Version 1.0

Future Tech Day

LED Drive Topologies

6/5/2019

www.diodes.com

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AGENDA

I. Company Overview - Broad Product Offering

II.Topology Introduction

- AC/DC (Offline)
  - FlyBack (Isolated)
  - Buck, Boost, Buck-Boost (Non-isolated – inductor switching), Linear (NO inductor)
  - HV Buck – Low Standby, Constant voltage
- DC/DC
  - Buck, Boost, Buck-Boost (Inductor switching), Linear (NO inductor)

III.Open Discussion

Company Overview

Global Operations and World-class Manufacturing & Packaging

- NASDAQ: DIOD
- Founded in 1959
- Headquartered in Plano, TX; 21 locations globally
- Manufacturing in UK, Germany, China, and Taiwan
- ISO9001:2008 Certified / TS16949:2009 Certified
  ISO14001 Certified
- Key acquisitions:
  - Anachip Corporation, Taiwan Jan. 2006
  - Advanced Power Devices Nov. 2006
  - Zetex June 2008
  - Power Analog Microelectronics (PAM) Oct. 2012
  - BCD Semiconductor Mar. 2013
  - Pericom Semiconductor Nov. 2015
- Over 7700 employees worldwide
- 27 consecutive years of profitability

Pericom Acquisition (Nov. 2015)

PERICOM Company Profile

- Founded: 1990
- HQ: Milpitas, CA USA
- Employees: 900
- Products: 26000+
- Markets: Communications, Consumer, Computing, and Automotive / Embedded
- IPO in 1997, Nasdaq: PSEM
- Revenue 2015: $128.8M

PERICOM Product Portfolio

Timing: Clocks, Oscillators
Switching: Signal Switches, Multiplexers (MUX)
Connectivity: Packet Switches, Bridges, UART
Signal Integrity: ReDrivers / Repeaters

PERICOM Automotive Focus

Telematics / Infotainment
Connected Car / Autonomous Driving
Advanced Driver Assistance Systems (ADAS)

Immediate Benefit to Customers

- Expanded product offering to include rapidly growing segments like embedded, mobile, storage
- Vertically integrated for all timing needs, broad timing portfolio includes:
  - Crystals, crystal oscillators, voltage control and temperature compensated crystal oscillators, as well as fully integrated multiple output clock ICs
- Switch products provide the highest signal integrity and achieve the most efficient and clear signal routing for data rates up to 12Gbps
- Technical Expertise

Broad Product Offering

Discrete

Diodes

- Schottky Diodes
- Zener Diodes
- Switching Diodes
- SBR® Diodes
- Power Zener Diodes
- Power Rectifier Diodes

Rectifiers

- Schottky
- Super Barrier Rectifiers
- Fast Recovery
- Bridge

MOSFETs

- Small Signal
- Power
- Protected
- High Voltage
- Complementary Pairs
- H-Bridges
- IntelliFET®

Protection Devices

- TVS
- Low CJ TVS
- Thyristor Surge Protection
- Data Line Protection

Bipolar Transistors

- Small Signal BJT
- Pre-biased BJT
- Medium Power BJT
- High Power BJT
- Darlington Transistors
- Gate-Drivers
- Low Saturation BJT
- H-Bridges

Function Specific Arrays

- Relay Drivers
- Discrete Load Switches
- Discrete Voltage Regulators
- MOSFET Gate-Drivers

IntelliFET and SBR are the registered trademark of Diodes Incorporated.

Standard Products

Standard Linear

Linear Voltage Regulators
- Standard Linear Regulators
- Low Dropout Regulators

Voltage References
- Shunt Regulators
- Micropower References

Current Monitors
- Current Output
- Voltage Output

Operational Amplifiers

Comparators

Timing Products
- Clocks/Buffers
- Real-Time Clocks (RTC)
- Timer ICs
- Crystals
- Oscillators

Standard Logic ICs

- Single Gate
- Dual Gate
- Standard Logic
- Translators
- Analog Switches
- Registers

ASSP

Power Management ICs

DC-DC Switching Regulators
- Buck
- Boost
- Buck/Boost/Inverter

AC-DC Solutions
- Primary-Side Regulators
- PWM Controllers
- CV-CC

Power Switches
- Load Switches
- HDMI Switches

USB
- USB Switches
- Charging Control

LED Drivers
- Offline LED Drivers
- DC-DC LED Drivers
- Linear LED Drivers
- LED Backlighting

Power Supply
- Synchronous Rectifiers
- Active OR-ing Controllers
- Chargers
- Gate Drivers

Connectivity

Switches
- Signal Switches
- Mux Controllers
- Type-C Switches

Signal Integrity
- Repeaters/ReDrivers

Connectivity
- PCIe Bridges
- PCIe Packet Switches
- UARTs

Sensors

- Hall Switches
- Hall Latches
- Smart Fan Drivers
- Motor Controllers
- Temperature Sensors

Digital Broadcast by Satellite

- Fixed Bias Generators
- Switched Bias Generators
- Multiplex Controllers
- Integrated Switch Matrix
- DBS Interface
- STB Power

Audio

- Class D Amplifiers
- Audio Switches

AC/DC Topologies

AC/DC Topologies Selection Guide

Topology	Isolation	Efficiency	Cost	PF/THD	Constant Voltage/ Current	Output Voltage	Application
Flyback	Yes	Middle	High	Best	CV/CC	Wide	Lighting Fixture, Isolated External Driver
Buck	No	High	Low	Good	CV/CC	< Input Voltage	Bulb, T-light
Boost	No	High	Low	Best	CV/CC	> Input Voltage	PFC Converter
Buck-Boost	No	Middle	Middle	Best	CC	Wide	Bulb
AC Linear	No	Low	Lowest	Poor	CC	< Input Voltage	Bulb, Ceiling Light

