DIODES INCORPORATED

AL1692, AL1697 Dimmable Solution Understanding & Application Guide

- LED Business Line
- Date: 2017-02-20

AL1692/7 Introduction and Operation Principle

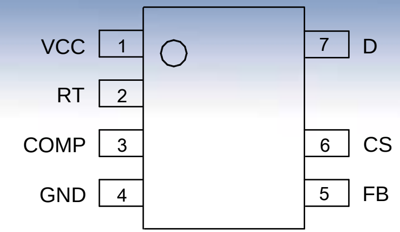
Agenda

- AL1692/7 Introduction
- AL1692/7 Operation Principle with no Dimmer
- AL1692/7 Dimming Control for Buck-boost

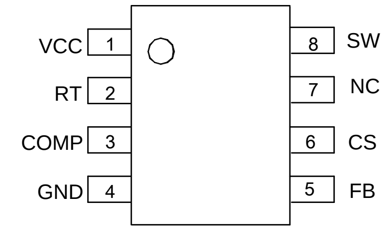
Brief Introduction of AL1692

Main Features

- Primary side control triac dimmable IC controller/driver;
- Achieve +/-3% system current accuracy;
- For 100/120/230Vac mains input, mainly for 100/120Vac input;
- CS 1.6V clamp and 15us $T_{on\text{-}max}$ limit;
- Support Buck-Boost and Flyback topology;
- Integrated 3A/400V, 3A/500V, 2A/600V,1A/700V Mosfet option;
- Ultra low start-up current(100uA) and operation current(210uA);
- BCM operation to achieve high efficiency and easy EMI;
- Good line and load regulation (+/-3%);
- High PF and low THD(PF>0.9, THD<30%);
- Single winding inductor;
- Wide dimmer compatibility and wide dimming range from 5% to 100%;
- Multiple protection features(UVLO, OVP, LED short, internal thermal foldback(TFP),OTP);
- For IC driver, can support 3W~15W application, for controller power can up to 25W;
- Suit for GU10,Candle,E27,A19, A60,Par16, Par20, Par38 lamps etc;



AL1692-Driver(SOP-7), Integrated 3A/400V, 3A/500V,2A/600V and 1A/700V Mos

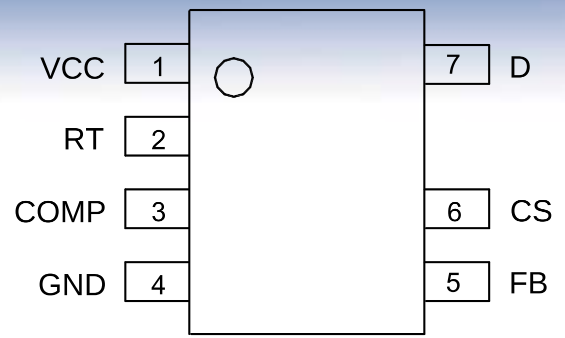


AL1692-Controller (SOP-8)

Brief Introduction of AL1697

Main Features

- Primary side control triac dimmable IC;
- Achieve +/-3% system current accuracy;
- Mainly for 230Vac mains input;
- CS 1.0V clamp and 10us $T_{on\text{-}max}$ limit;
- Support Buck-Boost and Flyback topology;
- Integrated 2A/600V and 4A/670V Mosfet option;
- Ultra low start-up current(130uA) and operation current(170uA);
- BCM operation to achieve high efficiency and easy EMI;
- Good line and load regulation (+/-3%);
- High PF and low THD(PF>0.9, THD<30%);
- Single winding inductor;
- Wide dimmer compatibility and wide dimming range from 5% to 100%;
- Multiple protection features(UVLO, OVP, LED short, internal thermal foldback(TFP),OTP);
- Available for SOIC-7 package, support 3W~15W application;
- Suit for GU10,Candle,E27,A19,A60,Par16,Par20 lamps etc;

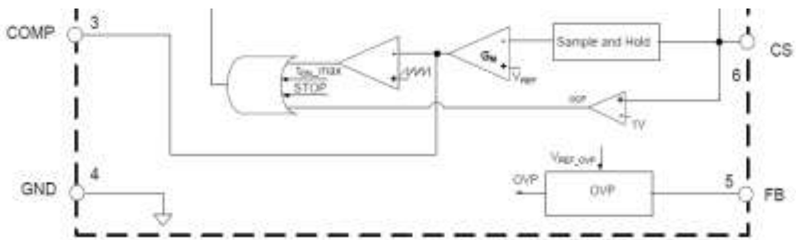


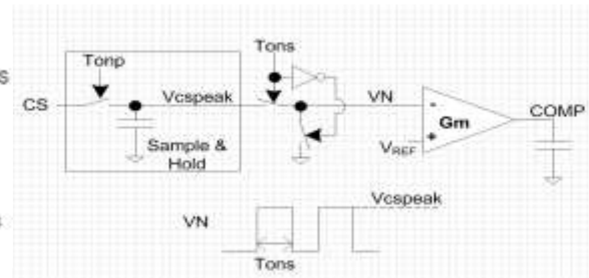
AL1697(SOP-7), Integrated 2A/600V, 4A/670V Mosfet

AL1692/7 Operation with no dimmer for Buck-boost

➢ Constant Current Control

The AL1692/7 adopts closed loop control, sample the CS peak value in each AC sine cycle and integrate the sample value to control system on time. It has below equation,





$$\sum V_{CS} \cdot T_{Off} = V_{REF} \cdot \sum T_{SW}$$

$$V_{REF} = \frac{1}{\pi} \cdot \int_0^{\pi} I_{PK} \cdot \sin(\theta) \cdot R_{CS} \cdot \frac{T_{off}}{T_{SW}} d\theta$$

Where V_{REF} is internal reference, typical 0.4V

For high PF buck-boost system, we can get output current as below.

$$I_{out}(\theta) = \frac{1}{2} \cdot I_{PK} \cdot \sin(\theta) \cdot \frac{T_{off}}{T_{SW}}$$

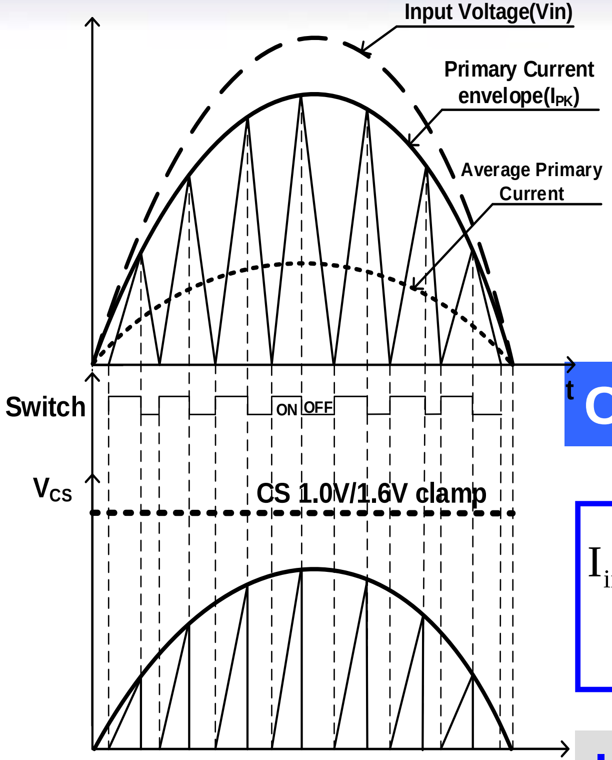
$$I_{o\_mean} = \frac{1}{2} \cdot \frac{1}{\pi} \int_0^{\pi} I_{PK} \cdot \sin(\theta) \cdot \frac{T_{off}}{T_{SW}} d\theta$$

So output constant current equation can be got.

$$I_{o\_mean} = \frac{1}{2} \cdot \frac{V_{REF}}{R_{CS}} = \frac{1}{2} \cdot \frac{0.4}{R_{CS}}$$

AL1692/7 Operation with no dimmer for Buck-boost

➤ High PF function



$$T_{on} = \frac{L \cdot i_{PK}(\theta)}{V_{in}(\theta)} = \frac{L \cdot I_{PK} \cdot \sin(\theta)}{V_{in-PK} \cdot \sin(\theta)} = \frac{L \cdot I_{PK}}{V_{in-PK}} \qquad T_{off} = \frac{L \cdot I_{PK} \cdot \sin(\theta)}{V_{out}}$$

$$I_{PK} = \frac{\pi \cdot V_{REF}}{R_{CS} \cdot \int_0^{\pi} \sin(\theta) \cdot \frac{T_{off}}{T_{on} + T_{off}} d\theta} = \frac{\pi \cdot V_{REF}}{R_{CS} \cdot \int_0^{\pi} \frac{V_{in-PK} \cdot \sin^2(\theta)}{V_{in-PK} \cdot \sin(\theta) + V_{out}} d\theta}$$

Constant Ton control method to realize high PFC

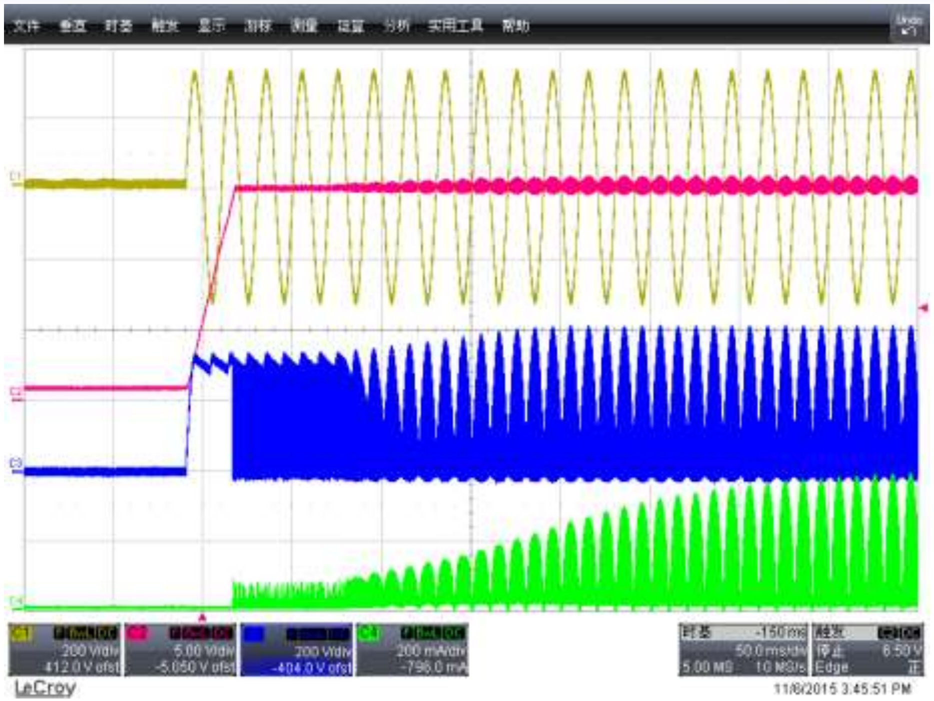
$$I_{in}(\theta) = \frac{i_{PK}(\theta) \cdot T_{on}}{2(T_{on} + T_{off})} = \frac{1}{2} \cdot I_{PK} \cdot \frac{\sin(\theta)}{1 + \frac{V_{in-PK}}{V_{out}} \cdot \sin(\theta)}$$

Input current follows input voltage sine waveform, realize PFC function.

