ECE 562

Exam 1 review

Fall 2008

Exam 1 review
Summary

- Section notes
  - Slides 3-14 -Considerations in choosing power devices
  - Slides 15-23 – Power device market trends
  - Slides 24-28– Buck-Boost review
  - Slides 29-34 – Converter efficiency
  - Slides 35-42 – Commercial devices
  - Slides 42-44– Review
  - Slides 45-50 – Synchronous converters
  - Slides 51-61 – Buck-Boost review
  - Slides 62-74 – Noise, EMC/EMI and overview

Architectural Trade-Offs: When do you use--

- A linear solution?
  - Linear
  - LDO
  - Controller
- An inductive-based Switcher?
  - Controller
  - Synchronous
  - Asynchronous
  - Multi-phase
- A switched capacitor converter?

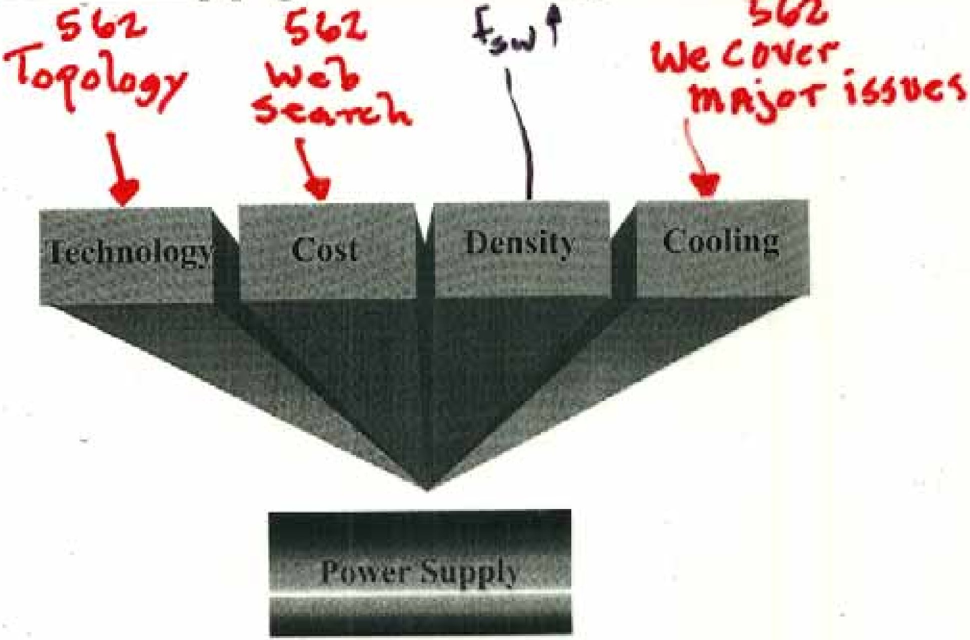
Architectural Trade-Offs: When do you use--

- **A linear solution?** (η<70%)
  - When simplicity and low-cost are key
  - When you have power to burn
    - Low currents
    - Low input V to output V differential
  - When you need noise isolation

Architectural Trade-Offs: When do you use--

- **An inductive-based Switcher?** $(60\% < \eta < 97\%)$
  - When conversion efficiency is needed
    - Heat concerns
    - Battery life
    - System reliability
  - For maximum power density where $I > 1A$

Power Supply Technology Drivers



Applications

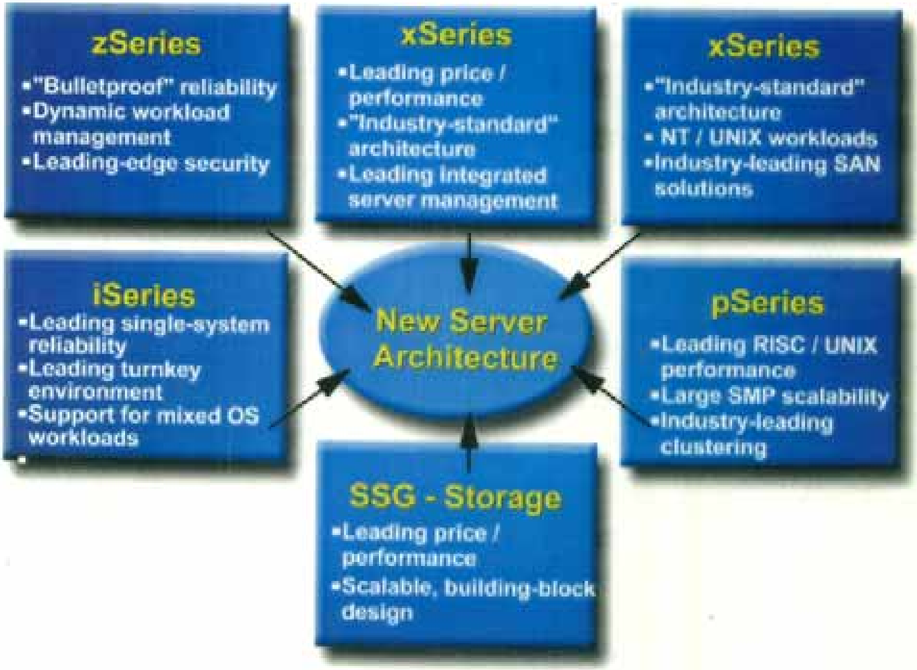
- **Line-Powered**
  - Computing systems
  - Automotive
  - Office automation
    - Printers
    - Scanners
    - Etc.
  - Consumer appliances
    - Set-Top Box
    - Audio-Video systems
  - Industrial applications
    - Process control
    - Data acquisition
    - Etc.

- **Battery-Powered**
  - Wireless
    - Mobile phones
    - Pagers
  - PDAs
    - Palm Pilots
    - Palm Computers
  - Cameras
  - Computing
  - Consumer appliances
    - Video recorders
    - MP3
    - DVD

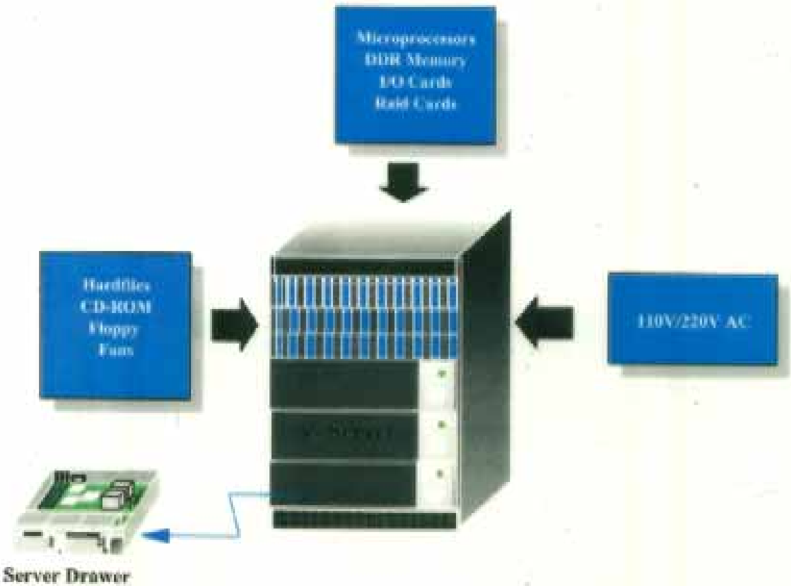
different customers

unique demands

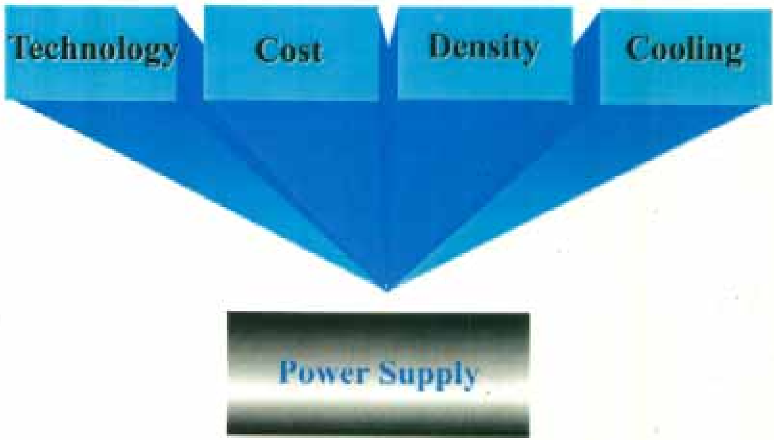
IBM Servers: Hardware Integration



Typical Server Application

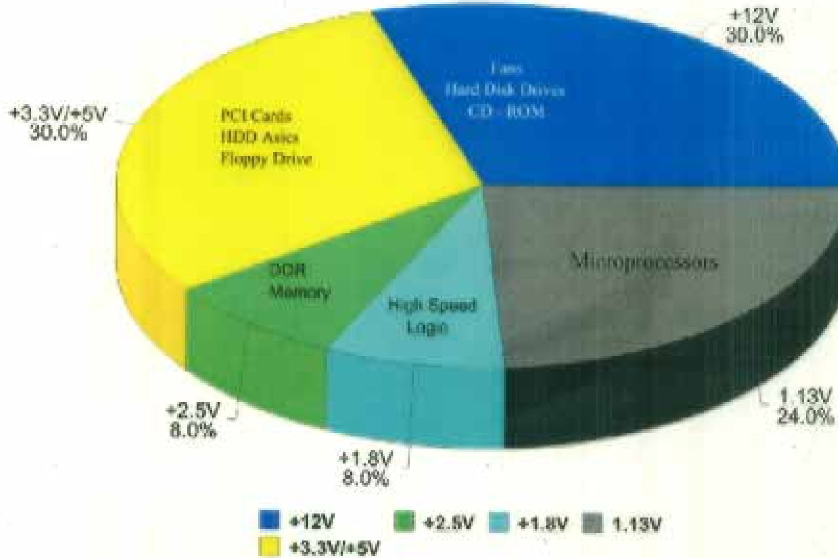


Power Supply Technology Drivers

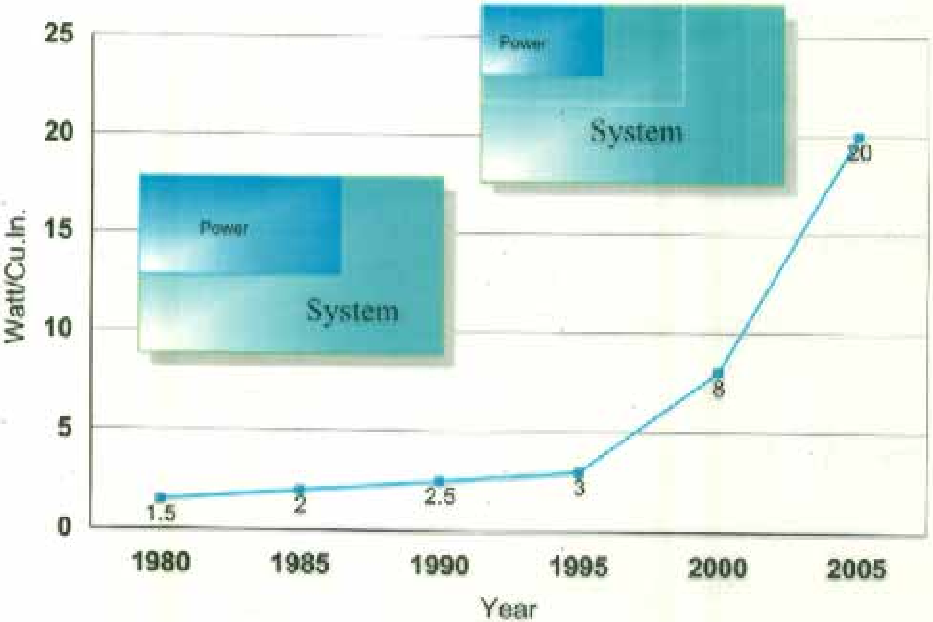


System Power Distribution

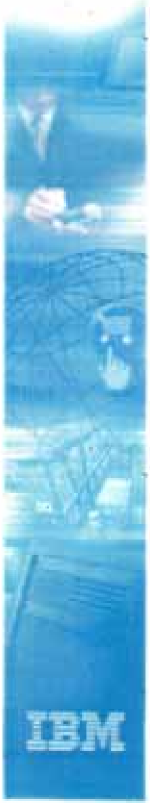
Why 12V?