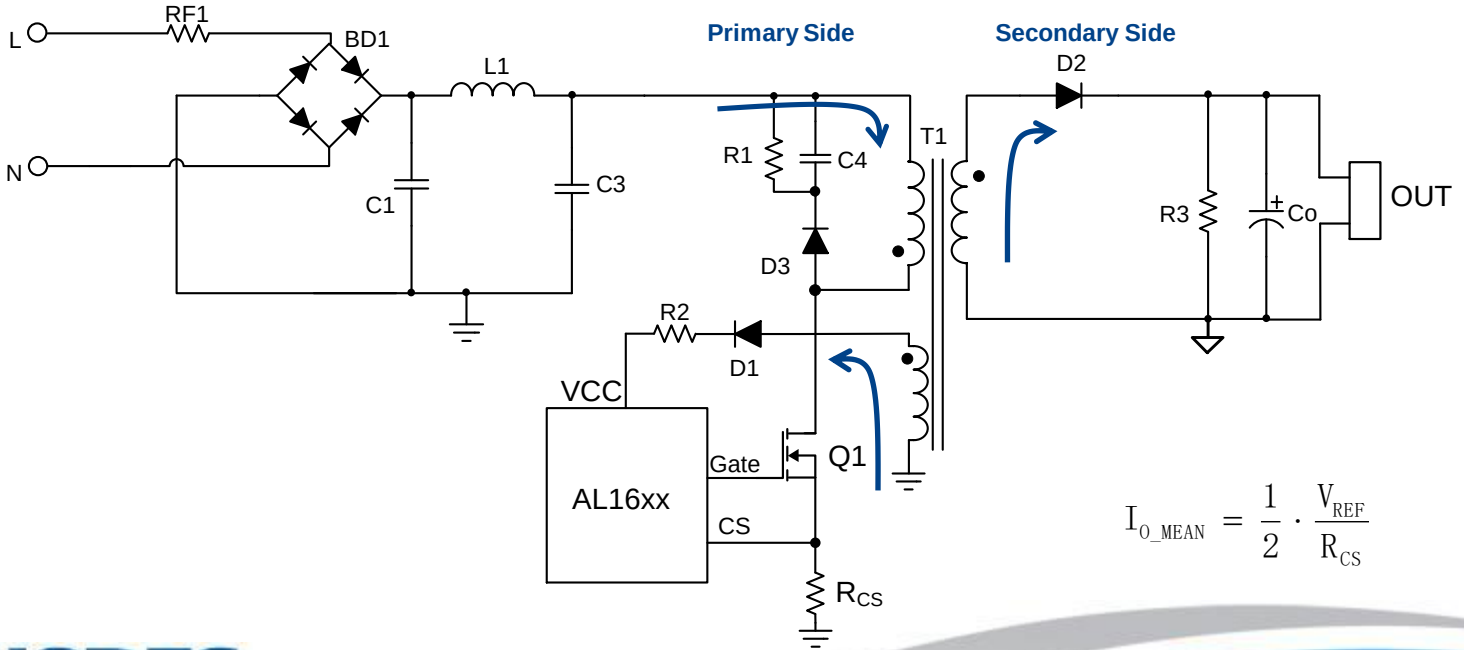
AC/DC Flyback Topology Introduction

➢ Flyback Topology Advantage

1) Provide safety isolation
2) Support wide range of output voltage
3) Better PF/THD

➢ Flyback Topology Disadvantage

1) Low efficiency
2) Need large size transformer
3) High BOM cost



$$I_{O\_MEAN} = \frac{1}{2} \cdot \frac{V_{REF}}{R_{CS}}$$

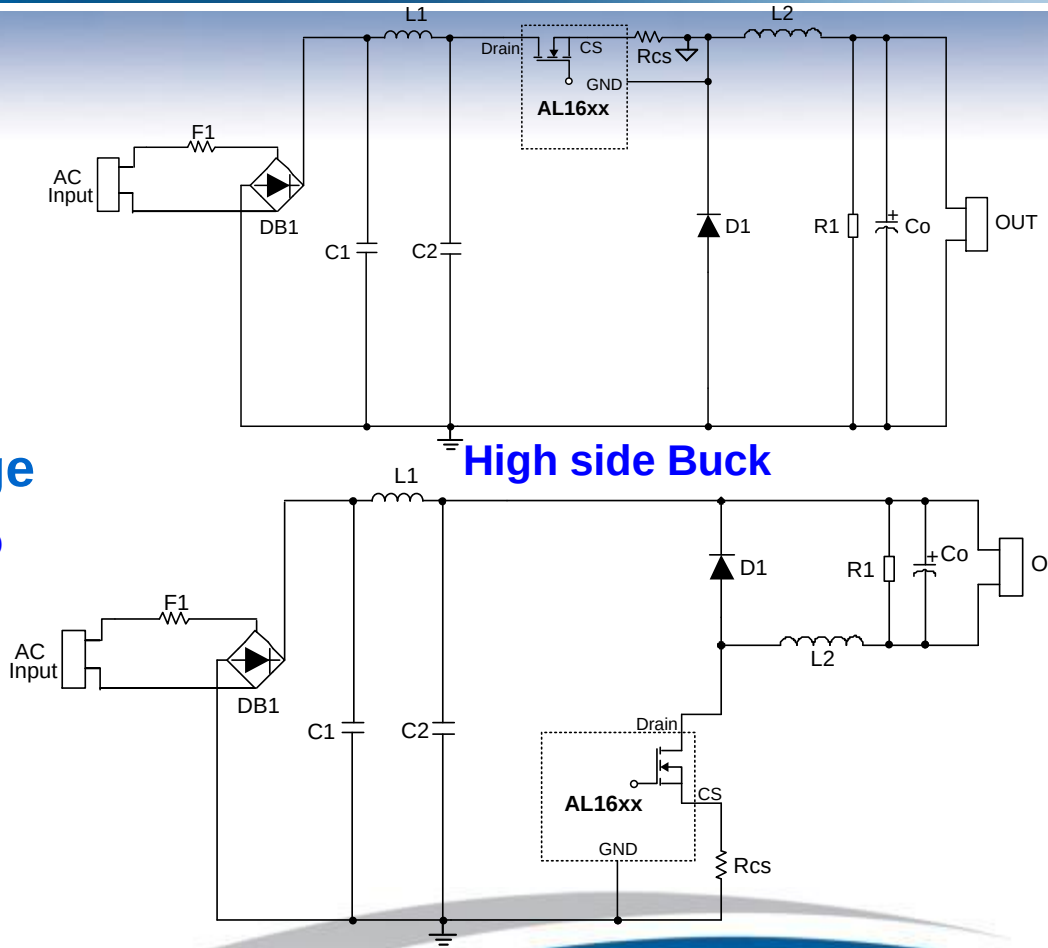
AC/DC Buck Topology Introduction

➢ Buck Topology Advantage

1) High Efficiency
2) Smaller size power inductor
3) Low BOM cost
4) Low voltage stress of power MOSFET
5) Better EMI

➢ Buck Topology Disadvantage

1) Limited input/output voltage ratio
2) Output voltage can't be higher than input voltage.



