

Switched Mode Power Conversion

Semester II Academic Year 2025-26

Lecture 29

7th April 2026

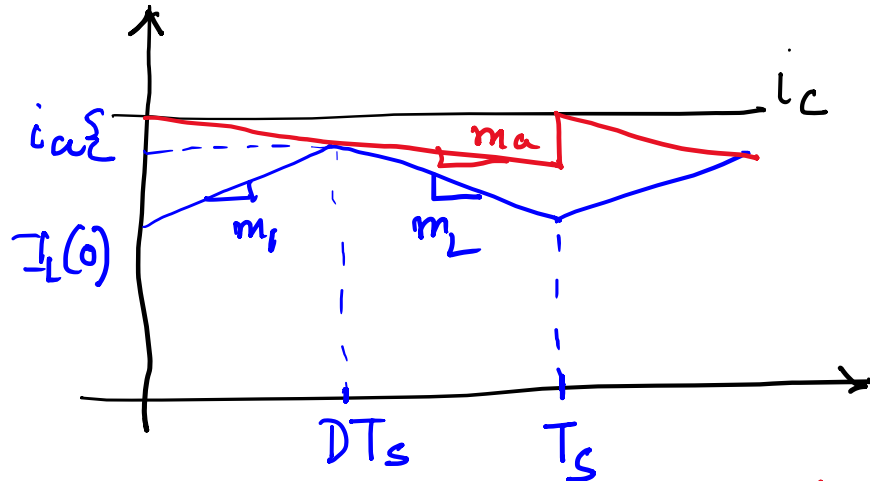
Current Programmed Control

Reducing Oscillations

⇒ Device S will turn OFF when

$$i_s + i_a > i_c$$

$$\Rightarrow \boxed{i_s > i_c - i_a}$$



Dead beat control ⇐

$$\hat{i}_L(nT_s)$$

$$= \hat{i}_L(0) \left[-\frac{m_2 - m_a}{m_1 + m_a} \right]^n$$

$$= \hat{i}_L(0) \alpha^n$$

For avoiding oscillations,

$$|\alpha| < 1$$

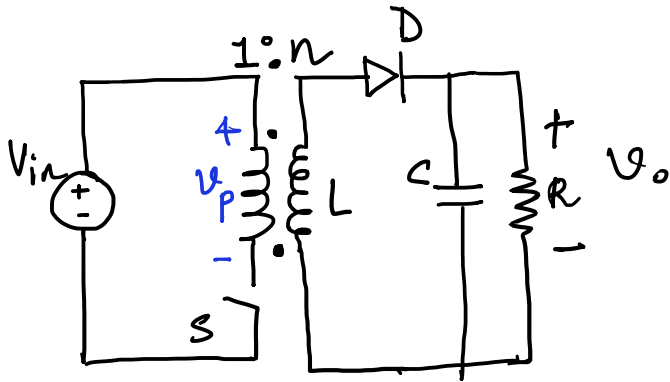
$$\Rightarrow \left| -\frac{m_2 - m_a}{m_1 + m_a} \right| < 1$$

$$m_2 = m_a \quad \alpha = 0$$

Perturbations become zero after one cycle

Current Programmed Control

Flyback Converter Model



[Flyback Converter]

$$\langle v_L \rangle = v_{in} D - \frac{v_o}{n} (1-D) = 0$$

$$\begin{aligned} \langle I_c \rangle &= -\left(\frac{v_o}{R}\right) D + \left(\frac{I_L}{n} - \frac{v_o}{R}\right) D' \\ &= \frac{I_L}{n} D - \frac{v_o}{R} = 0 \end{aligned}$$

$$\langle I_{in} \rangle = I_L D$$

$$\bar{v}_L + \hat{v}_L = (\bar{v}_{in} + \hat{v}_{in})(\bar{D} + \hat{d}) - \frac{(\bar{v}_o + \hat{v}_o)}{n} (\bar{D}' + \hat{d}')$$

$$\text{o.o } \hat{v}_L = \bar{v}_{in} \hat{d} + \bar{D} \hat{v}_{in} + \frac{\bar{v}_o}{n} \hat{d} - \bar{D}' \frac{\hat{v}_o}{n}$$

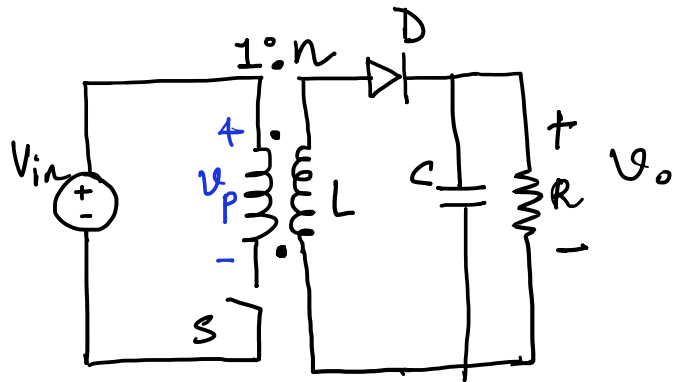
$$\Rightarrow L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + (\bar{v}_{in} + \frac{\bar{v}_o}{n}) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

$$C \frac{d\hat{v}_C}{dt} = \bar{D}' \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_L \bar{D} + i_L \hat{d}$$

