS} - I_L \cdot R_L - I_L \cdot R_{DSon\_LS} - \mathrm{D}_{on} \cdot I_L \cdot R_{DSon\_LS}$$

$$V_{out} = \mathrm{D}_{on} \cdot \left(V_{\mathbf{in}} - I_L \cdot R_{DSon\_HS} - I_L \cdot R_{DSon\_LS}\right) - I_L \cdot \left(R_L + R_{DSon\_LS}\right)$$

$$\langle I_C \rangle = I_L - I_{out}$$

$$0 = I_L - I_{out}$$

$$\boldsymbol{I_L = I_{out}}$$

$$\boldsymbol{I_{out} = \frac{V_{out}}{R_{out}}}$$

$$V_{out} = \mathrm{D}_{on} \cdot \left(V_{\mathbf{in}} - I_{out} \cdot R_{DSon\_HS} - I_{out} \cdot R_{DSon\_LS}\right) - I_{out} \cdot \left(R_L + R_{DSon\_LS}\right)$$

$$V_{out} = \mathrm{D}_{on} \cdot \left(V_{\mathbf{in}} - \frac{V_{out}}{R_{out}} \cdot R_{DSon\_HS} - \frac{V_{out}}{R_{out}} \cdot R_{DSon\_LS}\right) - \frac{V_{out}}{R_{out}} \cdot \left(R_L + R_{DSon\_LS}\right) = \mathrm{D}_{on} \cdot V_{\mathbf{in}} - \mathrm{D}_{on} \cdot \frac{V_{out}}{R_{out}} \cdot R_{DSon\_HS} - \mathrm{D}_{on} \cdot \frac{V_{out}}{R_{out}} \cdot R_{DSon\_LS} - \frac{V_{out}}{R_{out}} \cdot \left(R_L + R_{DSon\_LS}\right)$$

$$V_{out} + \mathrm{D}_{on} \cdot \frac{V_{out}}{R_{out}} \cdot \left(R_{DSon\_HS} + R_{DSon\_LS}\right) + \frac{V_{out}}{R_{out}} \cdot \left(R_L + R_{DSon\_LS}\right) = \mathrm{D}_{on} \cdot V_{\mathbf{in}}$$

$$V_{out} \cdot \left(1 + \mathrm{D}_{on} \cdot \frac{\left(R_{DSon\_HS} + R_{DSon\_LS}\right)}{R_{out}} + \frac{\left(R_L + R_{DSon\_LS}\right)}{R_{out}}\right) = \mathrm{D}_{on} \cdot V_{\mathbf{in}}$$

$$\boldsymbol{V_{out} = \left(\frac{\mathbf{D}_{on}}{\left(\mathbf{1} + \mathbf{D}_{on} \cdot \frac{\left(R_{DSon\_HS} + R_{DSon\_LS}\right)}{R_{out}} + \frac{\left(R_L + R_{DSon\_LS}\right)}{R_{out}}\right)}\right) \cdot V_{\mathbf{in}}}$$

Inductor Slope with losses

Up slope **:**

$$M_1 = \frac{\left(V_{\mathbf{in}} - V_{out} - I_L \cdot \left(R_{DSon\_HS} + R_L\right)\right)}{L}$$

$$m_1 = \frac{\left(v_{\mathbf{in}} - v_{out} - i_L \cdot \left(R_{DSon\_HS} + R_L\right)\right)}{L}$$

Down slope **:**

$$M_2 = -\frac{\left(V_{out} + I_L \cdot \left(R_{DSon\_LS} + R_L\right)\right)}{L}$$

$$m_2 = -\frac{\left(v_{out} + i_L \cdot \left(R_{DSon\_LS} + R_L\right)\right)}{L}$$

Slope Compensation **:**

$M_a = \textit{Device dependent}$

AC versions

$$\langle \boldsymbol{Total} \rangle = \boldsymbol{AC} + \boldsymbol{DC}$$

$$\langle \boldsymbol{V}_{\mathbf{in}} \rangle = \boldsymbol{V}_{\mathbf{in}} + \boldsymbol{v}_{\mathbf{in}}$$

$$\langle \boldsymbol{V}_L \rangle = \boldsymbol{V}_L + \boldsymbol{v}_L$$

$$\langle \mathbf{D}_{on} \rangle = \mathbf{D}_{on} + \boldsymbol{d}$$

$$\langle \mathbf{D}_{off} \rangle = \mathbf{D}_{off} - \boldsymbol{d}$$

$$\langle \boldsymbol{I}_L \rangle = \boldsymbol{I}_L + \boldsymbol{i}_L$$

$$\langle V_{out} \rangle = V_{out} + v_{out}$$

Adding AC Inductor Voltage to formulas

$$\langle V_L + v_L \rangle = (D_{on} + d) \cdot [V_{in} + v_{in} - (I_L + i_L)\cdot R_{DSon\_HS} - (I_L + i_L)\cdot R_L - (V_{out} + v_{out})] + (D_{off} - d)\cdot[-(V_{out} + v_{out}) - (I_L + i_L)\cdot R_{DSon\_L} - (I_L + i_L)\cdot R_L]$$

