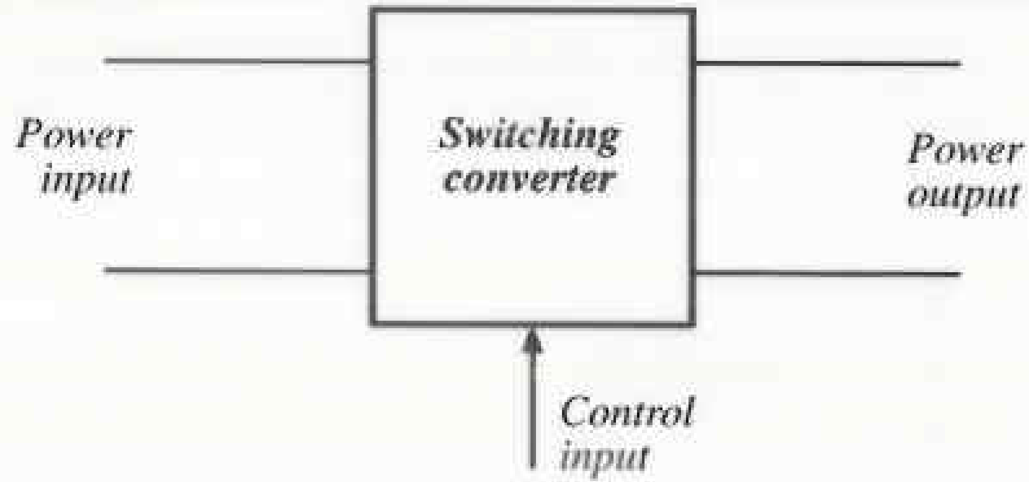
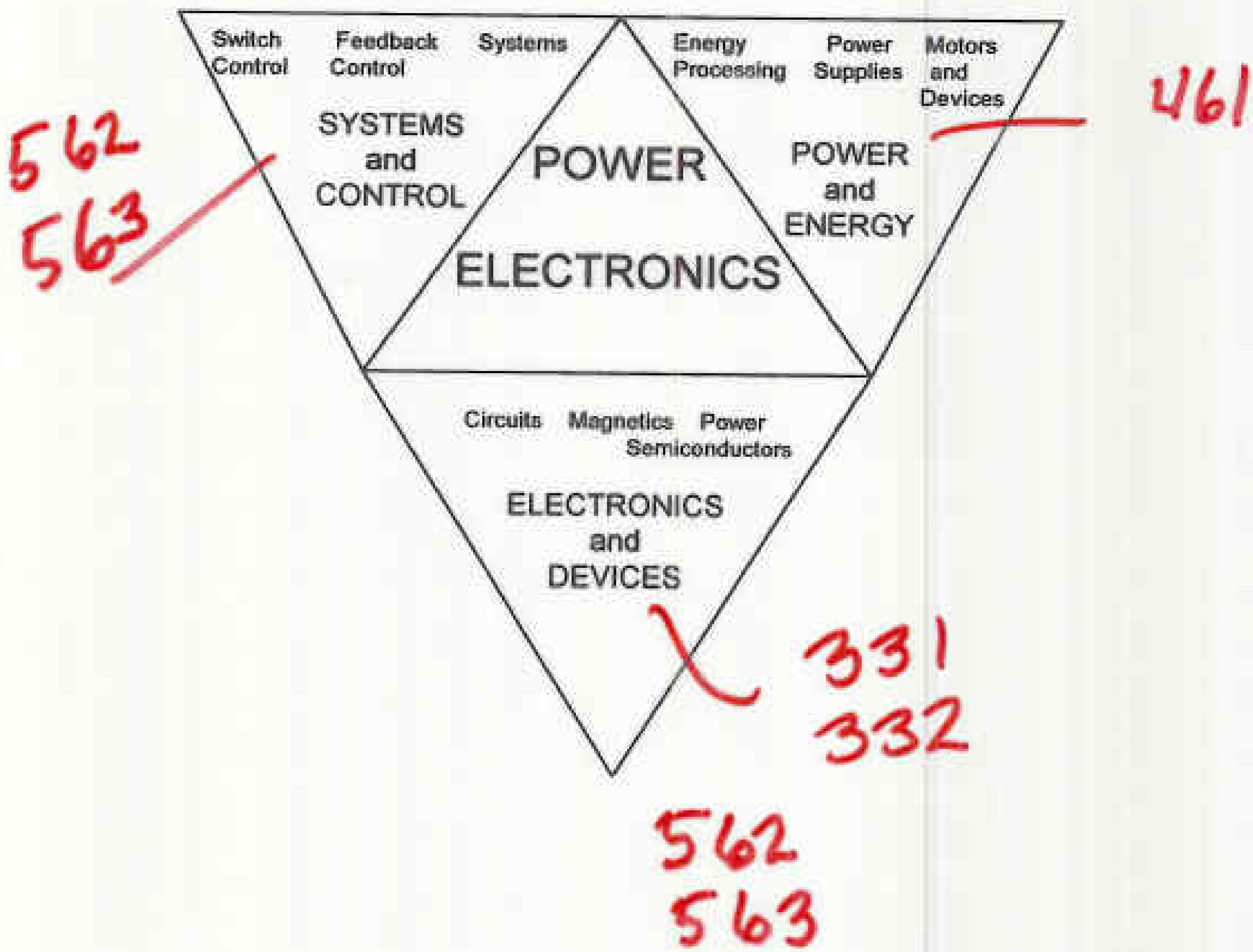
1.1 Introduction to Power Processing



Dc-dc conversion:	Change and control voltage magnitude
Ac-dc rectification:	Possibly control dc voltage, ac current
Dc-ac inversion:	Produce sinusoid of controllable magnitude and frequency
Ac-ac cycloconversion:	Change and control voltage magnitude and frequency