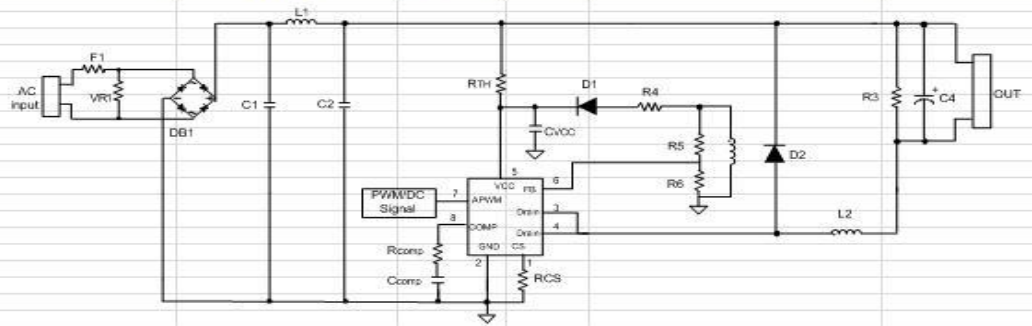
Design Calculator – AL1672

https://www.diodes.com/design/tools/calculators/

AL1672 buck LED driver design sheet v1.0

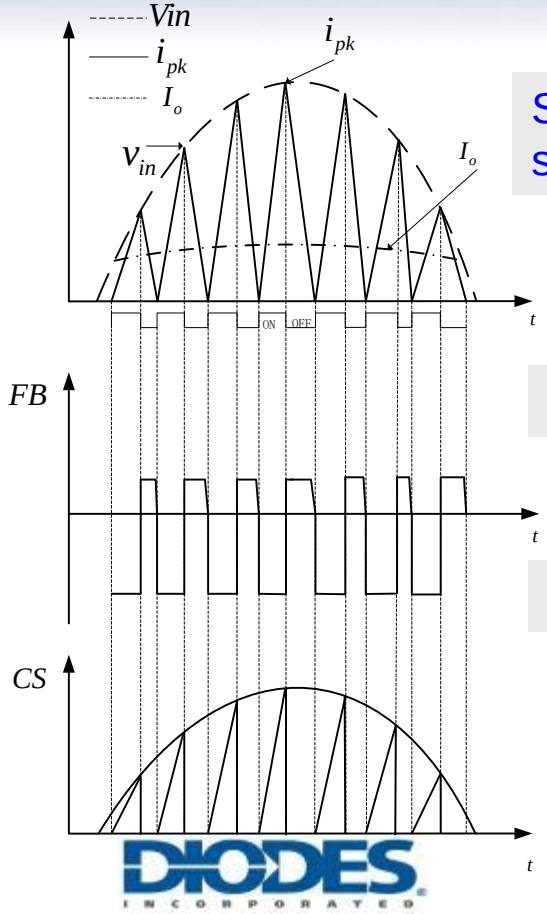
User instructions: This tool is used in diodes AL1672 Buck's Led Driver IC theory design. The red font in the software is based on the actual electrical parameters required to fill in, the system will automatically calculate the relevant component parameters (blue font) and system

Design Spec.				LED Load Spec.		
Minimum input voltage Vac_min	100.0	Vac		LED output voltage Vo	60.00	Vdc
max input voltage Vac_max	265.0	Vac		LED output current Io	240.00	mA
operating frequency at minimum input voltage	42.0	Khz				
Design Data （工作参数计算）						
minimum Crest voltage Vdc_min	141.40	Vdc		maximum Crest voltage Vdc_max	374.71	Vdc
maximum Drain voltage Vds_max	374.71	Vdc		maximum reversing voltage of D2	374.71	Vdc
maximum peak current of internal HVMO	1.02	A		maximum peak current of D2 Ispk	1.02	A
maximum RMS current of the HV MOSFET:	0.244	A		maximum RMS current of D2 Isrms	0.264	A
maximum RMS value of the inductor cur	0.360	A		MOS maximum conduction time at	10.103	us
开关管最小峰值电流(最高输入电压下)	0.832	A		MOS minimum conduction time at	2.128	us
Current Sense Resistor 采样电阻						
current sense resistor_RCS=	0.63	Ω	由于工作参数的精度问题，实际阻值可能需微调。			
power loss of current sense resistor_	37	mWatt				
Inductor design						
maximum flux density Bmax	0.28	T		BUCK L2 inductance_L2p=	0.81	mH
core type of inductor L2_Ttype=	EE13			Cross-section area of the core_Ae=	12.100	mm²
turns of buck inductor L2_Np=	243	Turns		RMS value of buck inductor curr	0.24	A
current density of L2	8.00	A/mm²		minimum diameter of buck induct	0.20	mm
auxiliary winding voltage	15.00	V		auxiliary winding turns Na	60.00	Turns
FB resistor network						
OVP voltage	81	V	1压设定为LED电压的1.35倍）			
upper resitor R5	100.00	Kohm	lower resistor R6		8	Kohm
Rcomp resistor						
Rcomp resistor	0.69	Kohm				



AC/DC Buck Topology Introduction – Peak Current

➢ High PF Buck CC Operation Principle(BCM)



Constant Current Control

Samples the CS peak value in each AC sine cycle and integrate the sample value to control system on time. It has below equation.

$$V_{REF} = \frac{1}{\pi} \cdot \int_{\theta}^{\pi-\theta} I_{PK} \cdot \left(\sin(\theta) - \frac{V_0}{\sqrt{2} \cdot V_{in}} \right) \cdot R_{CS} \cdot \frac{T_{on} + T_{off}}{T_{on} + T_{off} + T_{Delay}} d\theta$$