$$\langle V_L + v_L \rangle = [D_{on}\cdot V_{in} + D_{on}\cdot v_{in} - D_{on}\cdot I_L\cdot R_{DSon\_HS} - D_{on}\cdot i_L R_{DSon\_HS} - D_{on}\cdot I_L\cdot R_L - D_{on}\cdot i_L\cdot R_L - D_{on}\cdot V_{out} - D_{on}\cdot v_{out} + d\cdot V_{\mathbf{in}} + d\cdot v_{\mathbf{in}} - d\cdot I_L \cdot R_{DSon\_HS} - d\cdot i_L\cdot R_{DSon\_HS} - d\cdot I_L\cdot R_L - d\cdot i_L\cdot R_L - d\cdot V_{out} - d\cdot v_{out}] + [-D_{off}\cdot V_{out} - D_{off}\cdot v_{out} - D_{off}\cdot I_L\cdot R_{DSon\_LS} - D_{off}\cdot i_L\cdot R_{DSon\_LS} - D_{off}\cdot I_L \cdot R_L - D_{off}\cdot i_L\cdot R_L + d\cdot V_{out} + d\cdot v_{out} + d\cdot I_L\cdot R_{DSon\_LS} + d\cdot i_L\cdot R_{DSon\_LS} + d\cdot I_L\cdot R_L + d\cdot i_L\cdot R_L]$$

− Remove DC and very small variables

$$\langle v_L \rangle = [D_{on}\cdot v_{\mathbf{in}} - D_{on}\cdot i_L\cdot R_{DSon\_HS} - D_{on}\cdot i_L\cdot R_L - D_{on}\cdot v_{out} + d\cdot V_{\mathbf{in}} - d\cdot I_L\cdot R_{DSon\_HS} - d\cdot I_L\cdot R_L - d\cdot V_{out}] + [-D_{off}\cdot v_{out} - D_{off}\cdot i_L\cdot R_{DSon\_LS} - D_{off}\cdot i_L \cdot R_L + d\cdot V_{out} + d\cdot I_L\cdot R_{DSon\_LS} + d\cdot I_L\cdot R_L]$$

$-D_{on} + D_{off} = 1$

$$\langle v_L \rangle = D_{on}\cdot v_{\mathbf{in}} - D_{on}\cdot i_L\cdot R_{DSon\_HS} - i_L\cdot R_L - v_{out} + d\cdot V_{\mathbf{in}} - d\cdot I_L\cdot R_{DSon\_HS} - D_{off}\cdot i_L\cdot R_{DSon\_LS} + d\cdot I_L\cdot R_{DSon\_LS}$$

$$\langle v_L \rangle = s\cdot L\cdot i_L = D_{on} v_{\mathbf{in}} - i_L(D_{on}\cdot R_{DSon\_HS} + R_L + D_{off}\cdot R_{DSon\_LS}) + d(V_{\mathbf{in}} + I_L\cdot(-R_{DSon\_HS} + R_{DSon\_LS})) - v_{out}$$

$$v_{out} = D_{on} v_{\mathbf{in}} - i_L(D_{on}\cdot R_{DSon\_HS} + R_L + D_{off}\cdot R_{DSon\_LS}) + d(V_{\mathbf{in}} + I_L\cdot(-R_{DSon\_HS} + R_{DSon\_LS})) - s\cdot L\cdot i_L \quad :::$$

Voltage divider with series impedance

$$v_{out} = D_{on} v_{\mathbf{in}} - i_L(s\cdot L + D_{on}\cdot R_{DSon\_HS} + R_L + D_{off}\cdot R_{DSon\_LS}) + d(V_{\mathbf{in}} + I_L\cdot(-R_{DSon\_HS} + R_{DSon\_LS}))$$

Adding AC Capacitor Currents to formulas

$$\langle I_C + i_C \rangle = (D_{on} + d)\cdot((I_L + i_L) - (I_{out} + i_{out})) + (D_{off} - d)\cdot((I_L + i_L) - (I_{out} + i_{out}))$$

$$\langle i_c \rangle = [D_{on}\cdot I_L + D_{on}\cdot i_L - D_{on}\cdot I_{out} - D_{on}\cdot i_{out} + d\cdot I_L + d\cdot i_L - d\cdot I_{out} - d\cdot i_{out}] + [D_{off}\cdot I_L + D_{off}\cdot i_L - D_{off}\cdot I_{out} - D_{off}\cdot i_{out} - d\cdot I_L - d\cdot i_L + d\cdot I_{out}$$

$$+ d\cdot i_{out}]$$

$\langle i_c \rangle = i_L - i_{out}$ ::: *Output Capacitor is* ***in*** *parallel with* v_{out}

