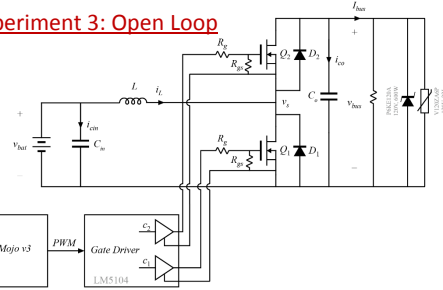
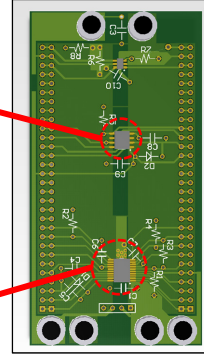
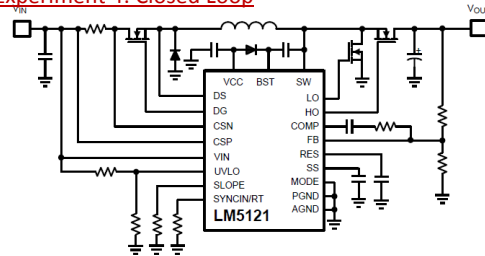


Experiment 4: Closed-Loop Boost

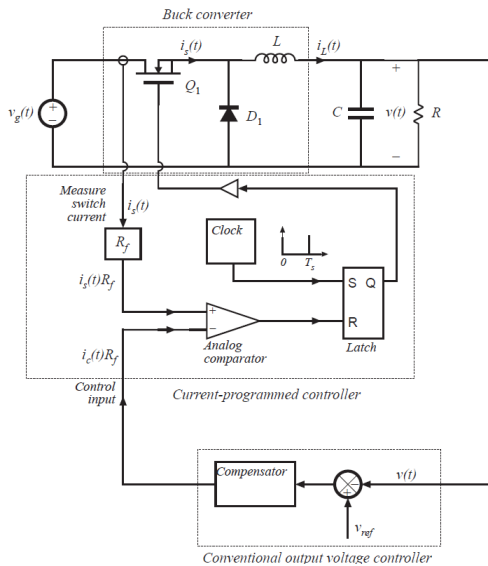
Experiment 3: Open Loop



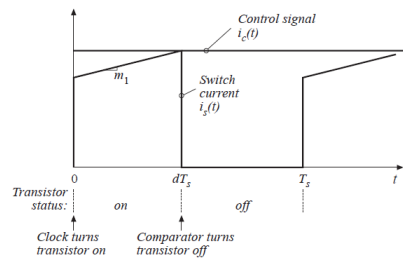
Experiment 4: Closed Loop



Current Programmed Control (CPM)



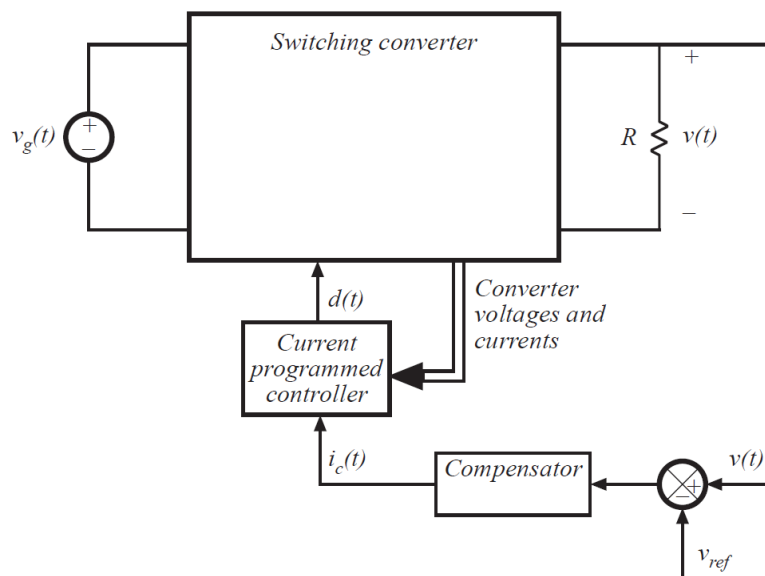
The peak transistor current replaces the duty cycle as the converter control input.