The output current of Buck is

$$I_{O\_MEAN} = \frac{1}{\pi} \cdot \int_{\theta}^{\pi-\theta} \frac{1}{2} I_{PK} \cdot \left(\sin(\theta) - \frac{V_0}{\sqrt{2} \cdot V_{in}} \right) \cdot R_{CS} \cdot \frac{T_{on} + T_{off}}{T_{on} + T_{off} + T_{Delay}} d\theta$$

For Buck structure, the dead zone angle is

$$\theta = \arcsin \frac{V_0}{\sqrt{2} \cdot V_{in}}$$

So the output current can be got

$$I_{O\_MEAN} = \frac{1}{2} \cdot \frac{V_{REF}}{R_{CS}}$$

Design Calculator – AL9910

https://www.diodes.com/design/tools/calculators/

AL9910/A Calculator revision 2

Click below to select device: AL9910 SO8-EP

Click below to select if PFC is required: With PFC

INPUTS

Enter your LED driver requirements here		
Minimum input voltage	85 V	Minimum Vin from 85 to 265V
Maximum input voltag	265 V	Maximum Vin from 85 to 265V
Line Frequency	50 Hz	Line Frequency from 47 - 63Hz
LED Forward Voltage	3.3 V	Typically 3.3V
Number of LEDs	14	No. of Leds > 4
LED Current	180 mA	ILED from 80 to 1000mA

Enter extra parameters here		
Ripple Factor	0.5	Ripple factor from 0.2 to 1.4
Max. switching freque	60 kHz	Max. switching freq. from 50 to 125kH
Inductor's DCR	5.0 Ω	Inductor's DCR from 1 to 30Ω
Vf of DB1	1.1 V	Vf of DB1 from 0 to 1.3V
Vf of D1, D2 & D3	1.1 V	Vf of D1, D2, D3 from 0 to 1.3V
Vf of D4	1.1 V	Vf of D4 from 0 to 1.3V
Preferred Cbulk Value	10 µF	Value 3.3 to 1000µF
MOSFET Q parameters		
Rds(ON)	1.4 Ω	Rds(ON) from 0.5 to 10Ω
Qg @ Vg = 7.5V	16 nC	Qg value from 5 to 30nC
Output Capacitor Cout parameters		
LED output Ripple vol	300 mV	Ripple voltage from 200 to500mV
Cout ESR value	500 mΩ	ESR from 10 to 500mΩ
Thermal parameters		
Ambient temperature	25 °C	Ambient Temperature from 0 to 50°C

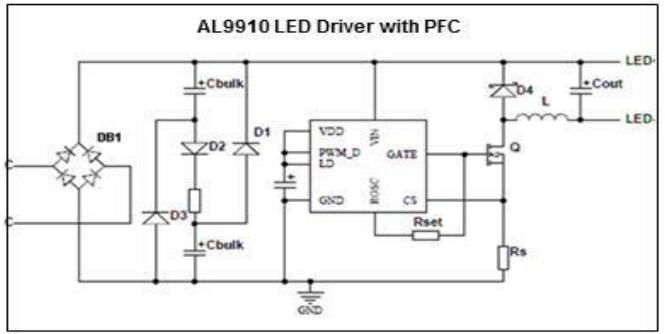
OUTPUTS

Component values	
ROSC (Rset)	342.5 kΩ
Inductor parameters	
Inductor (L)	7.49 mH
RMS Inductor Current	181.9 mA
Peak Inductor Current	225 mA
Sense resistor parameters	
Rs Value	1.111 Ω
Rs Power Dissipation	39.9 mW
Rectifiers	
DB1	DF06S
D4	SF30JG
D1 D2 D3	S1J-13F
Cout parameters	
Cout Value	5.15 µF
Cout Voltage Rating	400 V
Cbulk parameters	
Cbulk Value	30.2 µF
Cbulk Voltage Rating	400 V

Note:
For the given Preferred Cbulk value 10µF, LED Current will roll off with VIN less than 102.4V

PERFORMANCE RESULTS

Electrical result	
Output Power	8.3 W
Efficiency and Losses	
Theoretical Efficiency (worst ca	82.4 %
AL9910 SO8-EP power consump	361.9 mW
Inductor Copper Loss	165.4 mW
Maximum MOSFET Q loss	329.4 mW
Maximum D4 Loss	173.2 mW
Maximum DB1 loss	155.0 mW
Maximum D1 D2 D3 loss	234.7 mW
Thermal result	
AL9910 SO8-EP temperature	28.3 °C
MOSFET Q junction temperatur	45.4 °C
DB1 junction temperature	31.2 °C
D4 junction temperature	30.5 °C
D1 D2 D3 junction temperature	27.3 °C



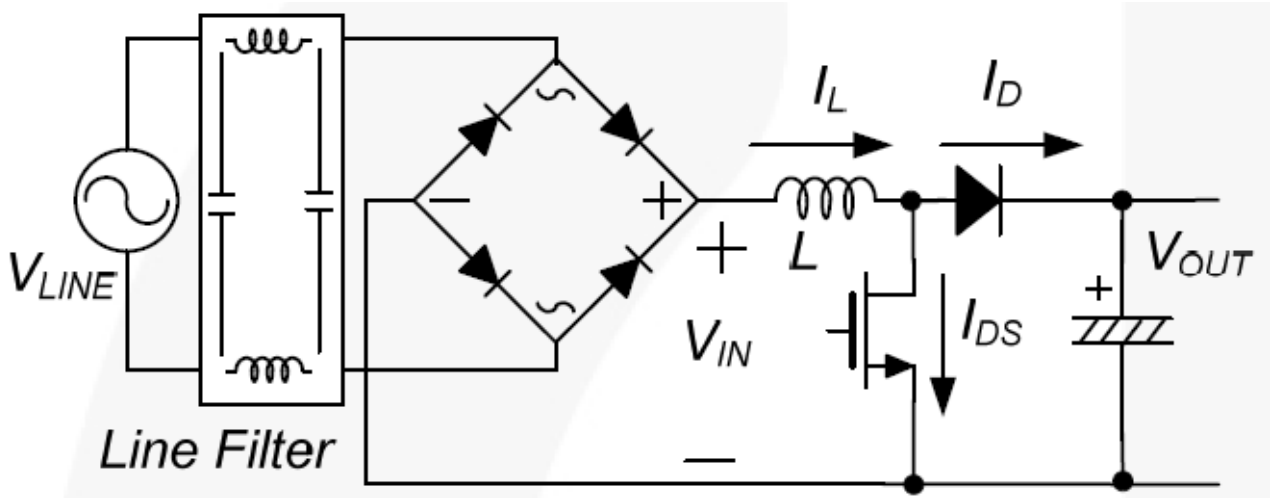
AC/DC Boost Topology Introduction

➢ Boost Topology Advantage

1) High Efficiency
2) Smaller size power inductor
3) Best PFC/THD

➢ Boost Topology Disadvantage

1) Output Cap needs high voltage stress
2) Output voltage can't be lower than input voltage.