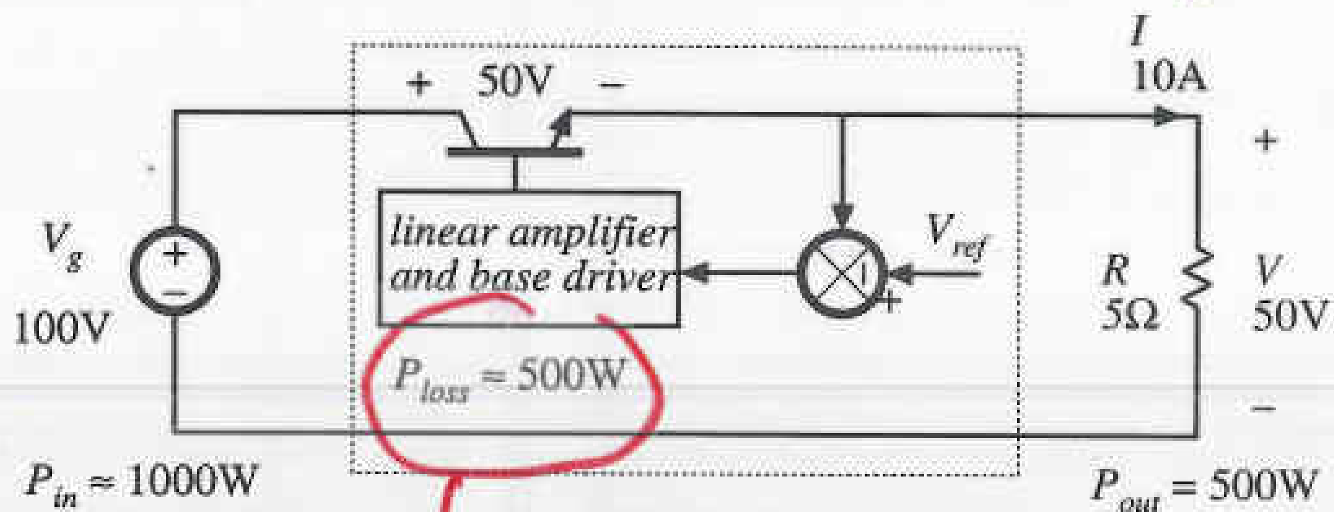
In reality actual efficiency values are 85% to 90% due to losses in the parasitics.
The switching regulator generates very high transients of the electric and magnetic fields at 200 kHz. This generates both conducted and radiated electromagnetic noise. This noise can be easily higher than the 5% tolerance window of the supply voltage 3.1 V for the Pentium. To avoid malfunction of the processor it is necessary to filter this noise for all conditions. Moreover, this noise must not pollute the ac mains.

Which regulator, Example 1 or 2 is a best choice for a laptop computer?



Dissipative realization

Series pass regulator: transistor operates in active region



Can we drop voltage w/o power loss?

Overview prior to reading text

Chapter 2
Principles of Steady-State Converter Analysis

2.1. Introduction

2.2. Inductor volt-second balance, capacitor charge balance, and the small ripple approximation

Today

2.3. Boost converter example

2.4. Cuk converter example

read for next class

2.5. Estimating the ripple in converters containing two-pole low-pass filters

2.6. Summary of key points

Ch 2

Objectives of this chapter

- Develop techniques for easily determining output voltage of an arbitrary converter circuit
- Derive the principles of *inductor volt-second balance* and *capacitor charge (amp-second) balance*
- Introduce the key *small ripple approximation*
- Develop simple methods for selecting filter element values
- Illustrate via examples

