Single Phase Buck

Q_1 ON
L_1 stores E

Q_1 off
Q_2 ON
L_1 sources load

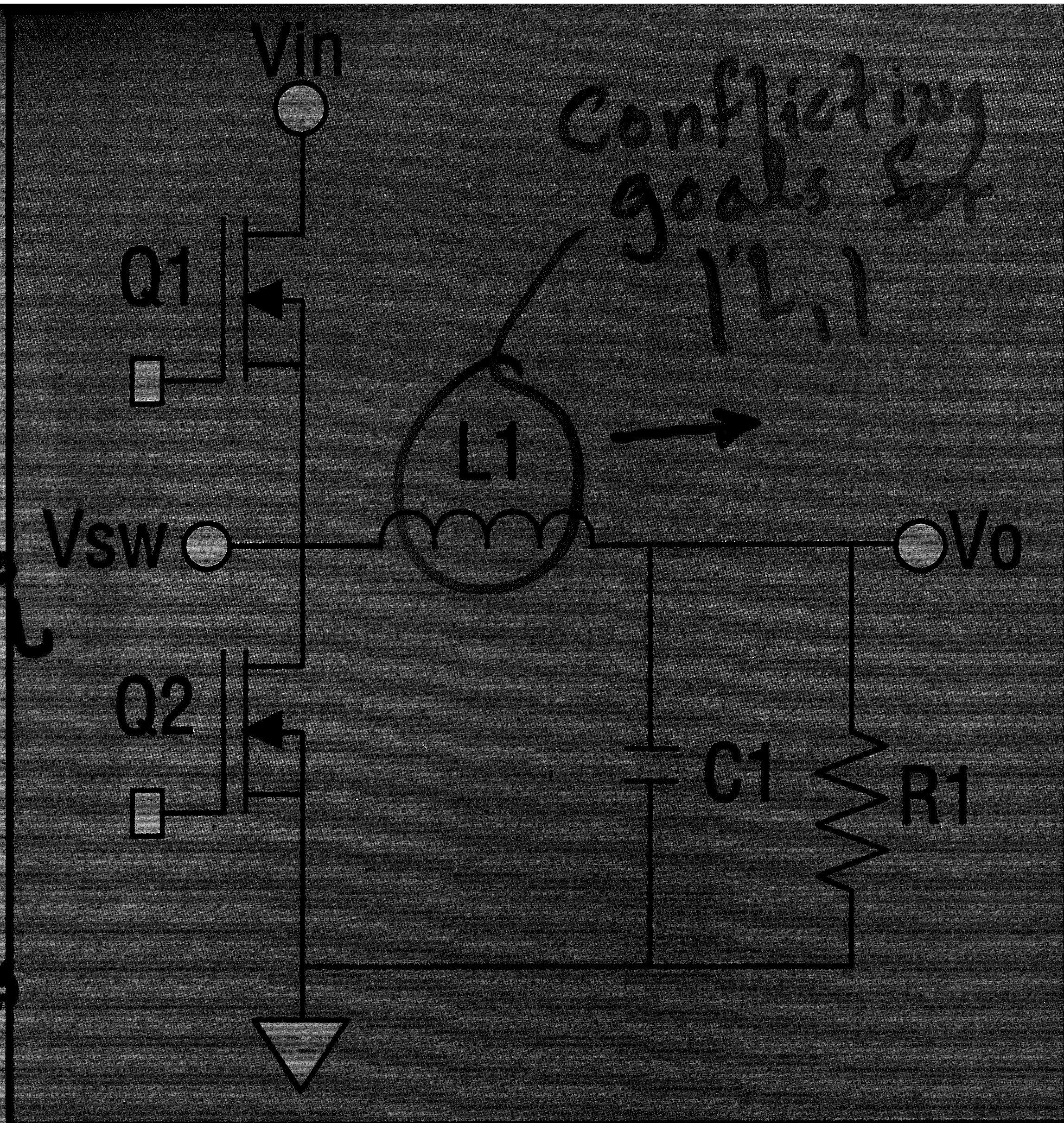

Fig. 1. *Simplified schematic of a typical synchronous buck converter. The inductor current always flows through either Q1 or Q2. During the on-time, Q1 is ON, and inductor current increases. During the off-time, Q2 is ON, and the inductor current decreases. At the on/off transition times, the inductor current has to quickly switch from one FET to the other one.*