Current Programmed Control

Flyback Converter Model

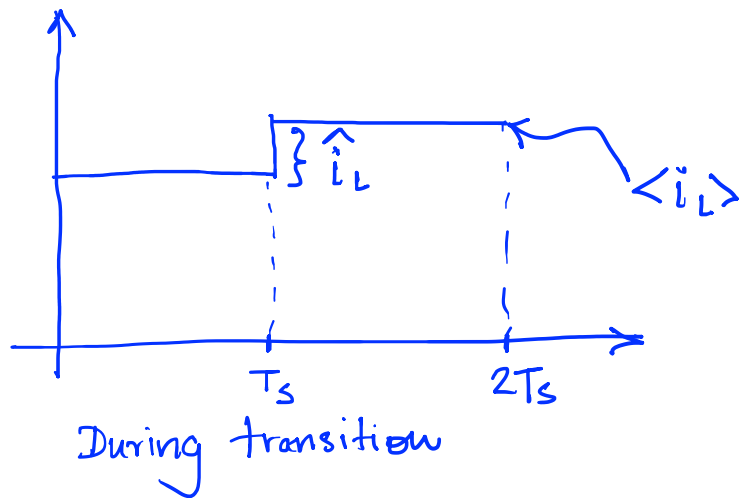


[Flyback Converter]

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + \left(\bar{v}_{in} + \frac{\bar{v}_o}{n} \right) \hat{d} - \frac{\bar{D}}{n} \hat{v}_o$$

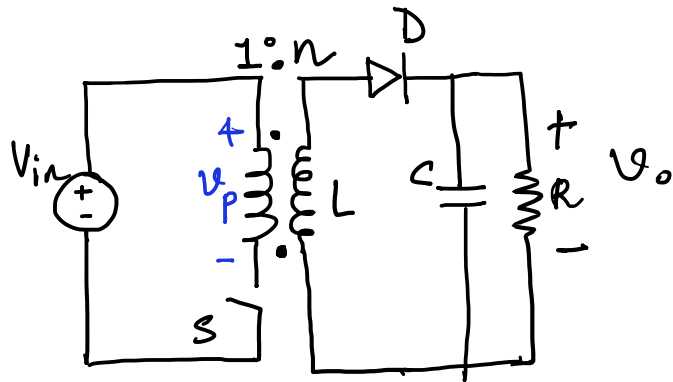
$$C \frac{d\hat{v}_c}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_L \bar{D} + i_L \hat{d}$$



Current Programmed Control

Flyback Converter Model

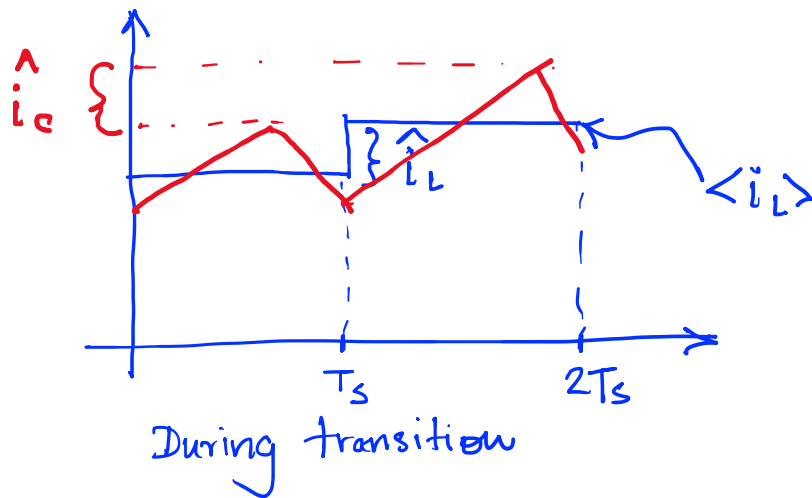


[Flyback Converter]

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + \left(\bar{v}_{in} + \frac{\bar{v}_o}{n} \right) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o \quad \text{--- (1)}$$

$$C \frac{d\hat{v}_C}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R} \quad \text{--- (2)}$$

$$\hat{i}_{in} = \hat{i}_L \bar{D} + i_L \hat{d} \quad \text{--- (3)}$$



Assuming that Δi_L doesn't change much appreciably during transients,

$$\hat{i}_C \approx \hat{i}_L$$

Substituting this in 1, 2, 3

Current Programmed Control

Flyback Converter Model

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + \left(\bar{v}_{in} + \frac{\bar{v}_o}{n} \right) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o \rightarrow L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + \left(\bar{v}_{in} + \frac{\bar{v}_o}{n} \right) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

$$C \frac{d\hat{v}_C}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_C \bar{D} + \hat{i}_L \hat{d}$$

Applying Laplace transformation;

$$sL \hat{i}_L(s) = \bar{D} \hat{v}_{in}(s) + \left(\bar{v}_{in} + \frac{\bar{v}_o}{n} \right) \hat{d}(s) - \frac{\bar{D}'}{n} \hat{v}_o(s)$$

$$\Rightarrow \hat{d}(s) = \frac{sL \hat{i}_L(s) - \bar{D} \hat{v}_{in}(s) + \frac{\bar{D}'}{n} \hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

Current Programmed Control

Flyback Converter Model

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + (\bar{v}_{in} + \frac{\bar{v}_o}{n}) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

$$C \frac{d\hat{v}_o}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_L \bar{D} + i_L \hat{d}$$

$$\rightarrow sC \hat{v}_o(s) = \frac{\bar{D}'}{n} \hat{i}_L(s) - \frac{\hat{v}_o(s)}{R} -$$

$$\frac{\bar{I}_L}{n} \frac{sL \hat{i}_L(s) - \bar{D} \hat{v}_{in}(s) + \frac{\bar{D}'}{n} \hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

$$\hat{d}(s) = \frac{sL \hat{i}_L(s) - \bar{D} \hat{v}_{in}(s) + \frac{\bar{D}'}{n} \hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