Adding Input Currents to formulas

$$\langle I_{\mathbf{in}} + i_{\mathbf{in}} \rangle = (\mathrm{D}_{on} + d)\cdot(I_L + i_L)$$

$$\langle i_{\mathbf{in}} \rangle = \mathrm{D}_{on}\cdot I_L + \mathrm{D}_{on}\cdot i_L + d\cdot I_L + d\cdot i_L$$

$$\langle i_{\mathbf{in}} \rangle = \mathrm{D}_{on}\cdot i_L + d\cdot I_L$$

Equivalent Circuit from Formulas

$$\text{Output Impedance} = R_{load} \,\Big\|\, \text{Capacitor}_{out} = \frac{(R_{load})\cdot\left(\frac{1}{s\cdot C}\right)}{\left(\frac{1}{s\cdot C} + R_{load}\right)} = \frac{R_{load}}{1 + s\cdot R_{load}\cdot C_{out}}$$

$$\text{Series Impedance} = s\cdot L + R\cdot x = s\cdot L + (\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}) = s\cdot L + R_L + \mathrm{D}_{on}\cdot R_{DSon\_HS} + (1 - \mathrm{D}_{on})\cdot R_{DSon\_LS} = s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS}))$$

$$\text{Transfer function voltage divider} = \frac{\left(\frac{R_{load}}{1 + s\cdot R_{load}\cdot C_{out}}\right)}{\left(\frac{R_{load}}{1 + s\cdot R_{load}\cdot C_{out}}\right) + (s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS})))}$$
$$= \frac{R_{load}}{R_{load} + (s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS})))\cdot(1 + s\cdot R_{load}\cdot C_{out})}$$
$$= R_{load} \Big/ (R_{load} + (s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS}))) + (s\cdot R_{load}\cdot C_{out})\cdot(s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS})))) = R_{load} \Big/ (R_{load} + (s\cdot L + (R_L + R_{DSon\_LS} + \mathrm{D}_{on}\cdot(R_{DSon\_HS} - R_{DSon\_LS}))) + (s^2\cdot R_{load}\cdot L\cdot C_{out}) + s\cdot(R_{load}\cdot C_{out}\cdot(R_L$$

$$+ R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right)))) = R_{load} \Big/ \left(\left(R_{load} + R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) + s \cdot \left(L + R_{load} \cdot C_{out} \right.\right.$$

$$\left.\left. \cdot \left(R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) \right) + \left(s^2 \cdot R_{load} \cdot L \cdot C_{out} \right) \right)$$

$$Total\ Voltage\ from\ divider = D_{on} \cdot v_{\mathbf{in}} - d \cdot \left(V_{\mathbf{in}} + I_L \cdot \left(-R_{DSon\_HS} + R_{DSon\_LS} \right) \right)$$

$$Transfer\ function = \left(R_{load} \Big/ \left(\left(R_{load} + R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) + s \cdot \left(L + R_{load} \cdot C_{out} \cdot \left(R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} \right.\right.\right.\right.\right.$$

$$\left.\left.\left.\left.\left. - R_{DSon\_LS} \right) \right) \right) + \left(s^2 \cdot R_{load} \cdot L \cdot C_{out} \right) \right) \right) \cdot \left(D_{on} \cdot v_{\mathbf{in}} - d \cdot \left(V_{\mathbf{in}} + I_L \cdot \left(-R_{DSon\_HS} + R_{DSon\_LS} \right) \right) \right)$$

$$\boldsymbol{G_{v_{out} \cdot v_{\mathbf{in}}}} \Big|_{d=0}$$

$$\underline{\boldsymbol{Input-\mathbf{to}-output}}\ Transfer\ Functions = \left(\frac{\boldsymbol{v_{out}}}{\boldsymbol{v_{\mathbf{in}}}} \right) = \left(\left(R_{load} \cdot D_{on} \right) \Big/ \left(\left(R_{load} + R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) + s \cdot \left(L + R_{load} \right.\right.\right.$$

$$\left.\left.\left. \cdot C_{out} \cdot \left(R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) \right) + \left(s^2 \cdot R_{load} \cdot L \cdot C_{out} \right) \right) \right) = \left(\left(\left(\frac{V_{out}}{I_{out}} \right) \cdot D_{on} \right) \Big/ \left(\left(\left(\frac{V_{out}}{I_{out}} \right) + R_L + R_{DSon\_LS} \right.\right.\right.$$

$$\left.\left.\left. + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) + s \cdot \left(L + \left(\frac{V_{out}}{I_{out}} \right) \cdot C_{out} \cdot \left(R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) \right) + \left(s^2 \cdot \left(\frac{V_{out}}{I_{out}} \right) \cdot L \cdot C_{out} \right) \right) \right)$$

$$R_{load} = \frac{V_{out}}{I_{out}}$$

$$\boldsymbol{G_{v_{out} \cdot d}} \Big|_{v_{\mathbf{in}}=0}$$

$$\underline{\boldsymbol{Control-\mathbf{to}-output}}\ Transfer\ function = \left(\frac{\boldsymbol{v_{out}}}{\boldsymbol{d}} \right) = \left(\left(R_{load} \cdot \left(V_{\mathbf{in}} + I_L \cdot \left(R_{DSon\_LS} - R_{DSon\_HS} \right) \right) \right) \Big/ \left(\left(R_{load} + R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} \right.\right.\right.\right.$$