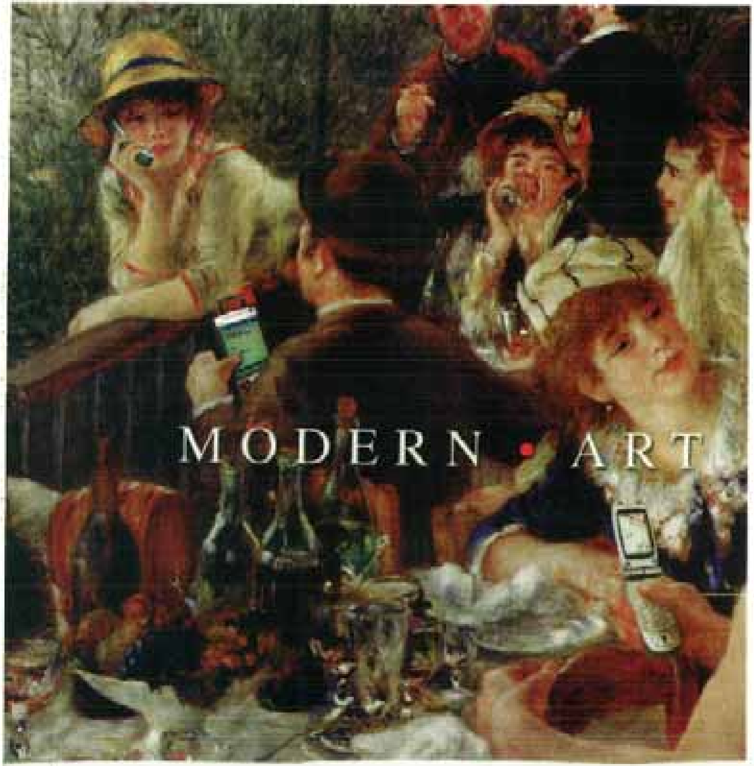
Power Density Trend



Power Architectures



CLASS	ARCHITECTURES
Mobile	▪ Battery Technology Main Power Source ▪ Efficient DC/DC Converters & Power Management
Low End	▪ Centralized Power Supply ▪ Point-Of-Load Regulator (uP or Memory)
Mid-Range	▪ Centralized Power Supply * Point-Of-Load Regulator (uP or Memory) * DC/DC Regulators Imbedded in PS ▪ Fully Distributed Power Supply * +12V Bus Voltage * +12V Input DC/DC ▪ Telco (-48V) Version
High End	▪ Fully Distributed Power Supply * +350V Bus Voltage * +350V Input DC/DC ▪ Fully Distributed Power Supply * +48V Bus Voltage * +48V Input DC/DC

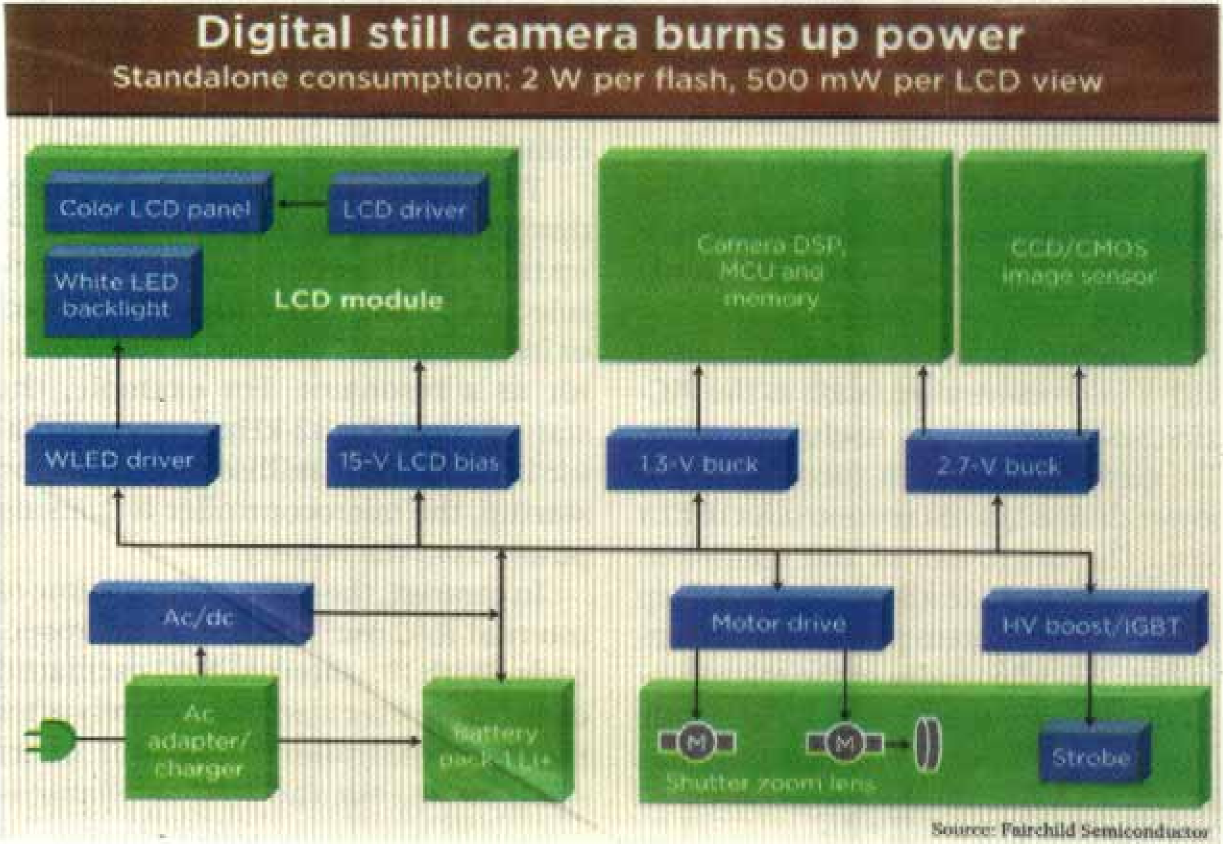

MODERN • ART

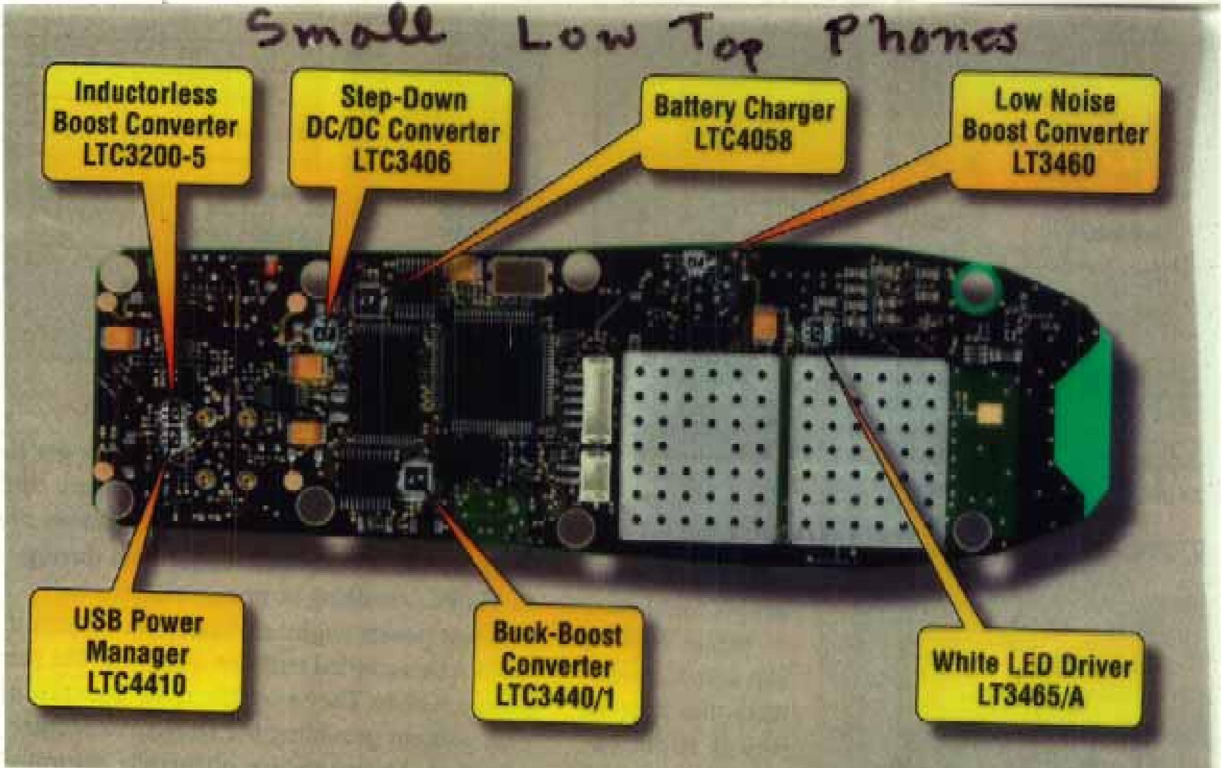
Power Management Market Drivers[1]

- **Growth Drivers**
  - 1. Demand for higher-efficiency portable electronics
  - 2. *42V Automotive power*
  - 3. Need for greener products
  - 4. Adoption of power management standards
  - 5. Growth in telecom and computer applications
- **I.C. Technical/Feature Trends**
  - 1. Lower quiescent current
  - 2. Tighter tolerances
  - 3. Switchers will replace some linear solutions
  - 4. Integrated switchers will grow faster than controllers for <4A
  - Increased use of synchronous rectification

[1] Venture Development Corp.

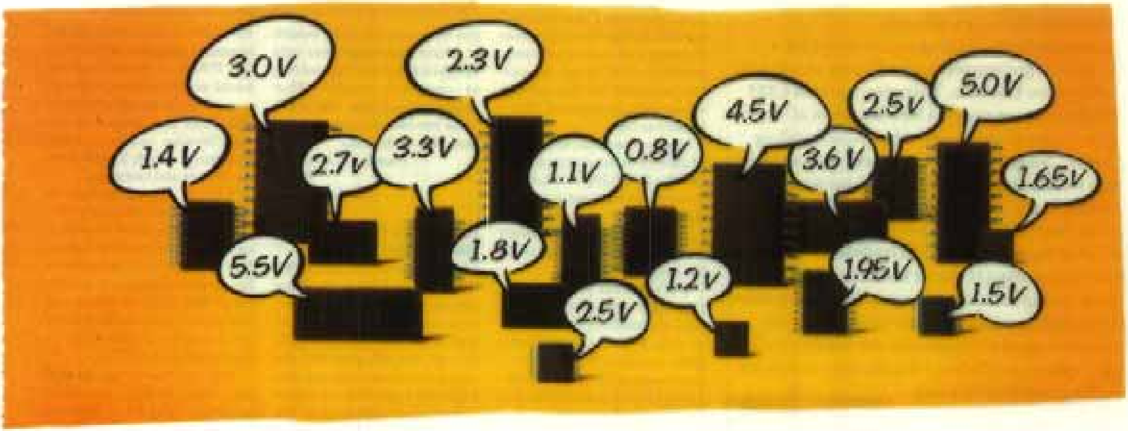
even "portable" draws power



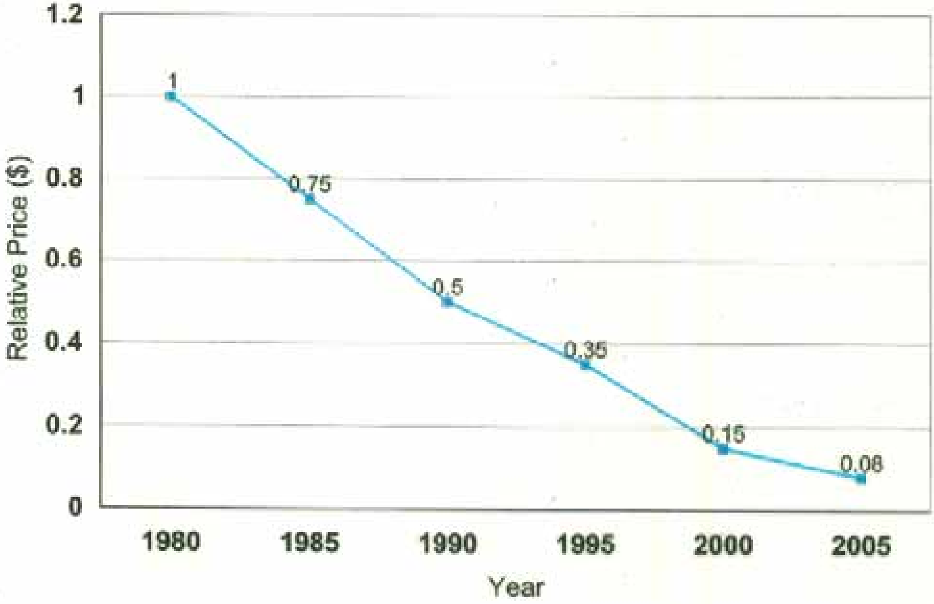


Tiny & Efficient Power Solutions for Handheld Products

Ch 2 3 Ch 4

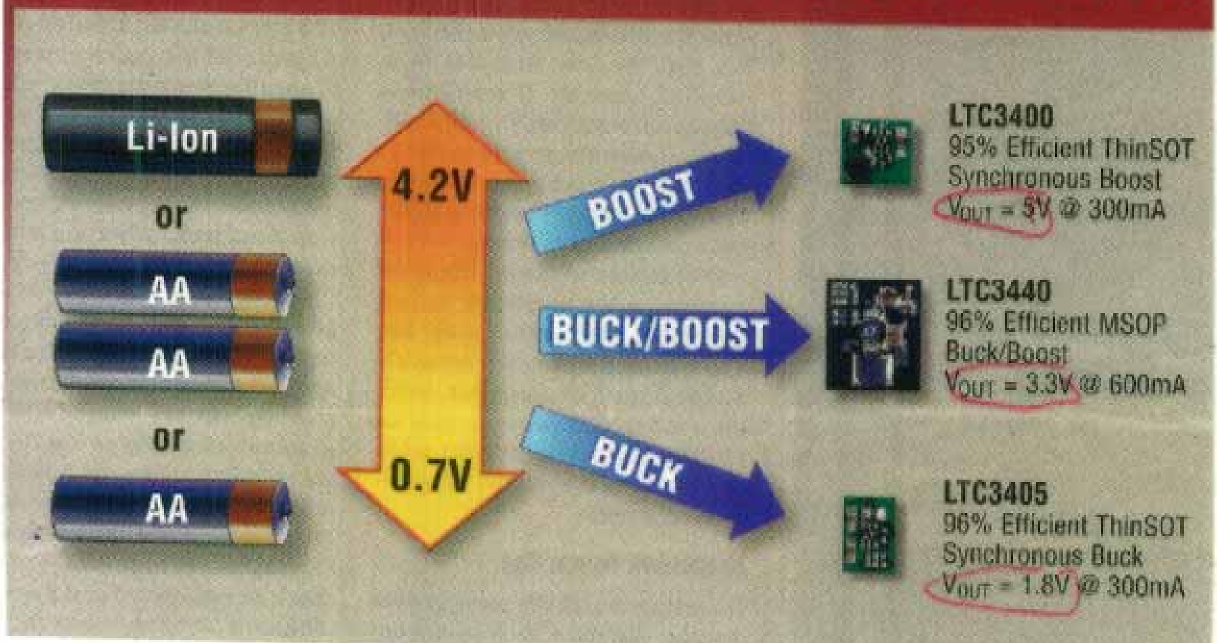

3.0V
2.3V
4.5V
2.5V
5.0V
1.4V
2.7V
3.3V
1.1V
0.8V
3.6V
1.65V
5.5V
1.8V
2.5V
1.2V
1.95V
1.5V

Price Trend



1.2
1
0.8
0.6
0.4
0.2
0
Relative Price ($)
1
0.75
0.5
0.35
0.15
0.08
1980
1985
1990
1995
2000
2005
Year