High L for low ripple
Low L for fast di(out)/dt

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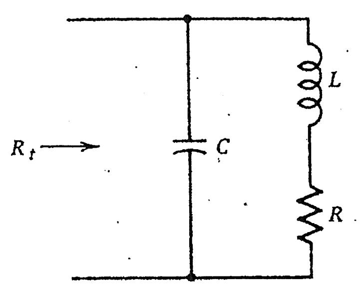
EE 576 Homework Set 10

1. You have just graduated and started a new job at a semiconductor equipment manufacturer. You are now PAID to work on processes driven by RF generators at 13.56 MHz. These generators want to work into a 50Ω resistive load, but, amazingly, your process looks like a 5Ω resistive load.

   You need to match the generator to the load, but are, unfortunately, mystified, until one of your friends points you to a book entitled "Solid State Radio Engineering" by Krauss, Bostian, and Raab. Use the circuit and "exact equations" in Table 3-3.1 from the book (see below) to make your 5Ω resistive load look like a 50Ω resistive load and show that you have gotten the correct L and C.

   Alternatively, you look at the network below and write an expression for the input impedance, knowing it must be 50 Ohms or real impedance and zero Ohms of reactive impedance. With two equations and two unknowns –you are ready for Mathcad/Matlab etc.solutions. Show all work and document each step with comment statements.

TABLE 3-3.1 Design Formulas for the Resonant *RL*‖*C* Circuit



Quantity	*Exact Expression*	*Units*	*Approximate Expression, $Q_t \geq 10$*
ω_o	$=\left(\frac{1}{LC}-\frac{R^2}{L^2}\right)^{1/2}$	rad/s	$\approx \frac{1}{\sqrt{LC}}$
Q_t	$\equiv \frac{\omega_o L}{R} = \omega_o C R_t$		$\approx \frac{1}{\omega_o C R}$
$\omega_o L$	$= \frac{1}{\omega_o C}\left(\frac{Q_t^2}{Q_t^2+1}\right)$	ohms	$\approx \frac{1}{\omega_o C}$
R_t	$= \frac{L}{CR} = \frac{Q_t}{\omega_o C}$ $= R(Q_t^2+1)$	ohms	$\approx Q_t^2 R = \omega_o L Q_t$
B		hertz	$\approx \frac{1}{2\pi C R_t} = \frac{R}{2\pi L} = \frac{f_o}{Q_t}$

1ϕ Buck

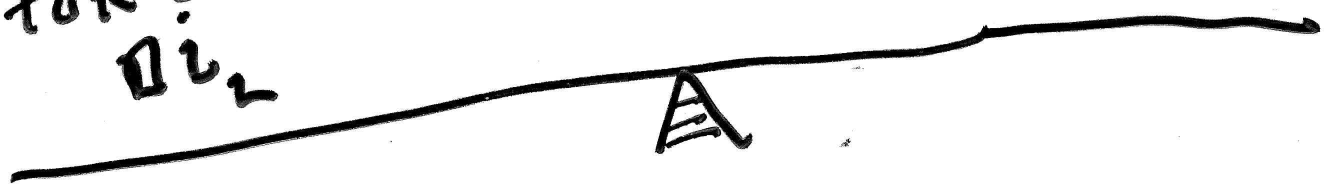
I_{out}: 50A notebook
100A desktop
150A server