AL1692/7 Operation with no dimmer for Buck-boost

➢ Start-up Process

V_{IN-AC} V_{CC} V_{DS} I_{Source}

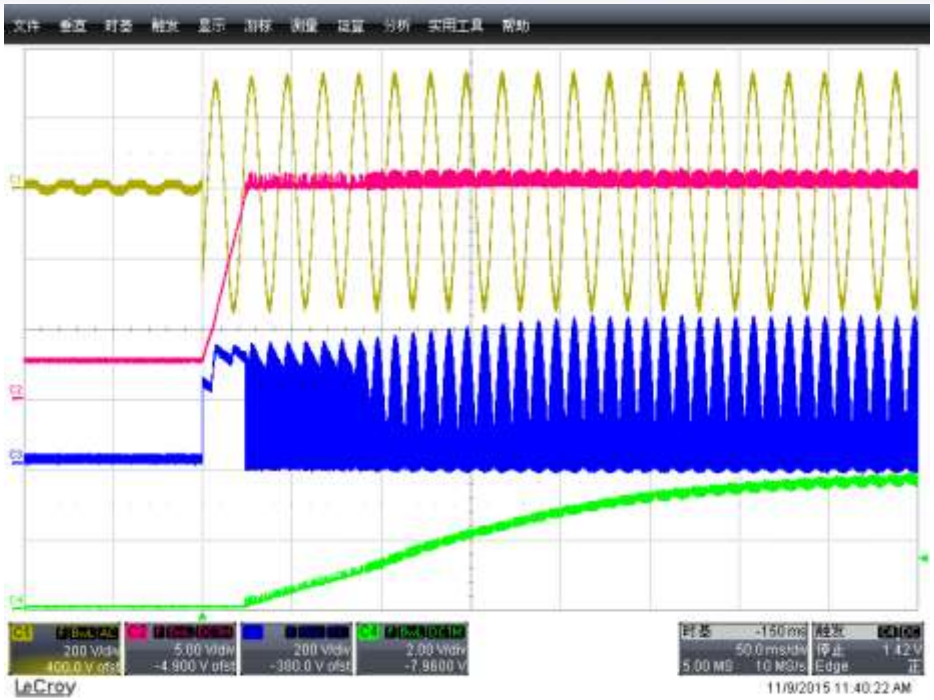


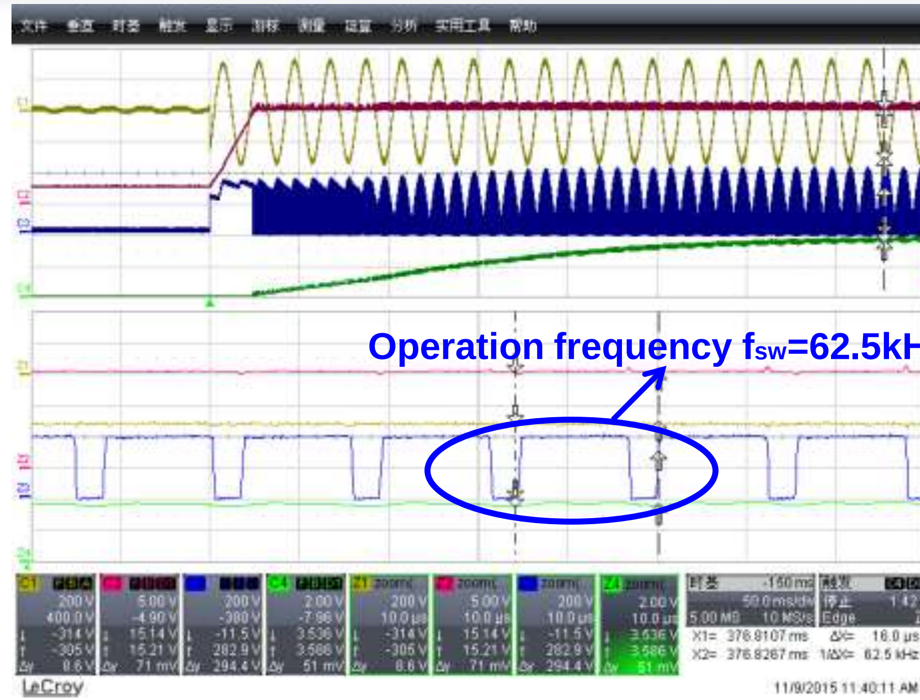
1) AC input voltage is open;
2) VCC is charged to start-up threshold and IC starts to output switching pulse;
3) Before LED current reach rated vale, IC operates at low switching frequency(around 3.5kHz);

AP1692/7 Operation with no dimmer for Buck-boost

➢ Start-up Process

V_{IN-AC} | V_{CC} | V_{DS} | V_{COMP}



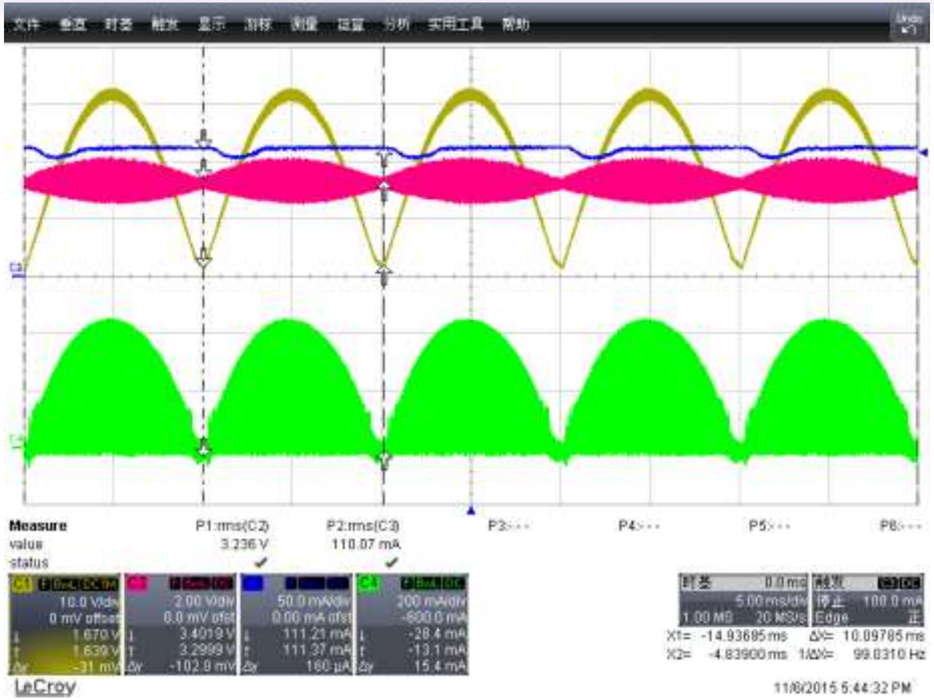


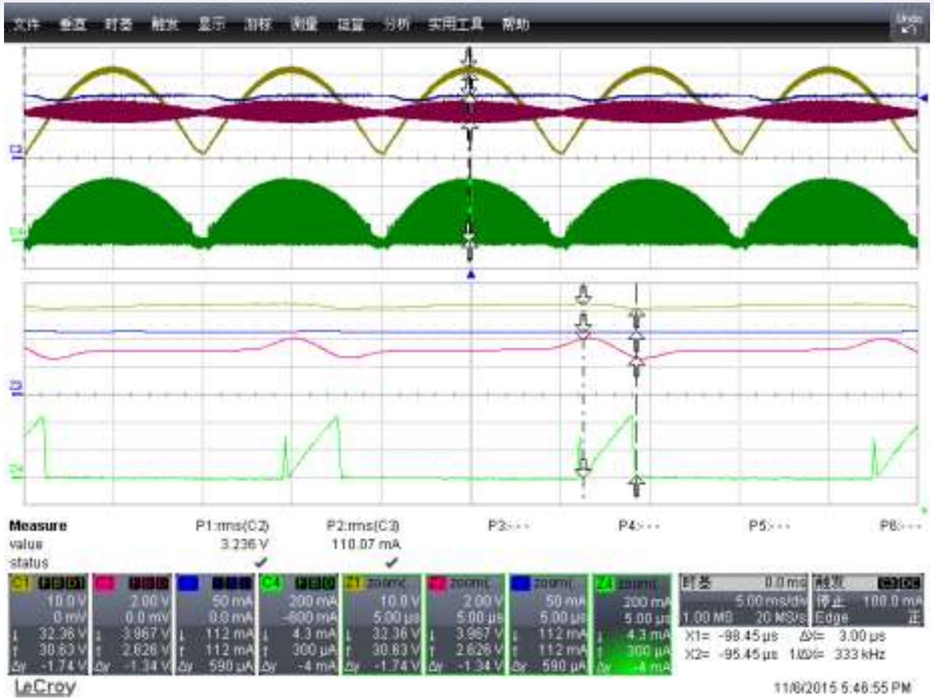
4) COMP voltage is adjusted to suitable value to reach rated current output.

AL1692/7 Operation with no dimmer for Buck-boost

➢ Operation with no dimmer

V_{BUS} V_{COMP} I_{LED} I_{Source}





1) IC samples CS peak value in each AC cycle and integrates the value to get COMP voltage, which controls switching on time;
2) Closed loop control to achieve tight current accuracy;
3) Adopt valley-mode switching to minimize switching loss and get easy EMI.

AL1692/7 Dimming Control Operation for Buck-boost

➢ Closed Loop and Maximum T_{on} Control

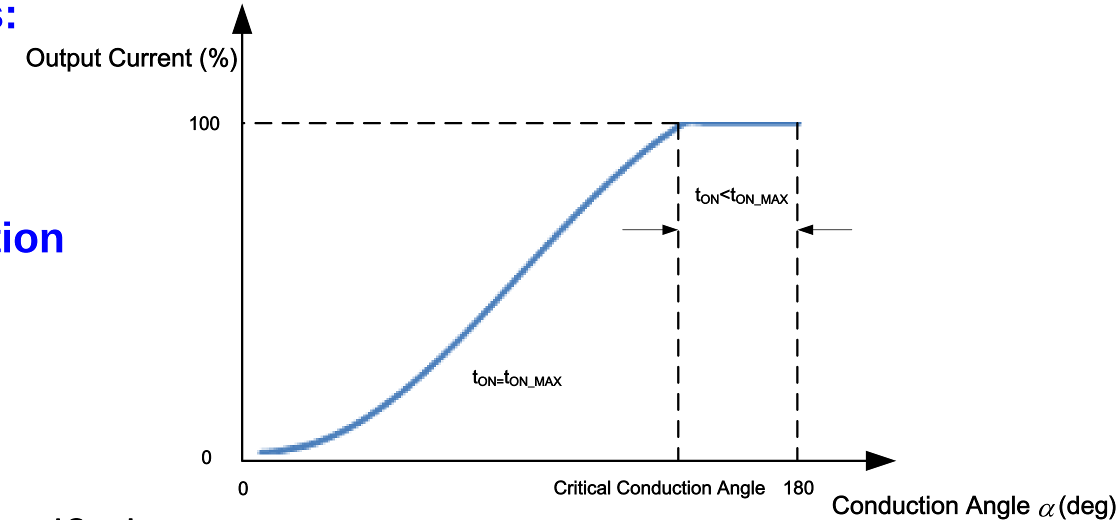
1) At larger conduction angle with dimmer(V_{COMP}<4V), $T_{on}<T_{on\_Max}$, output constant current;
2) At smaller conduction angle with dimmer($V_{COMP} \geq 4V$), $T_{on}=T_{on\_Max}$, limits output current.

Under T_{on_Max} mode, peak current is:

$$I_{PK\_DIM} = \frac{V_{in-PK} \cdot \sin(\theta) \cdot T_{on\_Max}}{L}$$

So we can get output current equation with dimmer:

$$I_o(\theta) = \begin{cases} \frac{1}{2} \cdot \frac{V_{REF}}{R_{CS}}, & \text{if } T_{on} < T_{on\_Max} \\ \frac{1}{\pi} \cdot \int_0^{\alpha} \frac{1}{2} \cdot I_{PK\_DIM} \cdot \frac{V_{in-PK} \cdot \sin(\theta)}{V_{in-PK} \cdot \sin(\theta) + V_{out}} d\theta, & else \end{cases}$$



Dimming Curve

AL1692/7 Dimming Control Operation for Buck-boost

➤T_{on_Max} setting

Considering the good line regulation and dimming depth, a suitable T_{on_Max} value should be set, IC sets T_{on_Max} through external resistor RT as below equation.

For AL1692, $$T_{on\_Max} = \frac{3.3 \cdot C_{REF}}{\frac{V_{RT\_REF}}{10 \cdot RT} + 0.33uA}$$

For AL1697, $$T_{on\_Max} = \frac{3.3 \cdot C_{REF}}{\frac{V_{RT\_REF}}{10 \cdot RT} + 0.5uA}$$

Where V_{RT_REF} is RT pin internal 0.5V reference, C_{REF} is internal 1.5pF capacitor.

AL1697 controls output current constant before T_{on} increases to T_{on_Max}(V_{COMP}=4V), so we should set the operation T_{on} value at $V_{in\_PK\_Min}$ as T_{on_Max}, and RT resistor value can be calculated as below.

$$T_{on\_Max} = \frac{L \cdot I_{PK}}{V_{in-PK-Min}}$$

$$I_{PK} = \frac{\pi \cdot V_{REF}}{R_{CS} \cdot \int_0^{\pi} \frac{V_{in-PK-Min} \cdot \sin^2(\theta)}{V_{in-PK-Min} \cdot \sin(\theta) + V_{out}} d\theta}$$

For AL1692, $$RT = \frac{V_{RT\_REF}}{\frac{33 \cdot C_{REF} \cdot V_{in-PK-Min}}{L \cdot I_{PK}} - 3.3uA}$$

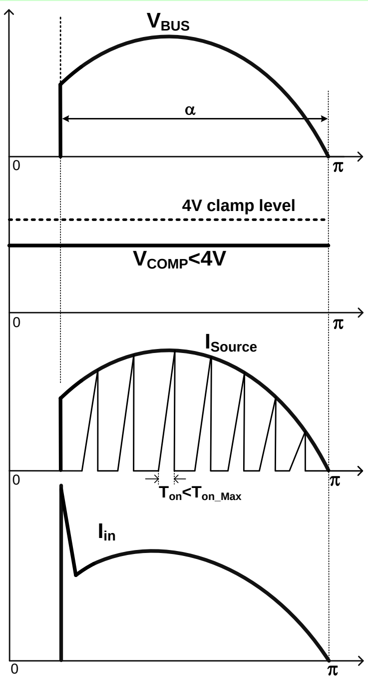
For AL1697, $$RT = \frac{V_{RT\_REF}}{\frac{33 \cdot C_{REF} \cdot V_{in-PK-Min}}{L \cdot I_{PK}} - 5uA}$$

AL1692/7 Operation with Leading-edge dimmer for Buck-boost

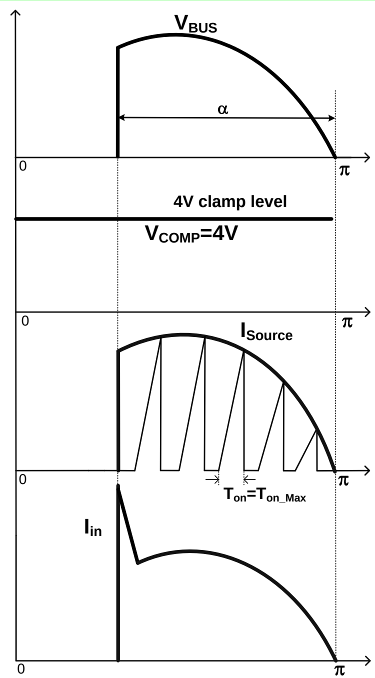
➢ Closed Loop and Maximum T_{on} Control

1) COMP voltage is adjusted to control switching on time T_{on};
2) Before COMP voltage is adjusted to 4V clamp level, $T_{on}<T_{on\_Max}$, system keeps constant current output, when COMP voltage reaches 4V, $T_{on}=T_{on\_Max}$, limits output current.