95% Efficient DC/DC Converters

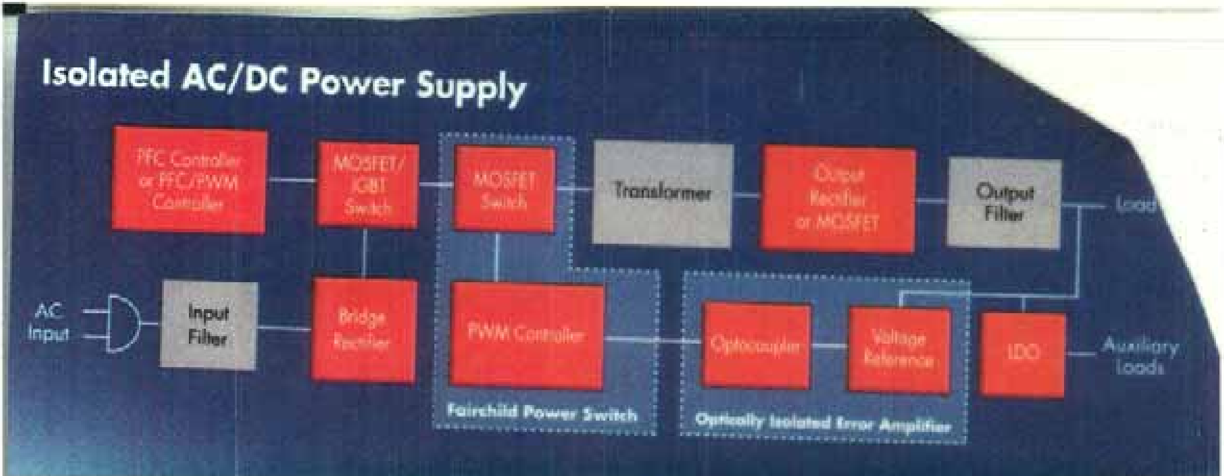


1mm Tall Power ICs Shrink Handheld Products

Entry Level Engineer Expectations

	Proficiency
✓ Switching power supply technology	4
✓ Analog circuit design and analysis techniques	3
✓ Understanding of magnetics	3
✓ Simulation skills • Basic understanding	3
✓ Communication skills • Written • Oral	5
✓ Teamwork experience and skills	5

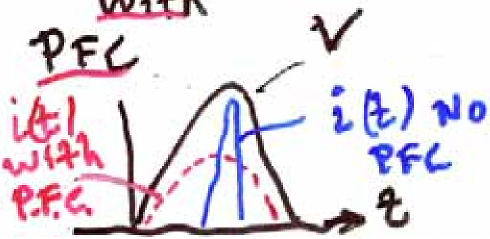
Talks / Papers



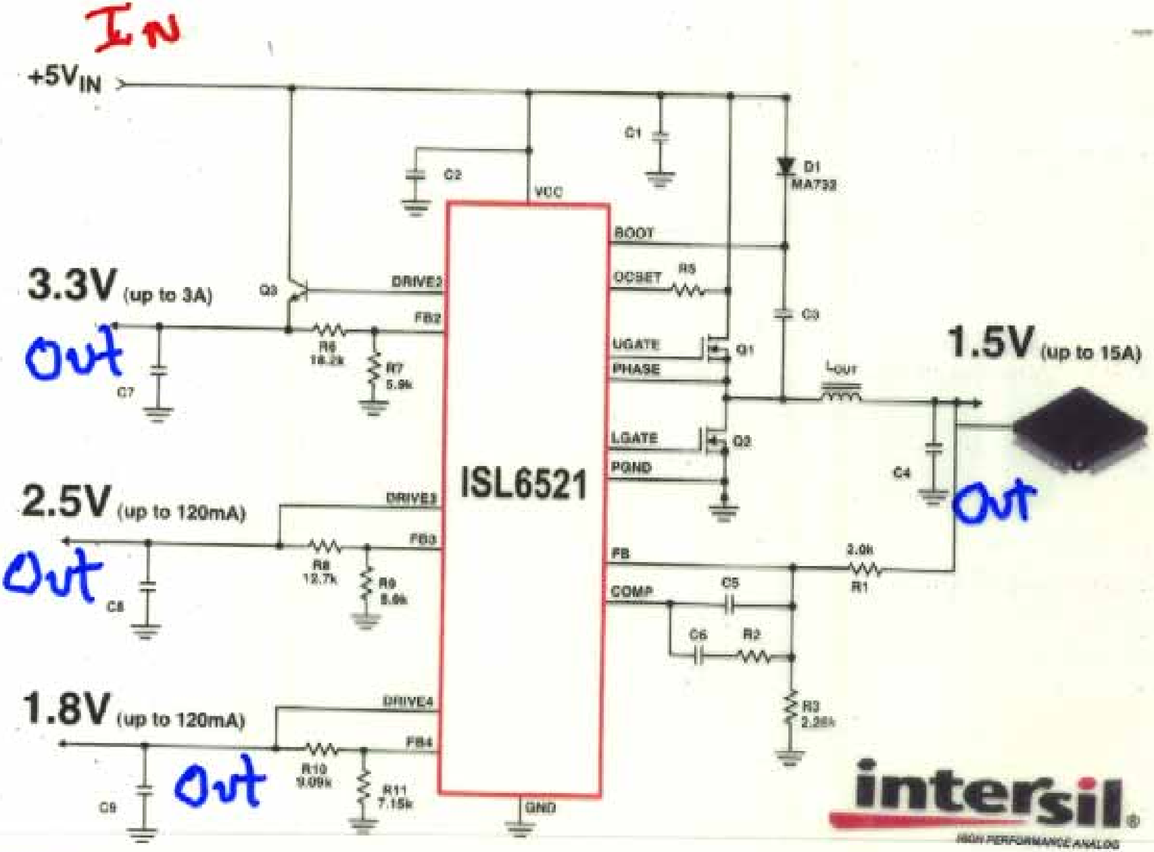
AC → DC rectification with PFC

Inverter making □-waves

AC - DC PWM Rectifing via big L



resonant converter via rectifers



IN
+5V IN
3.3V (up to 3A)
Out
2.5V (up to 120mA)
Out
1.8V (up to 120mA)
Out
1.5V (up to 15A)
Out
ISL6521
VCC
BOOT
OCSET
UGATE
PHASE
LGATE
PGND
FB
COMP
GND
DRIVE2
FB2
DRIVE3
FB3
DRIVE4
FB4
C1
C2
C3
C4
C5
C6
C7
C8
C9
D1
MA732
Q1
Q2
Q3
R1
R2
R3
2.26k
R5
R6
16.2k
R7
5.9k
R8
12.7k
R9
5.6k
R10
9.09k
R11
7.15k
L OUT
intersil

Three basic dc-dc converters

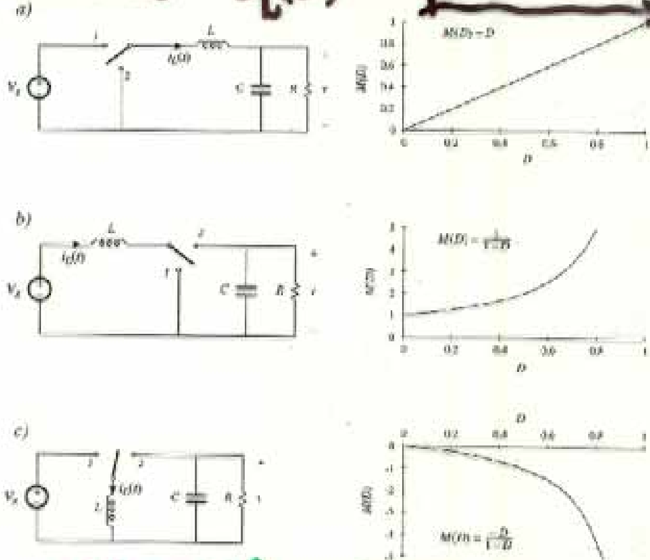
Fig 2.5 P16

All have $i_L(t)$

Buck
down

Boost
up

Buck-boost
either way



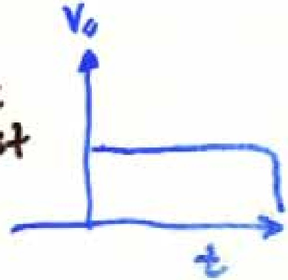
Pbm 2.1
3.8

exam review

Review

V_{IN} (DC) — Buck — $V_0 < V_{IN}$
Boost — $V_0 > V_{IN}$
Buck-Boost

— Buck Boost



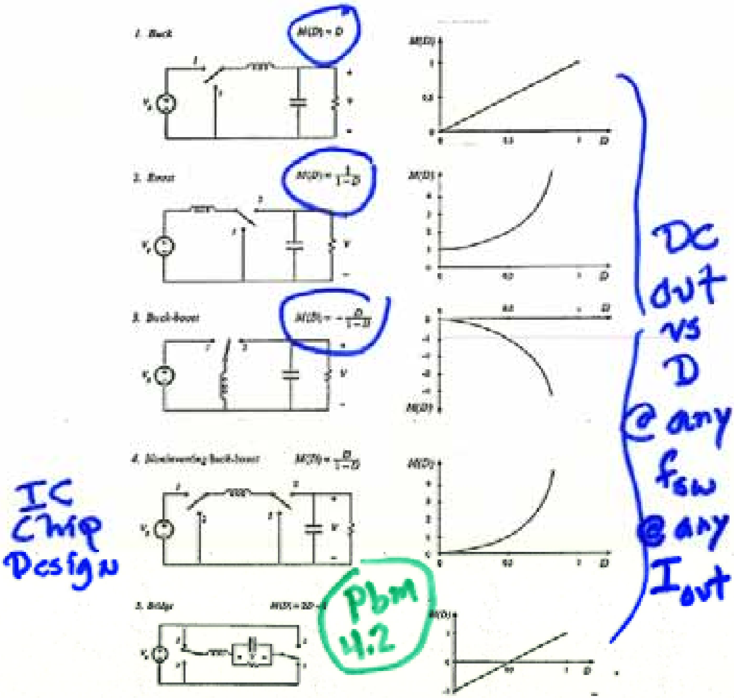
Linear Regulator (L.R.) : LDO
Use as $\Delta i / \Delta v$ ripple killer

V_{IN} — drop $10\% \, V_{IN}$ — V_{out} $\eta = 90\%$

Buck drop $90\% \, V_{IN}$ — V_{out} $\eta = 90\%$

I. Summary - PWM single inductor converters

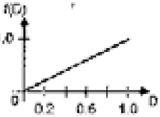
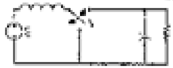
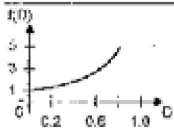
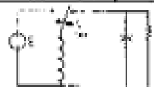
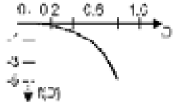
A. Eight circuit topologies and DC transfer functions M(D) where $M(D) = V_o/V_g = f(D)$. Its crucial to emphasize that we assume LOSS LESS CIRCUITS BELOW.



if $D = \frac{1}{2} + D_m \sin \omega t$

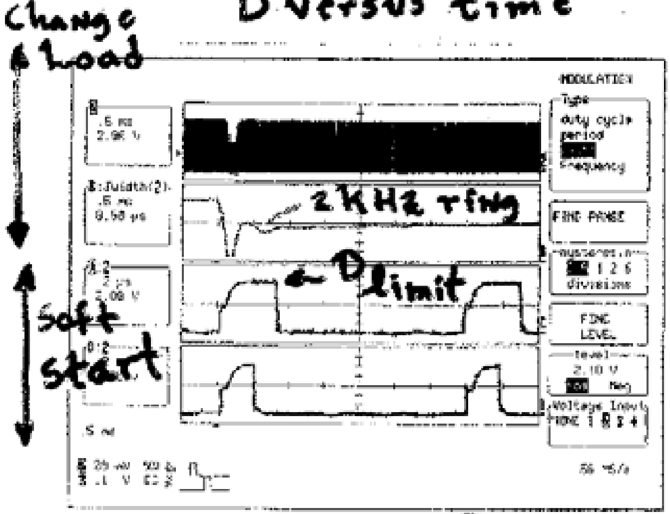
DC to AC Converter!

SIMPLE SWITCH MODE CONVERTERS

 BUCK The buck is limited in that $V_{out} < V_s$ only		$V_L = V_s$ or $V_{DC} - V_s$ •f(D)=D •Never get negative output •V_o(min) = 0
 BOOST The boost is limited in that $V_{out} > V_s$ only		•f(D)=1/(1-D) •Never get zero output: V_o(min) ≠ 0 $V_L = V_{DC} - V_s$ or V_s
 BUCK-BOOST The buck-boost is limited to negative voltages		•f(D)=-D/(1-D) •Inverting output w.r.t. V_s $V_L = V_s = -V_{DC}$ for D = ½

4. UNSYMMETRIC I_L AND v_C WAVEFORMS OF EQUAL INTEGRATED AREA IN THE ABOVE THREE CONVERTERS

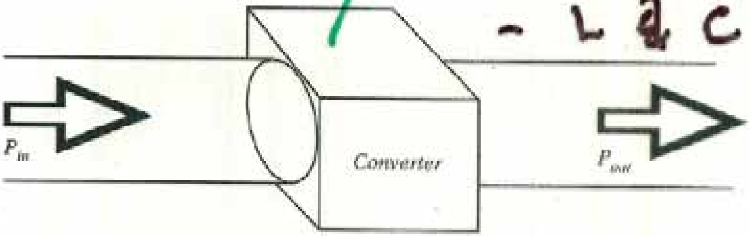
Transient Load Preformance D versus time



As seen on a LeCroy LT344L DSO, Trace 1 shows gate drive pulses over a 5-millisecond period that includes the transition from maximum to minimum load. Trace 2 displays Modulation Analysis that presents a record of each pulse width on the Y-axis. Traces 3 and 4 show individual gate drive pulses at full load and during recovery to minimum load, respectively.