Current Programmed Control

- Covered in Ch. 12 of *Fundamentals of Power Electronics*
- Advantages of current programmed control:
 - Simpler dynamics —inductor pole is moved to high frequency
 - Simple robust output voltage control, with large phase margin, can be obtained without use of compensator lead networks
 - It is always necessary to sense the transistor current, to protect against overcurrent failures. We may as well use the information during normal operation, to obtain better control
 - Transistor failures due to excessive current can be prevented simply by limiting $i_c(t)$
 - Transformer saturation problems in bridge or push-pull converters can be mitigated
- A disadvantage: susceptibility to noise

A Simple First-Order Model



The First-Order Approximation

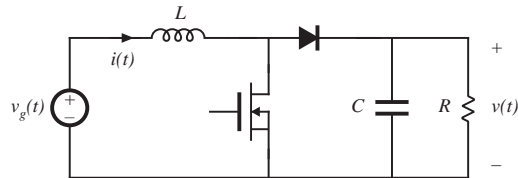
$$\langle i_L(t) \rangle_{T_s} = i_c(t)$$

- Neglects switching ripple
- Yields physical insight and simple first-order model
- Accurate when converter operates well into CCM (so that switching ripple is small)
- Accurate when artificial ramp (discussed later) small
- Resulting small-signal relation:

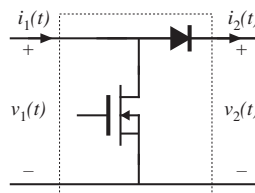
$$i_L(s) \approx i_c(s)$$

Boost Averaged Switch Modeling

Ideal boost converter
example

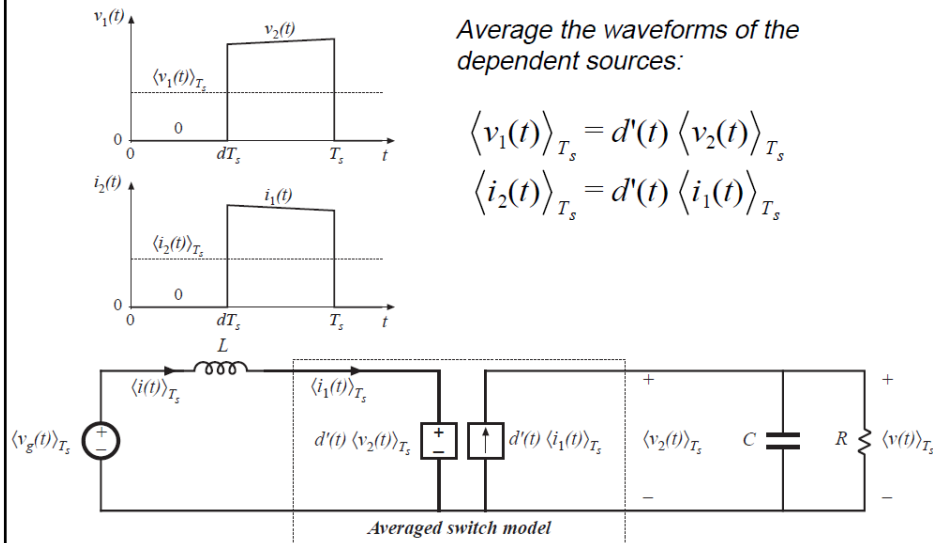


Boost-specific
switch network



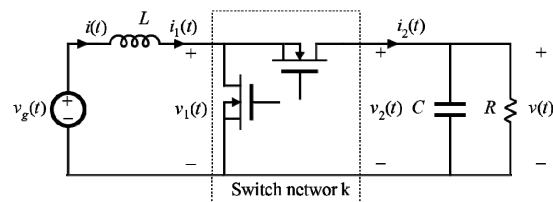
- Averaged switch model goal:
 - Express average of two waveforms ($i_1(t)$, $i_2(t)$, $v_1(t)$, $v_2(t)$) in terms of the other two