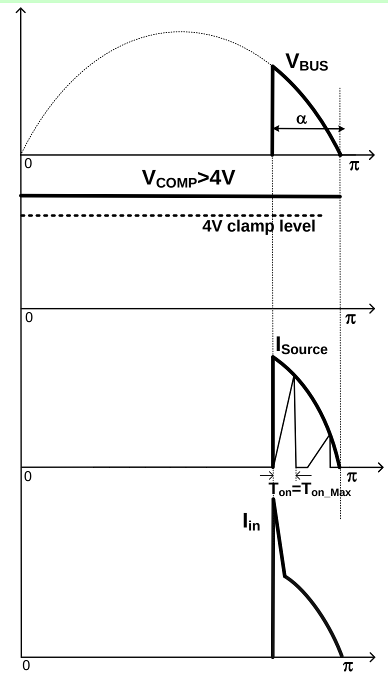
$V_{COMP} < 4V, T_{on} < T_{on\_Max}$



$V_{COMP} = 4V, T_{on} = T_{on\_Max}$



$V_{COMP} > 4V, T_{on} = T_{on\_Max}$

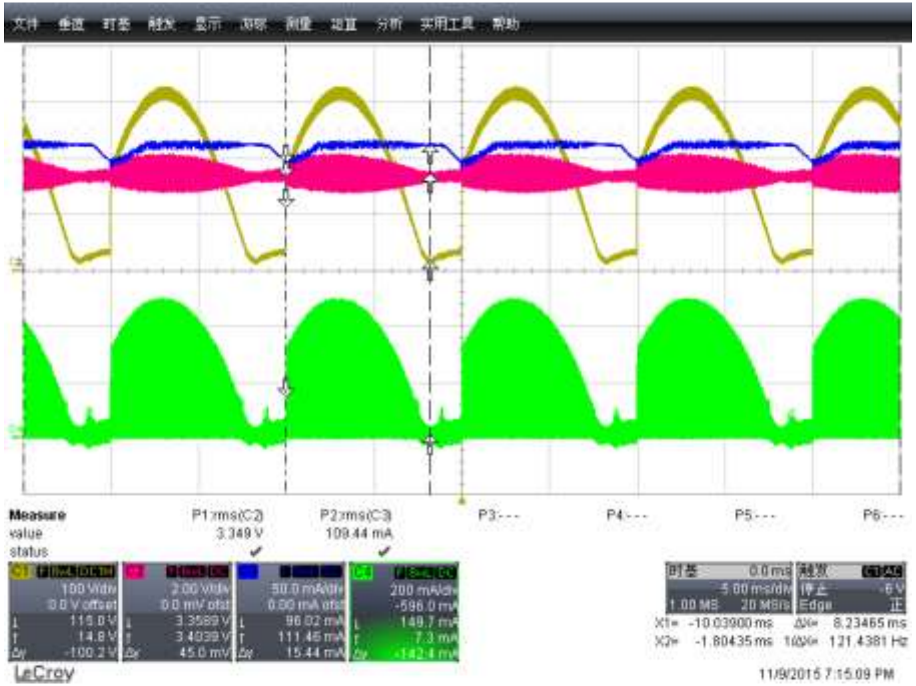


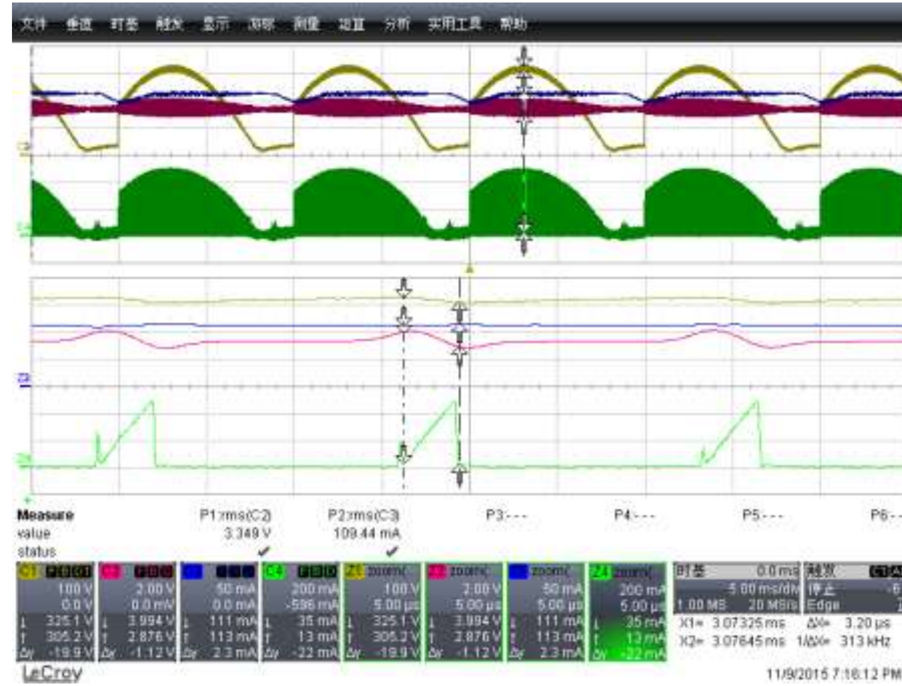
AL1692/7 Operation with Leading-edge dimmer for Buck-boost

➤ Closed Loop and Maximum T_{on} Control

V_{BUS} V_{COMP} I_{LED} I_{Source}

1) V_{COMP}<4V, T_{on}<T_{on_Max}





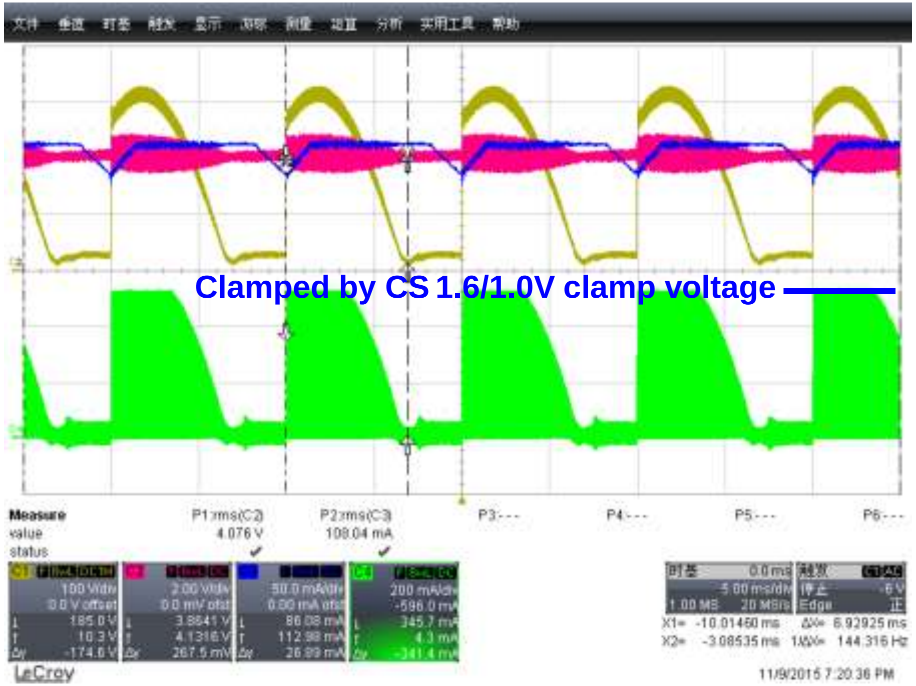
At largest conduction angle with dimmer, V_{COMP}=3.349V<4V, T_{on}=3.2us, output current keeps constant.

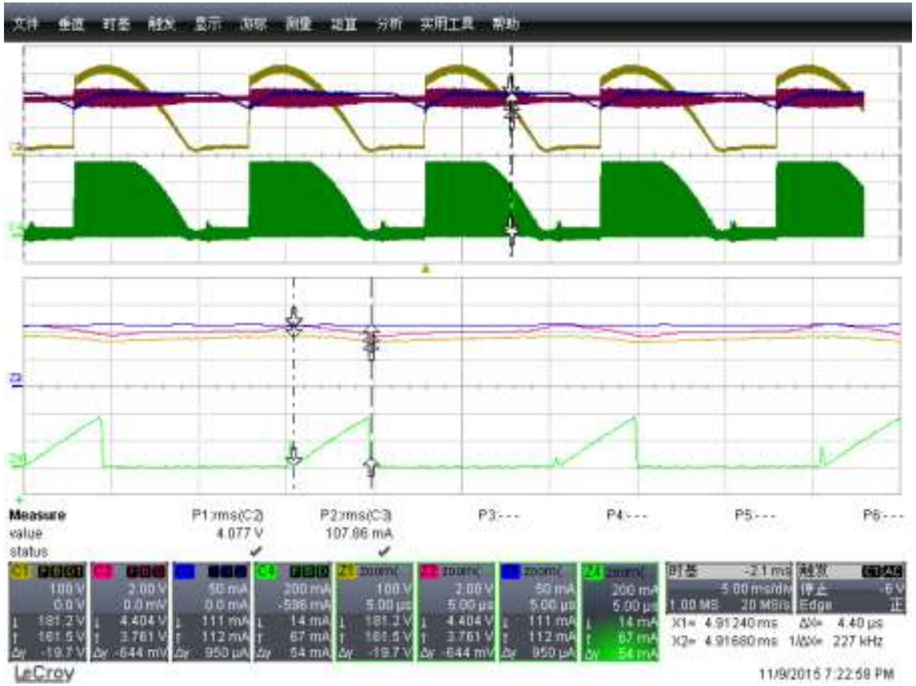
AL1692/7 Operation with Leading-edge dimmer for Buck-boost

➢ Closed Loop and Maximum T_{on} Control

V_{BUS}	V_{COMP}	I_{LED}	I_{Source}

2) V_{COMP}=4V, T_{on}=T_{on_Max}





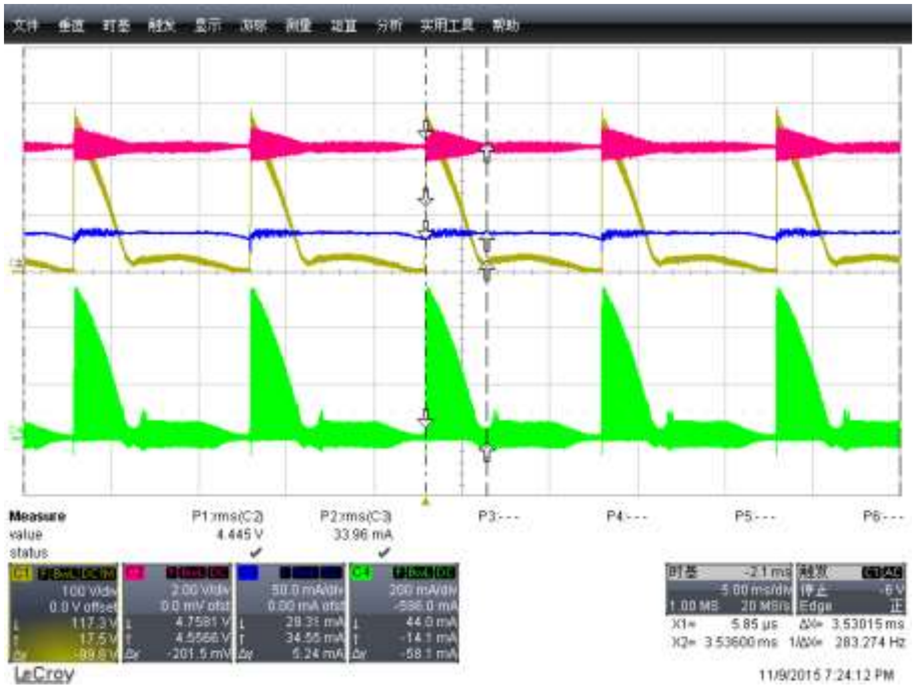
Decrease conduction angle, V_{COMP}=4.07V, increased T_{on}=4.4us reaches T_{on_Max}, output current begins to reduce.