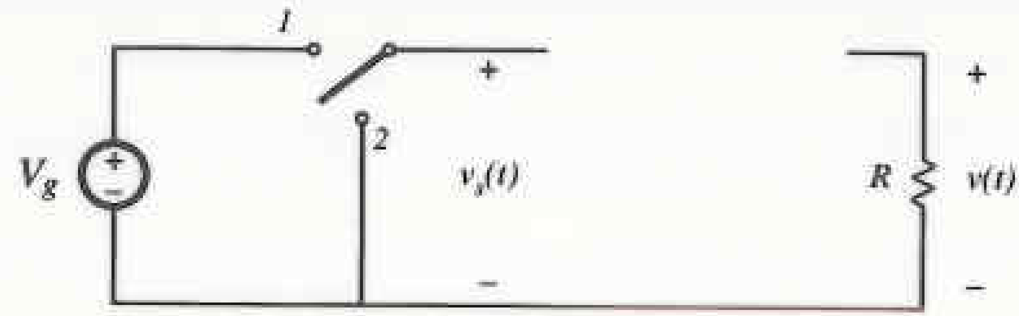
Choose L_{opt}

Choose C_{opt}

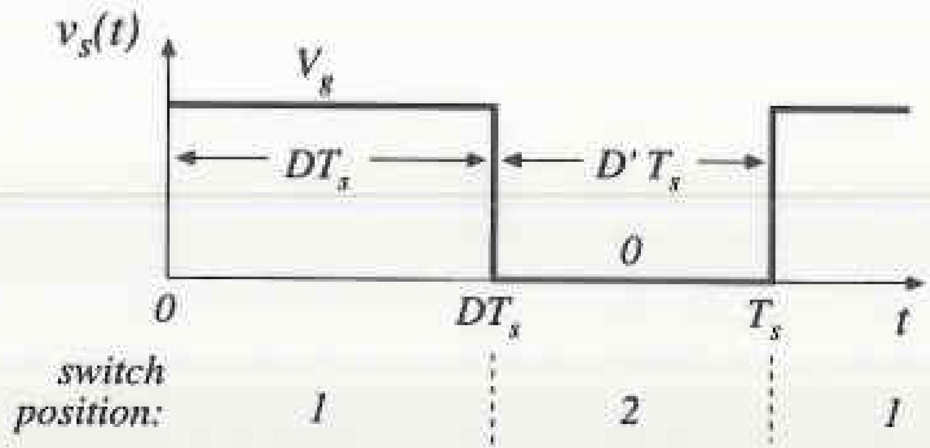
2.1 Introduction
Buck converter

Fig 2.1
Pg 13

SPDT switch changes dc component



Switch output voltage waveform



Duty cycle *D*:
$0 \le D \le 1$

complement D':
$D' = 1 - D$

Dc component of switch output voltage

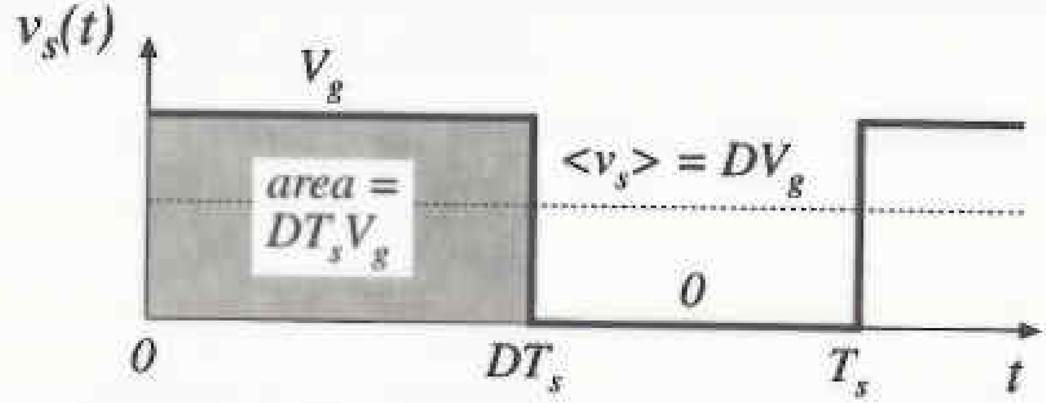


Fig 2.2
pg 14

Fourier analysis: Dc component = average value

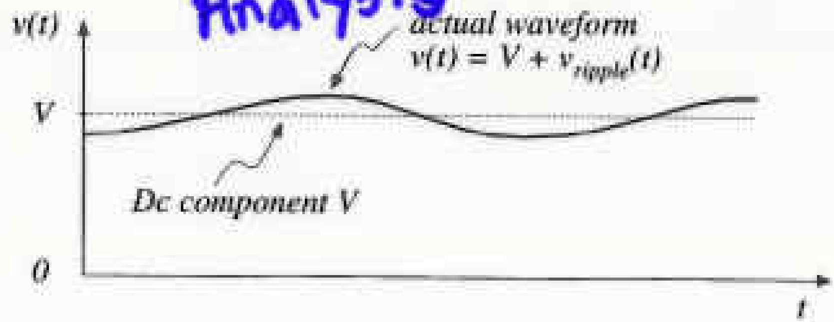
$$\langle v_s \rangle = \frac{1}{T_s}\int_0^{T_s} v_s(t)\, dt$$

$$\langle v_s \rangle = \frac{1}{T_s}(DT_s V_g) = DV_g$$

The small ripple approximation

Avoids ① Spice Transient Analysis ② Complex Analysis

$$v(t) = V + v_{ripple}(t)$$



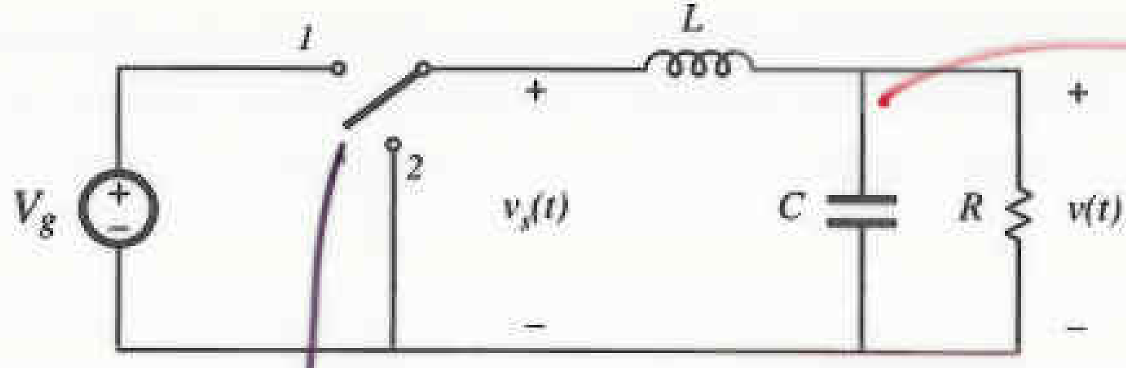
In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:

$$\left\| v_{ripple} \right\| << V$$

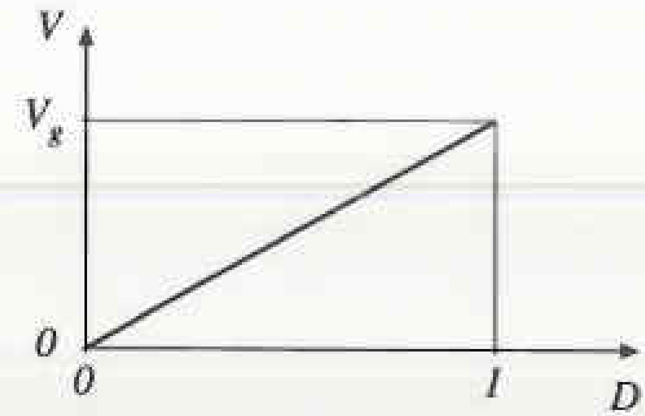
$$v(t) \approx V$$

Insertion of low-pass filter to remove switching harmonics and pass only dc component

f_{sw}
noise
ripple



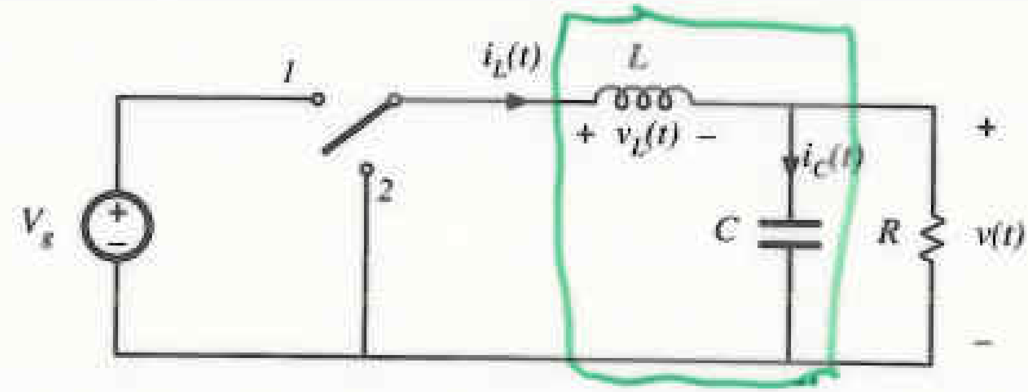
$$v \approx \langle v_s \rangle = DV_g$$