$$\left.\left.\left.\left. - R_{DSon\_LS} \right) \right) + s \cdot \left(L + R_{load} \cdot C_{out} \cdot \left(R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) \right) + \left(s^2 \cdot R_{load} \cdot L \cdot C_{out} \right) \right) \right) = \left(\left(\left(\frac{V_{out}}{I_{out}} \right) \left(V_{\mathbf{in}} + I_L \right.\right.\right.$$

$$\left.\left.\left. \cdot \left(R_{DSon\_LS} - R_{DSon\_HS} \right) \right) \Big/ \left(\left(\left(\frac{V_{out}}{I_{out}} \right) + R_L + R_{DSon\_LS} + D_{on} \cdot \left(R_{DSon\_HS} - R_{DSon\_LS} \right) \right) + s \cdot \left(L + \left(\frac{V_{out}}{I_{out}} \right) \cdot C_{out} \cdot \left(R_L + R_{DSon\_LS} + D_{on} \right.\right.\right.\right.$$

$$\cdot\left(R_{DSon\_HS}-R_{DSon\_LS}\right)\Big)\Bigg)+\left(s^2\cdot\left(\frac{V_{out}}{I_{out}}\right)\cdot L\cdot C_{out}\right)\Bigg)\Bigg)=$$

Converter Transfer functions

$G_{i_L\cdot d}\,|_{v_{\mathbf{in}}=0}$

Circuit model

$$R_x=\left(\mathrm{D}_{on}\cdot R_{DSon\_HS}+R_L+\mathrm{D}_{off}\cdot R_{DSon\_LS}\right)$$

$$V_x=d\cdot\left(V_{\mathbf{in}}+I_L\cdot\left(R_{DSon\_LS}-R_{DSon\_HS}\right)\right)$$

$$Impedance=R_x+s\cdot L+\frac{R_{out}}{1+s\cdot C\cdot R_{out}}$$

$$i_L=\frac{V_x}{\left(R_x+s\cdot L+\frac{R_{out}}{1+s\cdot C\cdot R_{out}}\right)}=\frac{d\cdot\left(V_{\mathbf{in}}+I_L\cdot\left(R_{DSon\_LS}-R_{DSon\_HS}\right)\right)}{\left(\mathrm{D}_{on}\cdot R_{DSon\_HS}+R_L+\mathrm{D}_{off}\cdot R_{DSon\_LS}+s\cdot L+\frac{R_{out}}{1+s\cdot C\cdot R_{out}}\right)}$$

$$i_L=\frac{d\cdot\left(V_{\mathbf{in}}+I_L\cdot\left(R_{DSon\_LS}-R_{DSon\_HS}\right)\right)\cdot\left(1+s\cdot C\cdot R_{out}\right)}{\left(\mathrm{D}_{on}\cdot R_{DSon\_HS}\cdot\left(1+s\cdot C\cdot R_{out}\right)+R_L\cdot\left(1+s\cdot C\cdot R_{out}\right)+\mathrm{D}_{off}\cdot R_{DSon\_LS}\cdot\left(1+s\cdot C\cdot R_{out}\right)+s\cdot L\cdot\left(1+s\cdot C\cdot R_{out}\right)+R_{out}\right)}$$

$$\frac{i_L}{d}=\left(V_{\mathbf{in}}+I_L\cdot\left(R_{DSon\_LS}-R_{DSon\_HS}\right)+s\cdot C\cdot R_{out}\cdot V_{\mathbf{in}}+s\cdot C\cdot R_{out}\cdot I_L\cdot\left(R_{DSon\_LS}-R_{DSon\_HS}\right)\right)\Big/\Big(\Big(\left(\mathrm{D}_{on}\cdot R_{DSon\_HS}+s\cdot C\cdot R_{out}\cdot\mathrm{D}_{on}\cdot R_{DSon\_HS}\right)$$
$$+\left(R_L+s\cdot C\cdot R_{out}\cdot R_L\right)+\left(\mathrm{D}_{off}\cdot R_{DSon\_LS}+s\cdot C\cdot R_{out}\cdot\left(\mathrm{D}_{off}\cdot R_{DSon\_LS}\right)\right)+\left(s\cdot L+s\cdot C\cdot R_{out}\cdot(s\cdot L)\right)+R_{out}\Big)\Big)$$

$$\frac{i_L}{d} = \frac{\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right) + s\cdot C\cdot R_{out}\cdot V_{\mathbf{in}} + s\cdot C\cdot R_{out}\cdot I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right)\right)}{\left(\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS} + R_{out}\right) + s\cdot\left(C\cdot R_{out}\cdot R_L + C\cdot R_{out}\cdot \mathrm{D}_{on}\cdot R_{DSon\_HS} + C\cdot R_{out}\cdot \mathrm{D}_{off}\cdot R_{DSon\_LS} + L\right) + s^2\cdot L\cdot C\cdot R_{out}\right)}$$