I^2R losses high for one path

Conflict / Compromise on single
"L" is necessary

Big "L" for small Δi_L

small "L" for fast $\frac{di_L}{dt}$



Solution: "x" seperate current paths each with own

S_x and L_x

Shift phases to reduce $|\Delta i_L|$

$$\sum_{x=1}^{N} i_x = i_{out}$$

Phase shift Δi_x to minimize $\Delta i(out)$

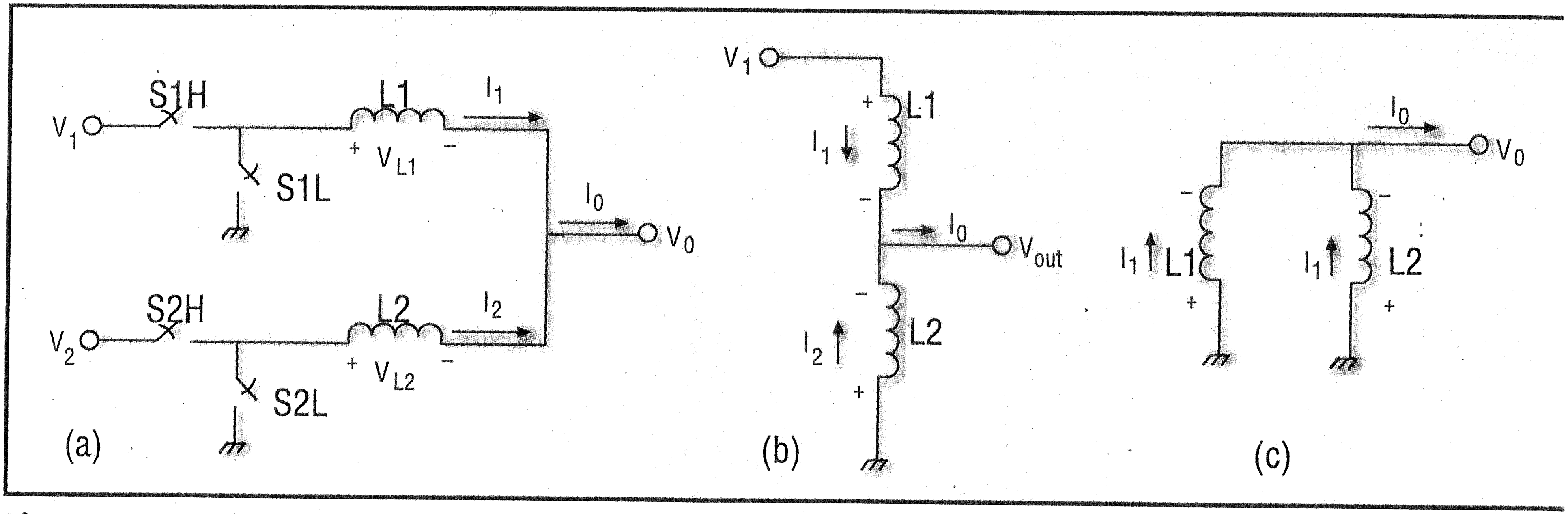


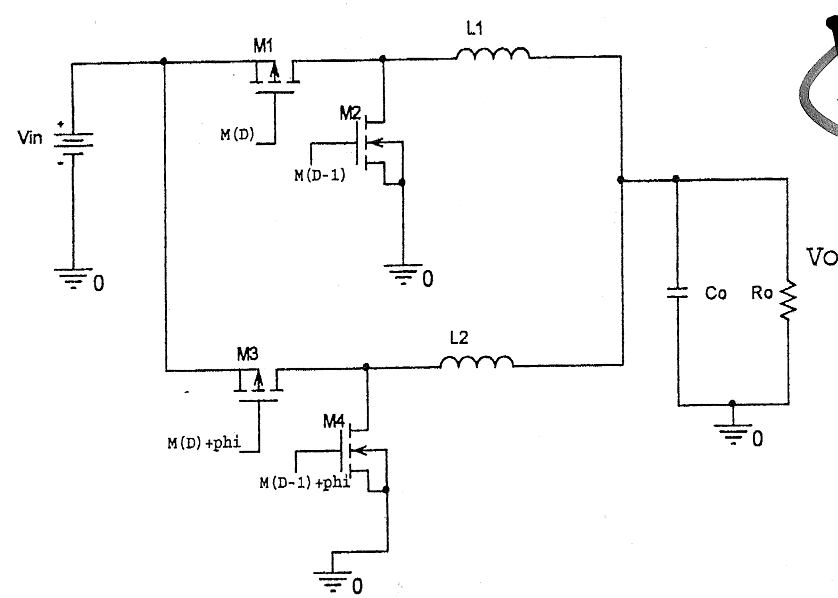
Fig. 2. *A simplified schematic of a multiphase uncoupled buck regulator (a) illustrates the two basic switching actions. In state one (b), S1H and S2L are closed while S1L and S2H are open. The input then sources energy to L1 and the output, and L2 sources energy to the output. In state two (c), S1L and S2L are closed, and S1H and S2H are open. Thus, both inductors source energy to the output. These operations are reversed for states three and four (not shown).*