Previous Definitions

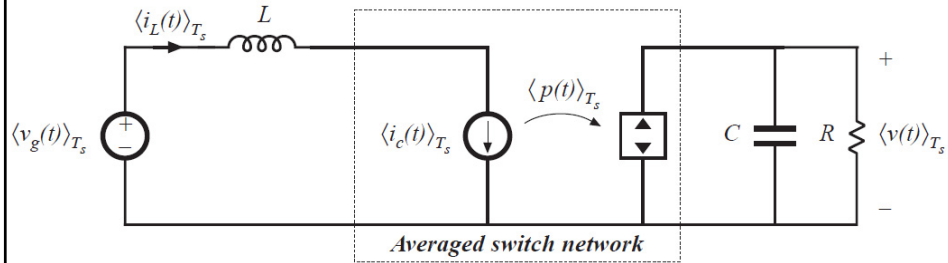


A More Useful Approach

- Instead select $i_1(t)$, $i_2(t)$

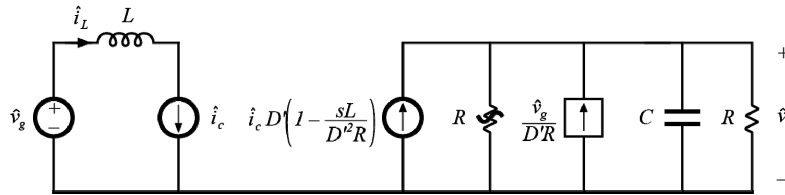


Large-Signal Nonlinear Model



Perturb and Linearize

Boost CCM CPM Small-Signal Model



- wsadsdfs

CPM Transfer Functions

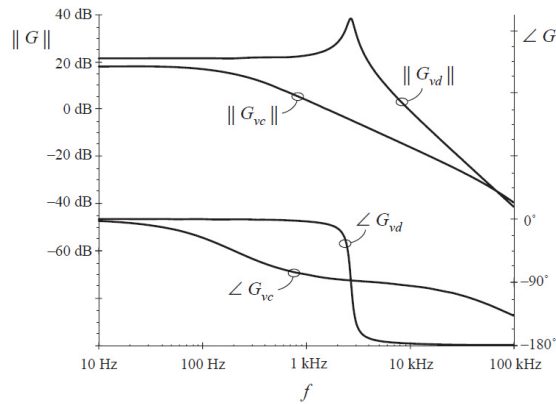
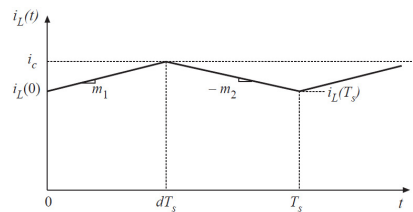


Fig. 12.28 Comparison of CPM control with duty-cycle control, for the control-to-output frequency response of the buck converter example.

CPM Oscillations for $D > 0.5$

- The current programmed controller is inherently unstable for $D > 0.5$, regardless of the converter topology
- Controller can be stabilized by addition of an artificial ramp

Inductor Current Waveform in CCM



Inductor current slopes m_1
and $-m_2$

buck converter

$$m_1 = \frac{v_g - v}{L} \quad -m_2 = -\frac{v}{L}$$

boost converter

$$m_1 = \frac{v_g}{L} \quad -m_2 = \frac{v_g - v}{L}$$

buck-boost converter

$$m_1 = \frac{v_g}{L} \quad -m_2 = \frac{v}{L}$$

Volt-Second Balancing

First interval:

$$i_L(dT_s) = i_c = i_L(0) + m_1 dT_s$$

Solve for d :

$$d = \frac{i_c - i_L(0)}{m_1 T_s}$$

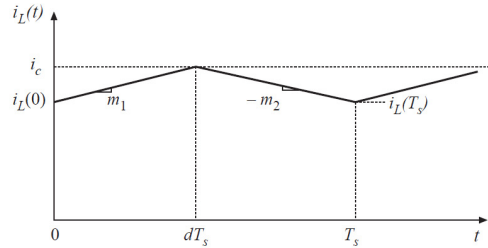
Second interval:

$$\begin{aligned} i_L(T_s) &= i_L(dT_s) - m_2 dT_s \\ &= i_L(0) + m_1 dT_s - m_2 dT_s \end{aligned}$$