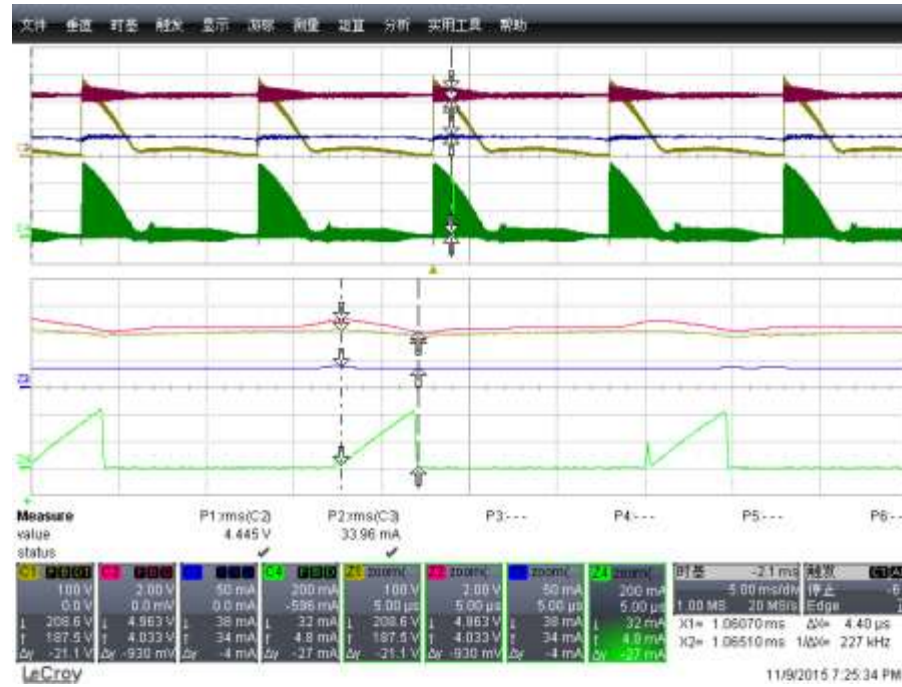
AL1692/7 Operation with Leading-edge dimmer for Buck-boost

➢ Closed Loop and Maximum T_{on} Control

V_{BUS} V_{COMP} I_{LED} I_{Source}

3) V_{COMP}>4V, T_{on}=T_{on_Max}





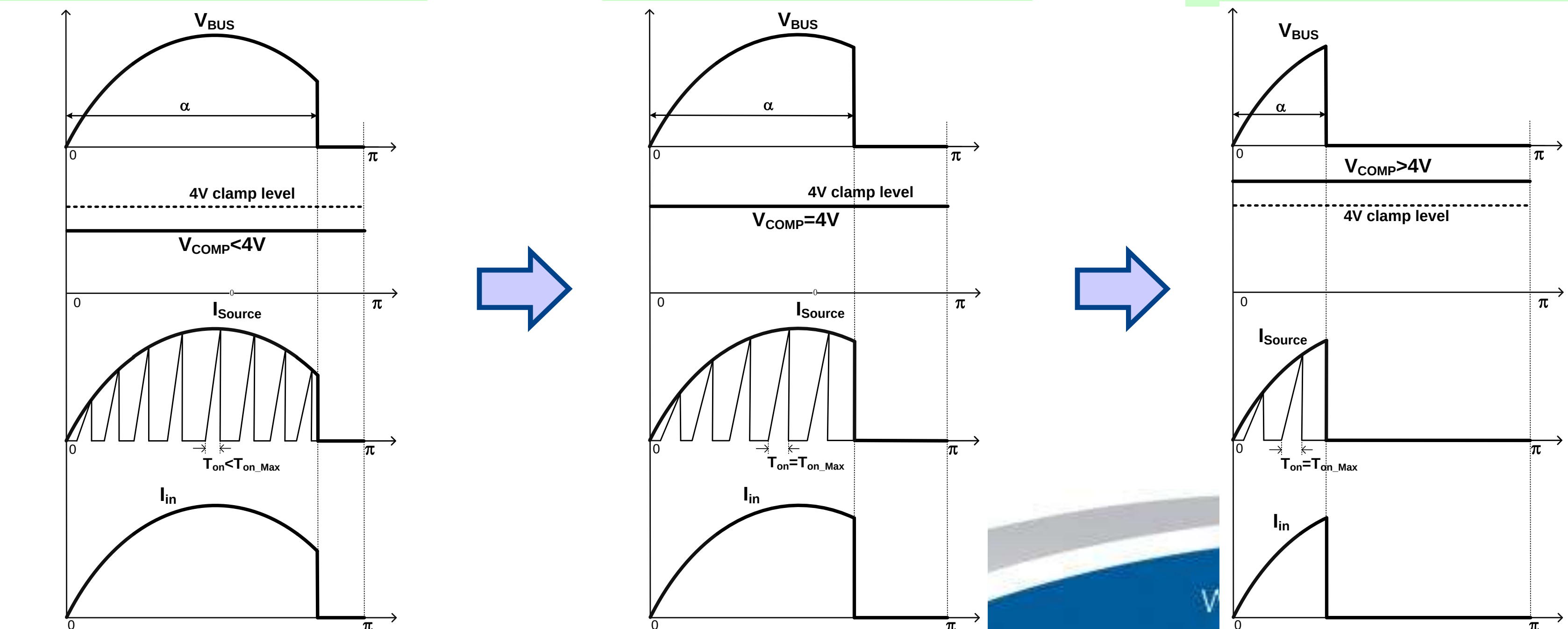
At smaller conduction angle with dimmer, V_{COMP}=4.45V>4V, T_{on}=T_{on_Max}=4.4us, output current continues to reduce.

AL1692/7 Operation with Trailing-edge dimmer for Buck-boost

➤ Closed Loop and Maximum T_{on} Control

1) COMP voltage is adjusted to control switching on time T_{on};
2) Before COMP voltage is adjusted to 4V clamp level, $T_{on}<T_{on\_Max}$, system keeps constant current output, when COMP voltage reaches 4V, $T_{on}=T_{on\_Max}$, limits output current.

$V_{COMP} < 4V, T_{on} < T_{on\_Max}$ | $V_{COMP} = 4V, T_{on} = T_{on\_Max}$ | $V_{COMP} > 4V, T_{on} = T_{on\_Max}$

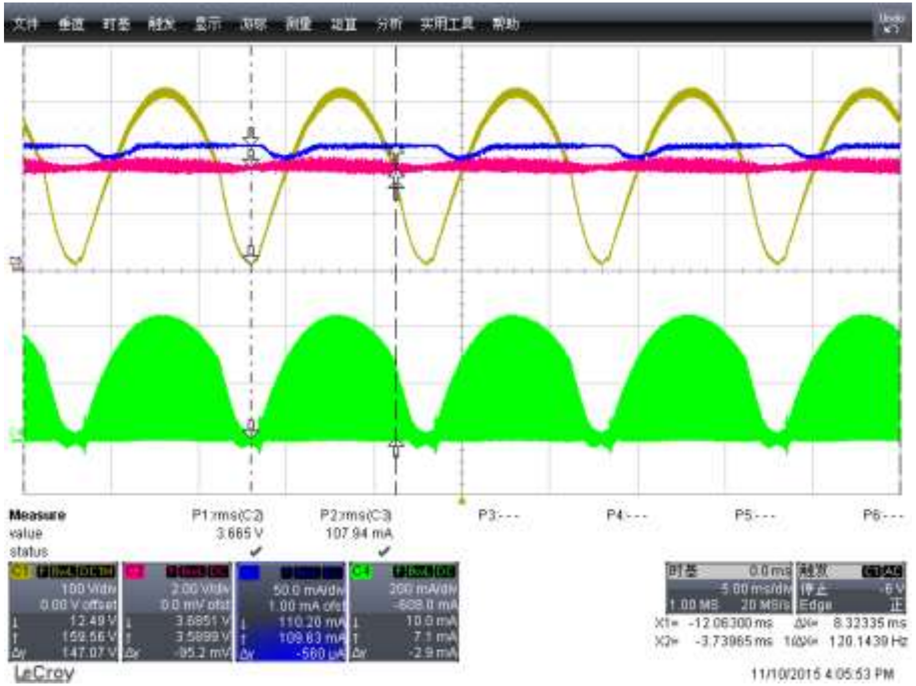


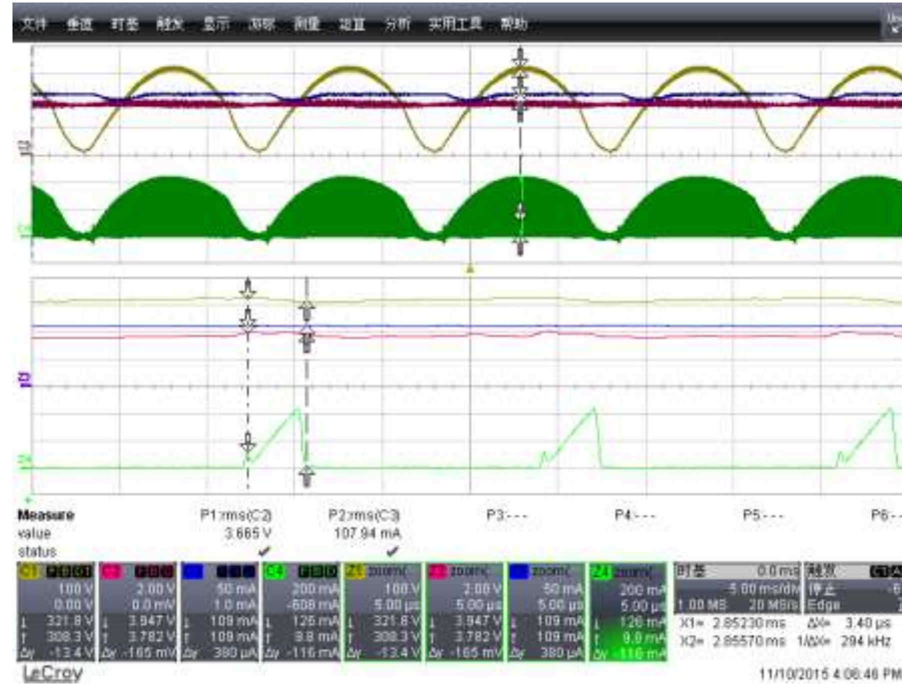
AL1692/7 Operation with Trailing-edge dimmer for Buck-boost

➤ Closed Loop and Maximum T_{on} Control

1) V_{COMP}<4V, T_{on}<T_{on_Max}

V_{BUS} | V_{COMP} | I_{LED} | I_{Source}





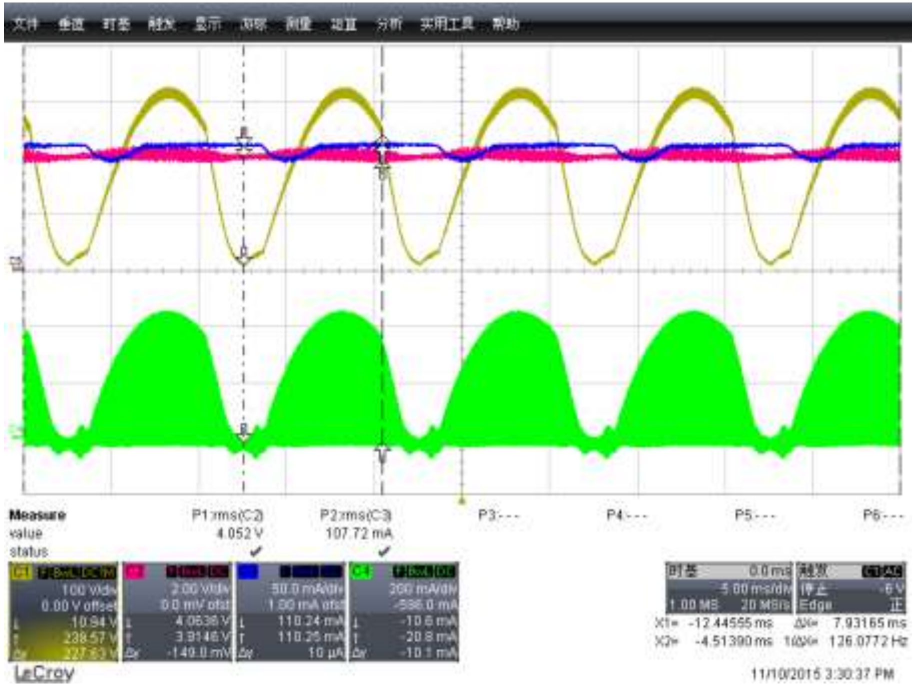
At largest conduction angle with dimmer, V_{COMP}=3.67V<4V, T_{on}=3.4us, output current keeps constant.