$$\frac{i_L}{d} = \frac{\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right) + s\cdot C\cdot R_{out}\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right)\right)\right)}{\left(\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS} + R_{out}\right) + s\cdot\left(C\cdot R_{out}\cdot\left(R_L + \mathrm{D}_{on}\cdot R_{DSon\_HS} + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right) + L\right) + s^2\cdot L\cdot C\cdot R_{out}\right)}$$

$$\frac{i_L}{d} = \frac{\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right) + s\cdot C\cdot R_{out}\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right)\right)\right)}{\left(\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \left(1 - \mathrm{D}_{on}\right)\cdot R_{DSon\_LS} + R_{out}\right) + s\cdot\left(C\cdot R_{out}\cdot\left(R_L + \mathrm{D}_{on}\cdot R_{DSon\_HS} + \left(1 - \mathrm{D}_{on}\right)\cdot R_{DSon\_LS}\right) + L\right) + s^2\cdot L\cdot C\cdot R_{out}\right)}$$

$$\frac{i_L}{d} = \left(\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right) + s\cdot C\cdot R_{out}\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right)\right)\right)\right) \Big/ \left(\left(\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + R_{DSon\_LS} - \mathrm{D}_{on}\cdot R_{DSon\_LS} + R_{out}\right) + s\cdot\left(C\cdot R_{out}\cdot\left(R_L + \mathrm{D}_{on}\cdot R_{DSon\_HS} + R_{DSon\_LS} - \mathrm{D}_{on}\cdot R_{DSon\_LS}\right) + L\right) + s^2\cdot L\cdot C\cdot R_{out}\right)\right)$$

$$\boldsymbol{\frac{i_L}{d} = \frac{\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right) + s\cdot C\cdot R_{out}\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(R_{DSon\_LS} - R_{DSon\_HS}\right)\right)\right)}{\left(\left(\mathrm{D}_{on}\cdot\left(R_{DSon\_HS} - R_{DSon\_LS}\right) + R_L + R_{DSon\_LS} + R_{out}\right) + s\cdot\left(C\cdot R_{out}\cdot\left(R_L + \mathrm{D}_{on}\cdot\left(R_{DSon\_HS} - R_{DSon\_LS}\right)\right) + L\right) + s^2\cdot L\cdot C\cdot R_{out}\right)}}$$

$G_{i_L\cdot d}\,|_{v_{\mathbf{in}}=0}$

Circuit model

Peak Current Mode Control Transfer Functions

$\langle i_L \rangle = i_{control}$ *average* i_L *is the same as control current* **in** *a stable system*

$$\langle v_L \rangle = s\cdot L\cdot i_L = \mathrm{D}_{on}\cdot v_{\mathbf{in}} - i_L\cdot\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right) + d\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right) - v_{out}$$

$$s\cdot L\cdot i_{control} = \mathrm{D}_{on}\cdot v_{\mathbf{in}} - i_{control}\cdot\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right) + d\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right) - v_{out}$$

$$d\cdot\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right) = s\cdot L\cdot i_{control} - \mathrm{D}_{on}\cdot v_{\mathbf{in}} + i_{control}\cdot\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right) + v_{out}$$

$$d = \frac{s\cdot L\cdot i_{control} - \mathrm{D}_{on}\cdot v_{\mathbf{in}} + i_{control}\cdot\left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right) + v_{out}}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)}$$
$$= \frac{\left(s\cdot L + \left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right)\right)\cdot i_{control} - \mathrm{D}_{on}\cdot v_{\mathbf{in}} + v_{out}}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)} = \left(\frac{\left(s\cdot L + \left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right)\right)}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)}\cdot i_{control}\right.$$
$$\left. - \frac{\mathrm{D}_{on}}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)}\cdot v_{\mathbf{in}} + \frac{1}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)}\cdot v_{out}\right)$$