Design Calculator – AL6562

https://www.diodes.com/design/tools/calculators/

AL6562 Boost PFC Driver Design Sheet

Red: practical electrical parameters
Blue: calculated component value by this tool
Pink: electrical parameter spec in AL6562 datasheet

Design Spec.		
Min Input AC Voltage(Vac_min)	90	[VACrms]
Max Input AC Voltage(Vac_max)	265	[VACrms]
AC Line Frequency	60	[Hz]
Output voltage (Vo)	390	[Vdc]
Output current (Io)	0.15	[A]
Output power (Po)	58.5	[W]
Max OVP voltage	430	[Vdc]
Min Switching Frequency (fsw_min)	50	[kHz]
Expected Power Conversion Efficiency (ηp)	96	[%]
Expected Power Factor	0.99	
Maximum Flux Density Bmax	0.3	[T]

Operating condition (@ min input voltage)		
Input Power	60.94	[W]
Input current	0.68	[A]
Peak current value for boost inductor, MOSFET and diode	1.93	[A]
BOOST inductor RMS Current Value	0.79	[A]
MOSFET RMS Current Value	0.67	[A]
Diode RMS Current Value	0.42	[A]

Current Sense Resistor Design		
CS min threshold voltage	1.4	[Vdc]
CS max threshold voltage	1.8	[Vdc]
Max Current Sense Resistor_Rcs	0.72	[Ω]
Customized Current Sense Resistor_Rcs	0.65	[Ω]
Rcs power dissipation	0.29	[W]
Max peak current for boost inductor, MOSFET and diode	2.769230769	[A]

BOOST Inductor Design		
Calculated Max Inductor Inductance	0.45	[mH]
Customized Inductance	0.45	[mH]
Customized Min Switching Frequency	50.20	[kHz]
Minimum AP(Ae*Aw) for Ferrite Core	0.0541	[cm4]
Ferrite Core Shape Type	EF25	
Effective Area of Ferrite Core_Ae	0.48	[cm2]
Effective Window Area of Ferrite Core_Aw	0.7344	[cm2]
AP	0.3525	[cm4]
Length of Magnetic Path_le	4.49	[cm]
Minimum Primary Winding Turns Number	87	[Ts]
Customized Primary Winding Turns Number	100	[Ts]
Maximum Flux Density_Bmax	0.26	[T]

Multiplier Block Design		
Multiplier minimum output slope	1.65	
Multiplier maximum input voltage	2.24	[V]
Maximum resisitor divider ratio_KP	0.0060	
Allowed current value flowing through lower resistor	200	[uA]
Calculated lower resistor	11.22	[KΩ]
Customized lower resistor	12.4	[KΩ]
Calculated upper resistor	2058.68	[KΩ]
Customized upper resistor	2000	[KΩ]
Customized KP	0.0062	

ZCD Block Design		
Maximum inductor winding turn ratio	7.28	
Customized inductor winding turn ratio	6	
Customized secondary winding turn number	17	[Ts]
Minmum ZCD resistor	21.15	[KΩ]
Customized ZCD resistor	100	[KΩ]

Feedback Loop Design		
Calculated upper resistor	1000.00	[KΩ]
Customized upper resistor	1000	[KΩ]
Calculated lower resistor	6.45	[KΩ]
Customized lower resistor	32	[KΩ]
Output voltage	80.63	[V]
Loop cut-off frequency	100	[HZ]
Calculated Compensation capacitance	0.05	[uF]
Customized Compensation capacitance	0.22	[uF]
Customized cut-off frequency	23.34	[HZ]