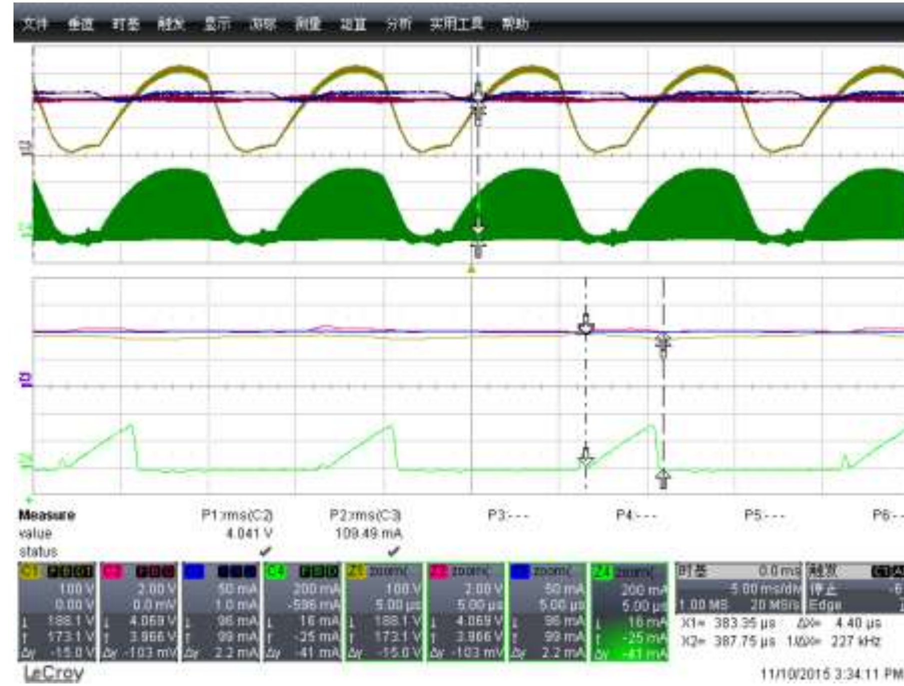
AL1692/7 Operation with Trailing-edge dimmer for Buck-boost

➢ Closed Loop and Maximum T_{on} Control

V_{BUS}	V_{COMP}	I_{LED}	I_{Source}

2) V_{COMP}=4V, T_{on}=T_{on_Max}





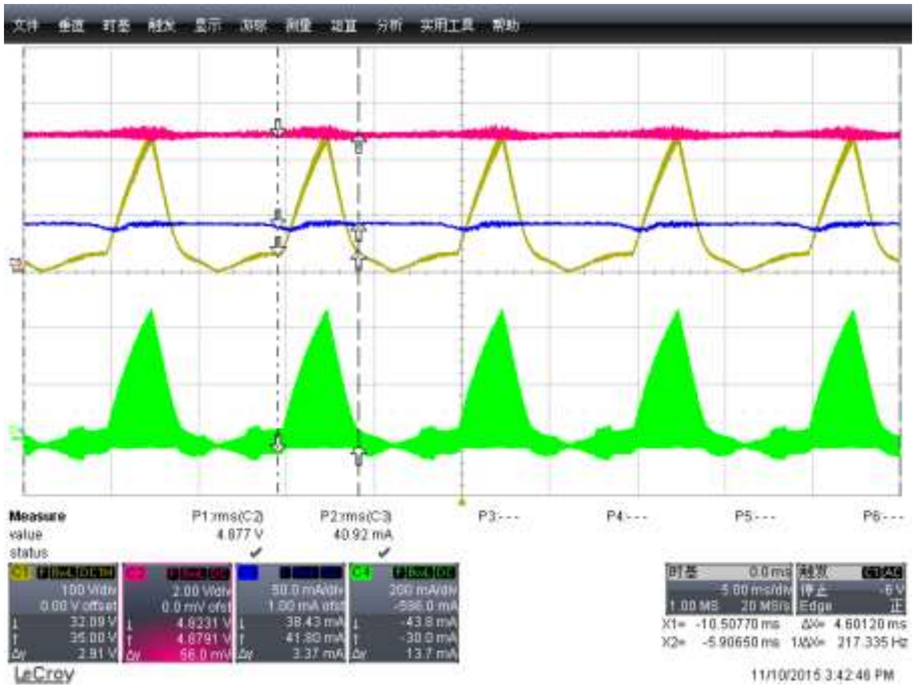
Decrease conduction angle, V_{COMP}=4.05V, increased T_{on}=4.4us reaches T_{on_Max}, output current begins to reduce.

AL1692/7 Operation with Trailing-edge dimmer for Buck-boost

➢ Closed Loop and Maximum T_{on} Control

V_{BUS} | V_{COMP} | I_{LED} | I_{Source}

3) $V_{COMP}>4V$, $T_{on}=T_{on\_Max}$



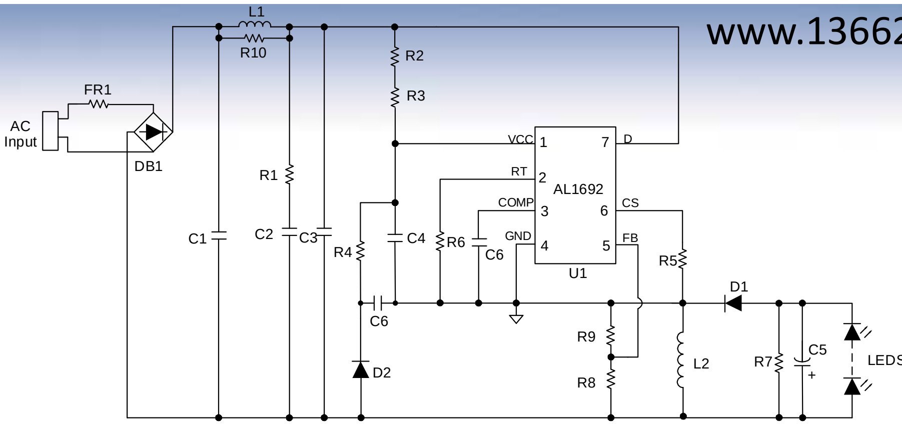
At smaller conduction angle with dimmer, $V_{COMP}=4.87V>4V$, $T_{on}=T_{on\_Max}=4.4us$, output current continues to reduce.

AL1692/7 Dimmable Driver System Design

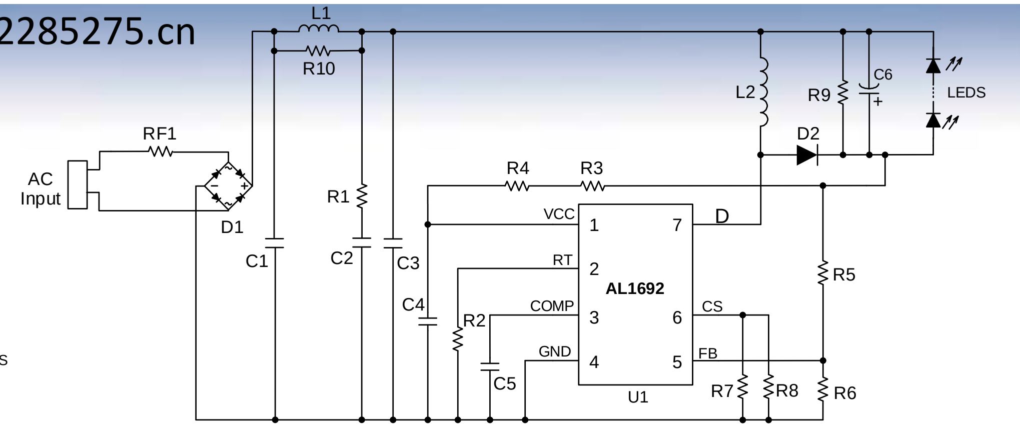
Agenda

- AL1692/7 Typical Application
- AL1692/7 Driver Topology Selection Guide
- Buck-boost (Flyback) System Design
- Auxiliary Circuit Design
- Dimmer Compatibility Optimization and Debug Experience
- EMI and Audible Noise Optimization
- PCB Layout Suggestion

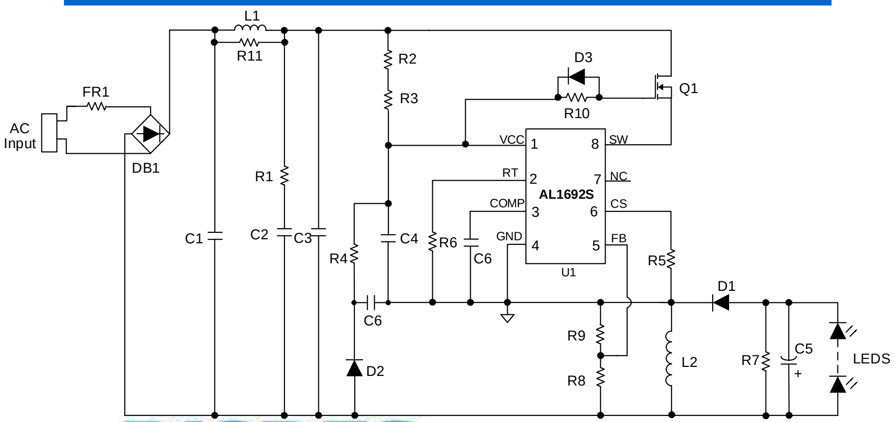
AL1692 Typical Application



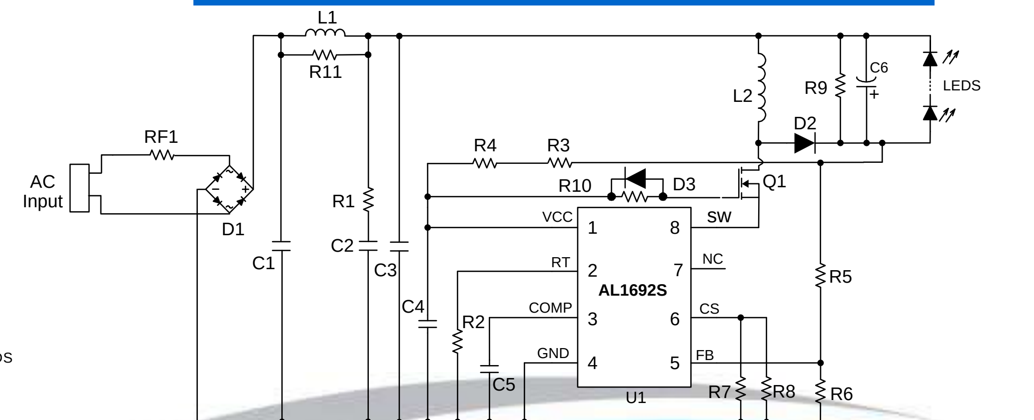
AL1692 Driver for Buck-boost(High-side)



AL1692 Driver for Buck-boost(Low-side)

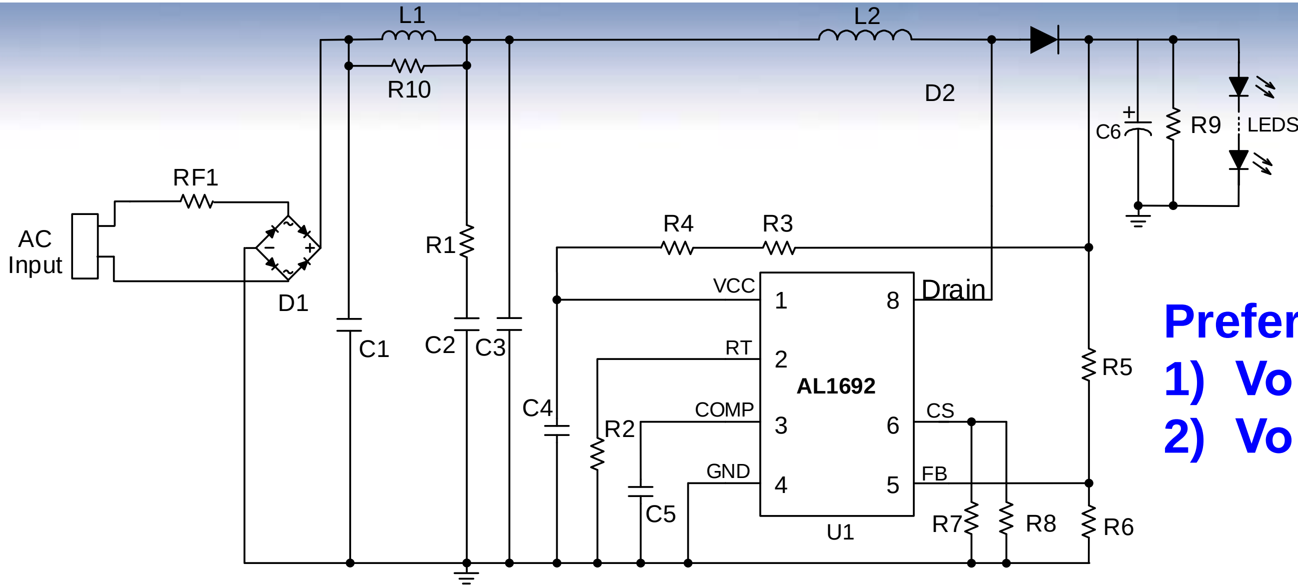


AL1692 Controller for Buck-boost(High-side)



AL1692 Controller for Buck-boost(Low-side)

AL1692 Typical Application

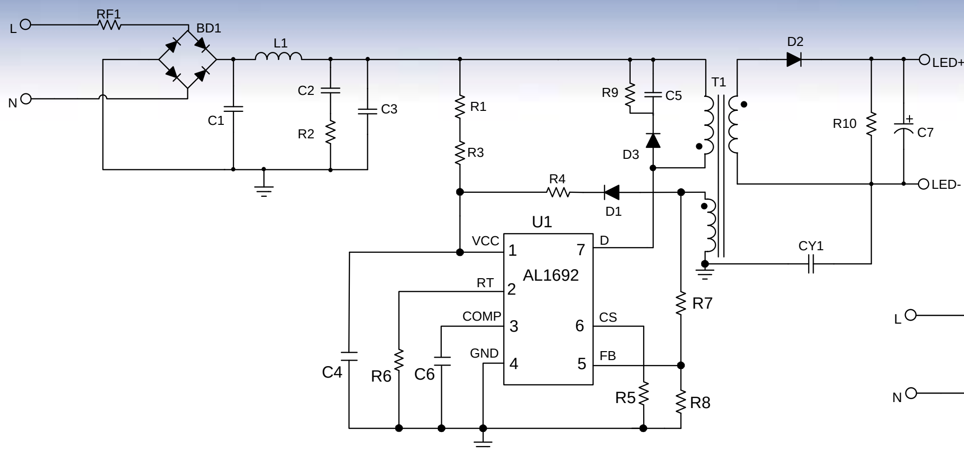


Preferred Application(Filament):
1) Vo ≥ 200V for 120Vac mains;
2) Vo ≥ 350V for 230Vac mains.