A high-efficiency converter

PWM Contains ?
~ switches
~ L & C

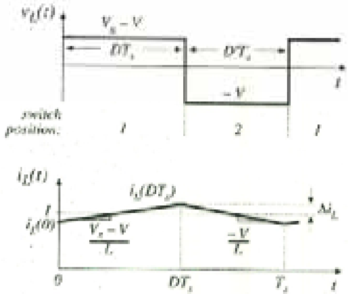


A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

why

Part I. Converters in equilibrium

Inductor waveforms



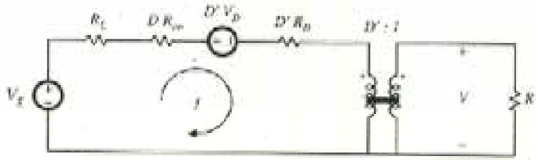
$\Delta i \sim \frac{1}{L}$ is key

Discontinuous conduction mode

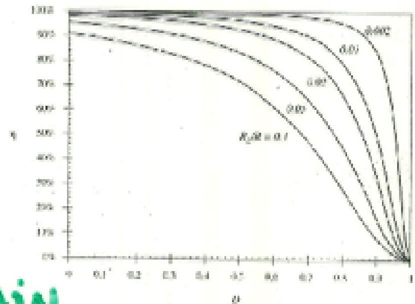
← explain

Transformer isolation

Averaged equivalent circuit

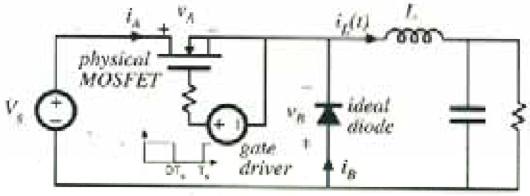


Predicted efficiency



4.3.1. Transistor switching with clamped inductive load

? real ?

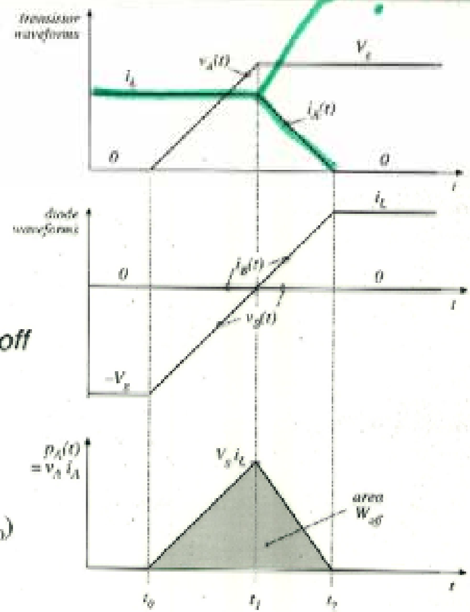


Buck converter example

$$v_B(t) = v_A(t) - V_g$$
$$i_A(t) + i_B(t) = i_L$$

transistor turn-off transition

$$W_{off} = \frac{1}{2} V_g i_L (t_2 - t_0)$$



Switching loss induced by transistor turn-off transition

Energy lost during transistor turn-off transition:

$$W_{off} = \frac{1}{2} V_g i_L (t_2 - t_0)$$

Similar result during transistor turn-on transition.
Average power loss:

$$P_{sw} = \frac{1}{T_s} \int_{\substack{switching \\ transitions}} p_A(t)\, dt = (W_{on} + W_{off})\, f_s$$

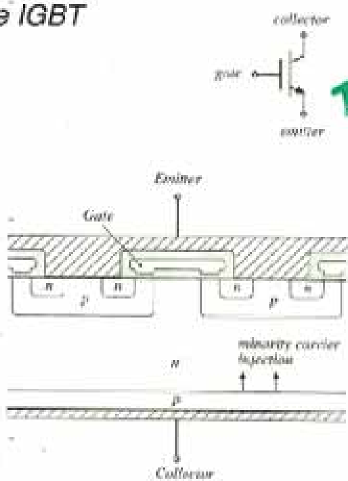
Joules

Switch realization: semiconductor devices

Explain Shootthrough loss

Q cycle is off → on

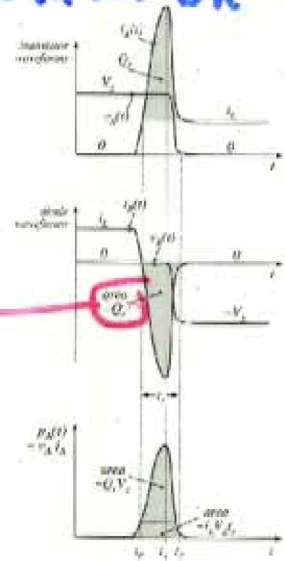
The IGBT



D cycle is on → off

Switching loss

Role of Q_{rr}



Sw Losses limit f_{max}

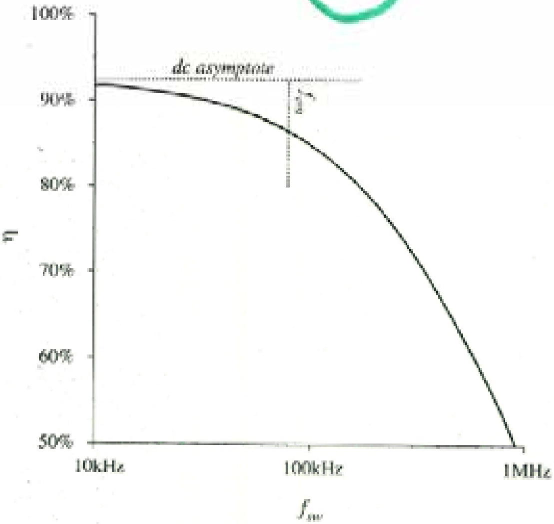
output switch → $E_{sw} f_{sw} = P$ (switch input)

input switch → $C_g V_g^2 f_{sw} = P$ (input sw)

Efficiency vs. switching frequency

be able to explain W_{tot} (switch) R load L load

$$P_{loss} = P_{cond} + P_{fixed} + W_{tot} f_{sw}$$

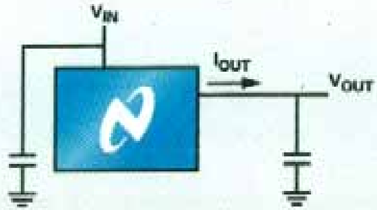


Switching losses are equal to the other converter losses at the critical frequency

$$f_{crit} = \frac{P_{cond} + P_{fixed}}{W_{tot}}$$

This can be taken as a rough upper limit on the switching frequency of a practical converter. For $f_{sw} > f_{crit}$, the efficiency decreases rapidly with frequency.

Linear regulator



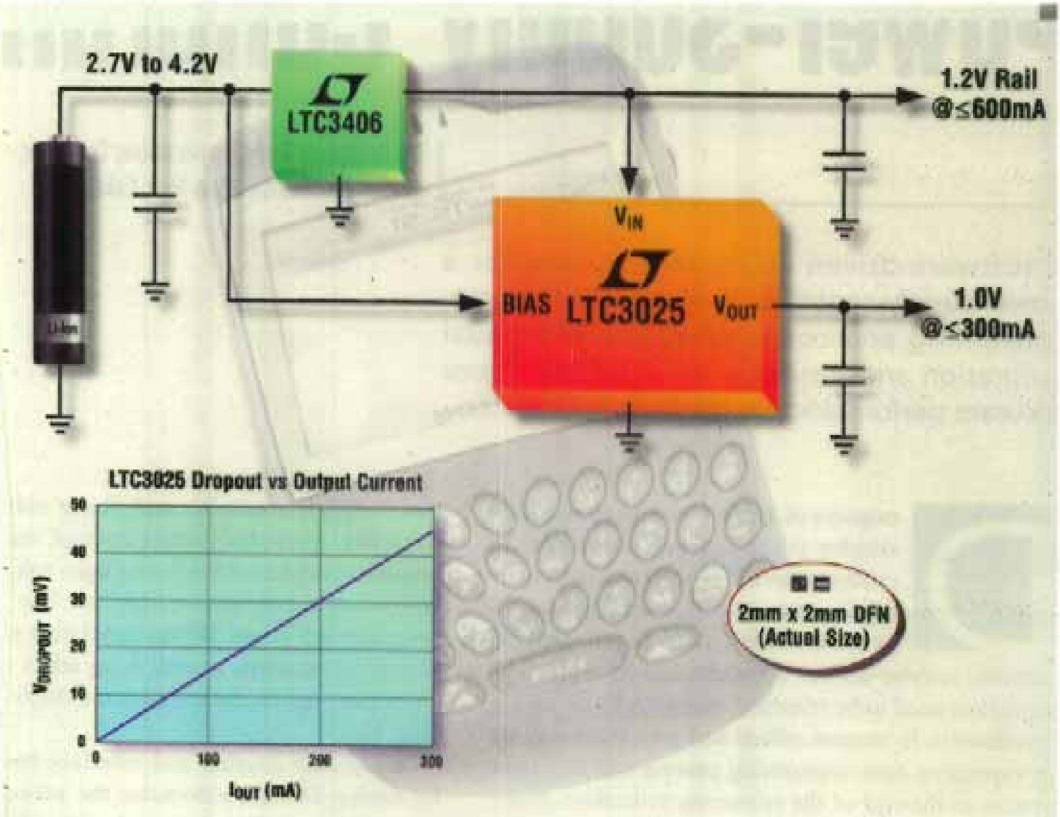
Function: Step-down ($V_{OUT} < V_{IN}$)

When to use: Typically when $I_{OUT} < 1A$, ultra low-dropout, and low-noise applications

Characteristics: Excellent option where fixed output, low current, and low voltage drops are required. Easy to implement

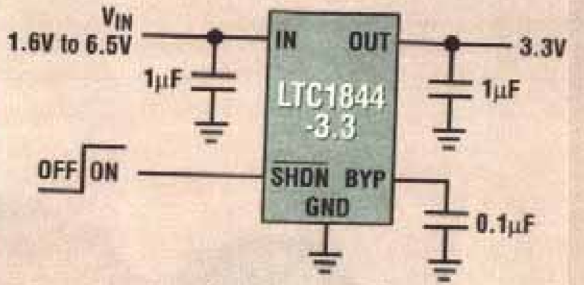
Devices to use: Any low-dropout, linear regulator

Comments: Great for micropower applications



VLDO™ Regulators Down to V_{IN} = 0.9V and V_{OUT} = 0.2V

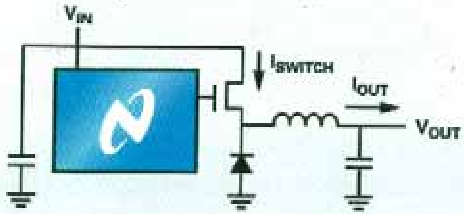
Micropower, Low Noise, Ultra Low Dropout 150mA Linear Regulator



Features:

- *V_{IN}: 1.6V to 6.5V*
- *Low 90mV Dropout at 150mA Output*
  30mV Dropout at 50mA Output
- *40µA Supply Current*
- *Low Profile (<1mm) ThinSOT Package*

Non-synchronous buck

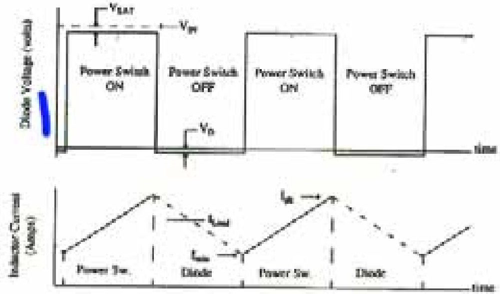


Function: Step-down ($V_{OUT} < V_{IN}$)

When to use: Typically when V_{IN} is 3x to 5x V_{OUT} and I_{OUT} is > 0.5A and < 5A

Characteristics: Easy to design and good efficiency for the above-mentioned typical $V_{IN}/V_{OUT}/I_{OUT}$ conditions

Devices to use: All buck integrated regulators and controllers



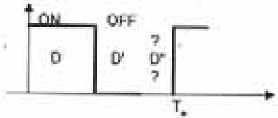
The voltage and current waveforms for a forward mode converter (buck).

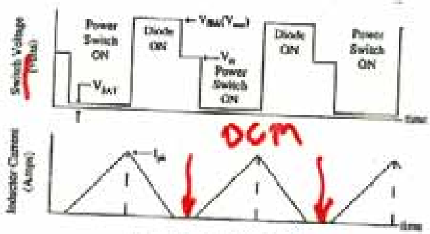
What if the inductor current wanted to go negative with a diode in the circuit?? What would occur??

2. <u>DISCONTINOUS CONDUCTION MODE</u>

An extra period "d" occurs in the switching that is created by circuit topology conditions, not by the switch drive alone. For example, switches may close or open due to circuit conditions alone as when a diode will not conduct in the opposite direction even though the controlled switch asks it to do so. This change occurs during a portion of a switch time interval and is independent of gate signals. Another example would be a bipolar transistor which conducts in only one direction and not in the opposite as MOS transistors can do.. The onset and duration of this "out of control" interval are not set by control switch signals but rather by the circuit conditions as we will see later.

Below we show this interval "d" and the associated switch voltage and inductor current waveforms.





Waveforms for a discontinuous mode boost converter

labs
$R_L \to \infty$
always
DCM

NOTICE ABOVE THAT THE INDUCTOR CURRENT CANNOT GO NEGATIVE IN THIS TOPOLOGY AND CHOICE OF SWITCHES. Be careful, other circuit topologies and switch choices could allow a negative inductor current to occur.