$$\langle i_c \rangle = i_{cap} = i_L - i_{out} = i_{control} - i_{out}$$

$$\langle i_{\mathbf{in}} \rangle = \mathrm{D}_{on}\cdot i_L + d\cdot I_L = \mathrm{D}_{on}\cdot i_{control} + d\cdot I_L = \mathrm{D}_{on}\cdot i_L + I_L\cdot\frac{\left(s\cdot L + \left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right)\right)\cdot i_{control} - \mathrm{D}_{on}\cdot v_{\mathbf{in}} + v_{out}}{\left(V_{\mathbf{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)} = \left(\mathbf{D}_{\boldsymbol{on}}\right.$$
$$\left. + \frac{\left(\boldsymbol{s\cdot L} + \left(\mathbf{D}_{\boldsymbol{on}}\cdot \boldsymbol{R}_{\boldsymbol{DSon\_HS}} + \boldsymbol{R_L} + \mathbf{D}_{\boldsymbol{off}}\cdot \boldsymbol{R}_{\boldsymbol{DSon\_LS}}\right)\right)}{\left(\boldsymbol{V}_{\mathbf{in}} + \boldsymbol{I_L}\cdot\left(-\boldsymbol{R}_{\boldsymbol{DSon\_HS}} + \boldsymbol{R}_{\boldsymbol{DSon\_LS}}\right)\right)}\right)\cdot \boldsymbol{i}_{\boldsymbol{control}} - \left(\frac{\mathbf{D}_{\boldsymbol{on}}}{\left(\boldsymbol{V}_{\mathbf{in}} + \boldsymbol{I_L}\cdot\left(-\boldsymbol{R}_{\boldsymbol{DSon\_HS}} + \boldsymbol{R}_{\boldsymbol{DSon\_LS}}\right)\right)}\right)\cdot \boldsymbol{v}_{\mathbf{in}}$$
$$+ \left(\frac{\mathbf{1}}{\left(\boldsymbol{V}_{\mathbf{in}} + \boldsymbol{I_L}\cdot\left(-\boldsymbol{R}_{\boldsymbol{DSon\_HS}} + \boldsymbol{R}_{\boldsymbol{DSon\_LS}}\right)\right)}\right)\cdot \boldsymbol{v}_{\boldsymbol{out}}$$

$$\langle i_{\mathbf{in}} \rangle = A\cdot i_{control} - B\cdot v_{\mathbf{in}} + C\cdot v_{out}$$

$$A = \mathrm{D}_{on} + \frac{\left(s\cdot L + \left(\mathrm{D}_{on}\cdot R_{DSon\_HS} + R_L + \mathrm{D}_{off}\cdot R_{DSon\_LS}\right)\right)}{\left(V_{\mathrm{in}} + I_L\cdot\left(-R_{DSon\_HS} + R_{DSon\_LS}\right)\right)} = \mathbf{D}_{on} + \frac{\boldsymbol{s\cdot L} + \left(\mathbf{D}_{on}\cdot \boldsymbol{R}_{DSon\_HS} + \boldsymbol{R}_L + \boldsymbol{R}_{DSon\_LS} - \mathbf{D}_{on}\cdot \boldsymbol{R}_{DSon\_LS}\right)}{\left(\boldsymbol{V}_{\mathrm{in}} + \boldsymbol{I}_L\cdot\left(-\boldsymbol{R}_{DSon\_HS} + \boldsymbol{R}_{DSon\_LS}\right)\right)}$$

$$\boldsymbol{B} = \frac{\mathbf{D}_{on}}{\left(\boldsymbol{V}_{\mathrm{in}} + \boldsymbol{I}_L\cdot\left(-\boldsymbol{R}_{DSon\_HS} + \boldsymbol{R}_{DSon\_LS}\right)\right)}$$

$$\boldsymbol{C} = \frac{\mathbf{1}}{\left(\boldsymbol{V}_{\mathrm{in}} + \boldsymbol{I}_L\cdot\left(-\boldsymbol{R}_{DSon\_HS} + \boldsymbol{R}_{DSon\_LS}\right)\right)}$$

$$\langle i_c\rangle = i_{control} - i_{out} = i_{control} - \frac{v_{out}}{R_{out}}$$

$$s\cdot C\cdot v_{out} = i_{cap} = i_{control} - \frac{v_{out}}{R_{out}}$$

More Accurate Model of Peak Current Mode Control: (***m**_a* *does* **not** *perturb*)

$$\langle i_L\rangle = \langle i_{control}\rangle - m_a\cdot d\cdot T_s - d\cdot\frac{m_1\cdot d\cdot T_s}{2} - d'\cdot\frac{m_2\cdot d'\cdot T_s}{2}$$

$$\langle i_L\rangle = \langle i_{control}\rangle - m_a\cdot d\cdot T_s - m_1\cdot\frac{d^2\cdot T_s}{2} - m_2\cdot\frac{d'^2\cdot T_s}{2}$$

$$\langle I_L + i_L\rangle = \langle I_{control} + i_{control}\rangle - M_a\cdot T_s\cdot\left(\mathrm{D}_{on} + d\right) - \frac{T_s}{2}\cdot\left(M_1 + m_1\right)\cdot\left(\mathrm{D}_{on} + d\right)^2 - \frac{T_s}{2}\cdot\left(M_2 + m_2\right)\cdot\left(\mathrm{D}_{off} - d\right)^2$$

$$\langle i_L\rangle = \langle i_{control}\rangle - M_a\cdot T_s\cdot \mathrm{D}_{on} - M_a\cdot T_s\cdot d - \frac{T_s}{2}\cdot\left(M_1 + m_1\right)\left(\mathrm{D}_{on}^2 + 2\cdot\mathrm{D}_{on}\cdot d + d^2\right) - \frac{T_s}{2}\cdot\left(M_2 + m_2\right)\cdot\left(\mathrm{D}_{off}^2 - 2\cdot\mathrm{D}_{off}\cdot d - d^2\right)$$