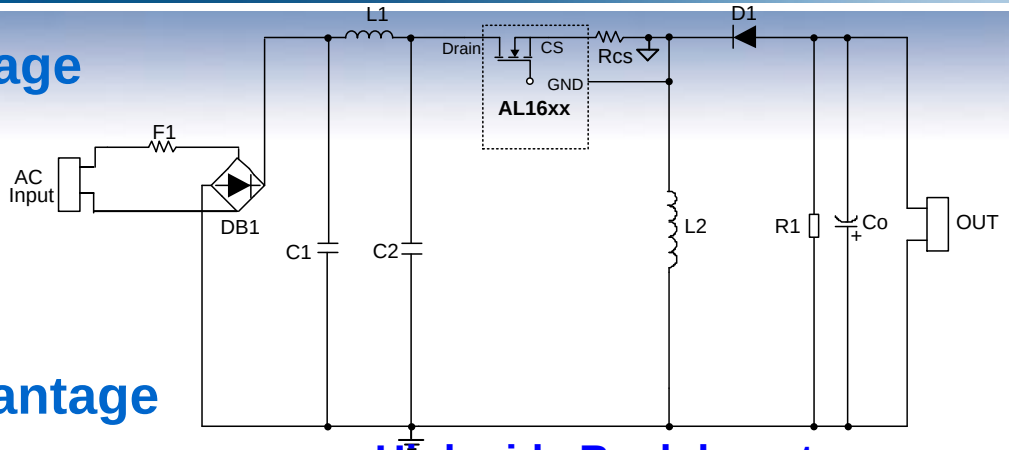
AC/DC Buck-Boost Topology Introduction

➢ Buck-boost Topology Advantage

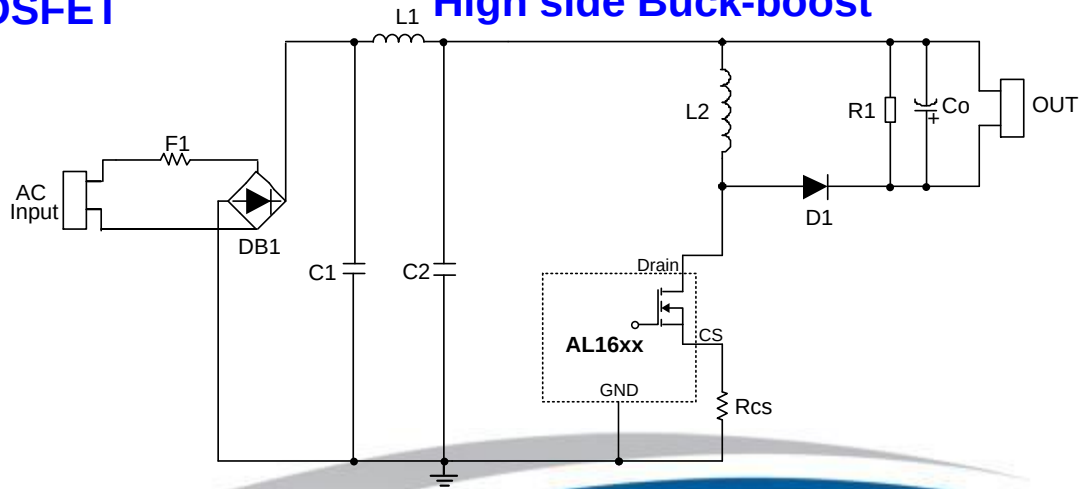
1) No input/output voltage ratio limit
2) Better PF/THD

➢ Buck-boost Topology Disadvantage

1) High voltage stress of Power MOSFET



High side Buck-boost



Low side Buck-boost

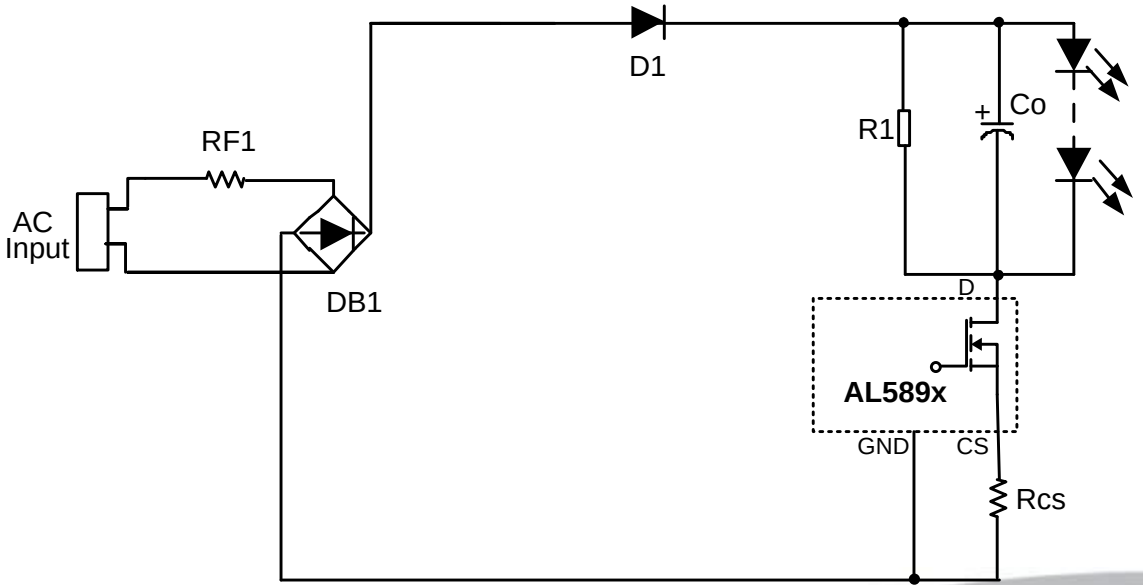
AC/DC Linear Topology Introduction

➢ Linear Topology Advantage

1) No magnetic component
2) Simple external circuit
3) Low BOM cost

➢ Linear Topology Disadvantage

1) Requires high voltage output
2) Max power limit for thermal issue
3) Can't support universal input



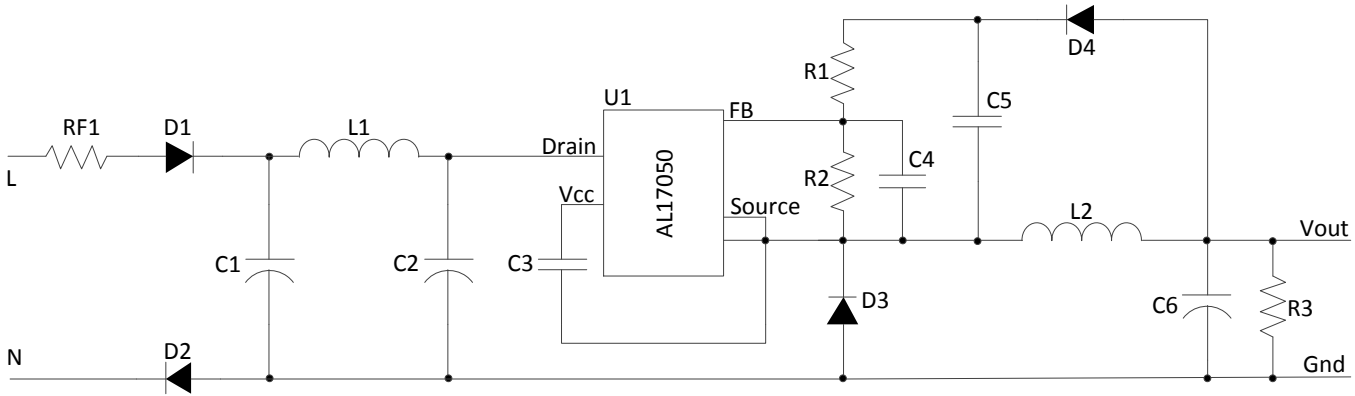
HV Buck Topology Introduction

➢ HV Buck Topology Advantage

1) Support universal input range(85~265Vac)
2) Simple external circuit
3) Low standby power