I^2R loss @ 150 A server too high for one path use several parallel paths

$|\Delta i_L| \downarrow$

Multiphase Output: $|I_M| \downarrow$ yet $|I_o|$ same

$|I_{IN}| \downarrow$



Loss due to $I_{IN} \Downarrow$ as N

$I_N^2 R_{Ln}$ loss down as N^2

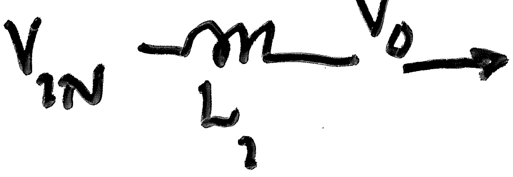
-Reduces output ripple due to cancellation of inductor ripple currents

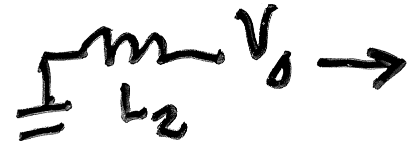
-Relaxes maximum current rating requirements of switches, inductors and caps

-Reduces stress and I^2R loss on input source by reducing amplitude of input current pulses

1 State 1: 2Φ $0 \rightarrow DT_{SW}$

$dt = DT_{SW}$





$L_1 = L_2 = L$

$$di_1 = \frac{V_1}{L_1}(1-D)\,DT_{SW}$$

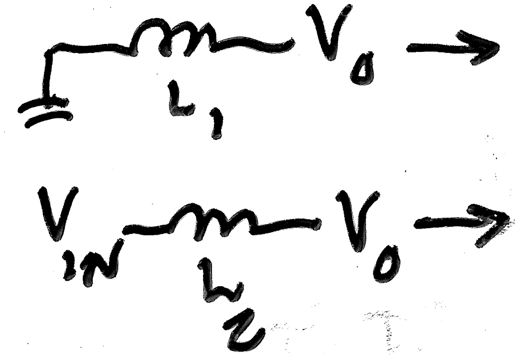
$$di_2 = \frac{V_{IN}}{L_2}(D)\,DT_{SW}$$

$L_1 = L_2$ $\quad di_{out} = di_1 + di_2$

$$di_{out} = \frac{V_{IN}}{L}(1-2D)\,DT_{SW}$$

2 State 2: 2Φ

$t = DT_{SW} \rightarrow \frac{T_{SW}}{2}$



ripple is at $2 f_{SW}$

$$di_{out} = -\frac{V_{IN}}{L}(1-2D)\,DT_{SW}$$

! Recall $\Delta i(out)$ 1Φ: $\frac{V_{IN}}{L}(1-D)\,D\,T_{SW}$!

$$\frac{\Delta i_{out}(2\Phi)}{\Delta i_{out}(1\Phi)} = \frac{1-2D}{1-D}$$

lower Δi_{out} for all D

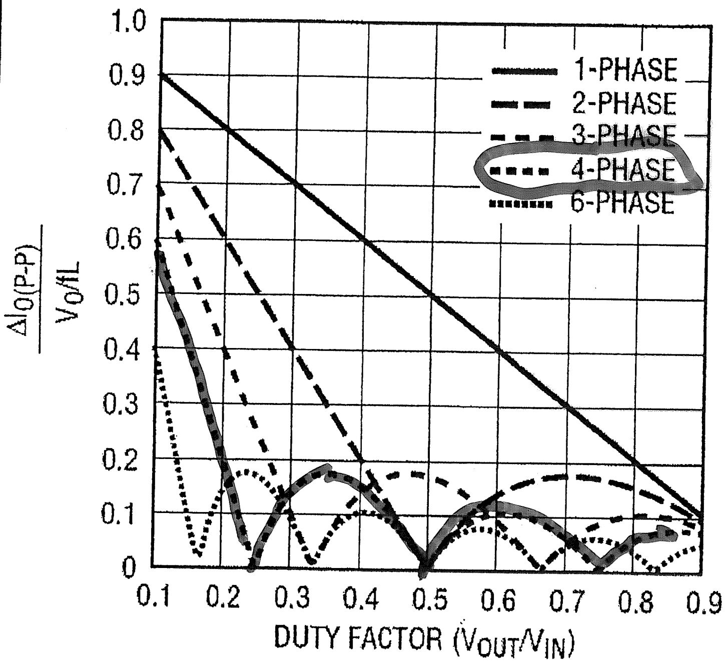
OR

L reduced for same Δi_{out} but faster di_L/dt

Δi_{out} (multiphase) can be zero for some D

Frequency and Phases

For Vin = 5V, Vout = 1.8V, D≈.35



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-Optimal number of phases 3 or 6