FOR A SPECIFIC EXAMPLE, consider below the switch mode circuit where l (leakage) of a transformer causes a dead-time t_d when

l (leakage) discharges. This leakage inductor is not on your original circuit design. It is a parasitic element of the real transformer which modifies the time durations expected from switching via control signals alone.

Features

- Complete, easy-to-use switcher solution has smallest footprint and highest power density in the industry
- State-of-the-art 13 ns minimum ON-time allows for high conversion ratios without the need to reduce switching frequency or increase solution size
- Choice of switching frequencies allows designers to trade off efficiency against solution size and EMI
- Current mode control improves phase margin, line regulation and rejection of transients
- PWM provides a predictable, easily filtered switching frequency for reduced output noise
- Internal softstart circuitry, cycle-by-cycle, thermal shutdown, and over-voltage protection
- Available in Thin SOT-23 packaging (1.0 mm height)

AVAILABLE LEAD-FREE

Ideal for systems that need to convert 3.3V, 5V, 12V, or 16V intermediate rails to 1.5V or less where solution size is critical

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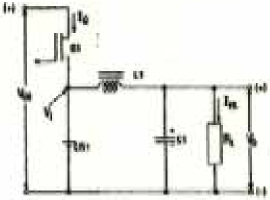
Instant 10A Power Supply

Complete, Quick & Ready.

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 *

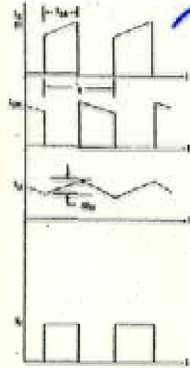
$$I_{CR1} = I_{RL}\ (1-D)$$

DIODE VOLTAGES (VRM) *

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

Exam

VOLTAGE AND CURRENT WAVEFORMS



Iin – EMC ?

Iout EMC

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 shorts. Only one output possible. High-side switch dive required. High input ripple current.

TYPICAL APPLICATIONS — Small size. Imbedded systems.

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

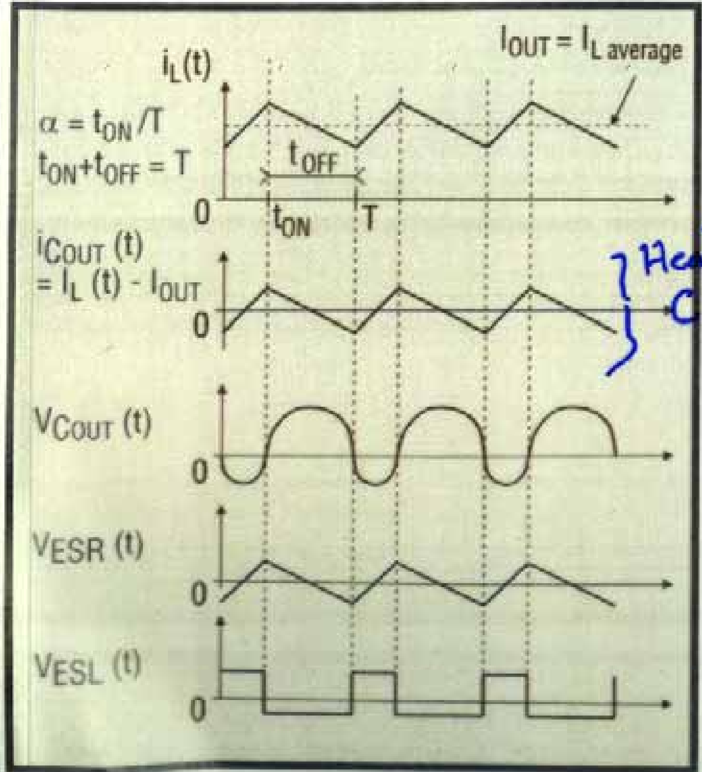
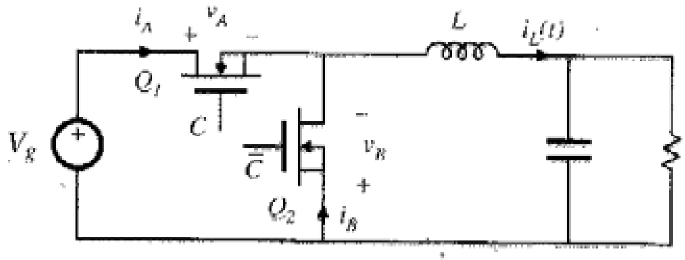


Fig. 3. *Currents in the inductor and filter capacitor (C_{OUT}) of a buck converter.*

Buck converter with synchronous rectifier

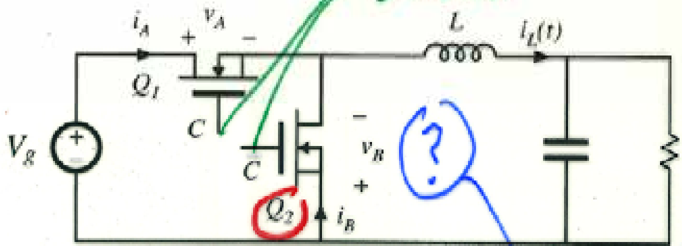


- MOSFET Q_2 is controlled to turn on when diode would normally conduct
- Semiconductor conduction loss can be made arbitrarily small, by reduction of MOSFET on-resistances
- Useful in low-voltage high-current applications

Buck converter with synchronous rectifier

know for boost too

Complementary Drive



?

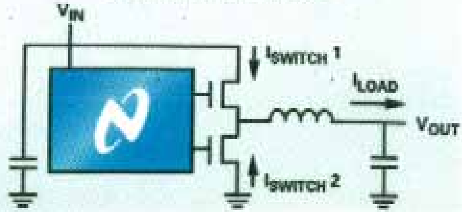
reality?

- MOSFET Q_2 is controlled to turn on when diode would normally conduct } i↑↓
- Semiconductor conduction loss can be made arbitrarily small, by reduction of MOSFET on-resistances
- Useful in low-voltage high-current applications

µP Chip: Power Supply 1V, 100A

Inverter for Solar Cell at $V_{out} = 1V$

Synchronous buck



Function: Step-down ($V_{OUT} < V_{IN}$)

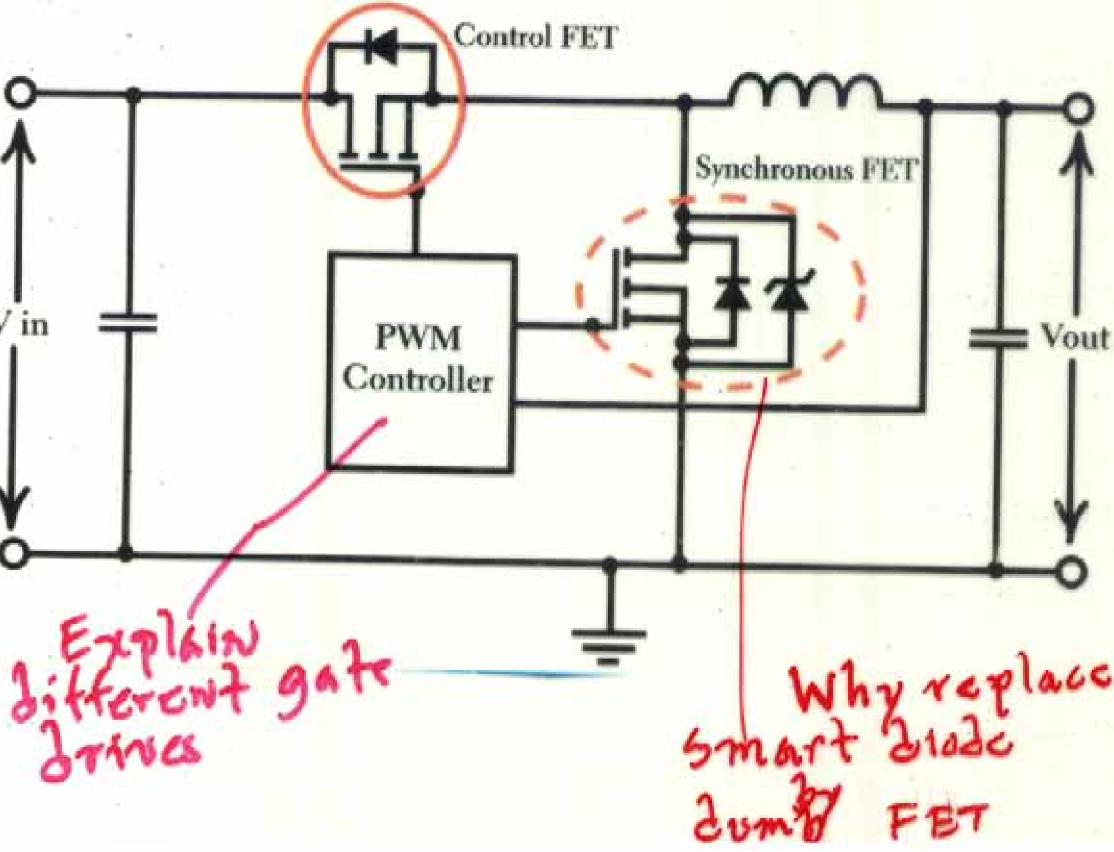
When to use: When high efficiency is required with high-output current (> 5A) or low duty cycles ($V_{IN} > 5 \times V_{OUT}$ and/or $I_{OUT} < 0.5A$)

Characteristics: A second switch replaces the diode in the basic buck topology, reducing losses in the conditions mentioned above

Devices to use: Any "synchronous rectification" buck integrated regulator or controller

Figure 2: Step-down configurations

BUCK CONVERTER



4.1.5. Synchronous rectifiers

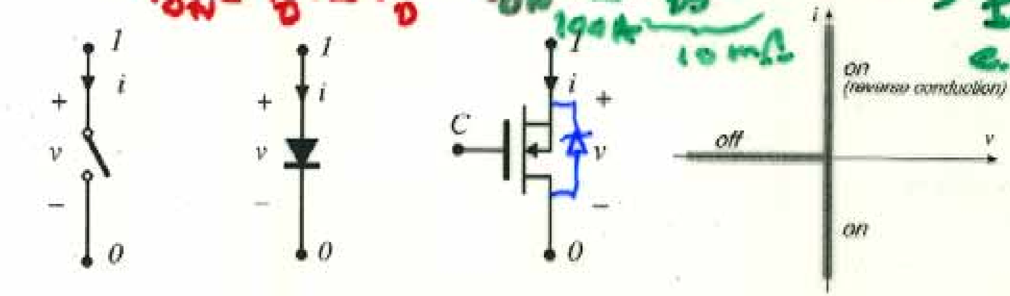
Replacement of diode with a backwards-connected MOSFET, to obtain reduced conduction loss

0.7

$V_{ON} = V_D + I R_D$

$V_{ON} = I R_{DS}(on) \approx 1V$ } less V_{ON} at High I e.g. μP

100A, 10 mΩ



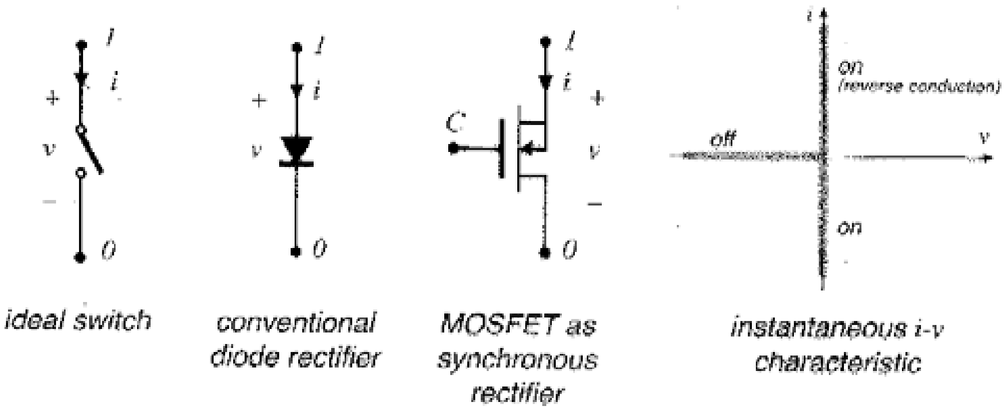
ideal switch | *conventional diode rectifier* | *MOSFET as synchronous rectifier* | *instantaneous i-v characteristic*

Diode: only has +i capability

FET: has ±i capability

4.1.5. Synchronous rectifiers

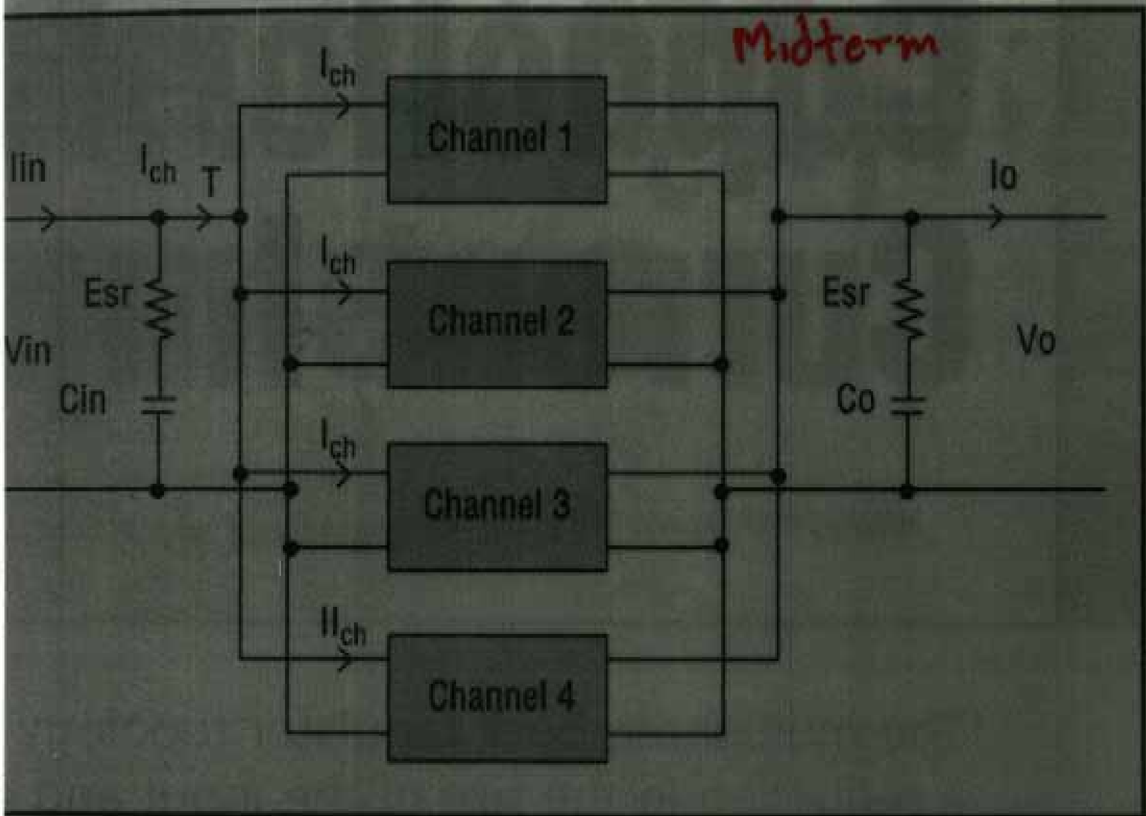
Replacement of diode with a backwards-connected MOSFET, to obtain reduced conduction loss



sum of the average channel currents

Fig. 4. Basic channel circuit.