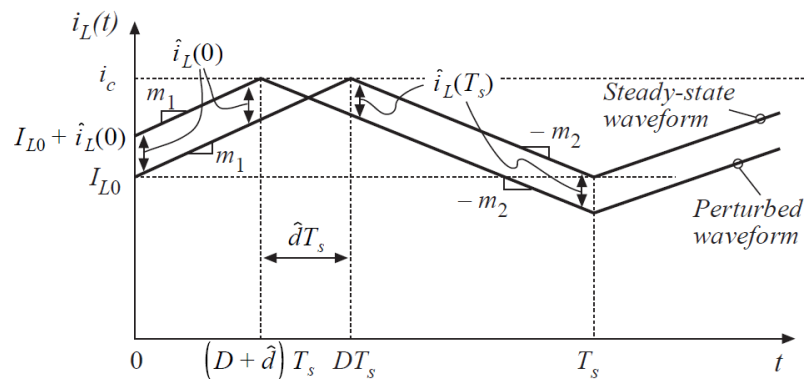
In steady state:

$$0 = M_1 dT_s - M_2 d'T_s$$

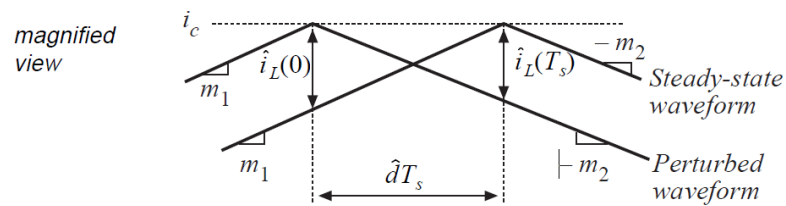
$$\frac{M_2}{M_1} = \frac{D}{D'}$$



Introducing a Perturbation



Change in Inductor Current Over T_s



$$\hat{i}_L(0) = -m_1 \hat{\Delta}T_s$$

$$\hat{i}_L(T_s) = m_2 \hat{\Delta}T_s$$

$$\hat{i}_L(T_s) = \hat{i}_L(0) \left(-\frac{D}{D'} \right)$$

$$\hat{i}_L(T_s) = \hat{i}_L(0) \left(-\frac{m_2}{m_1} \right)$$

Final Value of Inductor Current

$$\hat{i}_L(T_s) = \hat{i}_L(0) \left(-\frac{D}{D'} \right)$$

$$\hat{i}_L(2T_s) = \hat{i}_L(T_s) \left(-\frac{D}{D'} \right) = \hat{i}_L(0) \left(-\frac{D}{D'} \right)^2$$

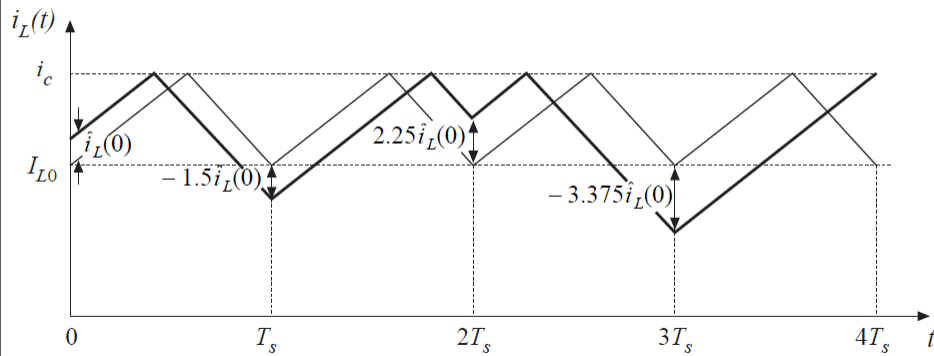
$$\hat{i}_L(nT_s) = \hat{i}_L((n-1)T_s) \left(-\frac{D}{D'} \right) = \hat{i}_L(0) \left(-\frac{D}{D'} \right)^n$$

$$\left| \hat{i}_L(nT_s) \right| \rightarrow \begin{cases} 0 & \text{when } \left| -\frac{D}{D'} \right| < 1 \\ \infty & \text{when } \left| -\frac{D}{D'} \right| > 1 \end{cases}$$