➢ HV Buck Topology Disadvantage

1) Max output load current limit



DC/DC LED Drivers

Topologies Selection Guide				
Topology	**Efficiency**	**Cost**	**Output Voltage**	**Application**
Buck	High	Low	< Input Voltage	Auto Door/Interior Light
Boost	High	Low	> Input Voltage	Backlight, Infotainment
Buck-Boost	Middle	Middle	Wide	Auto Headlight, DRL
Linear	Low	Lowest	< Input Voltage	Auto Signal/Position/Rear Light

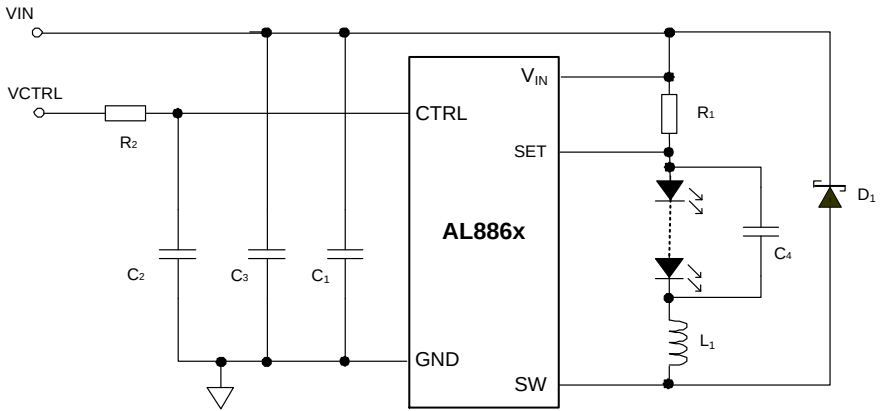
DC/DC Hysteresis Buck Topology

➢ Buck Topology Advantage

1) High Efficiency
2) Smaller size Power inductor
3) Low BOM cost
4) Low voltage stress of power MOSFET

➢ Buck Topology Disadvantage

1) Limited input/output voltage ratio
2) Output voltage can't be higher than input voltage

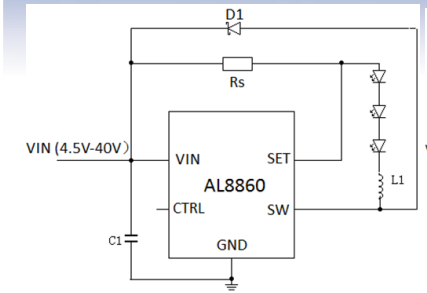


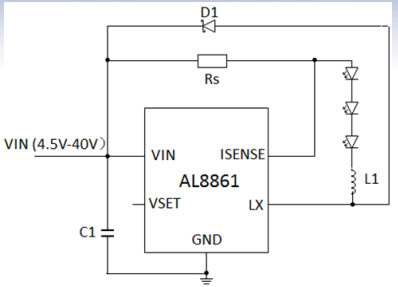
Buck Power Stage Schematic

40V, 1.5A Buck Driver : AL8860/61Q

Diodes Advantages

- Extended input voltage Range: 4.5V to 40V
  - Supports stop-start 1-LED apps
- Pin to Pin AL8806Q/AL8807Q
- Output current up to 1.5A (> AL8807Q)
- Supports PWM/Analog Dimming
  - With low I_Q mode
- Inductor Current current-Limit – AL8861Q
- Configurable Soft Start via CTRL/SET pin





Part	Min Input Voltage	Max Input Voltage	I_{LED}	Nom. ILED Acc.	Max f_{SW}	Hysteresis	Dimming		Inductor Current Limit	Sense Voltage	Temp Range	Package
							PWM	Analog				
	V	V	A	%	kHz	%			A	mV	ºC	
AL8860Q	4.5	40	1.5	5	1000	20	Y	Y	N	100	-40~+125	MSOP-8EP
AL8861Q	4.5	40	1.5	5	1000	13	Y	Y	Y	100	-40~+125	MSOP-8EP

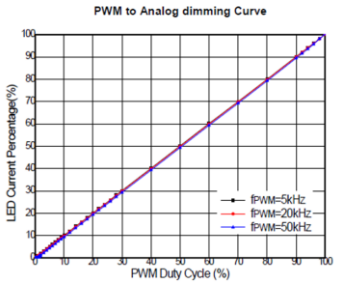
DC/DC Boost Topology

➢ Boost Topology Advantage

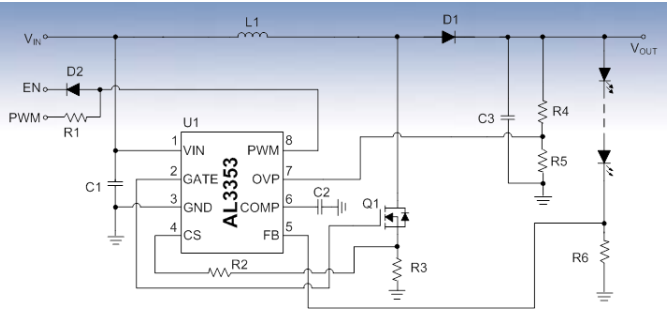
1) High Efficiency
2) Input current is continues, non-pulsating
3) Low BOM cost

➢ Boost Topology Disadvantage

1) Output voltage can't be lower than input voltage.

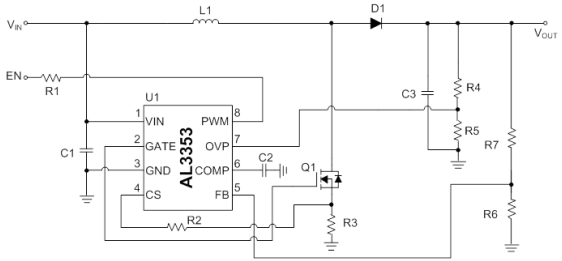


IC supports PWM to analog dimming ranging from 5kHz to 50kHz, with dimming depth down to 1%.