Current Programmed Control

Flyback Converter Model

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + (\bar{v}_{in} + \frac{\bar{v}_o}{n}) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

$$C \frac{d\hat{v}_c}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_c \bar{D} + i_L \hat{d}$$

$$\frac{\bar{v}_o}{n} = \frac{v_{in} \bar{D}}{\bar{D}'}$$

$$\bar{I}_L = \frac{I_{in}}{\bar{D}} = \frac{\bar{v}_o \bar{I}_o}{\bar{D} \bar{v}_{in}}$$

$$\Rightarrow \frac{\bar{I}_L}{n} = \frac{1}{\bar{D}'} \frac{\bar{v}_o}{R}$$

$$\hat{d}(s) = \frac{sL\hat{i}_c(s) - \bar{D}\hat{v}_{in}(s) + \frac{\bar{D}'}{n}\hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

$$sC\hat{v}_o(s) = \frac{\bar{D}'}{n}\hat{i}_c(s) - \frac{\hat{v}_o(s)}{R} -$$

$$\frac{\bar{I}_L}{n} \frac{sL\hat{i}_c(s) - \bar{D}\hat{v}_{in}(s) + \frac{\bar{D}'}{n}\hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

Current Programmed Control

Flyback Converter Model

$$\frac{\bar{V}_o}{n} = \frac{V_{in} \bar{D}}{\bar{D}'}$$

$$\frac{n \bar{I}_L}{\bar{D}'} = \frac{1}{\bar{D}'} \frac{\bar{V}_o}{R}$$

$$sC \hat{V}_o(s) = \frac{\bar{D}'}{n} \hat{i}_c(s) - \frac{\hat{V}_o(s)}{R} - \frac{\bar{I}_L}{n} \frac{sL \hat{i}_c(s) - \bar{D} \hat{V}_{in}(s) + \frac{\bar{D}'}{n} \hat{V}_o(s)}{\bar{V}_{in} + \frac{\bar{V}_o}{n}}$$

$$= \frac{\bar{D}'}{n} \hat{i}_c(s) - \frac{\hat{V}_o(s)}{R} - \frac{1}{\bar{D}'} \frac{\bar{V}_o}{R} \frac{1}{\frac{\bar{V}_o}{n} (1 + \frac{\bar{D}'}{\bar{D}})} \left[sL \hat{i}_c(s) - \bar{D} \hat{V}_{in}(s) + \frac{\bar{D}'}{n} \hat{V}_o(s) \right]$$

$$= \left[\frac{\bar{D}'}{n} - s \frac{L \bar{D} n}{\bar{D}' R} \right] \hat{i}_c(s) - \frac{n \bar{D}^2}{\bar{D}' R} \hat{V}_{in}(s) - \left(\frac{1}{R} + \frac{\bar{D}}{\bar{D}' R} \right) \hat{V}_o(s)$$

Current Programmed Control

Flyback Converter Model

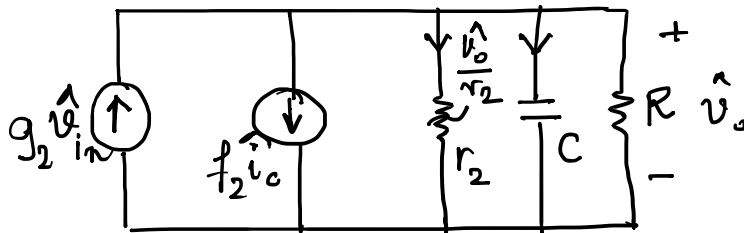
$$\frac{\bar{V}_o}{n} = \frac{V_{in} \bar{D}}{\bar{D}'}$$

$$sC \hat{V}_o(s) = \frac{\bar{D}'}{n} \hat{i}_c(s) - \frac{\hat{V}_o(s)}{R} - \frac{\bar{I}_L}{n} \frac{sL \hat{i}_c(s) - \bar{D} \hat{V}_{in}(s) + \frac{\bar{D}'}{n} \hat{V}_o(s)}{\bar{V}_{in} + \frac{\bar{V}_o}{n}}$$

$$\frac{\bar{I}_L}{n} = \frac{1}{\bar{D}'} \frac{\bar{V}_o}{R}$$

$$= \frac{\bar{D}'}{n} \hat{i}_c(s) - \frac{\hat{V}_o(s)}{R} - \frac{1}{\bar{D}'} \frac{\bar{V}_o}{R} \frac{1}{\frac{\bar{V}_o}{n} (1 + \frac{\bar{D}'}{\bar{D}})} \left[sL \hat{i}_c(s) - \bar{D} \hat{V}_{in}(s) + \frac{\bar{D}'}{n} \hat{V}_o(s) \right]$$

$$= \underbrace{\left[\frac{\bar{D}'}{n} - s \frac{L \bar{D} n}{\bar{D}' R} \right]}_{f_2} \hat{i}_c(s) - \underbrace{\frac{n \bar{D}^2}{\bar{D}' R}}_{g_2} \hat{V}_{in}(s) - \underbrace{\left(\frac{1}{R} + \frac{\bar{D}}{R} \right)}_{1/r_2} \hat{V}_o(s)$$



Current Programmed Control

Flyback Converter Model

$$L \frac{d\hat{i}_L}{dt} = \bar{D} \hat{v}_{in} + (\bar{v}_{in} + \frac{\bar{v}_o}{n}) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

$$C \frac{d\hat{v}_c}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_c \bar{D} + \hat{i}_L \hat{d}$$

$$\hat{d}(s) = \frac{sL\hat{i}_c(s) - \bar{D}\hat{v}_{in}(s) + \frac{\bar{D}'}{n}\hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

$$\hat{i}_{in} = \hat{i}_c \bar{D} + \frac{n\bar{v}_o}{\bar{D}'R} \frac{1}{\frac{\bar{v}_o}{n} \frac{1}{\bar{D}}} \left[sL\hat{i}_c(s) - \bar{D}\hat{v}_{in}(s) - \frac{\bar{D}'}{n}\hat{v}_o(s) \right]$$

$$\Rightarrow \hat{i}_{in}(s) = \hat{i}_c \left[\bar{D} + s \frac{Ln^2\bar{D}}{\bar{D}'R} \right] - \frac{n^2\bar{D}^2}{\bar{D}'R} \hat{v}_{in}(s) - \frac{n\bar{D}}{R} \hat{v}_o(s)$$

$$\frac{\bar{v}_o}{n} = \frac{v_{in}\bar{D}}{\bar{D}'}$$

$$\bar{I}_L = \frac{I_{in}}{\bar{D}} = \frac{\bar{v}_o \bar{I}_o}{\bar{D} \bar{v}_{in}}$$

$$\Rightarrow \frac{\bar{I}_L}{n} = \frac{1}{\bar{D}'} \frac{\bar{v}_o}{R}$$

Current Programmed Control

Flyback Converter Model

$$L \frac{di_L}{dt} = \bar{D} \hat{v}_{in} + (\bar{v}_{in} + \frac{\bar{v}_o}{n}) \hat{d} - \frac{\bar{D}'}{n} \hat{v}_o$$