2.2. Inductor volt-second balance, capacitor charge balance, and the small ripple approximation

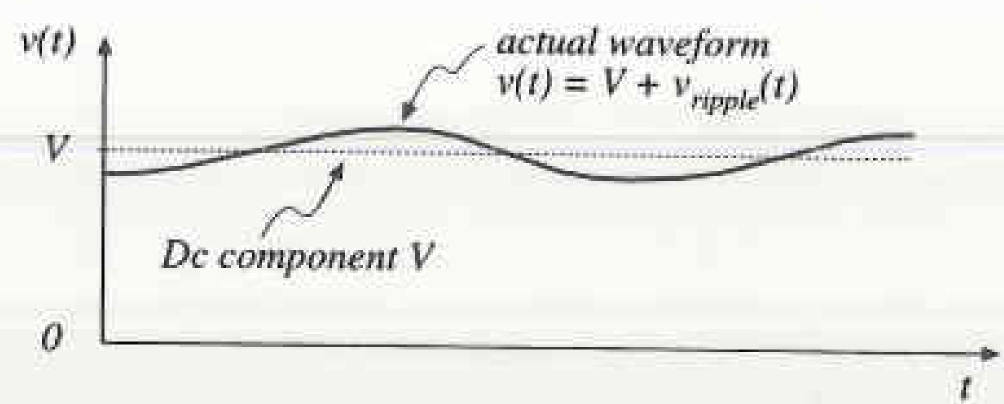
Actual output voltage waveform, buck converter

Buck converter containing practical low-pass filter



Actual output voltage waveform

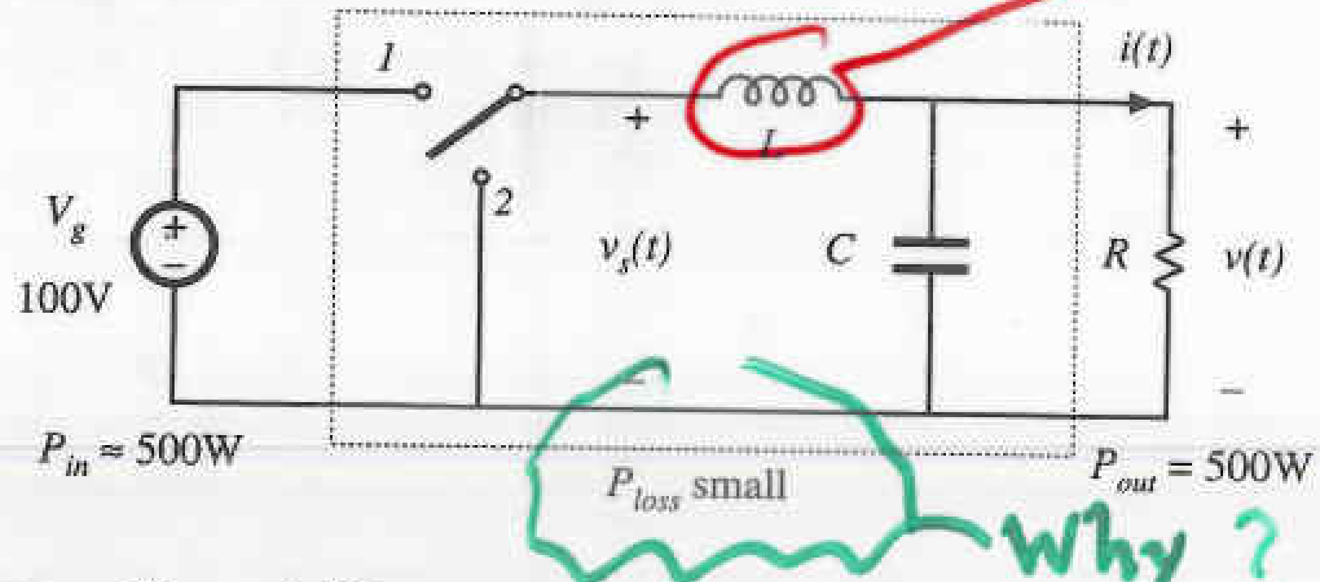
$v(t) = V + v_{ripple}(t)$



Addition of low pass filter

Role of L

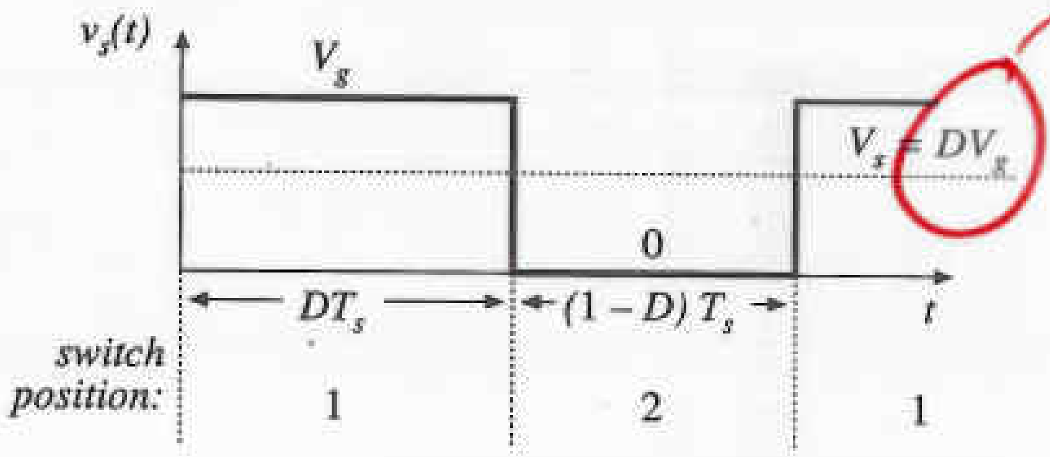
Addition of (ideally lossless) L-C low-pass filter, for removal of switching harmonics



- Choose filter cutoff frequency f_0 much smaller than switching frequency f_s
- This circuit is known as the "buck converter"

The switch changes the dc voltage level

$\neq f(f_{sw})$ why?



D = switch duty cycle
$0 \le D \le 1$

T_s = switching period

f_s = switching frequency
$= 1 / T_s$

$f_s \uparrow$ good why?

DC component of $v_s(t)$ = average value:

$$V_s = \frac{1}{T_s}\int_0^{T_s} v_s(t)\, dt = DV_g$$

z_c effects
z_L

Trf effects
Trend?