Constant Current Control

$$I_{LED} = \frac{400mV}{R_{FB}} (\text{mA})$$



Constant Voltage Control

$$V_{OUT} = \frac{R6 + R7}{R6} \cdot 0.4V$$

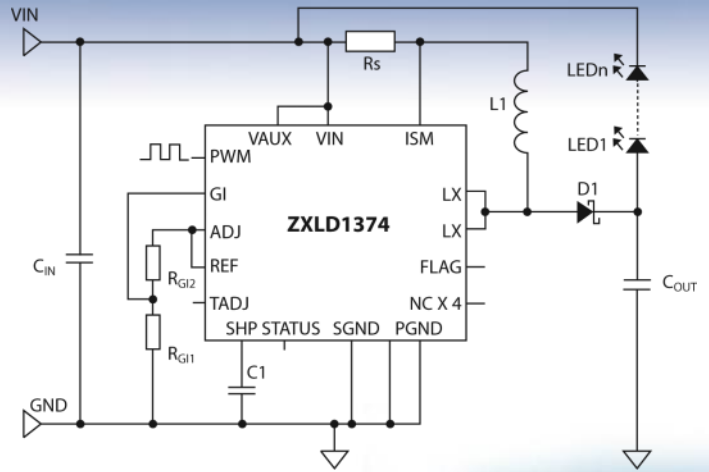
60V Buck-Boost Driver and Controller

Requirements

- Operate over whole battery (9~48V) voltage range
- High efficiency drive of LEDs
- Wide temperature range -40 to125ºC
- Withstand load dump
- Meet AEC-Q100 automotive quality requirements

Diodes Advantage

- Multi-topology LED drivers → Buck-boost mode works over V_{BATT} range driving LED chain used in DRL
- 2% accuracy → better matching between DRL pair
- Qualified to AEC-Q100 grade 1
- Ambient temperature range up to +125ºC
- LED Thermal protection loop



Key Products	
ZXLD1374	
ZXLD1371	
ZXLD1370	
DMN6068LK3	MOSFET
PDS3S140 PDS3200	D1

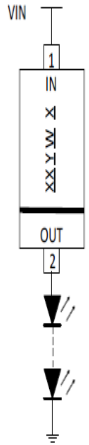
Linear LED Driver Topology

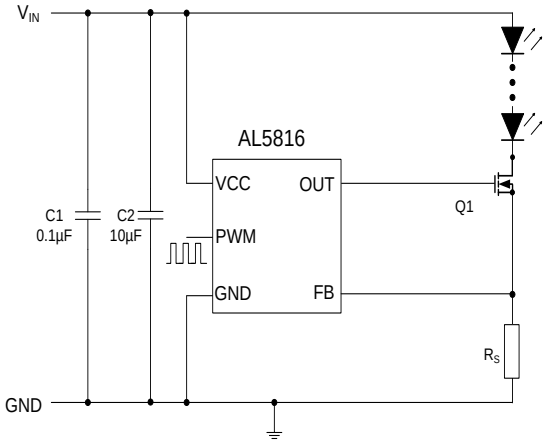
➢ DC Linear Topology Advantage

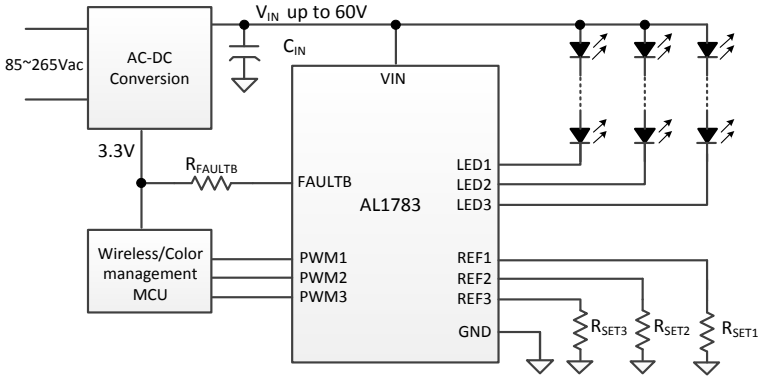
1) No magnetic component
2) Simple external circuit
3) Low BOM cost

➢ DC Linear Topology Drawback

1) Max power limit for thermal issue







60V Two terminal single channel constant current linear driver

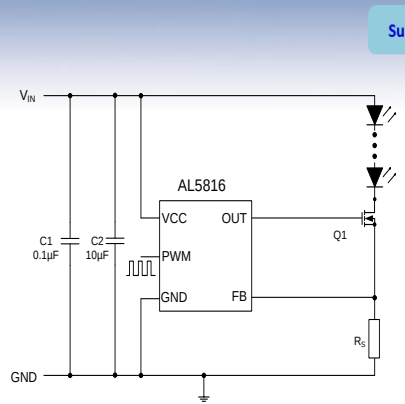
60V Adjustable single channel constant current linear driver

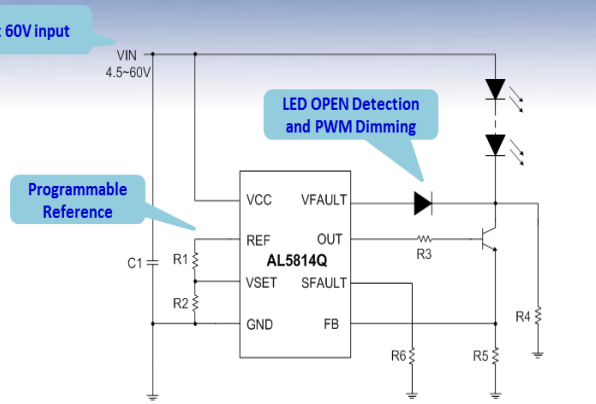
60V 3-channel constant current linear driver with independent PWM dimming

60V Linear LED Driver-Controller

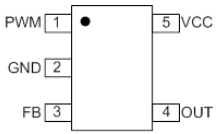
Diodes Advantages

- Constant Current Linear Controller
  - Low EMI, No Inductor
- 4.5V to 60V Input Voltage Range
  - Supports Start-stop & load-dumps
- Up to 15mA Drive for BJT
  - Use external BJT or MOSFET
- Over-Temperature Protection (OTP)
- AL5816: 60V PWM Dimmable Pin
- AL5814:
  - LED-Open Fault detection & activation
  - Analog adjustment of V_{FB} - Supports thermal foldback
- 5% Reference Voltage Tolerance

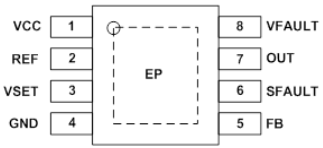




AL5816Q



AL5814Q



AL5816/4 use BJT or MOSFET

Thank you