AL1692 Driver for Boost

Advantage:
1) Better PFC and THD;
2) Much higher efficiency than buck-boost;
3) Accurate OVP setting;
4) Smaller size power inductor can be used.

AL1692 Typical Application



AL1692 Driver for Flyback (Low-side)

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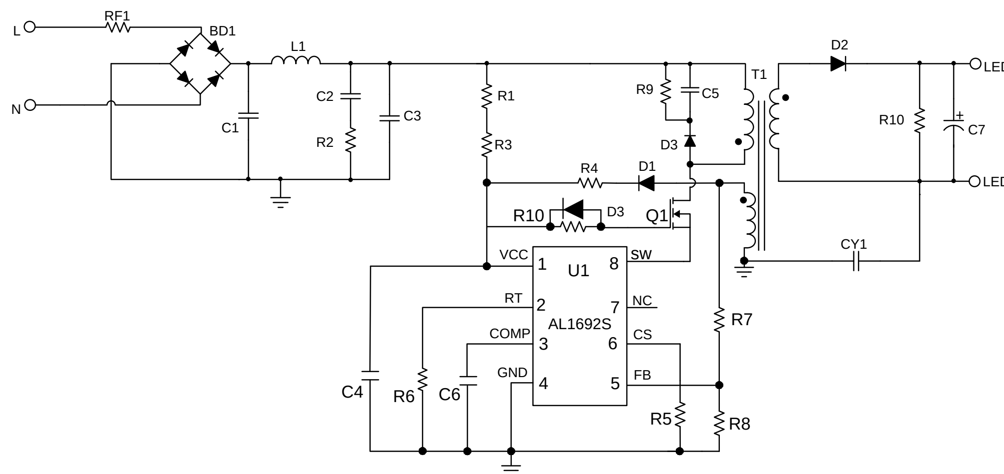
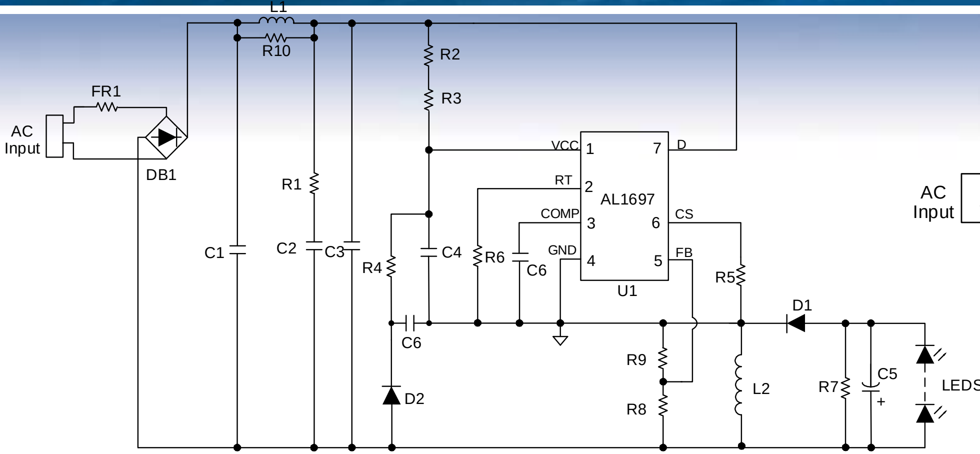
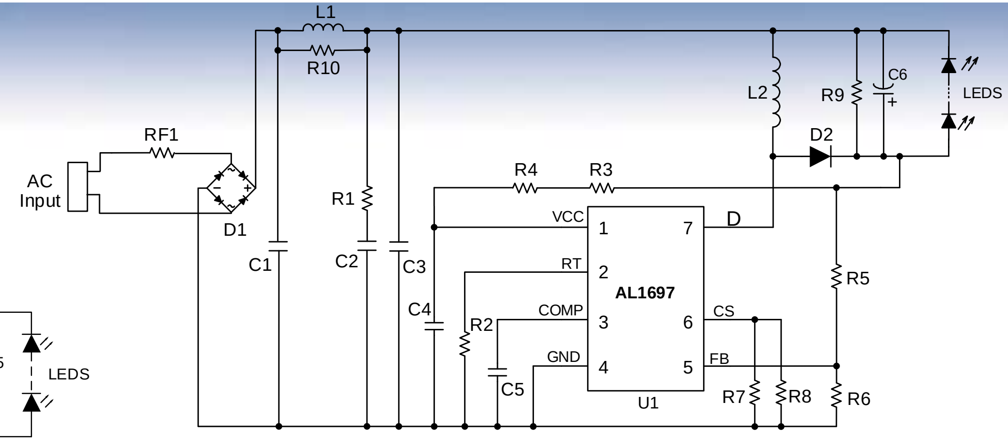


AL1692 Controller for Flyback(Low-side)

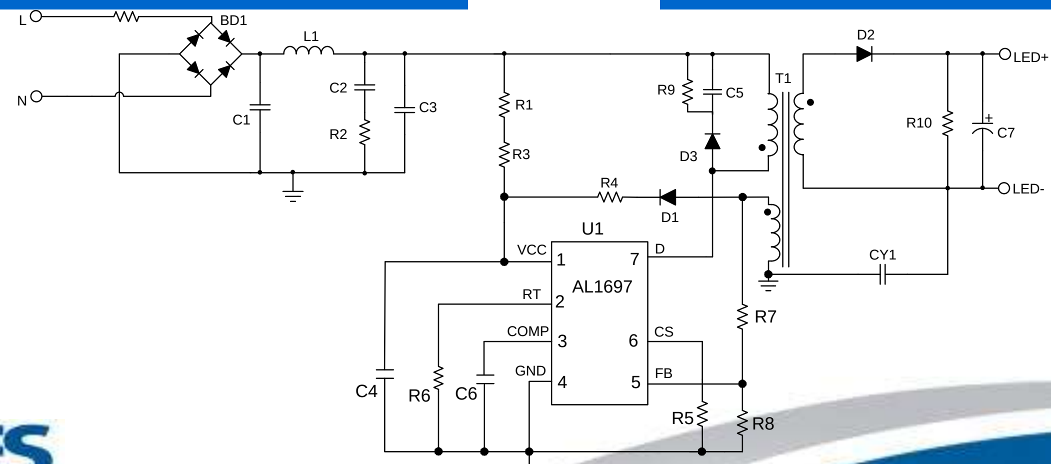
AL1697 Typical Application



AL1697 Driver for Buck-boost(High-side)



AL1697 Driver for Buck-boost(Low-side)



AL1697 Driver for Flyback (Low-side)

AL1692/7 Dimmable Solution Topology Selection Guide

Input Voltage	Application	Output Power	Diodes Part	Output Voltage	Preferred Topology
120VAC	GU10, Candle, A lamp, Filament	≤10W	AL1692-30BA/30B	Vo≤40V	Buck-boost (High side)
			AL1692-30B/20C	40V<Vo<200V	Buck-Boost (Low side)
			AL1692-30B/20C	Vo≥200V	Boost
	Par38, Down Light, External Power	10W<Po <25W	AL1692S	Vo≤40V	Buck-boost (High side)
				40V<Vo<200V	Buck-Boost (Low side)
				Vo≥200V	Boost
				10V≤Vo≤50V	Flyback

AL1692/7 Dimmable Solution Topology Selection Guide

Input Voltage	Application	Output Power	Diodes Part	Output Voltage	Preferred Topology
230VAC	GU10, Candle, A lamp, Filament	≤10W	AL1697-20C	Vo≤120V	Buck-boost (High side)
			AL1697-20C AL1692-20C/10E	120V<Vo<300V	Buck-Boost (High side)
			AL1692-20C/10E	Vo≥350V	Boost
	Down Light, External Power	≤10W	AL1697-20C/40D AL1692-20C/10E	10V≤Vo≤50V	Flyback

AL1692/7 Buck-boost System Design--Using AL1692/7 Calculator

- Fill in application spec and set designed switching frequency

Non-Isolated AL1692 Buck-Boost LED Driver Design					
Design Spec			LED Load Spec		
Minimum Input Voltage, Vac_min	108.0	Vac	LED Output Voltage, Vo	64.00	Vdc
Maximum Input Voltage,Vac_max	135.0	Vac	LED Output Current, Io	0.22	A
AC Input Frequency	60.0	Hz	Output Power, Pout	14.08	Walt
Designed Minimum Switching Frequency, fsw_min	50	Khz			

Fill in input voltage range and frequency, preferred switching frequency ranges from 40kHz to 80kHz, some special application (Filament) can be up to ~100kHz.

Fill in LED output voltage and current

Non-Isolated AL1697 Buck-Boost LED Driver Design					
Design Spec			LED Load Spec		
Minimum Input Voltage, Vac_min	198.0	Vac	LED Output Voltage, Vo	55.00	Vdc
Maximum Input Voltage,Vac_max	264.0	Vac	LED Output Current, Io	126.00	mA
AC Input Frequency	50.0	Hz	Output Power, Pout	6.93	Walt
Designed Minimum Switching Frequency, fsw_min	60	Khz			

AL1692/7 Buck-boost System Design--Using AL1692/7 Calculator

➢ Calculate Current Sense Resistor

Current Sense Resistor Calculation		
Current Sense Resistor_R5=	1.59	Ω
Power Loss of Current Sense Resistor_P_{R5}=	50.8	mWalt

Actual current sense resistor value can be adjusted according to setting LED current.

➢ Choose and Design Power Inductor/Transformer

Power Inductor Design					
Maximum Flux Density Bmax	0.24	T			
Calculated Inductance_Lp	1.70	mH	Selected Inductance_Lp=	1.70	mH
Selected Bobbin and Core Type_Ttype	EE13		Effective Area of Ferrite Core_Ae=	17.20	mm^2
Inductor Winding Turns	208				
Winding Current Density	5.00	A/mm^2	Selected Winding Diameter	0.22	mm

According to driver power and PCB size to select suitable core, fill in Ae value of selected core and calculate winding turns. Set maximum flux density of ferrite core(Bmax), due to larger inductor peak current with dimmer(Ton-max operation), to avoid core saturation, we usually set Bmax<0.25T.

Need to test actual inductor peak current waveform and check the Bmax value with dimmer condition.

AL1692/7 Buck-boost System Design--Using AL1692/7 Calculator

➢ RT Resistor Selection

RT Resistor Selection			
RT Resistor Calculated Value	37	KΩ	

Basing on the RT calculated value, we should check the system line regulation, inductor peak current with dimmer condition and consider the factor of Ton-max distribution (related to RT resistor), then fix the suitable RT resistor.

➢ FB OVP Resistor Setting

FB Section						
OVP Voltage Setting	70	Vdc				
FB Pull Up Resistor	330	KΩ		FB Pull Down Resistor	20.00	KΩ

FB OVP resistor calculation in AL1692/7 excel calculator is used for buck-boost high side topology. For Flyback/Buck-boost low side structure, accurate OVP setting can be calculated through auxiliary winding.

AL1692/7 Buck-boost System Design--Using AL1692/7 Calculator

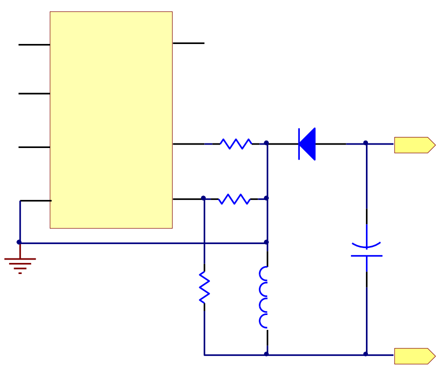
➢ OVP Setting Consideration

VCC | V_{FB} | V_{OUT} | I_{LED}

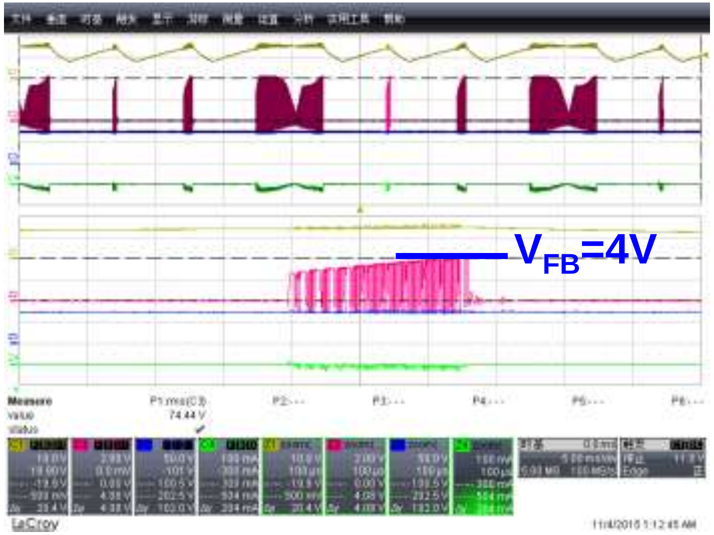
AL1692/7 provides OVP through FB pin sensing output voltage. When output is open or large transient occurs, result in FB pin sense voltage exceeds V_{FB_CV} threshold(typical 4V), OVP is triggered and IC will discharge VCC, when VCC is below UVLO, IC will restart and VCC is charged again. System work in hiccup mode at OVP condition.

FB sense resistor setting

$$\frac{V_{FB\_CV}}{R8} = \frac{V_{out\_OVP}}{R8+R9}$$



- ➢ V_{out_OVP} should be set around 1.3~1.4V_{out} and consider C3 voltage ripple especially at low T_A condition;
- ➢ V_{FB_CV} has tolerance ±6%, should take V_{FB_CV} lower limit(3.76V) for OVP design;
- ➢ FB resistor R8/R9 select should consider affect to efficiency and avoid interference, usually set R8 as 10~30K.