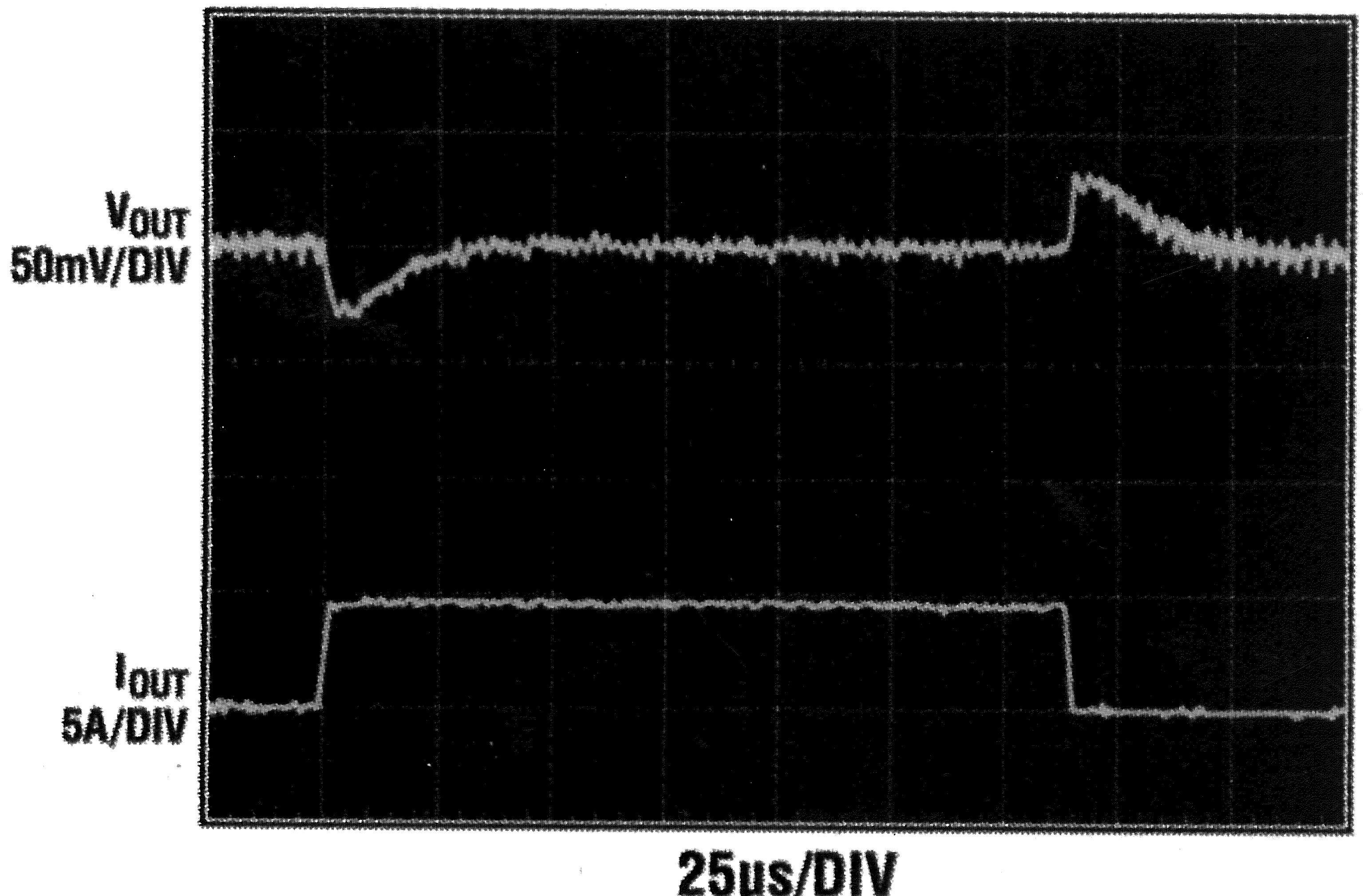
-Though 4 or even 2 phases also provides good output ripple cancellation versus a single phase

$\Delta i_4(out) = 0$

@ D = 0.25, 0.50, 0.75

Ultrafast Transient Response

2% ΔV_{OUT} with a 5A Step



V_{IN} = 12V, V_{OUT} = 1.5V, 0A to 5A Load Step

(C_{OUT} = 3 x 22μF CERAMICS, 470μF POS CAP)