Control is invariably required

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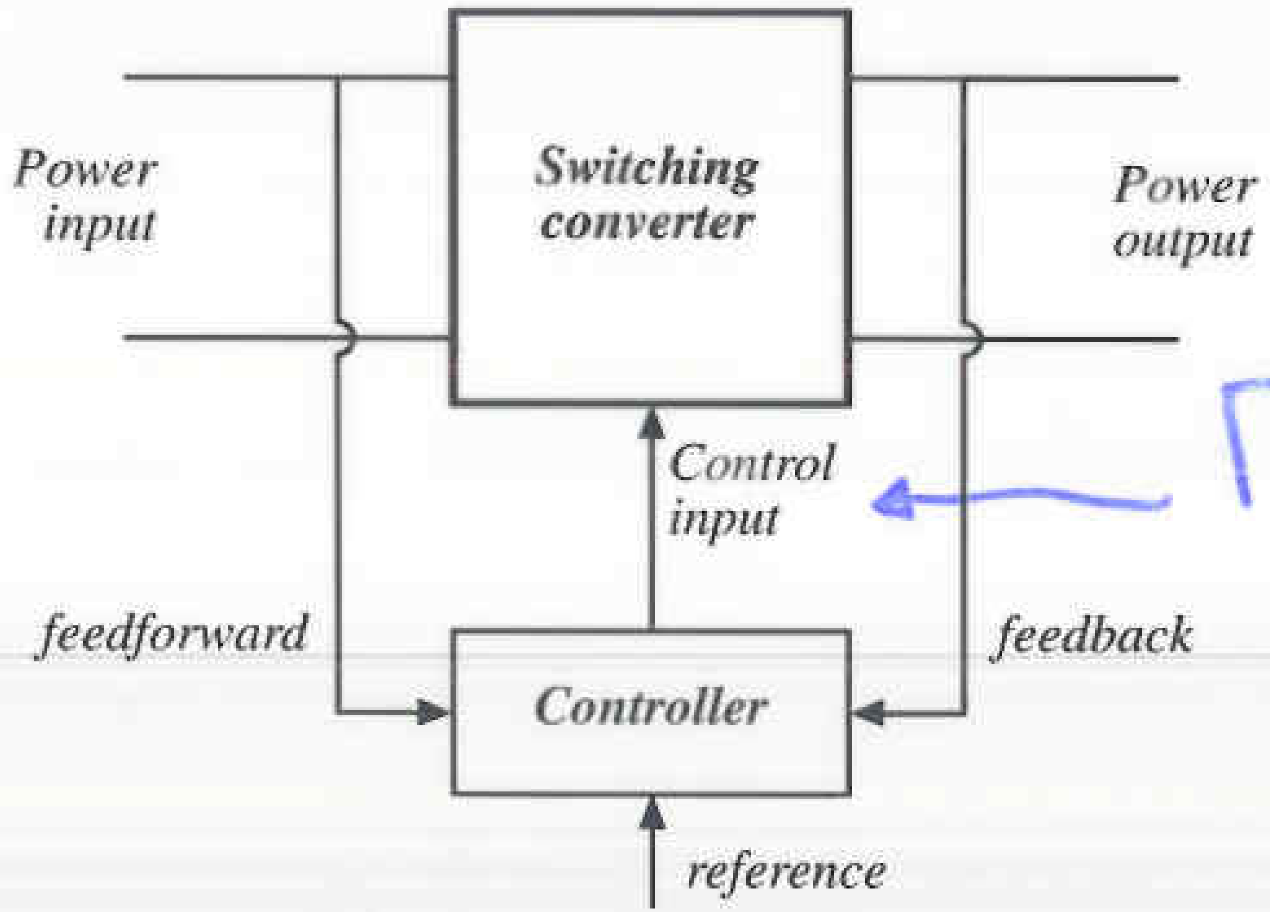
V_{out}, V_{in} } const during T_{sw}

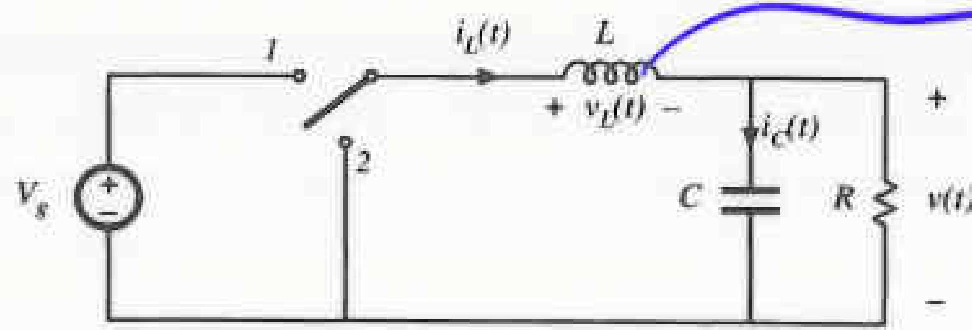


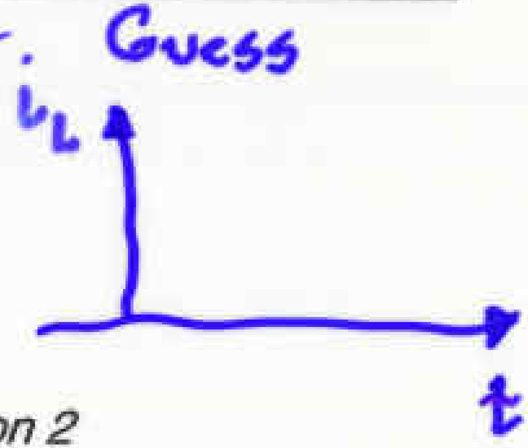
ON duty cycle "D"