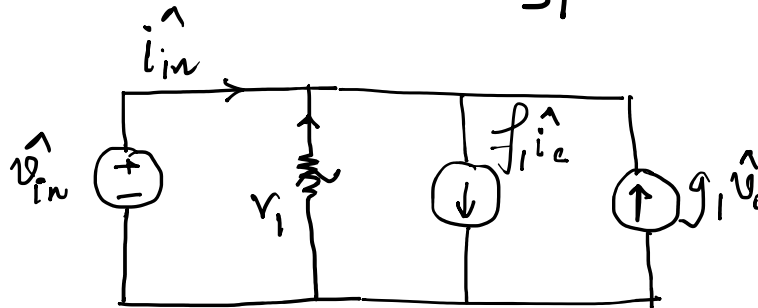
$$C \frac{d\hat{v}_c}{dt} = \bar{D} \frac{\hat{i}_L}{n} - \frac{\bar{I}_L}{n} \hat{d} - \frac{\hat{v}_o}{R}$$

$$\hat{i}_{in} = \hat{i}_c \bar{D} + i_L \hat{d}$$

$$\hat{d}(s) = \frac{sL\hat{i}_c(s) - \bar{D} \hat{v}_{in}(s) + \frac{\bar{D}'}{n} \hat{v}_o(s)}{\bar{v}_{in} + \frac{\bar{v}_o}{n}}$$

$$\hat{i}_{in} = \hat{i}_c \bar{D} + \frac{n\bar{v}_o}{\bar{D}'R} \frac{1}{\frac{\bar{v}_o}{n} \frac{1}{\bar{D}}} \left[sL\hat{i}_c(s) - \bar{D} \hat{v}_{in}(s) - \frac{\bar{D}'}{n} \hat{v}_o(s) \right]$$

$$\Rightarrow \hat{i}_{in}(s) = \underbrace{\hat{i}_c \left[\bar{D} + s \frac{L n^2 \bar{D}}{\bar{D}' R} \right]}_{g_1} - \underbrace{\frac{n \bar{D}^2}{\bar{D}' R}}_{1/r_1} \hat{v}_{in}(s) - \underbrace{\frac{n \bar{D}}{R}}_{f_1} \hat{v}_o(s)$$



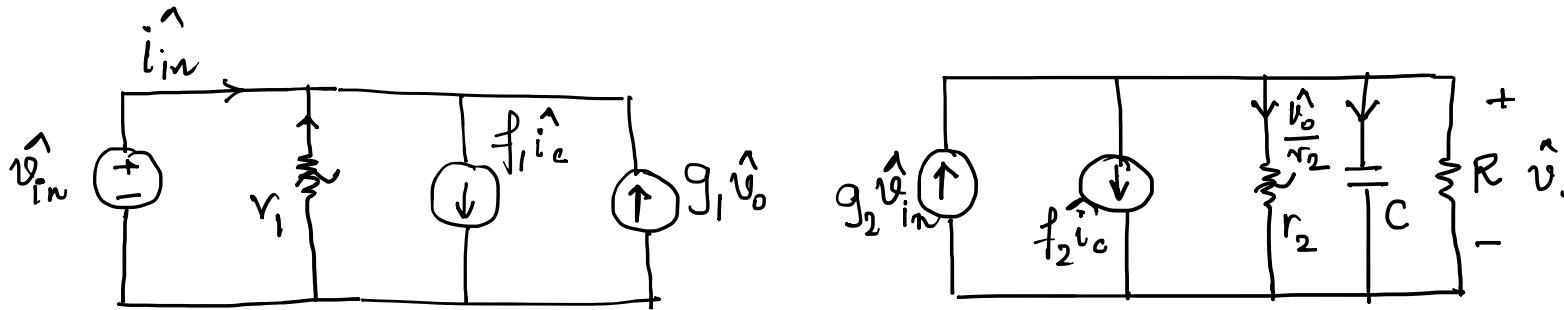
$$\frac{\bar{v}_o}{n} = \frac{v_{in} \bar{D}}{\bar{D}'}$$

$$\bar{I}_L = \frac{I_{in}}{\bar{D}} = \frac{\bar{v}_o \bar{I}_o}{\bar{D} \bar{v}_{in}}$$

$$\Rightarrow \frac{\bar{v}_o}{n} = \frac{1}{\bar{D}'} \frac{\bar{v}_o}{R}$$

Current Programmed Control

Flyback Converter Model



$$\begin{aligned}
 G_{v_c} \Big|_{\hat{v}_{in}=0} &= \frac{\hat{v}_o}{\hat{i}_c} = -f_2 \left(r_2 \parallel R \parallel \frac{1}{sC} \right) \\
 &= - \left[\frac{\bar{D}'}{n} - s \frac{L \bar{D} n}{\bar{D}' R} \right] \frac{1}{sC + \frac{1}{R} + \left(\frac{1}{R} + \frac{\bar{D}'}{R} \right)} \\
 &= - \frac{\bar{D}' R}{n(2 + \bar{D})} \frac{1 - s L \bar{D} n^2 / \bar{D}' R}{1 + s \frac{CR}{2 + \bar{D}}}
 \end{aligned}$$