[redacted]



5. Four-channel multiphase buck regulator.

Midterm

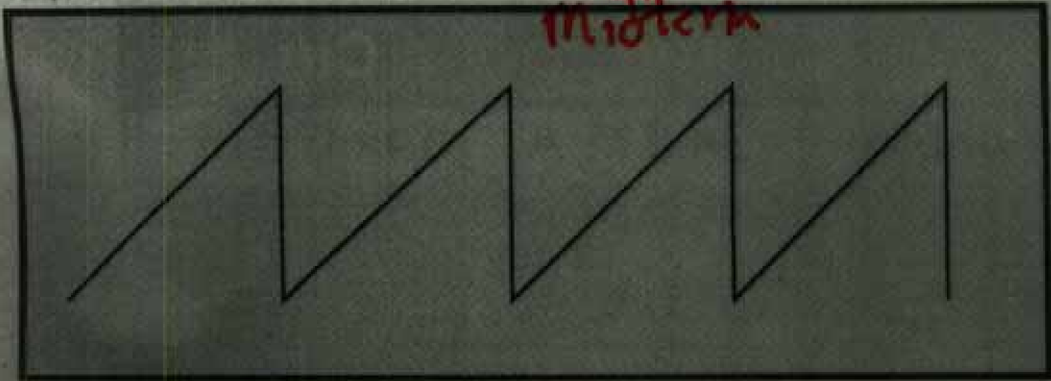


Fig. 6. *Input current for N*D = integer.*

a
ezo
qu
tin
fre
oth
th
gr

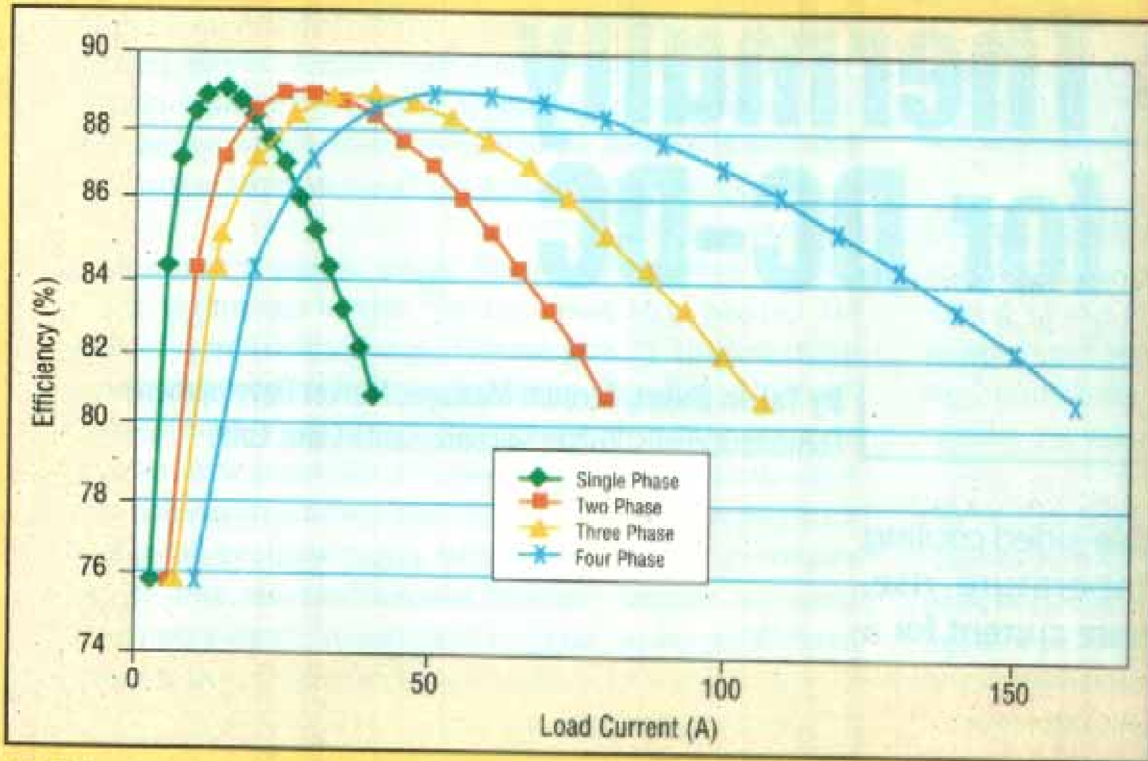
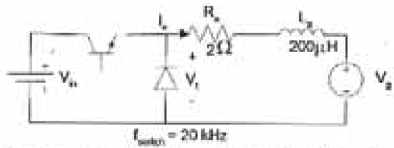


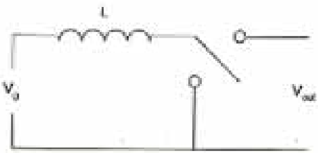
Fig. 7. *Power-conversion efficiency for different implementations of the VRM design.*



One can show for R_a small, V_g should be the average value of $V_t = D_1 V_{in}$ hence we can control motor speed by varying either V_{in} or D: w(motor) = DV_{in}/k — radians/sec

c. Boost Circuit Topology

The left side of L is fixed at V_g (raw dc) and the right side of L is switched from V_{out} to ground. Again L keeps KVL violations from occurring during switching.



For the switch to ground:

$$s_u = \frac{V_g}{L} (A/s)$$

For the switch to V_o:

$$s_d = \frac{-(V_g - V_o)}{L} (A/s)$$

Here, $V_o/V_{in} = 1/(1-D) = 1/D'$. This gives output greater than input.

Boost Example: $V_g = 20$, $V_{out} = 50$

$\Rightarrow V/V_g = 1/D' = 1/0.4$, $D = 0.6$

↑ Unique f(D) for Boost topology

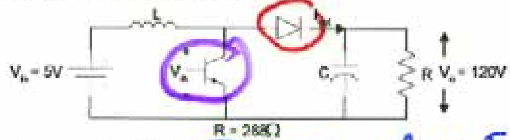
Verify $s_d/s_u = D/D' = 0.6/0.4 = 1.5 = 30/20$

We can consider the L as transforming V_g into a current source input to the switch to achieve:

$V_{out} = V_{in}/(1-D)$ and $I_{in} = I_{out}/(1-D)$.

Note $P_{in} = P_{out}$ both on average and instantaneously, as we assumed zero losses in the converter switches as well as L-C components.

Consider the boost circuit below:



Goal: V_{in} = 5V but I_{in} fixed $\pm$ 0.1% — low EMC on input i

V_o = 120V $\pm$ 0.1%

$P_{in} = P_o$ = 50W

Hence for zero loss I_{in} = 10A and I_o = 0.42 — ideal

f_{sw} is fixed at 20 kHz

or T_{sw} = 50 μs

Solution ⇒ The off time of the switch transistor is:

$D' = 5/120 = 0.042$ Recall $D + D' = 1$

So the diode is on for (0.042)(50) = 2.1 μs out of 50 μs and the transistor is on for 47.9 μs. This makes sense as we need more time to build from 5V to 120V than to discharge the 120V.

For the lossless operation I_{in} = 50/5 = 10A and we specify $\Delta I_{in} = \pm 0.1\% = \pm .1A$. This Δi specification sets the L choice

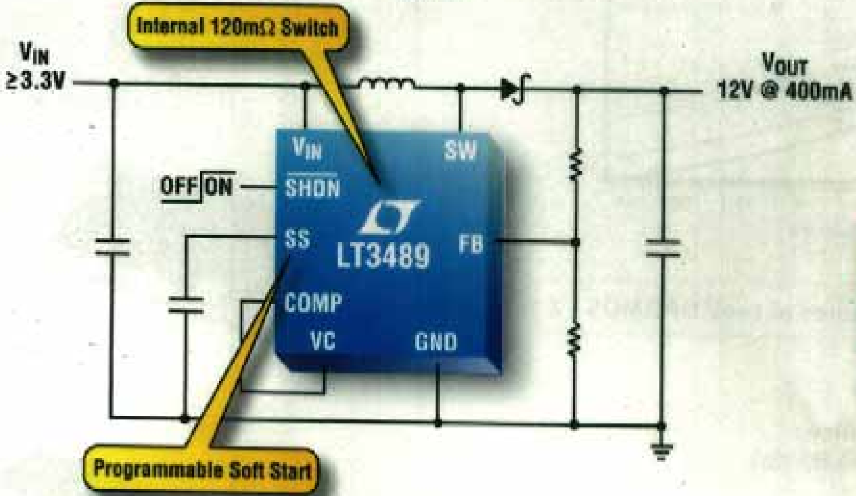
$e = L\, di/dt$(on time of transistor)

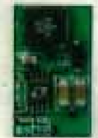
$5 = L\,(0.2\ A/47.9\ \mu s)$

$L \geq 1.2$ mH to insure $\Delta I_{in} < 0.01$. For lossless operation I_{out} = 50/120 = 0.42 A. Our $\Delta V_{out} = 120 * \pm 0.01 = \pm 1.2V$ this ΔV_c sets the C choice

3A, 40V Boost Regulators

$f_{sw} \sim 3.5\,MHz$





Actual Size
Demo Board

High Frequency, Monolithic, Efficient & Tiny

Featured Boost Regulators

Part No.	V_{IN} Range	V_{OUT} Max.	$I_{(SW)}$	Switching Frequency	Package
.T®1935	2.3V to 16V	38.0V	2A	1.2MHz	ThinSOT™
.T3489	2.4V to 16V	38.0V	2.5A	2.2MHz	MS8E
.T3477	2.5V to 25V	40.0V	3A	3.5MHz	4mm x 4mm QFN-20, TSSOP-20E
.T3479	2.5V to 24V	40.0V	3A	3.5MHz	4mm x 3mm DFN-14 TSSOP-16E
.T1370HV	2.7V to 30V	40.0V	6A	500kHz	TO-220, TO-263

i = C dv/dt(off time of the diode)
0.42 = C 2.4/2.1 μs
C $\geq$ 83.3 μF for $\Delta V_o < 0.01$ } ΔV spec

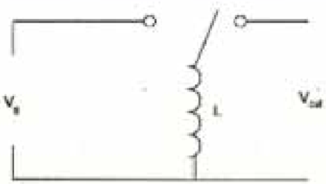
Finally prove to your self that a $\pm$ 50 ns time jitter on the transistor switch time causes V_{out} to vary from 117 to 123 V or $\pm$ 2.5%. on/off timing

d. Buck-Boost Circuit Topology

Bottom of L is fixed at ground while the top side switches from V_g to V_o. For the case of feedback in the circuit, V_g could be crude rectified DC and V_o regulated DC.

Here V_o/V_{in} = D/D' and the output is opposite polarity to the input moreover we overcome the $V_{out} < V_{in}$ limitation of the buck and the $V_{out} > V_{in}$ limitation of the boost. No KVL violations occur as each voltage supply only sees L which appears as a current source.

For analysis below we assume both do not vary over T_s.