For stability: $D < 0.5$

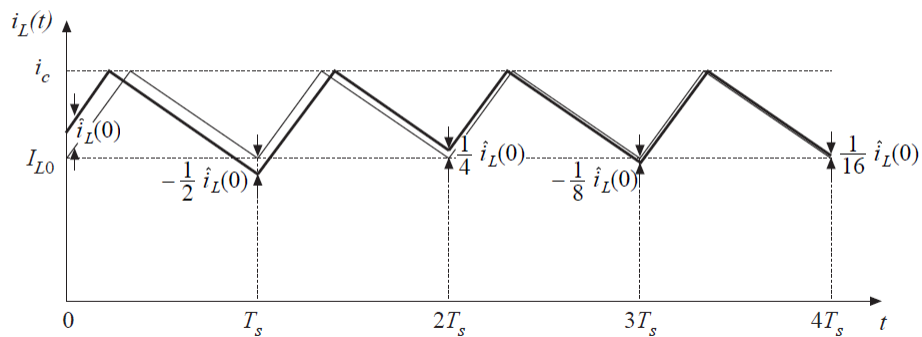
Example: Unstable operation for $D=0.6$

$$\alpha = -\frac{D}{D'} = \left(-\frac{0.6}{0.4}\right) = -1.5$$

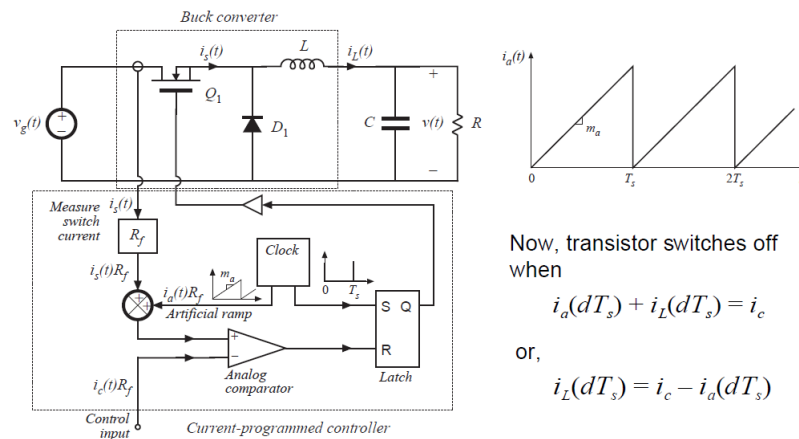


Example: Stable operation for $D=1/3$

$$\alpha = -\frac{D}{D'} = \left(-\frac{1/3}{2/3}\right) = -0.5$$



Stabilization Through Artificial Ramp



Final Value of Inductor Current

First subinterval:

$$\hat{i}_L(0) = -\hat{d}T_s (m_1 + m_a)$$

Second subinterval:

$$\hat{i}_L(T_s) = -\hat{d}T_s (m_a - m_2)$$

Net change over one switching period:

$$\hat{i}_L(T_s) = \hat{i}_L(0) \left(-\frac{m_2 - m_a}{m_1 + m_a} \right)$$

After n switching periods:

$$\hat{i}_L(nT_s) = \hat{i}_L((n-1)T_s) \left(-\frac{m_2 - m_a}{m_1 + m_a} \right) = \hat{i}_L(0) \left(-\frac{m_2 - m_a}{m_1 + m_a} \right)^n = \hat{i}_L(0) \alpha^n$$

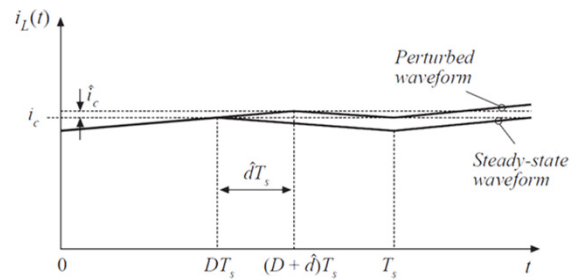
Characteristic value:

$$\alpha = -\frac{m_2 - m_a}{m_1 + m_a} \quad \left| \hat{i}_L(nT_s) \right| \rightarrow \begin{cases} 0 & \text{when } |\alpha| < 1 \\ \infty & \text{when } |\alpha| > 1 \end{cases}$$