Current Programmed Control

Flyback Example

$V_{in} = 400 \text{ V}$

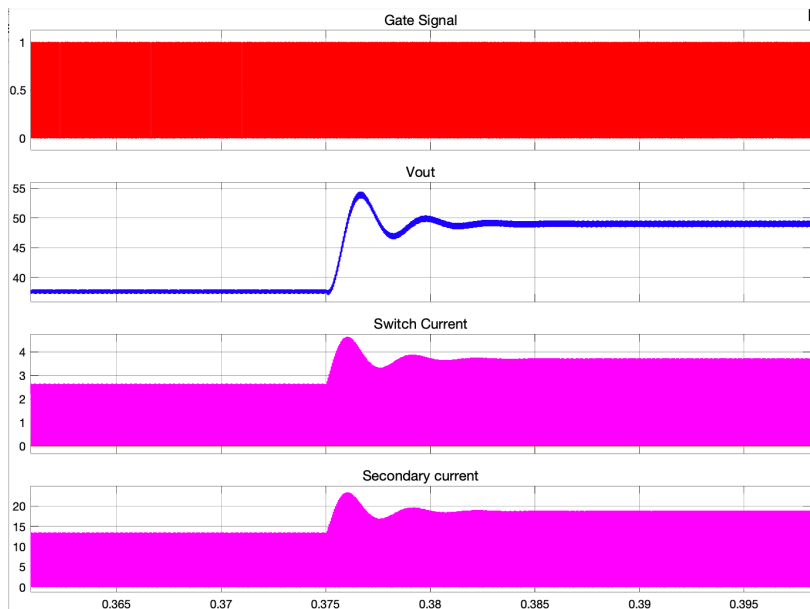
$V_{out} = 48 \text{ V}$

$P = 500 \text{ W}$

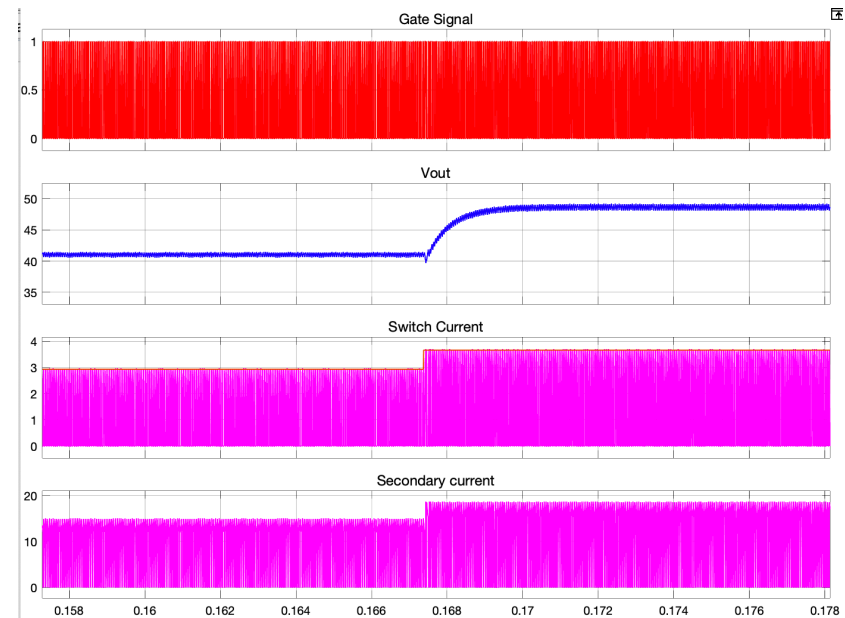
Voltage ripple = 1 V

Inductor current ripple = 20% of nominal average current $f_s = 20 \text{ kHz}$