$$\langle i_L\rangle = \langle i_{control}\rangle - M_a\cdot T_s\cdot d - \frac{T_s}{2}\cdot M_1\cdot\mathrm{D}_{on}^2 - T_s\cdot M_1\cdot\mathrm{D}_{on}\cdot d - \frac{T_s}{2}\cdot M_1\cdot d^2 - \frac{T_s}{2}\cdot m_1\cdot\mathrm{D}_{on}^2 - T_s\cdot m_1\cdot\mathrm{D}_{on}\cdot d - \frac{T_s}{2}\cdot m_1\cdot d^2 - \frac{T_s}{2}\cdot M_2\cdot\mathrm{D}_{off}^2 + T_s\cdot M_2\cdot\mathrm{D}_{o}$$

$$\cdot d + \frac{T_s}{2}\cdot M_2\cdot d^2 - \frac{T_s}{2}\cdot m_2\cdot \mathrm{D}_{off}^2 + T_s\cdot m_2\cdot \mathrm{D}_{off}\cdot d + \frac{T_s}{2}\cdot m_2\cdot d^2$$

$$\langle i_L\rangle = \langle i_{control}\rangle - M_a\cdot T_s\cdot d - M_1\cdot T_s\cdot \mathrm{D}_{on}\cdot d - \frac{T_s}{2}\cdot m_1\cdot \mathrm{D}_{on}^2 + M_2\cdot T_s\cdot \mathrm{D}_{off}\cdot d - \frac{T_s}{2}\cdot m_2\cdot \mathrm{D}_{off}^2 = \langle i_{control}\rangle - M_a\cdot T_s\cdot d - M_1\cdot T_s\cdot \mathrm{D}_{on}\cdot d + M_1\cdot T_s\cdot \mathrm{D}_{on}\cdot d$$
$$- \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot m_1 - \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot m_2$$

$$\langle i_L\rangle = \langle i_{control}\rangle - M_a\cdot T_s\cdot d - \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot m_1 - \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot m_2$$

$$d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle - \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot m_1 - \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot m_2\right) = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle - \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot\left(\frac{\left(v_{\mathbf{in}} - v_{out} - i_L\cdot\left(R_{DSon\_HS} + R_L\right)\right)}{L}\right)\right.$$
$$\left.- \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot\left(-\frac{\left(v_{out} + i_L\cdot\left(R_{DSon\_LS} + R_L\right)\right)}{L}\right)\right)$$

$$d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle - \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot\left(\frac{v_{\mathbf{in}}}{L}\right) + \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot\left(\frac{v_{out}}{L}\right) + \frac{T_s}{2}\cdot \mathrm{D}_{on}^2\cdot i_L\cdot\frac{\left(R_{DSon\_HS} + R_L\right)}{L} + \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot\left(\frac{v_{out}}{L}\right) + \frac{T_s}{2}\cdot \mathrm{D}_{off}^2\cdot i_L\right.$$
$$\left.\cdot\left(\frac{\left(R_{DSon\_LS} + R_L\right)}{L}\right)\right)$$

$$d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle\cdot\left(1 + \frac{T_s}{2}\cdot\left(\mathrm{D}_{on}^2\cdot\frac{\left(R_{DSon\_HS} + R_L\right)}{L} + \mathrm{D}_{off}^2\cdot\frac{\left(R_{DSon\_LS} + R_L\right)}{L}\right)\right) + v_{out}\cdot\left(\frac{T_s}{2}\cdot\left(\frac{\mathrm{D}_{on}^2 + \mathrm{D}_{off}^2}{L}\right)\right) - v_{\mathbf{in}}\cdot\left(\frac{T_s}{2}\right.\right.$$
$$\left.\left.\cdot\frac{\mathrm{D}_{on}^2}{L}\right)\right)$$