Switch at V_g:

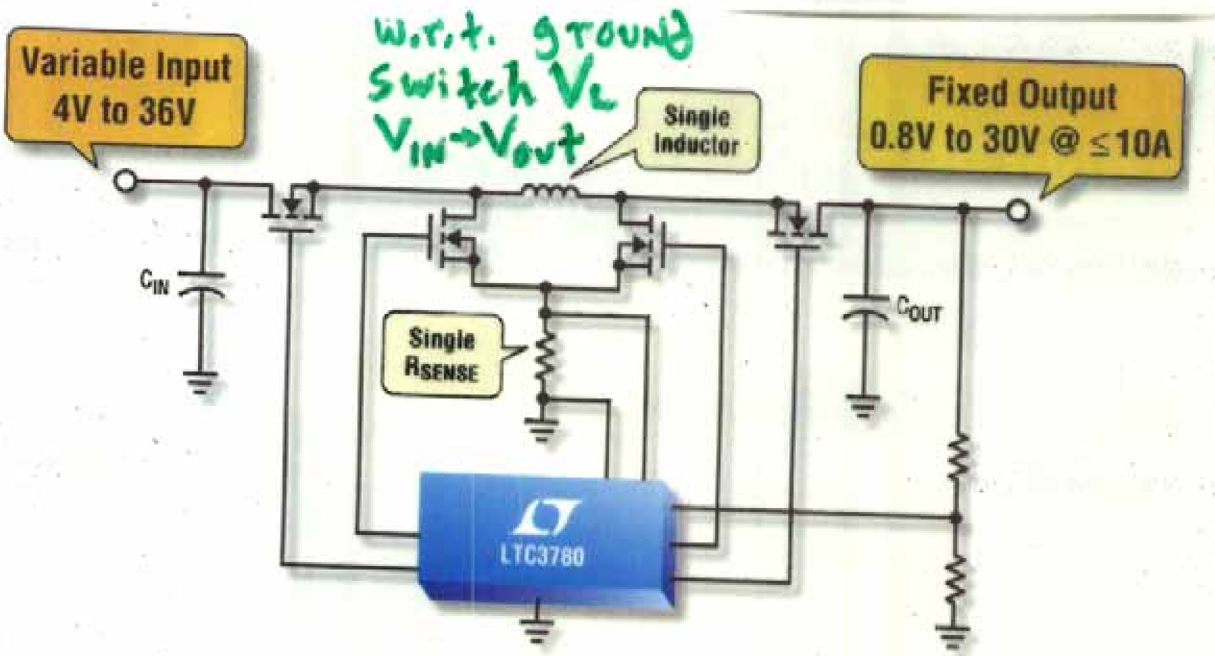
$$s_u = \frac{V_g}{L} (A/s)$$

Switch at V_{out}:

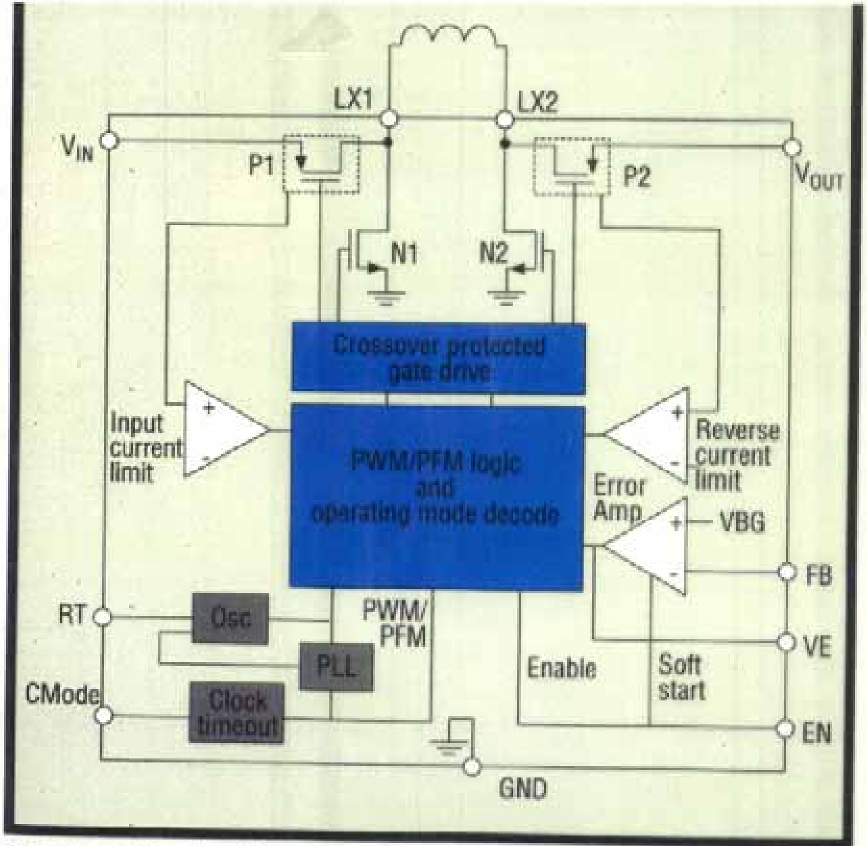
$$s_d = \frac{V_{out}}{L} (A/s)$$

s_s very fixed for feedback case

$$\Rightarrow \frac{V_{out}}{V_g} = \frac{-D}{D'}$$



97% Efficient Single Inductor Buck-Boost Controller

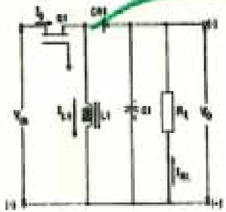


A noninverting buck-boost converter incorporates n- and p-channel power MOSFETs.

TYPE OF CONVERTER

Buck - Boost (Step Down/Up)

CIRCUIT CONFIGURATION



IDEAL TRANSFER FUNCTION

$$\frac{V_O}{V_{IN}} = -\left(\frac{t_{on}}{T_S - t_{on}}\right) = -\left(\frac{D}{1-D}\right)$$

PEAK DRAIN CURRENT *

$$I_{DMAX} = I_{RL}\left(\frac{1}{1-D}\right) + \frac{\Delta I_{L1}}{2}$$

PEAK DRAIN VOLTAGE *

$$V_{DS} = V_{IN} + V_O + V_D$$

AVERAGE DIODE CURRENTS *

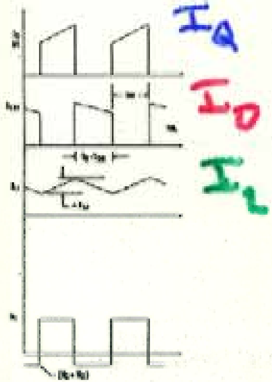
$$I_{CR1} = I_{RL}$$

DIODE VOLTAGES (VRM)

$$V_{RM} = V_O + V_{IN}$$

SW. V_L: V_{IN} w.r.t. V_{out} ground

VOLTAGE AND CURRENT WAVEFORMS



ADVANTAGES

Voltage inversion without using a transformer, simple, high frequency operation.

DISADVANTAGES

No isolation between input and output. Only one output is possible. Regulator loop hard to stabilize. High-side switch drive required. High output ripple. High input ripple current.

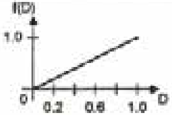
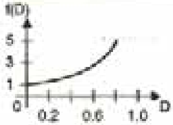
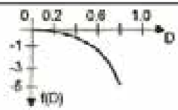
TYPICAL APPLICATIONS

Inverse output voltages.

APPLICABLE HARRIS PRODUCTS

Emc for L8

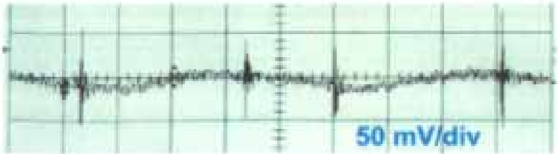
SIMPLE SWITCH MODE CONVERTERS

 BUCK The buck is limited in that $V_{out} < V_{in}$ only		$V_L = V_o$ or $V_{DC} - V_o$ •$f(D)=D$ •Never get negative output •$V_o(min) = 0$
 BOOST The boost is limited in that $V_{out} > V_{in}$ only		•$f(D)=1/(1-D)$ •Never get zero output: $V_o(min) \neq 0$ $V_L = V_{DC} - V_o$ or V_o
 BUCK-BOOST The buck-boost is limited to negative voltages		•$f(D)=-D/(1-D)$ •Inverting output w.r.t. V_s $V_L = V_o = -V_{DC}$ for $D = ½$

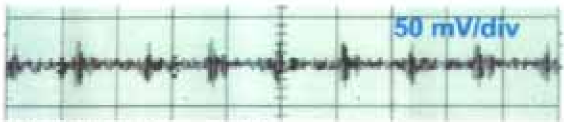
4. UNSYMMETRIC I_L AND v_C WAVEFORMS OF EQUAL INTEGRATED AREA IN THE ABOVE THREE CONVERTERS

EMC high!
Why?
How to reduce

Common-Mode Noise Vicor 48:12 Bus Converter Module Compared to PWM Supply



5(a) 100 kHz PWM Forward



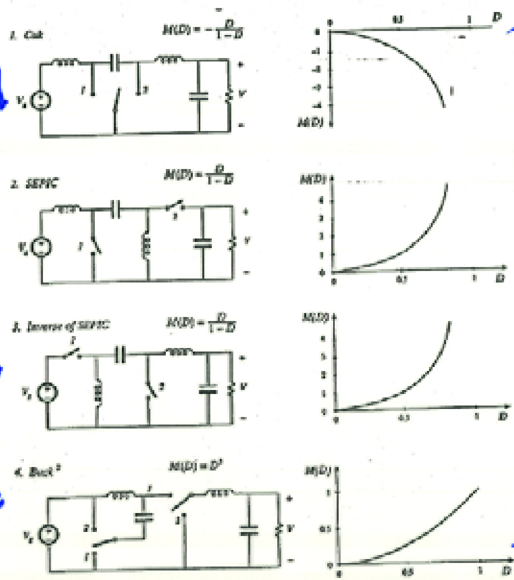
5(b) 3.5 MHz Vicor BCM

supplies. It will then be possible to do three-stage power conversion (PFC, Bus Conversion, Point-of-Load Conversion) that will exceed the performance of conventional power supply design.

Review 2L/2C Converters for lower EMC/EMI } Same DC

transfer function follows the same principles. All provide V_{out} from 0 to nV_g.

$\Delta i_{IN}\downarrow$ $\Delta i_{out}\downarrow$



$\Delta i_{IN}\downarrow$

$\Delta i_{out}\downarrow$

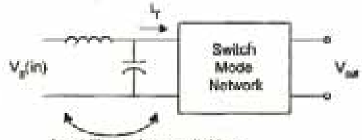
Double Buck IC chip

M(D) DC

Fig. 6.16. Several members of the basic class of single-input single-output converters containing two inductors.

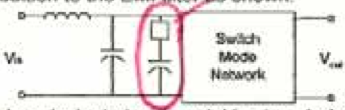
Note: Of the above, only Cuk has negative V_{out} w.r.t. V_g and V_{out} varies from 0 to $M(D)V_g$ for all of the double L/C converters.

B. Lossless Cuk converter M(D) analysis

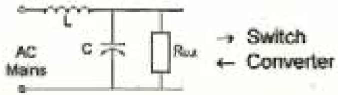


Input filter to keep switching harmonics from entering the mains. EMI noise issue is now a legal one.

Incidentally, some switching signals have very sharp transients that can be better reduced by an RC snubber circuit in addition to the EMI filter as shown:



A simplified equivalent circuit model is given below:



Previously, we saw that for an equal duration square wave (d = d') the **fundamental ac component** of the signal has an amplitude $2v_{dc}/\pi$. We will consider the attenuation of the filter in two ways on the next page:

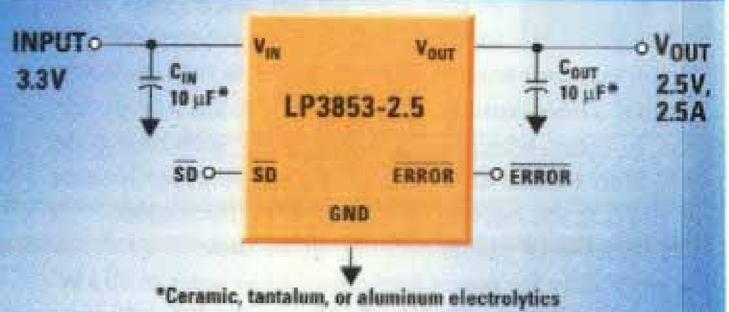
- A rough transfer function approach
- An intuitive ripple estimate approach

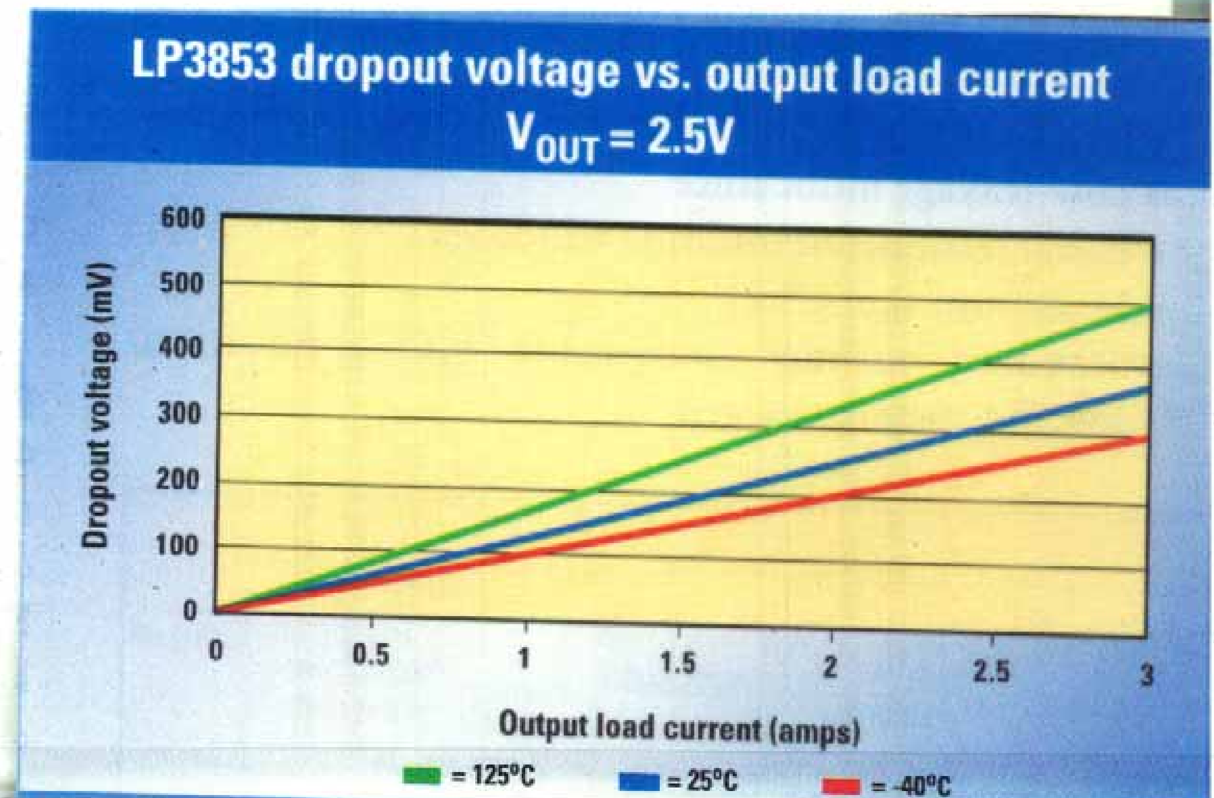
Ch 10
Why needed?
R (switch) in mode is ?