$$L = 11.2 \text{ mH} \quad C = 1953 \text{ } \mu\text{F}$$



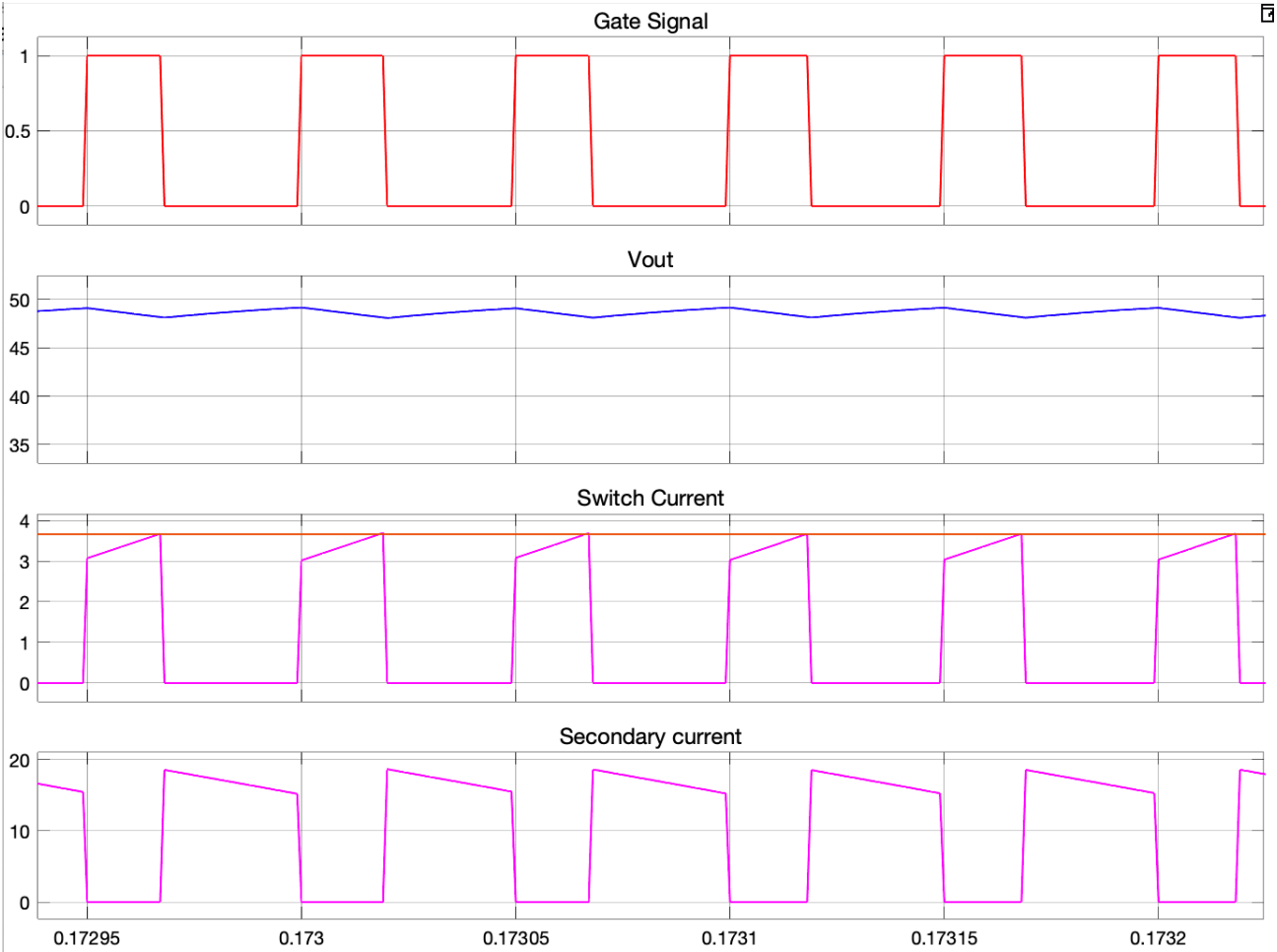
Step Change in Duty



Step change in peak current reference

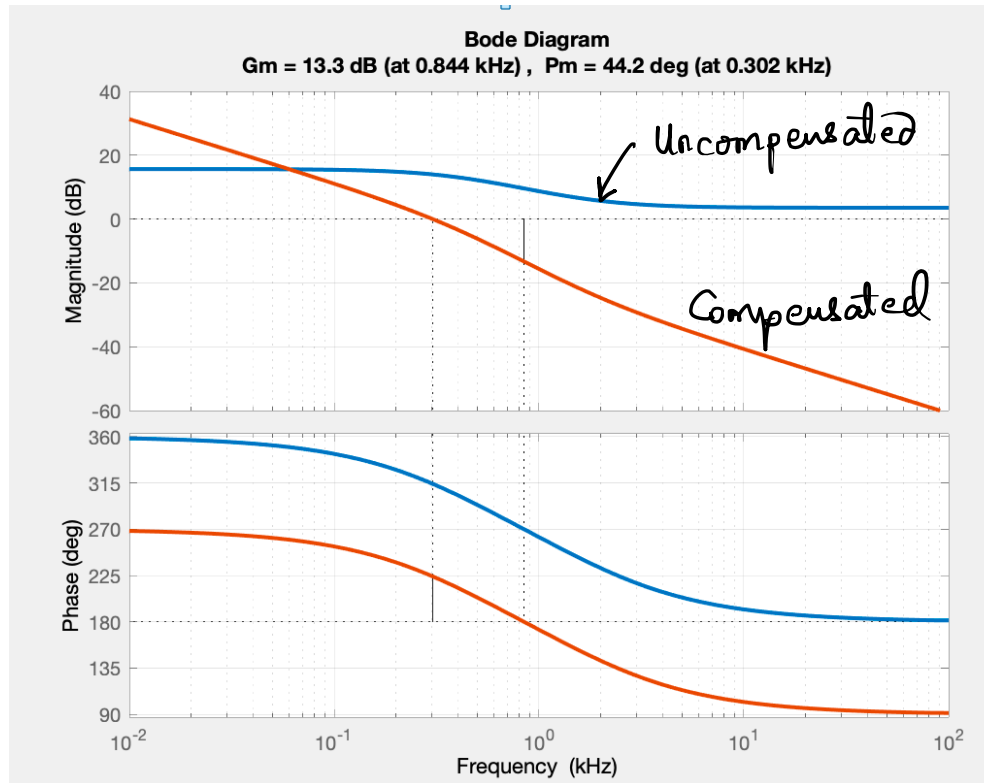
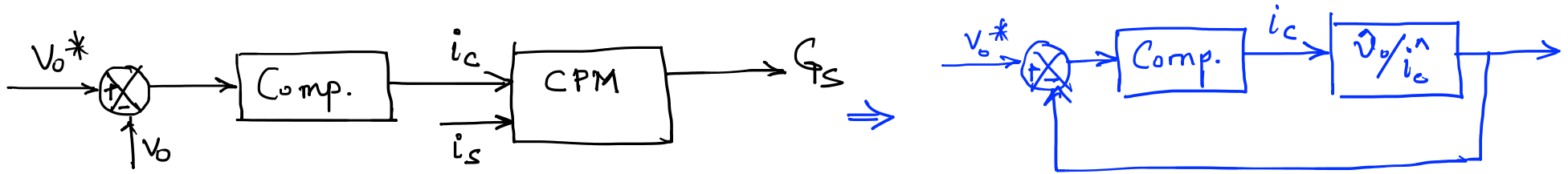
Current Programmed Control