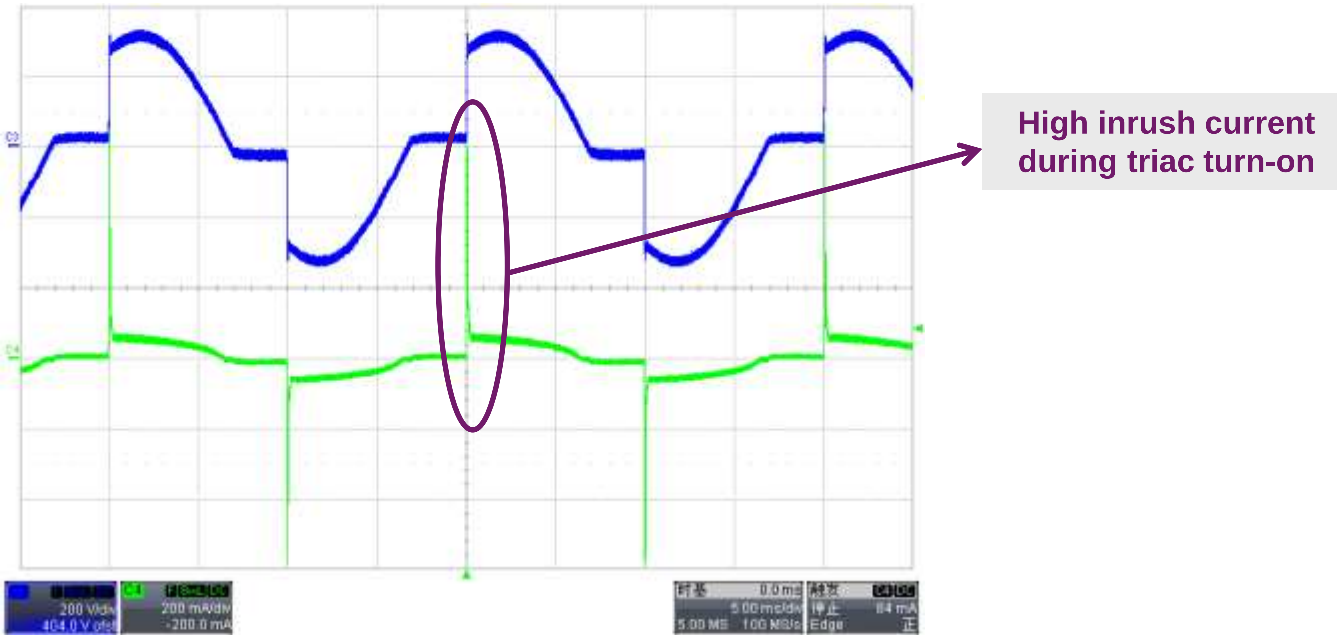


AL1692/7 Dimming Auxiliary Circuit Design

➢ AC Damping

V_{BUS}	I_{IN}

During leading-edge triac dimming, high DV/DT ratio will induce high inrush current, which should be limited.



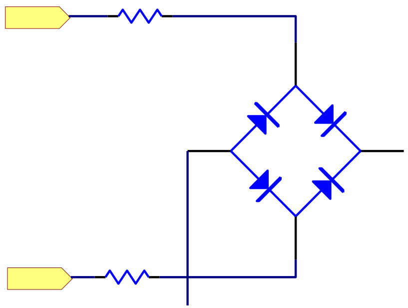
➢If no AC damping, the high inrush current will induce oscillation in dimmer and drivers, maybe the current will oscillate to below triac holding current, and triac will be turned off unexpectedly.

➢If multi-lamp connecting, the inrush current will be multiplied, which would be a huge current, should be limited for reliable triac operation.

AL1692/7 Dimming Auxiliary Circuit Design

➢ AC Damping

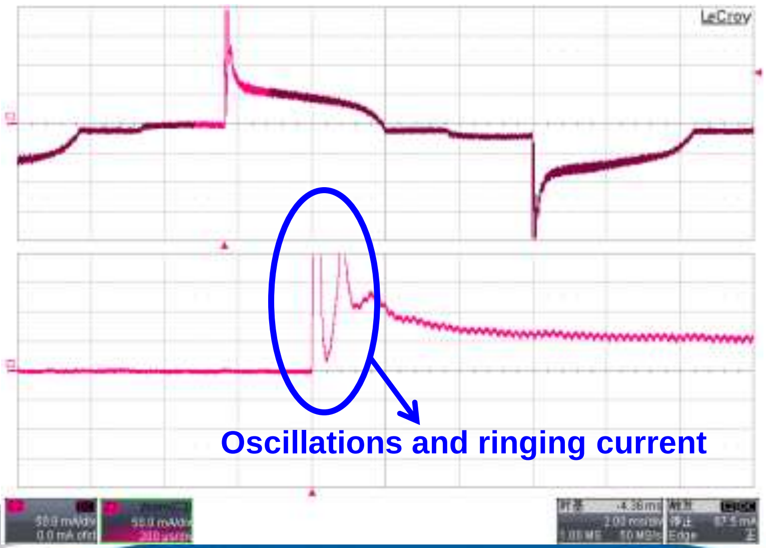
A serial-connected resistor before bridge will be a simple way for AC damping.



Resistor value

1) The inrush current should be less than 2A pk value;
2) The resistor should be large enough that the AC current has no oscillation;
3) System efficiency and resistor temp should also be considered.

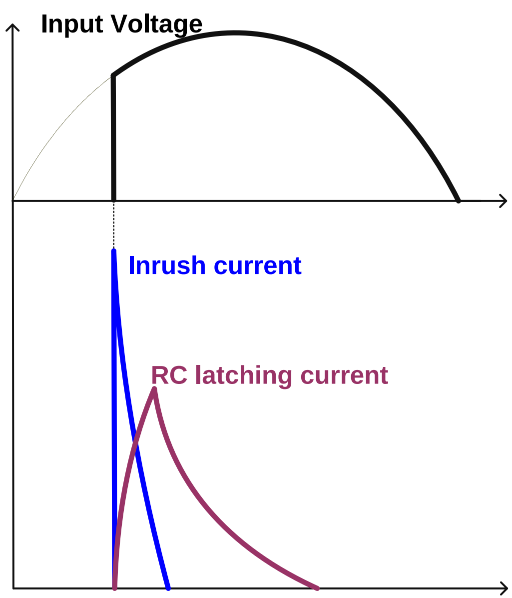
Application	Damper Resistor Value Selection
120V mains input	20~100R/1W
230V mains input	68~200R/1W

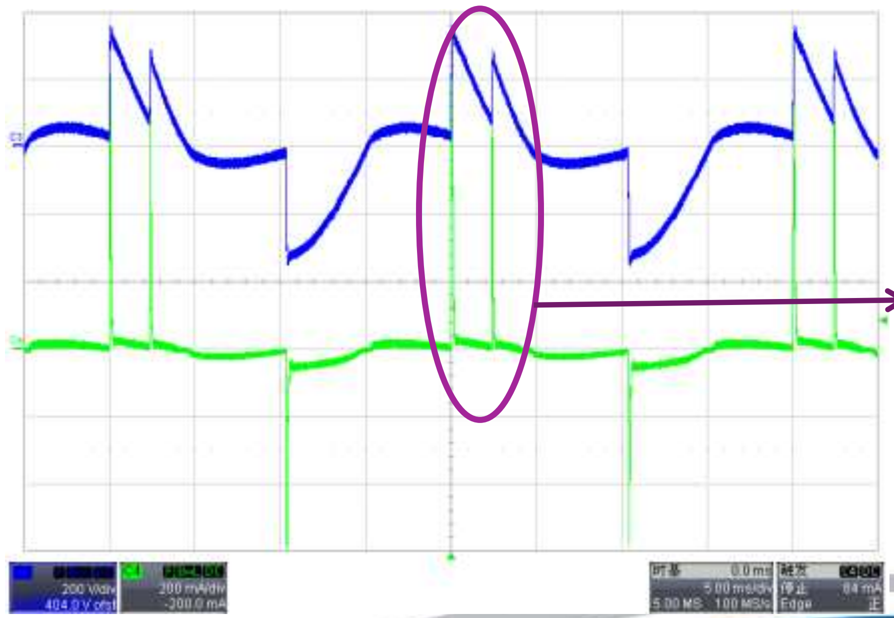


AL1692/7 Dimming Auxiliary Circuit Design

➢ Latching Circuit (Passive Bleeder)

Additional latching current should be provided to the dimmer to latch the triac conduction, generally it will be 3 times holding current, 100~200mA rating with duration of ~200us. Inrush current width is too short(~10us), can not meet the duration timing requirement for triac latching.





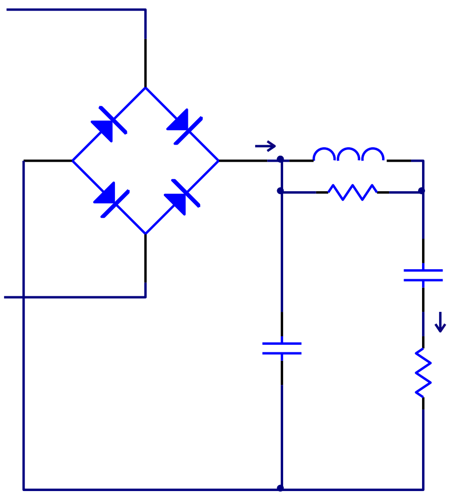
Insufficient latching current and latching time, cause dimmer misfire.

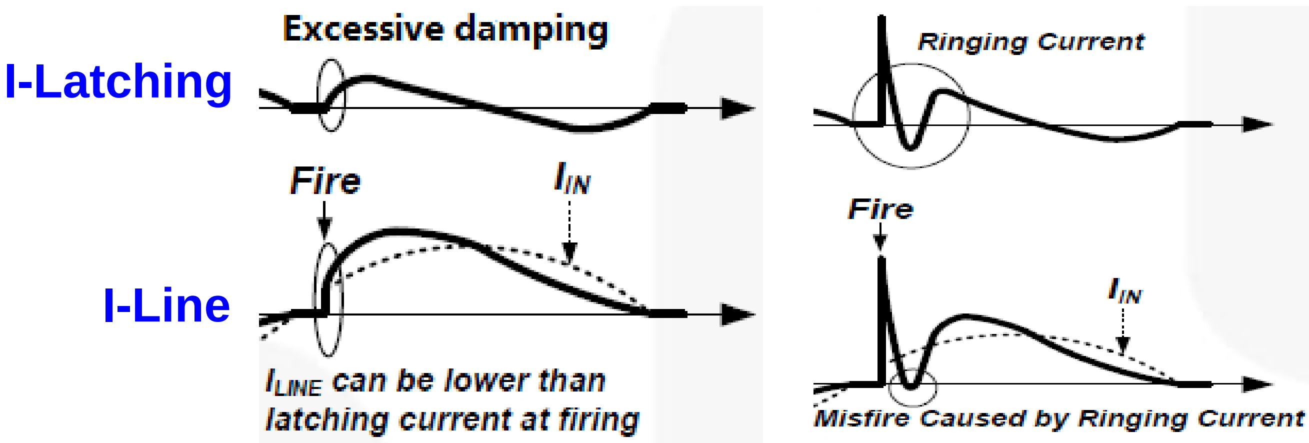
AL1692/7 Dimming Auxiliary Circuit Design

➢Latching Circuit (Passive Bleeder)

A RC latching network usually used in the dimming application to provide latching current.

1) **R-latch is the damper for reducing spike current caused by quick charging C-latch at firing. Too large resistor dampens I-Latching too much and limits I-Latching less than latching current at firing. If R-latch is too small, it can't fully dampen spike current and ringing current occurs, result in misfire of triac and flicker.**





Too large R-latch

Too small R-latch

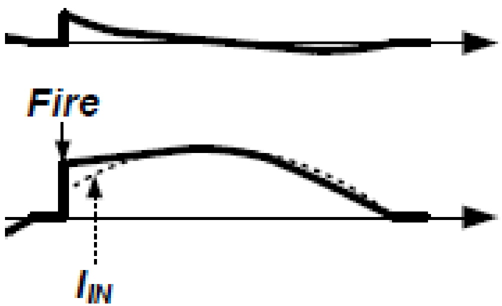
AL1692/7 Dimming Auxiliary Circuit Design

➢Latching Circuit (Passive Bleeder)

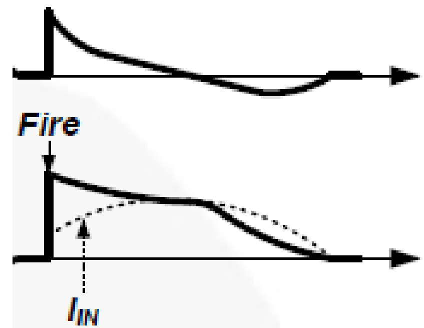
2) Capacitor value should be high enough (hundred-of-nF) for providing enough latching current to avoid misfire. Small C-latch can't provide large enough I-Line, may cause dimmer misfire right after firing. While I-Line is higher at dimmer firing with large C-latch, which can maintain normal turn-on state of dimmer. Also, a large C-latch has a drawback in PF, THD and efficiency.