$$d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle\cdot\left(1 + \frac{T_s}{2}\cdot\left(\mathrm{D}_{on}^2\cdot\frac{\left(R_{DSon\_HS} + R_L\right)}{L} + \left(1 - \mathrm{D}_{on}\right)^2\cdot\frac{\left(R_{DSon\_LS} + R_L\right)}{L}\right)\right) + v_{out}\cdot\left(\frac{T_s}{2}\cdot\left(\frac{\mathrm{D}_{on}^2 + \left(1 - \mathrm{D}_{on}\right)^2}{L}\right)\right)\right.$$
$$\left.- v_{\mathbf{in}}\cdot\left(\frac{T_s}{2}\cdot\frac{\mathrm{D}_{on}^2}{L}\right)\right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{(R_{DSon\_HS} + R_L)}{L} + (1 - 2 \cdot \mathrm{D}_{on} - \mathrm{D}_{on}^2) \cdot \frac{(R_{DSon\_LS} + R_L)}{L} \right) \right) + v_{out} \cdot \left(\frac{T_s}{2} \cdot \left(\frac{\mathrm{D}_{on}^2 + (1 - 2 \cdot \mathrm{D}_{on} - \mathrm{D}_{on}^2)}{L} \right) \right) - v_{\mathbf{in}} \cdot \left(\frac{T_s}{2} \cdot \frac{\mathrm{D}_{on}^2}{L} \right) \right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{(R_{DSon\_HS} + R_L)}{L} + (1 - 2 \cdot \mathrm{D}_{on} - \mathrm{D}_{on}^2) \cdot \frac{(R_{DSon\_LS} + R_L)}{L} \right) \right) + v_{out} \cdot \left(\frac{T_s}{2} \cdot \frac{(1 - 2 \cdot \mathrm{D}_{on})}{L} \right) - v_{\mathbf{in}} \cdot \left(\frac{T_s}{2} \cdot \frac{\mathrm{D}_{on}^2}{L} \right) \right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{(R_{DSon\_HS} + R_L)}{L} + \frac{(R_{DSon\_LS} + R_L)}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{(R_{DSon\_LS} + R_L)}{L} - \mathrm{D}_{on}^2 \cdot \frac{(R_{DSon\_LS} + R_L)}{L} \right) \right) + v_{out} \cdot \left(\frac{T_s}{2} \cdot \frac{(1 - 2 \cdot \mathrm{D}_{on})}{L} \right) - v_{\mathbf{in}} \cdot \left(\frac{T_s}{2} \cdot \frac{\mathrm{D}_{on}^2}{L} \right) \right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_HS}}{L} + \mathrm{D}_{on}^2 \cdot \frac{R_L}{L} + \frac{R_{DSon\_LS}}{L} + \frac{R_L}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_{DSon\_LS}}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_L}{L} - \mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_LS}}{L} - \mathrm{D}_{on}^2 \cdot \frac{R_L}{L} \right) \right) + v_{out} \cdot \left(\frac{T_s}{2} \cdot \frac{(1 - 2 \cdot \mathrm{D}_{on})}{L} \right) - v_{\mathbf{in}} \cdot \left(\frac{T_s}{2} \cdot \frac{\mathrm{D}_{on}^2}{L} \right) \right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_HS}}{L} + \frac{R_{DSon\_LS}}{L} + \frac{R_L}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_{DSon\_LS}}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_L}{L} - \mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_LS}}{L} \right) \right) + v_{out} \cdot \left(\frac{T_s}{2} \cdot \frac{(1 - 2 \cdot \mathrm{D}_{on})}{L} \right) - v_{\mathbf{in}} \cdot \left(\frac{T_s}{2} \cdot \frac{\mathrm{D}_{on}^2}{L} \right) \right)$$

$$d = \frac{1}{M_a \cdot T_s} \cdot \left(\langle i_{control} \rangle - \langle i_L \rangle \cdot \left(1 + \frac{T_s}{2} \cdot \left(\mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_HS}}{L} - \mathrm{D}_{on}^2 \cdot \frac{R_{DSon\_LS}}{L} + \frac{R_{DSon\_LS}}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_{DSon\_LS}}{L} + \frac{R_L}{L} - 2 \cdot \mathrm{D}_{on} \cdot \frac{R_L}{L} \right) \right) + v_{out}$$

$$\cdot\left(\frac{T_s}{2}\cdot\frac{(1-2\cdot \mathrm{D}_{on})}{L}\right) - v_{\mathbf{in}}\cdot\left(\frac{T_s}{2}\cdot\frac{\mathrm{D}_{on}^2}{L}\right)\Bigg)$$

$$d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle\cdot\left(1+\frac{T_s}{2}\cdot\left(\mathrm{D}_{on}^2\cdot\frac{(R_{DSon\_HS}-R_{DSon\_LS})}{L} + (1-2\cdot \mathrm{D}_{on})\cdot\frac{R_{DSon\_LS}}{L} + (1-2\cdot \mathrm{D}_{on})\cdot\frac{R_L}{L}\right)\right) + v_{out}\cdot\left(\frac{T_s}{2}\right.\right.$$
$$\left.\left.\cdot\frac{(1-2\cdot \mathrm{D}_{on})}{L}\right) - v_{\mathbf{in}}\cdot\left(\frac{T_s}{2}\cdot\frac{\mathrm{D}_{on}^2}{L}\right)\right)$$

$$\boldsymbol{d = \frac{1}{M_a\cdot T_s}\cdot\left(\langle i_{control}\rangle - \langle i_L\rangle\cdot\left(1+\frac{T_s}{2}\cdot\left(\mathbf{D}_{on}^2\cdot\frac{(R_{DSon\_HS}-R_{DSon\_LS})}{L} + (1-2\cdot \mathbf{D}_{on})\cdot\frac{(R_{DSon\_LS}+R_L)}{L}\right)\right) + v_{out}\cdot\left(\frac{T_s}{2}\right.\right.}$$
$$\boldsymbol{\left.\left.\cdot\frac{(1-2\cdot \mathbf{D}_{on})}{L}\right) - v_{\mathbf{in}}\cdot\left(\frac{T_s}{2}\cdot\frac{\mathbf{D}_{on}^2}{L}\right)\right)}$$

controller transfer function · (**not** *plant function*)