Flyback Example



Current Programmed Control

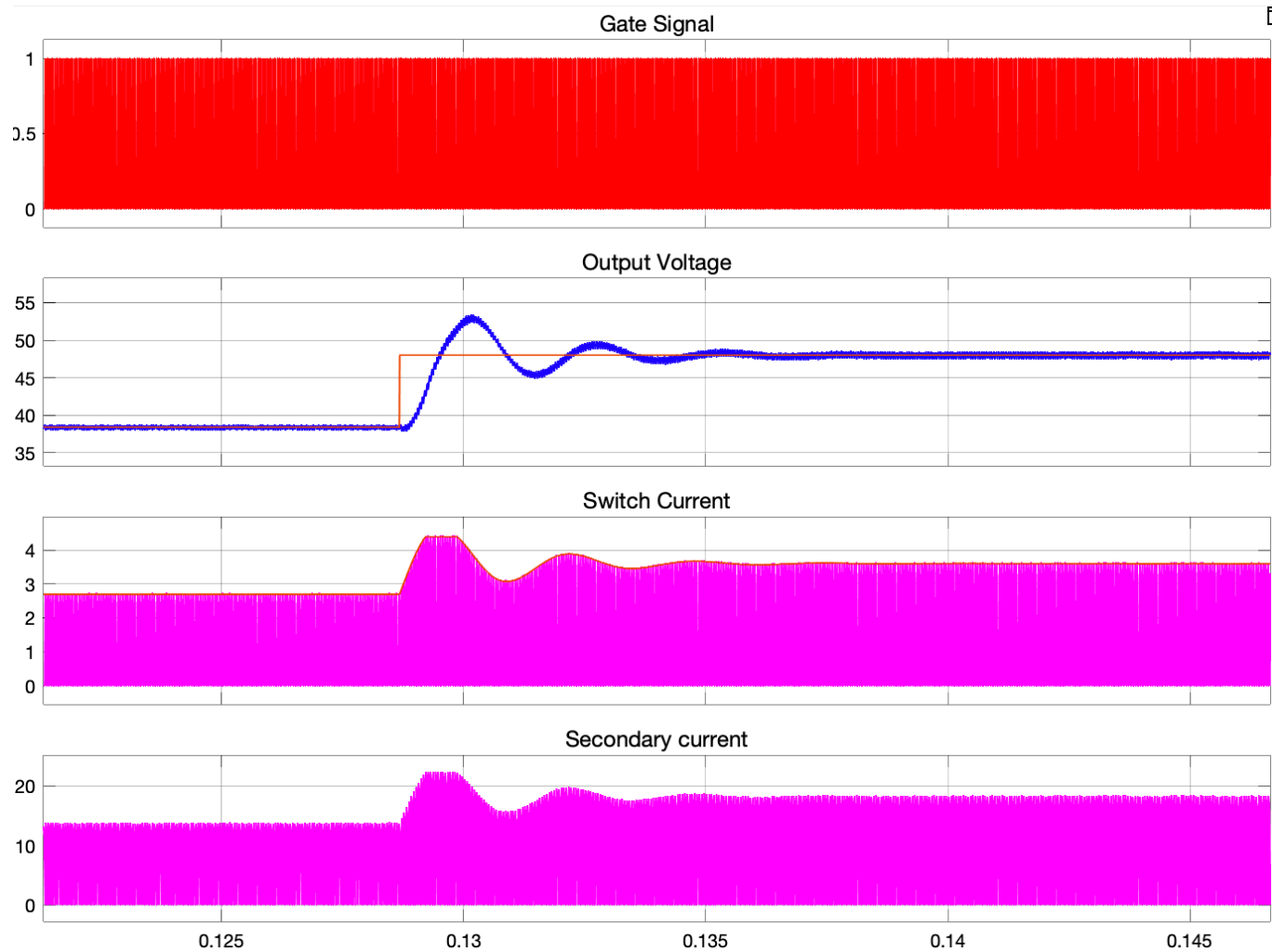
Flyback Example – voltage regulator design