Artificial Ramp: Additional Notes

- For stability, require $|\alpha| < 1$
- Common choices:
 - $m_a = 0.5 m_2$
 - $m_a = m_2$
- Artificial ramp decreases sensitivity to noise

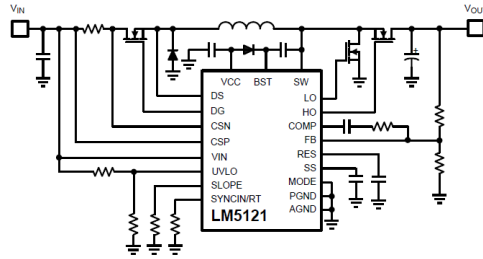
$$\alpha = -\frac{1 - \frac{m_a}{m_2}}{\frac{D'}{D} + \frac{m_a}{m_2}}$$



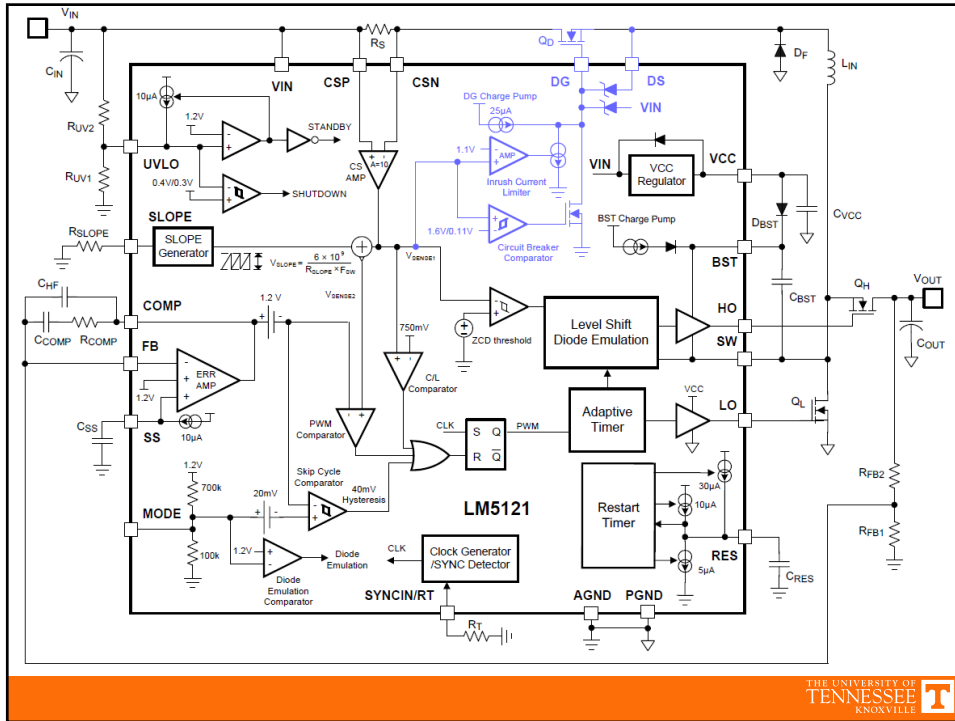
More Accurate Models

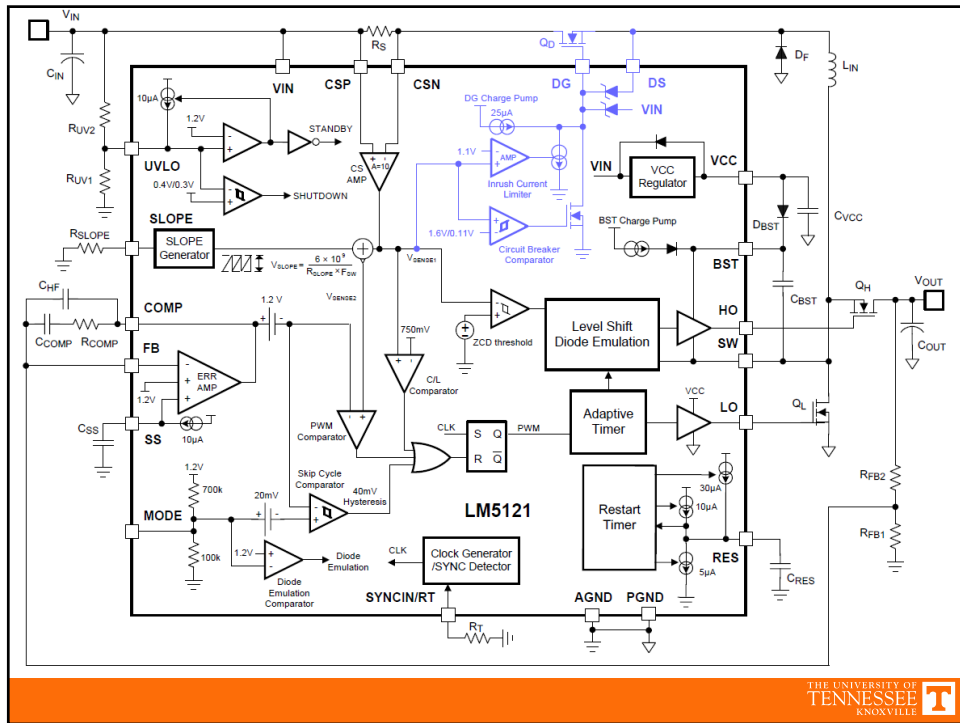
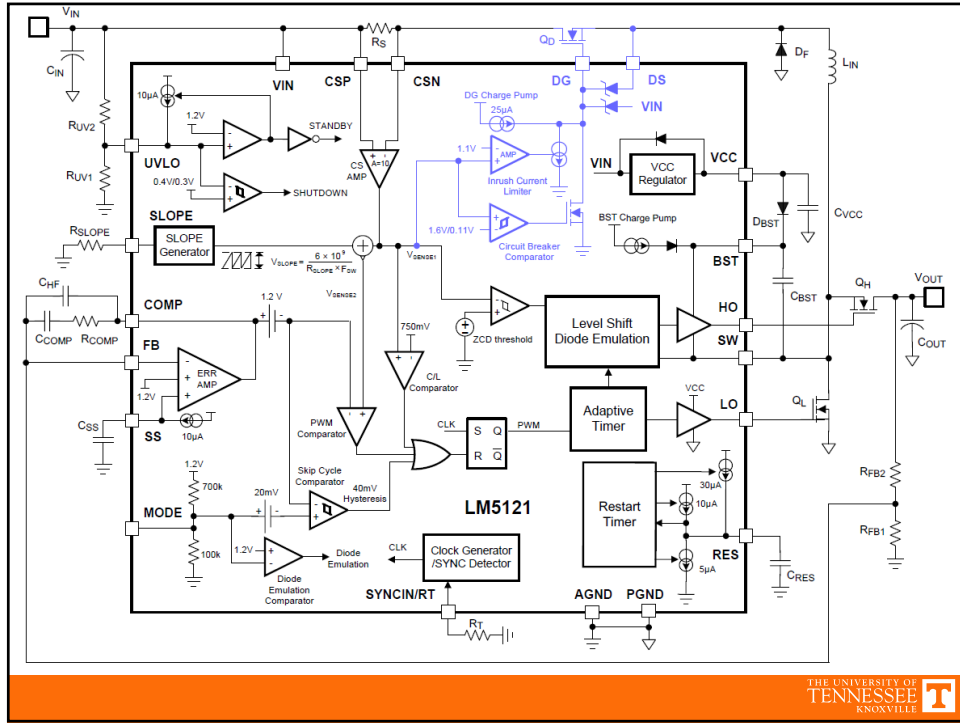
- The simple models of the previous section yield insight into the low-frequency behavior of CPM converters
- Unfortunately, they do not always predict everything that we need to know:
 - Line-to-output transfer function of the buck converter
 - Dynamics at frequencies approaching f_s
- More accurate model accounts for nonideal operation of current mode controller built-in feedback loop
- Converter duty-cycle-controlled model, plus block diagram that accurately models equations of current mode controller
- See Section 12.3 for additional info