Buck converter analysis: inductor current waveform

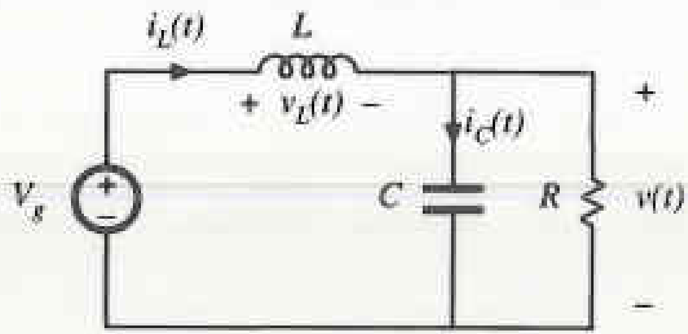
Fig 2.8
P 17

original converter

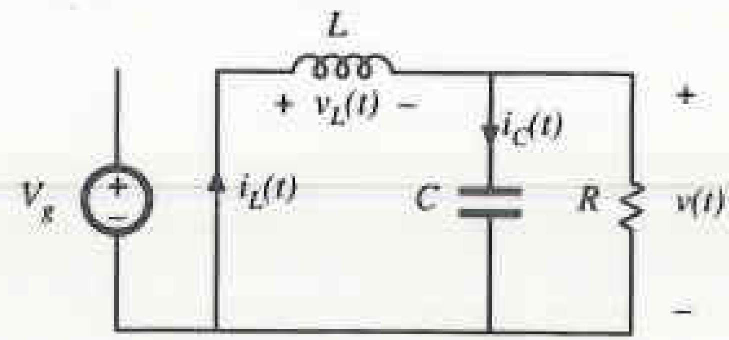




switch in position 1



switch in position 2



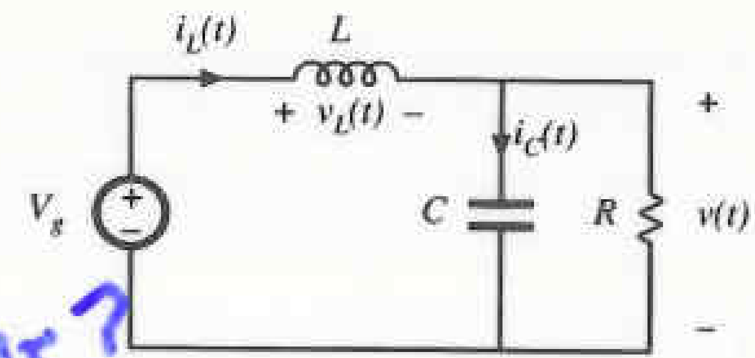
Inductor voltage and current
Subinterval 1: switch in position 1

Inductor voltage

$$v_L = V_g - v(t)$$

Small ripple approximation:

$$v_L \approx V_g - V$$ ≈ constant over?



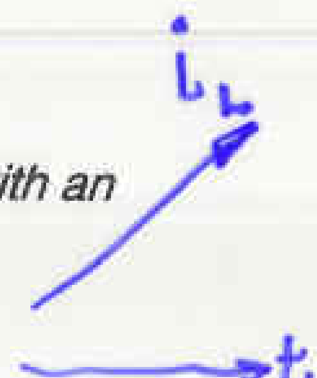
Knowing the inductor voltage, we can now find the inductor current via

$$v_L(t) = L\frac{di_L(t)}{dt}$$

Solve for the slope:

$$\frac{di_L(t)}{dt} = \frac{v_L(t)}{L} \approx \frac{V_g - V}{L}$$

⇒ *The inductor current changes with an essentially constant slope*



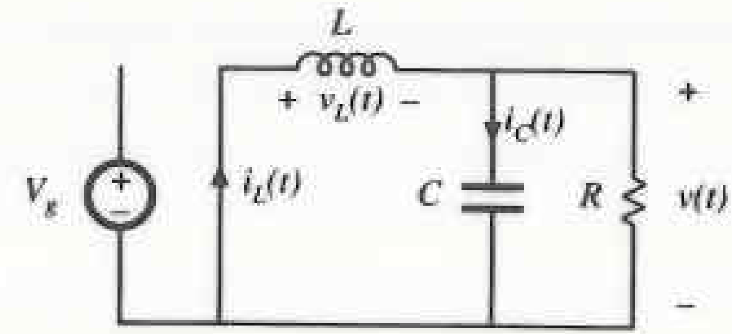
Inductor voltage and current Subinterval 2: switch in position 2

Inductor voltage

$$v_L(t) = -v(t)$$

Small ripple approximation:

$$v_L(t) \approx -V$$ Constant



Knowing the inductor voltage, we can again find the inductor current via

$$v_L(t) = L\frac{di_L(t)}{dt}$$

Solve for the slope:

$$\frac{di_L(t)}{dt} \approx -\frac{V}{L}$$

⇒ *The inductor current changes with an essentially constant slope*

i_L

Inductor voltage and current waveforms

Fig 2.9
2.10
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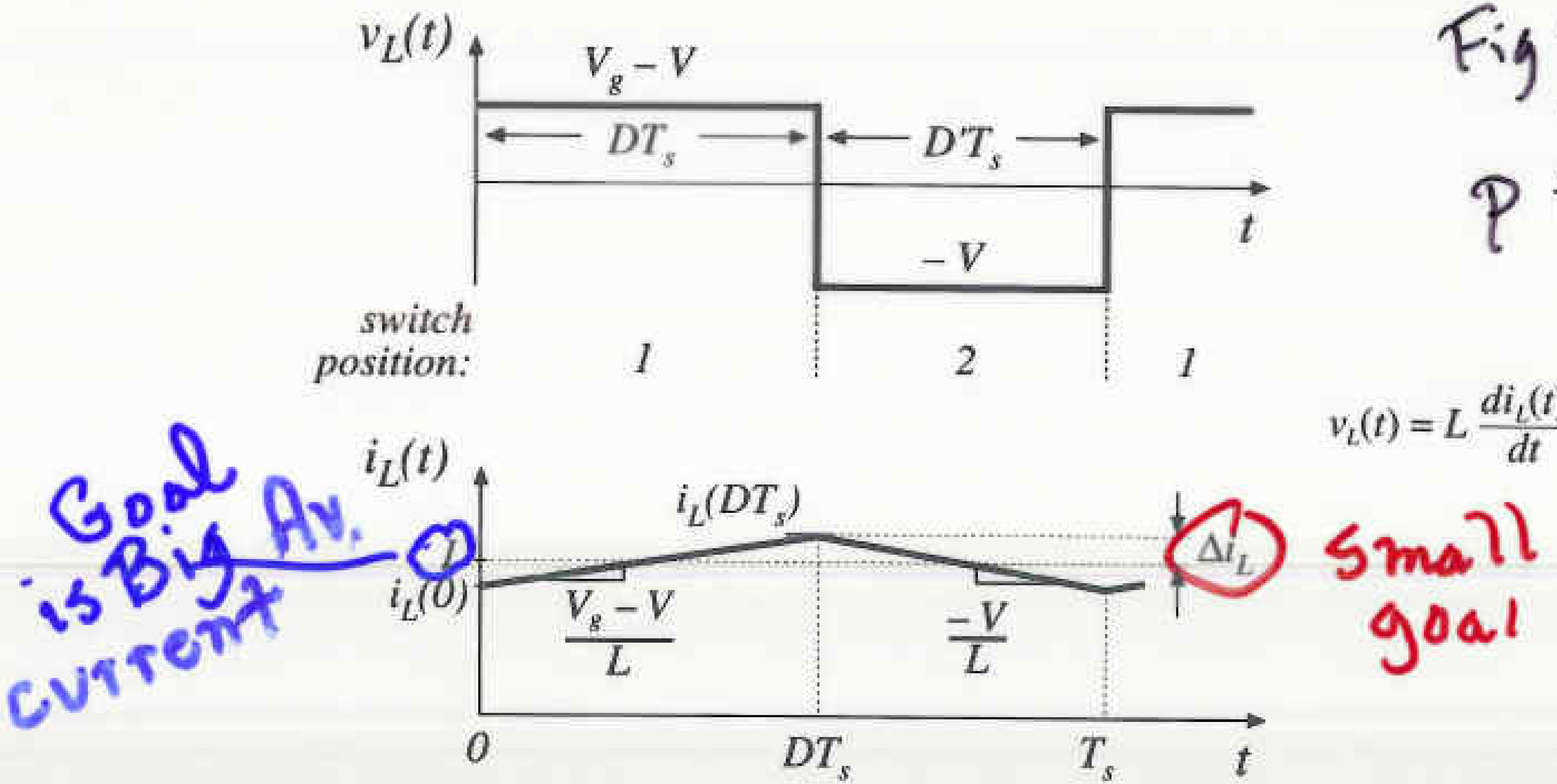
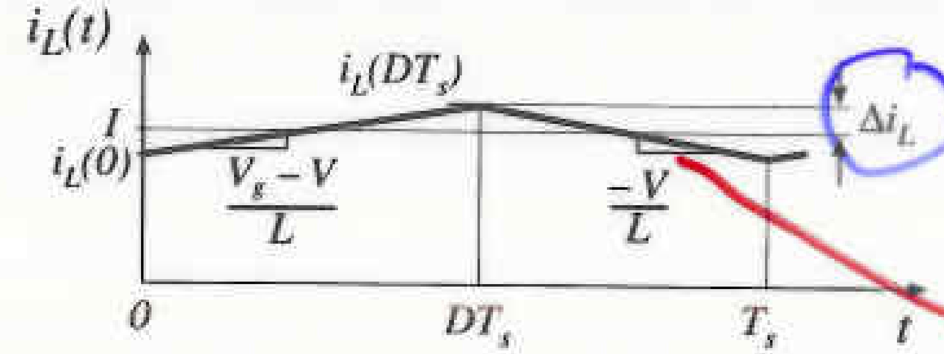