$$\text{Compensator} = \frac{380}{s}$$

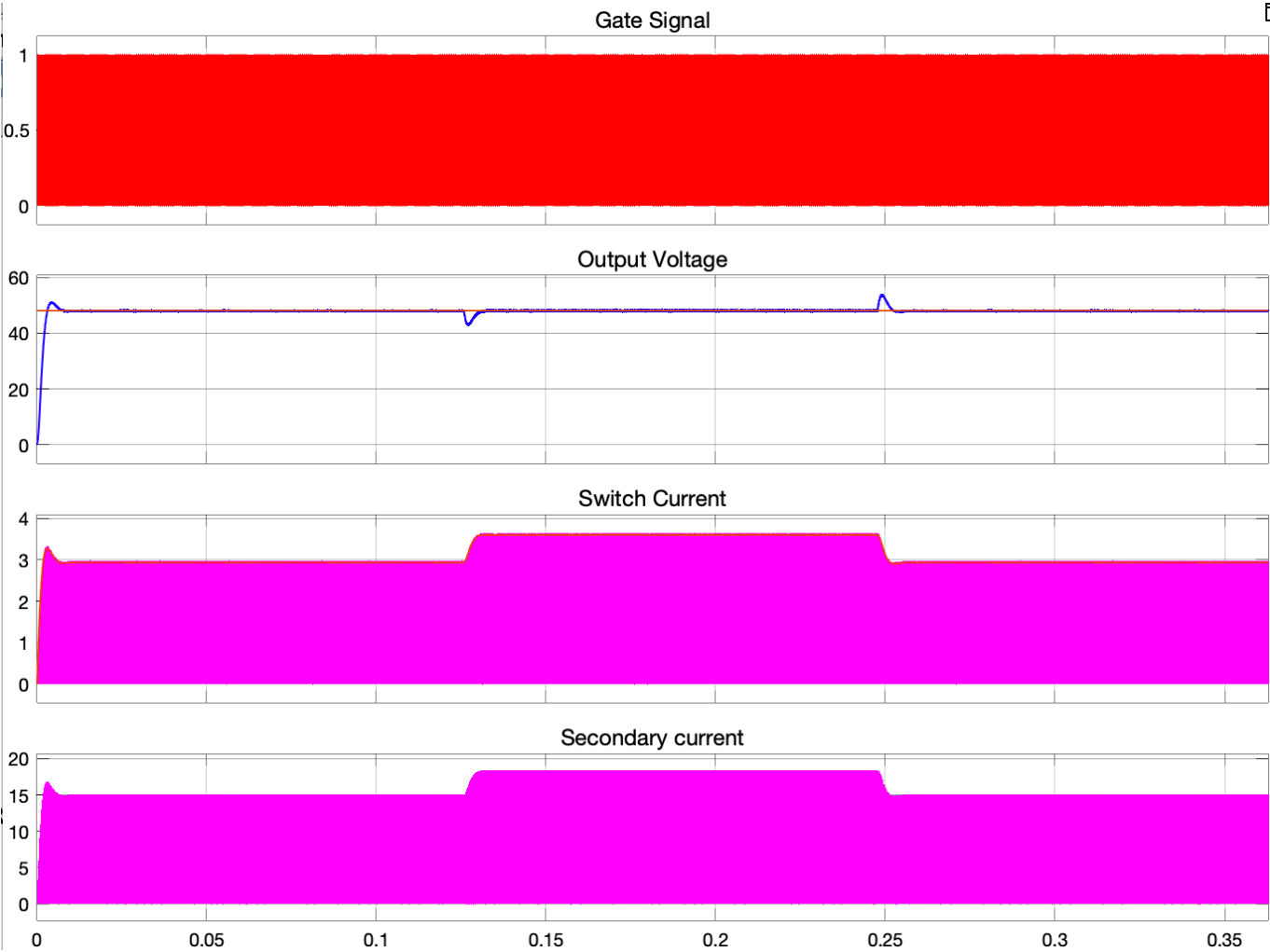
Current Programmed Control

Flyback Example – voltage regulator design



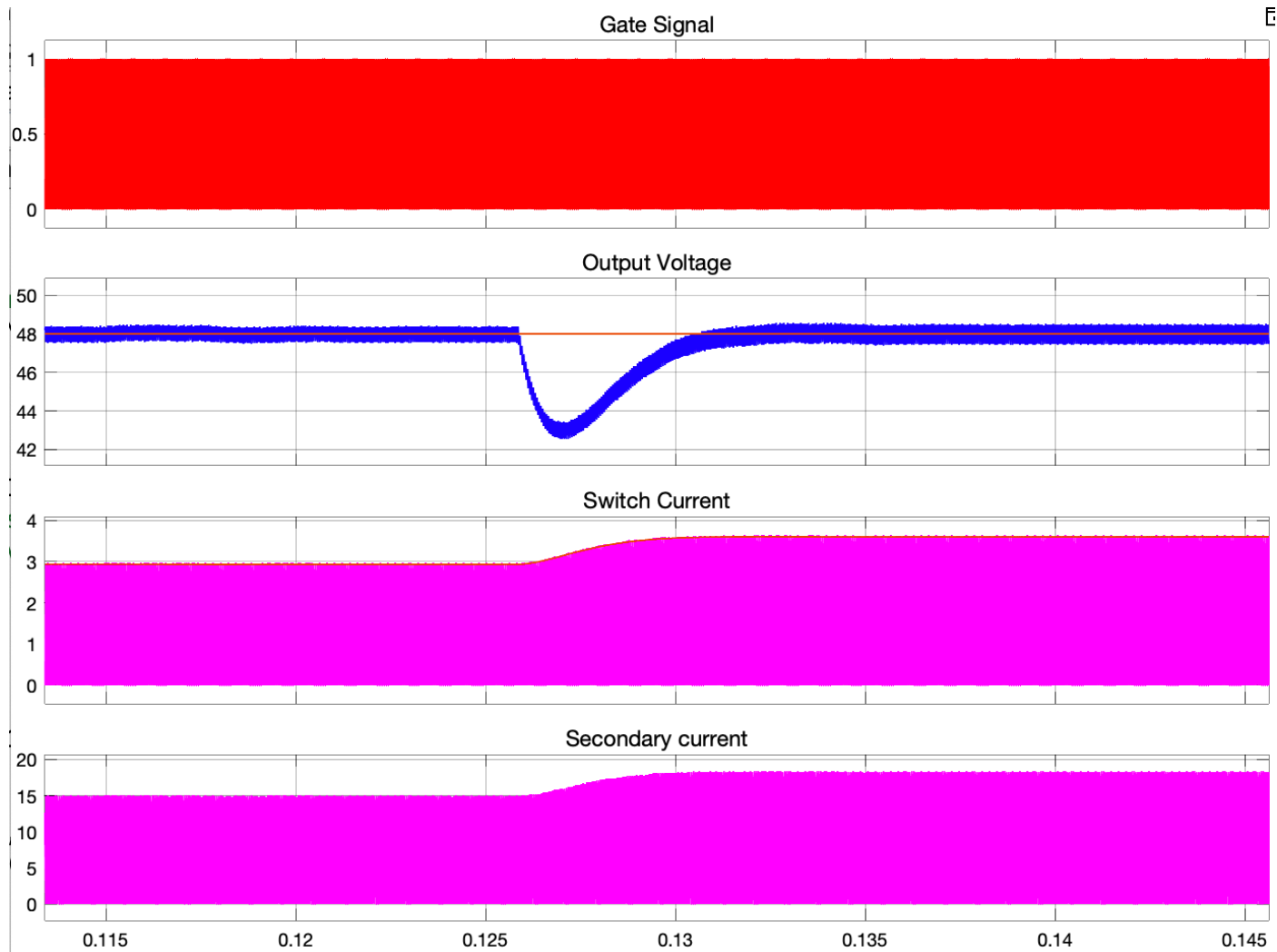
Current Programmed Control

Flyback Example – voltage regulator design



Current Programmed Control

Flyback Example – voltage regulator design



Current Programmed Control

Flyback Example – voltage regulator design