Application to Experiment 4

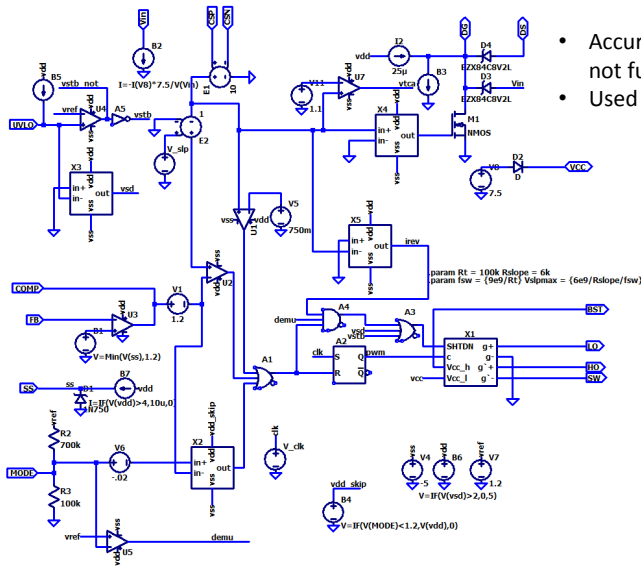


- Complex switching controller
- **Read the datasheet first**





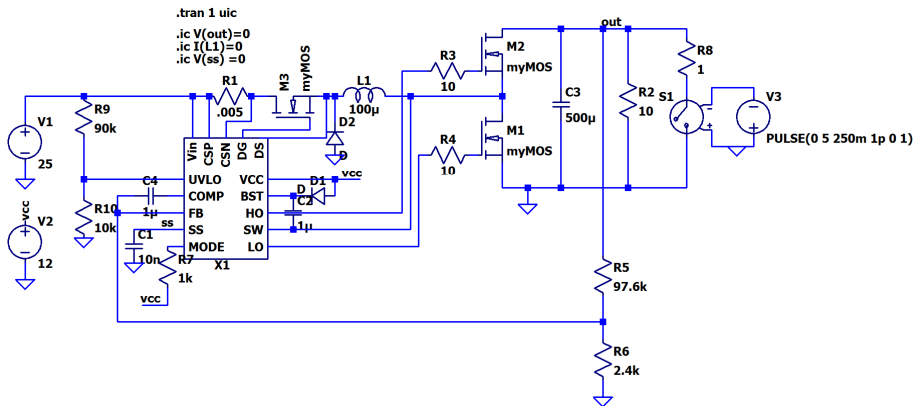
Internal Functional Model in LTSpice



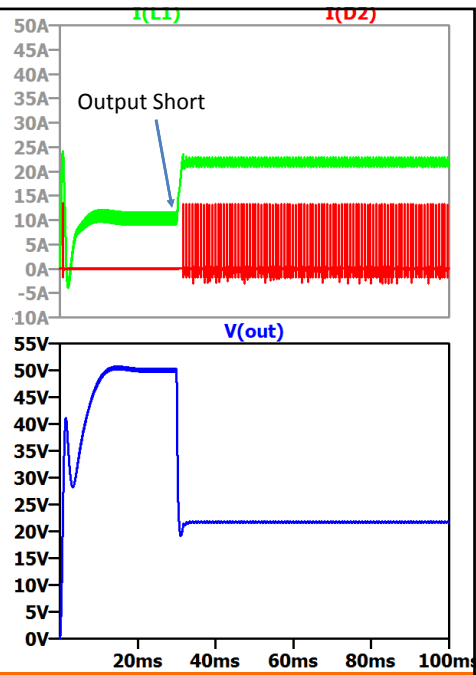
- Accuracy/functionality not fully tested
- Used for insight only

In-Circuit Simulation

```
.model mysW sw(Von=3 Voff=2 Ron=.1 Roff = 1Meg)
.model myMOS VDMOS(Rg=1 Vto=4.5 Rd=14m Rs=10m Rb=17m Kp=30 Cgdmax=.5p Cgdmin=.05n Cgs=.2n Cjo=.03p Is=88p)
```



Sim Results



A Tip: Debug Internal of Subcircuit