$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Determination of inductor current ripple magnitude



$$(change\ in\ i_L) = (slope)(length\ of\ subinterval)$$

$$\left(2\Delta i_L\right) = \left(\frac{V_g - V}{L}\right)\left(DT_s\right)$$

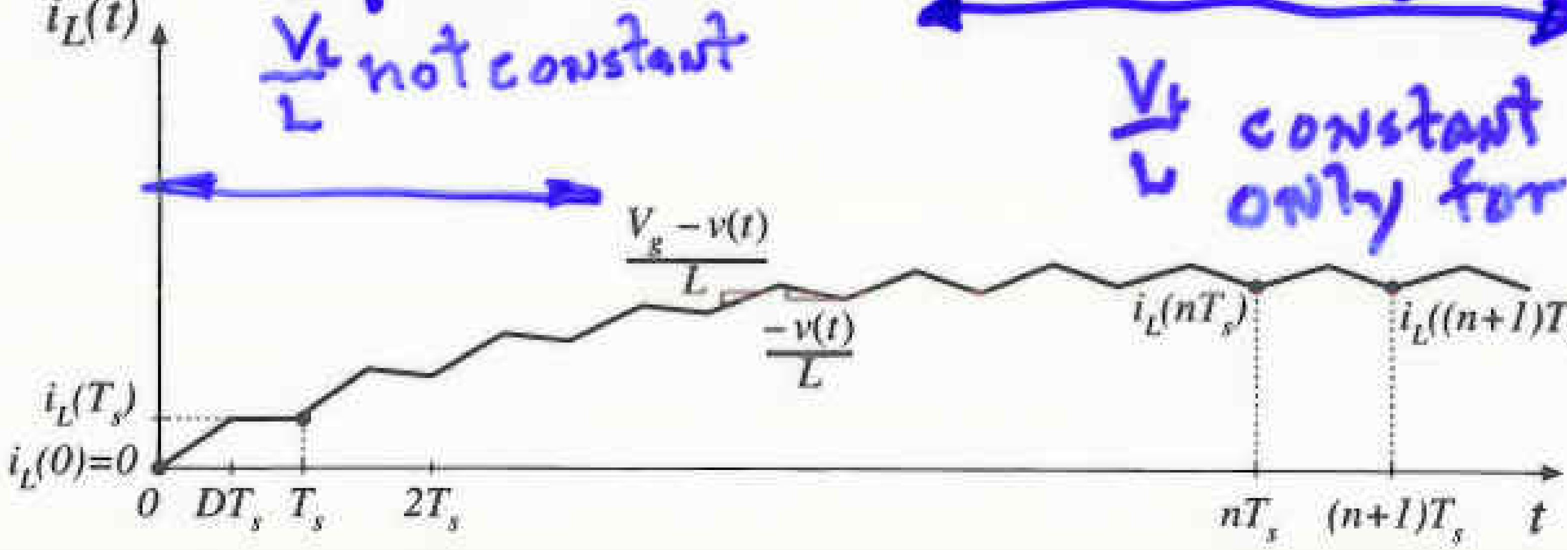
$$\Rightarrow \qquad \Delta i_L = \frac{V_g - V}{2L} DT_s \qquad\qquad L = \frac{V_g - V}{2\Delta i_L} DT_s$$

t_{ON} Sw1

Inductor current waveform during turn-on transient

Early time
Spice Lab
$\frac{V_L}{L}$ not constant

Spice
Small signal Approx
$\frac{V_L}{L}$ constant only for long t



When the converter operates in equilibrium:

$$i_L((n+1)T_s) = i_L(nT_s)$$

The principle of inductor volt-second balance: Derivation

Inductor defining relation:

$$v_L(t) = L\frac{di_L(t)}{dt}$$

Integrate over one complete switching period:

$$i_L(T_s) - i_L(0) = \frac{1}{L}\int_0^{T_s} v_L(t)\, dt$$

In periodic steady state, the net change in inductor current is zero:

$$0 = \int_0^{T_s} v_L(t)\, dt$$

Hence, the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state.