LP385x family of CMOS low dropout regulators

Part number	Output current (A)	Features
LP3852	1.5	On/off, error flag
LP3855	1.5	On/off, separate sense pin, ADJ
LP3853	3.0	On/off, error flag
LP3856	3.0	On/off, separate sense pin, ADJ

LP3853 typical application diagram




LP3853 dropout voltage vs. output load current
V_{OUT} = 2.5V
Dropout voltage (mV)
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
Output load current (amps)
= 125°C
= 25°C
= -40°C

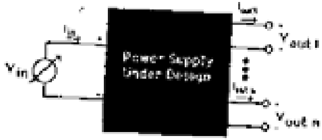


Figure 3-17 The SMPS treated like a black box.

1. Output power

$$P_{out} = \sum_{n=1}^{n} (V_{out(n)} I_{out(n)}).$$

2. Input power

$$P_{in} = \frac{P_{out}}{\text{est. efficiency}}.$$

3. Average input current

$$I_{in(avg)} = \frac{P_{in}}{V_{in(min)}}$$

4. The input peak current

This is completely determined by the topology chosen.

$$I_{pk} = \frac{kP_{out}}{V_{in(min)}}$$

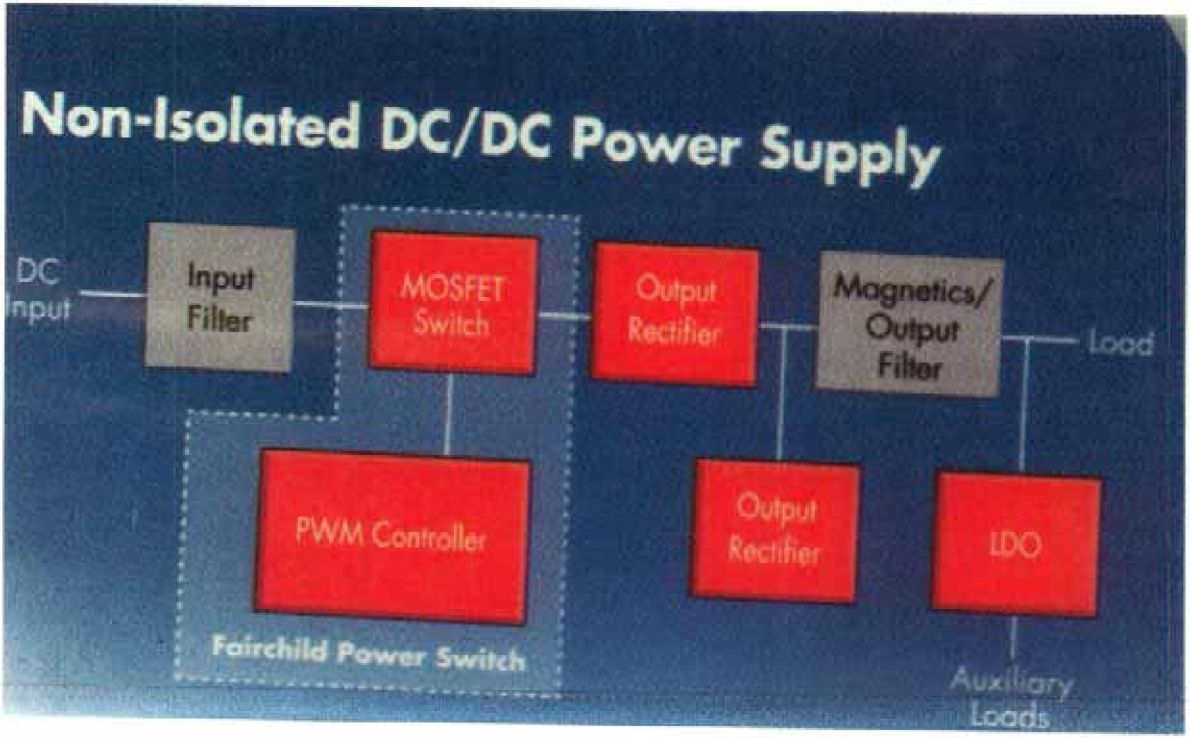
where k =: 1.4 for the buck, and full-bridge
=: 2.8 for the half-bridge, and half-forward
=: 5.5 for the boost, buck-boost, and flyback

The value of the peak current is useful in the design of the flyback-mode inductors and transformers. For the forward-mode supplies, k is just a curiosity at this time.

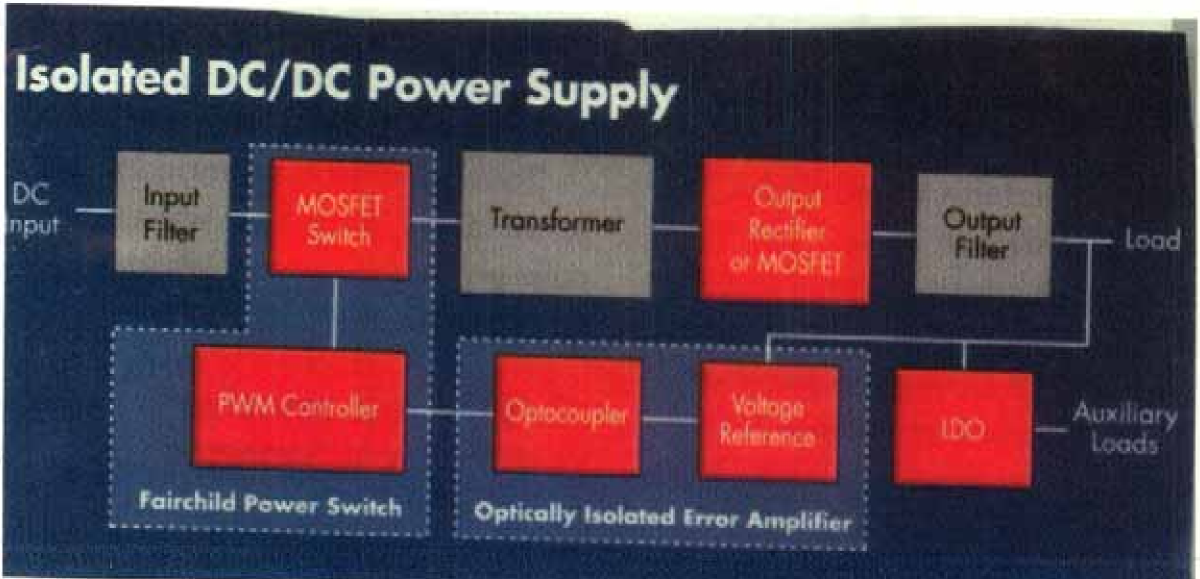
Hopefully this tilted overview will be kept in mind as we proceed in the course. Each subsection takes so much effort that we easily lose the overall goal.

In section B we start the introduction to the waveforms found in the PWM converters. Their shape and their mathematical representation. Again this material is meant

Ch 1-3


Non-Isolated DC/DC Power Supply
DC Input
Input Filter
MOSFET Switch
Output Rectifier
Magnetics/ Output Filter
Load
PWM Controller
Output Rectifier
LDO
Fairchild Power Switch
Auxiliary Loads

Ch 6

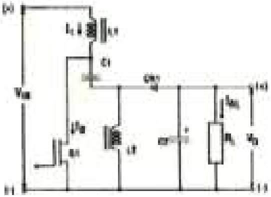

Isolated DC/DC Power Supply
DC
Input
Input
Filter
MOSFET
Switch
Transformer
Output
Rectifier
or MOSFET
Output
Filter
Load
PWM Controller
Optocoupler
Voltage
Reference
LDO
Auxiliary
Loads
Fairchild Power Switch
Optically Isolated Error Amplifier

Primary and Secondary Side DC/DC Controllers

Function	Part Number	Description	Package
Flyback Controllers	LTC®3803	Constant Frequency 200kHz with adjustable slope-compensation	ThinSOT™
	LT®1725	No optoisolator required; Senses V_{OUT} from primary side winding	SO-16, SSOP-16
	LT1737	No optoisolator required; Low $4.5V_{MIN}$ supply voltage	SO-16, SSOP-16
Single Switch Forward Controllers	LT1952	Synchronous; Programmable volt-second clamp	SSOP-16
	LT1950	3V to 25V input voltage range; Onboard auxiliary boost converter	SSOP-16
	LTC3900	Secondary side synchronous rectifier driver for forward controllers	SO-8
2-Switch Forward Controllers	LTC3705	PolyPhase™; No need for separate bias regulator	SSOP-16
	LT3781	72V operation; Synchronizable for multiple controller systems	SSOP-20
Push-Pull Half- & Full-Bridge PWM Controllers	LTC3723	Synchronous; Adjustable dead-time and synchronous timing	SSOP-16
	LTC3721-1	Adjustable dead-time; 4mm x 4mm QFN package	SSOP-16, QFN
	LTC3901	Secondary side synchronous driver for push-pull and full-bridge	SSOP-16
Full-Bridge ZVS Controller	LTC3722	Current and voltage mode with adaptive or manual delay control for zero voltage switching	SSOP-24
Secondary Side 2-Switch Forward Controllers	LTC3706	Fast, PolyPhase current mode	SSOP-24
	LTC1698	Secondary side synchronous rectifier controller	SO-16
Secondary Side Post Controllers	LT3710	Regulated auxiliary output in isolated DC/DC converters; Synchronous drivers; Programmable current limit	TSSOP-16
	LT3804	Regulates two secondary outputs; Integrated optocoupler driver	TSSOP-28
MOSFET Drivers	LTC4440	80V operation; 100V transient tolerant; Fast gate drive	ThinSOT, MSOP-8
	LTC4441	6A peak output current; 5V to 8V adjustable gate drive	MSOP-10; SO-8
	LTC1693	Single & dual N-, P-channel MOSFET drivers	SO-8, MSOP-8
Optocoupler Driver	LT4430	600mV, 1% accurate reference; prevents overshoot	ThinSOT
Overvoltage Protection Controller	LTC1696	±2% overvoltage threshold accuracy; Gate drive for SCR crowbar or N-channel disconnect MOSFET; Monitors two output voltages	ThinSOT

TYPE OF CONVERTER: SEPIC (Step Down/Up)

CIRCUIT CONFIGURATION



IDEAL TRANSFER FUNCTION

$$\frac{V_O}{V_I} = \frac{D}{1-D}$$

non-inverting

PEAK DRAIN CURRENT *

$$I_{DMAX} = I_1 + I_{RL} + \frac{\Delta I_{L1} + \Delta I_{L2}}{2}$$

PEAK DRAIN VOLTAGE *

$$V_{DS} = V_O + V_{IN} + V_D$$

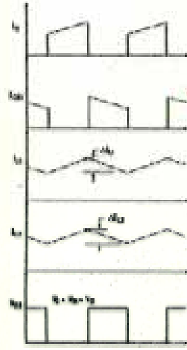
AVERAGE DIODE CURRENTS *

$$I_{CR1} = I_{RL}$$

DIODE VOLTAGES (VRM) *

$$V_{RM} = V_O + V_{IN}$$

VOLTAGE AND CURRENT WAVEFORMS



I_{out}

I_{IN}

ADVANTAGES

Low ripple input current, step-up or step-down with no inversion, no transformer. Capacitive isolation protects against switch failure (unlike Buck).

DISADVANTAGES

No isolation between input and output. Switch has high peak and rms currents which limit output power, C1 and C2 have high ripple current requirements (low ESR), continuous current mode makes loop stabilization difficult, potential instabilities with circuit-mode control. High output ripple.

TYPICAL APPLICATIONS

Power-factor correction. High reliability. Wide input voltage range.

APPLICABLE HARRIS PRODUCTS

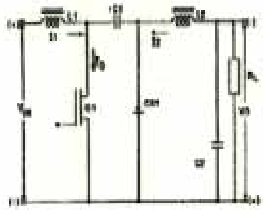
HIP5060, HIP5061, HIP5062, HIP5063

Pbm Cha #5 Next time

TYPE OF CONVERTER

CUK (Step Up/Down)

CIRCUIT CONFIGURATION



IDEAL TRANSFER FUNCTION

$$\frac{V_O}{V_{IN}} = -\left(\frac{t_{on}}{T_S - t_{on}}\right) = -\left(\frac{D}{1-D}\right)$$

PEAK DRAIN CURRENT •

$$I_{DMAX} = I_1 + I_2 = I_1\left(\frac{1}{D}\right)$$

PEAK DRAIN VOLTAGE •

$$V_{DS} = 2\,V_{IN}$$

AVERAGE DIODE CURRENTS •

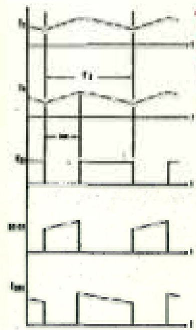
$$I_{CR1} = I_1 + I_2$$

$$I_1 + I_2 = I_1\left(\frac{1}{D}\right)$$

DIODE VOLTAGES (VRM)

$$V_{RM} = V_O + V_{IN}$$

VOLTAGE AND CURRENT WAVEFORMS



EMC

ADVANTAGES

Simple, low ripple input and output current, capacitive isolation protects against switch failure.

DISADVANTAGES

High drain current. C1 has high ripple current requirement (low ESR). High voltage required for Q1. Voltage inversion.

TYPICAL APPLICATIONS

Low noise, inverse output voltages.

APPLICABLE HARRIS PRODUCTS

HIP5060, HIP5061, HIP5062, HIP5063