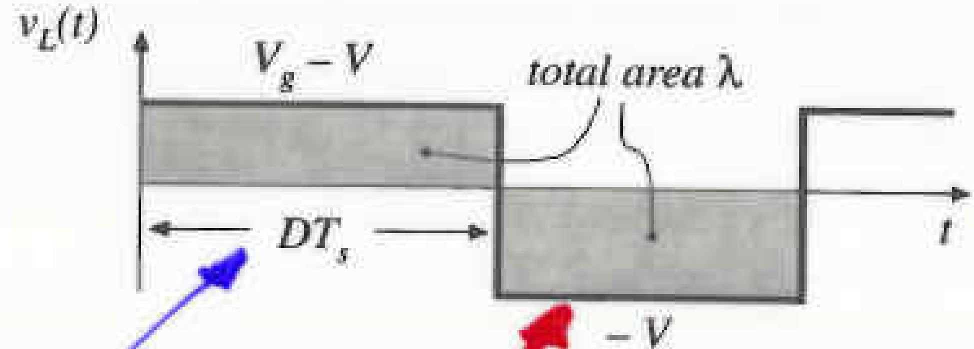
An equivalent form:

$$0 = \frac{1}{T_s}\int_0^{T_s} v_L(t)\, dt = \langle v_L \rangle$$

The average inductor voltage is zero in steady state.

Inductor volt-second balance: Buck converter example

Inductor voltage waveform, previously derived:



Integral of voltage waveform is area of rectangles:

$$\lambda = \int_0^{T_s} v_L(t)\, dt = (V_g - V)(DT_s) + (-V)(D'T_s)$$

Average voltage is SW 1 ON SW 2 ON

$$\langle v_L \rangle = \frac{\lambda}{T_s} = D(V_g - V) + D'(-V)$$

Equate to zero and solve for *V*:

$$0 = DV_g - (D + D')V = DV_g - V \qquad \Rightarrow \qquad V = DV_g$$

The "principle" of capacitor charge balance: Derivation

Capacitor defining relation:

$$i_C(t) = C\frac{dv_C(t)}{dt}$$

Integrate over one complete switching period:

$$v_C(T_s) - v_C(0) = \frac{1}{C}\int_0^{T_s} i_C(t)\, dt$$

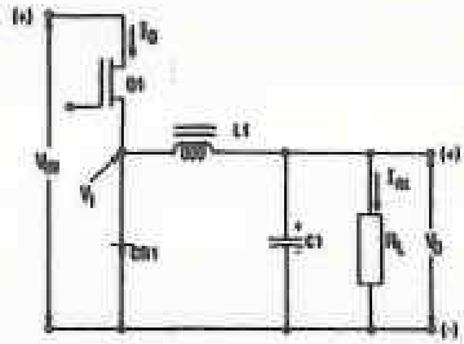
In periodic steady state, the net change in capacitor voltage is zero:

$$0 = \frac{1}{T_s}\int_0^{T_s} i_C(t)\, dt = \langle i_C \rangle$$

Hence, the total area (or charge) under the capacitor current waveform is zero whenever the converter operates in steady state. The average capacitor current is then zero.

TYPE OF CONVERTER Buck (Step Down)

CIRCUIT CONFIGURATION



IDEAL TRANSFER FUNCTION $\frac{V_O}{V_{IN}} = \frac{t_{on}}{T_S} = D$

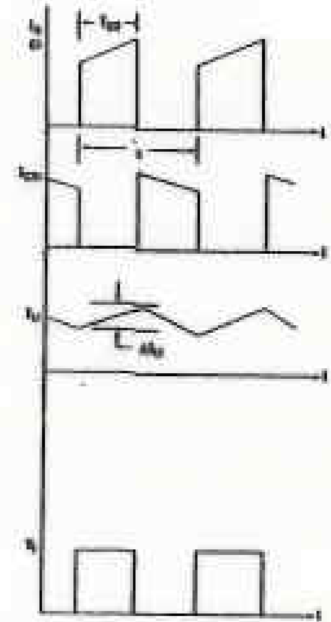
PEAK DRAIN CURRENT • $I_{DMAX} = I_{RL} + \frac{\Delta I_{L1}}{2}$

PEAK DRAIN VOLTAGE • $V_{DS} = V_{IN} + V_D$

AVERAGE DIODE CURRENTS • $I_{CR1} = I_{RL}\ (1\text{-}D)$

DIODE VOLTAGES (VRM) • $V_{RM} = V_{IN}$

VOLTAGE AND CURRENT WAVEFORMS



ADVANTAGES High efficiency, simple, no transformer, low switch stress. Small output filter, low ripple.

DISADVANTAGES No isolation betwen input and output. Potential over-voltage if Q1 sorts. Only one output possible. High-side switch dive required. High input ripple current.

TYPICAL APPLICATIONS Small size, imbeddd systems.

APPLICABLE HARRIS PRODUCTS HIP5600 w/P-IGBT For off line CKTS.

TYPE OF CONVERTER

Buck (Step Down)

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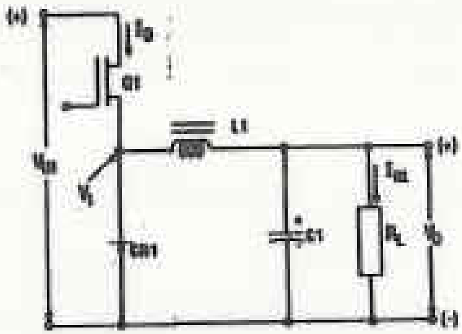

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AVERAGE DIODE CURRENTS

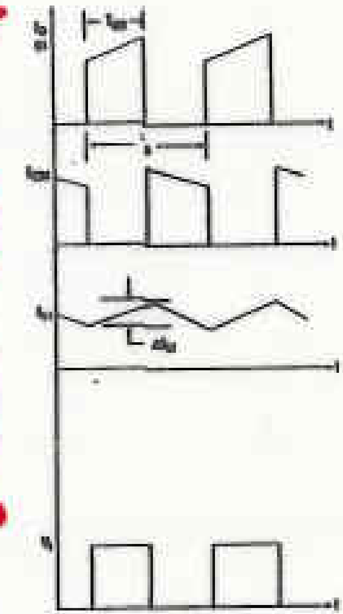
$$I_{CR1} = I_{RL}\,(1-D)$$

DIODE VOLTAGES (VRM)

$$V_{RM} = V_{IN}$$

VOLTAGE AND CURRENT WAVEFORMS

PSpice Simulation Lab #1



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