I-Latching

I-Line



Small C-latch



Large C-latch

Generally, the preferred RC parameters are listed as below.

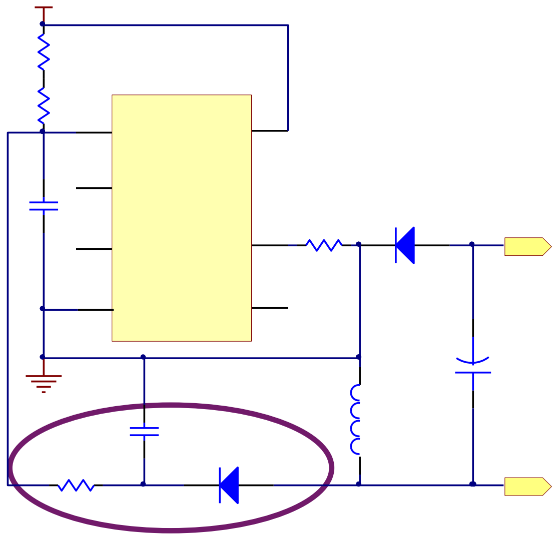
Typical RC latching parameter		
Application	120V Mains	230V Mains
C-latch	150nF~220nF/250V	100~150nF/400V
R-latch	330R, 470R,560R/1W	390R, 470R,560R/1W

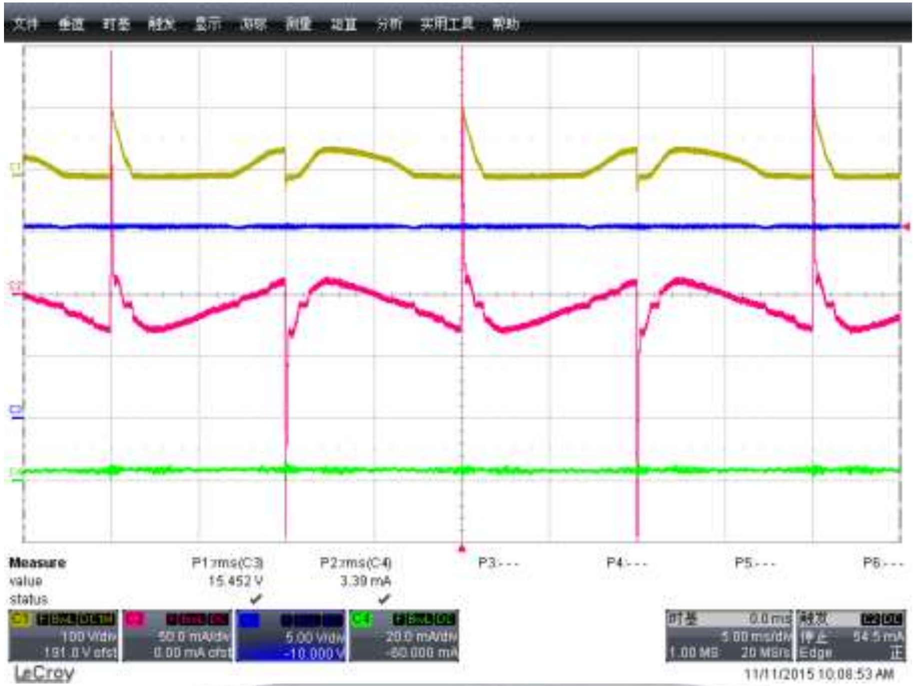
AL1692/7 Dimming Auxiliary Circuit Design

➢ VCC Supply Circuit--High Side

V_{BUS} | I_{IN} | V_{CC} | I_{LED}

For high side structure, D1/R3/C2 combines the VCC supply circuit as below, IC can get enough VCC supply from Vout even at lowest dimmer conduction angle.





C2 capacitor: several hundreds nF(such as 470nF);
R3 resistor: depends on V_{out}, consider no affect to efficiency and enough operation current, generally set I_{R3} at around 0.5mA (such as for 70V V_{out}, set R3=110K)

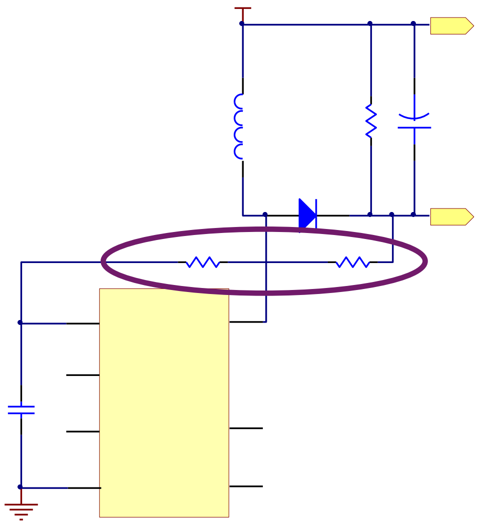
At lowest conduction angle

AL1692/7 Dimming Auxiliary Circuit Design

➢ VCC Supply Circuit--Low Side

V_{IN-AC} | V_{CC} | I_{LED}

For Low side structure, IC VCC supply can be got directly from output capacitor positive side through two start-up resistors(as below), which simplify the total BOM count. This kind of VCC supply is suitable for Vo>40V,120Vac mains application and partial high voltage output, 230Vac mains application such as filament(Vo>120V).



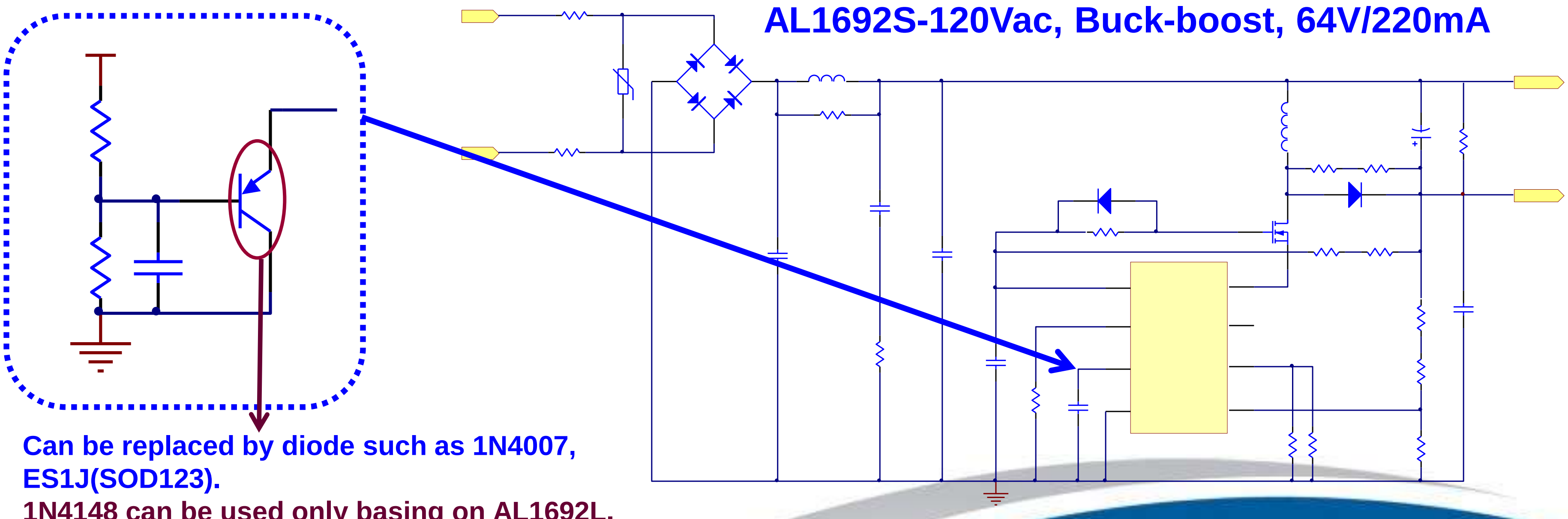
R3,R4 resistor: Trade-off between efficiency and enough ICC current, usually assure I_{R3}=0.5mA at lowest conduction angle for most dimmers.

At lowest conduction angle

AL1692/7 Dimming Auxiliary Circuit Design

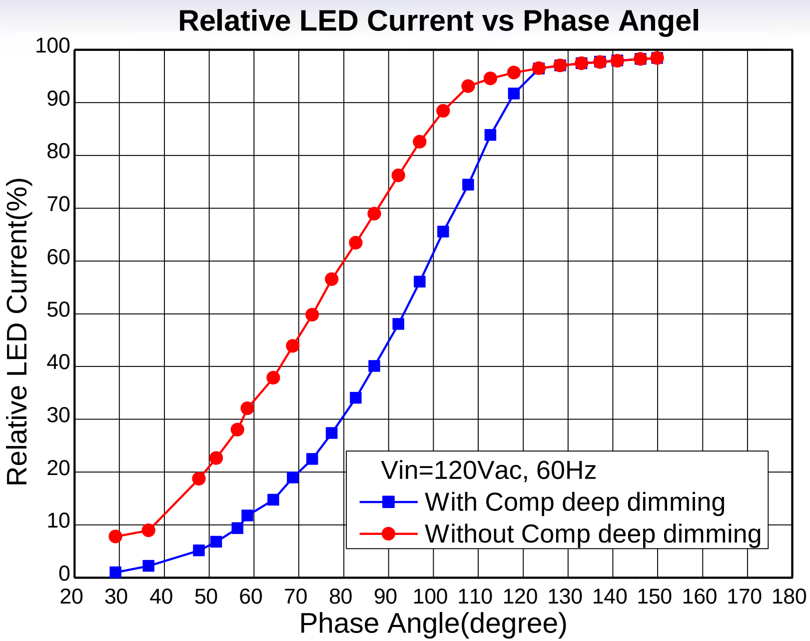
➢ Deep Dimming Circuit

Most of LV and HV mains application, customer has dimming range requirement such as I_{LED}<10%I_{RATED} at minimum dimmer angle and I_{LED}>90%I_{RATED} at maximum dimmer angle. Due to larger conduction angle at low end for partial dimmer, I_{LED}<10%I_{RATED} requirement can't be met. It's necessary to add deep dimming circuit. The dimming curve is also optimized.

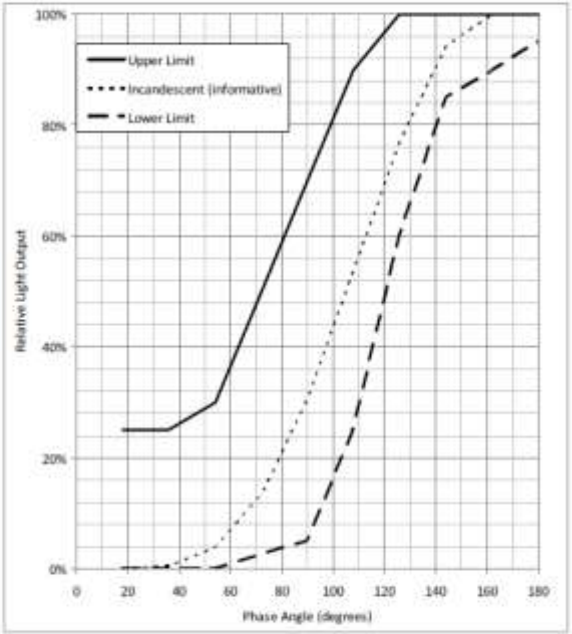


AL1692/7 Dimming Auxiliary Circuit Design

➢ Deep Dimming Circuit



NEMA SSL6 Standard



Phase Angle (deg)	Lower Limit	Upper Limit
18	0%	25%
36	0%	25%
54	0%	30%
72	3%	50%
90	5%	70%
108	25%	90%
126	60%	100%
144	85%	100%
162	90%	100%
180	95%	100%

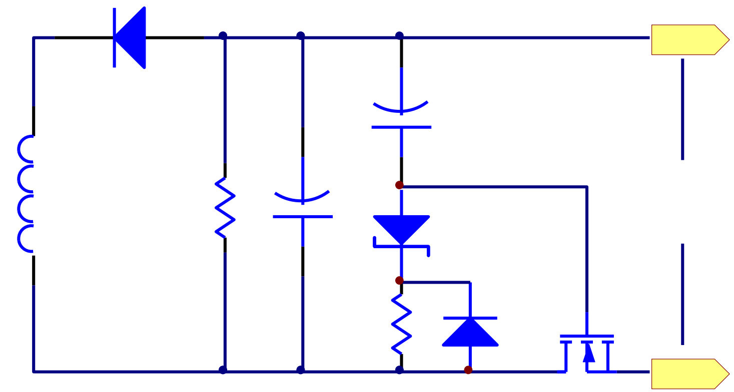
Add comp deep dimming circuit can optimize dimming depth and curve efficiently.

AL1692/7 Dimming Auxiliary Circuit Design

➢ Output Ripple Suppressor Circuit

During deep dimming operation of distorted mains input, LED would shimmer even flicker caused by variable or asymmetric dimming on duty in each AC cycle. Current ripple suppressor can be used for shrinking LED current ripple obviously, which also eliminate the shimmer or flicker at low end.

- R2, C combines RC filter to get mean value of V_{co} minus zener D3 voltage to driver Mosfet Q1;
- During start-up process, zener D3 will be breakdown to charge C quickly to turn on Q1;
- Mosfet Q1 operates in variable resistance area, holds the ripple voltage, Q1 is preferred to adopt low $V_{GS(th)}$ to reduce power loss;
- For a certain Co, D3 zener voltage can be adjusted to reduce current ripple. The larger for D3 zener voltage, the better ripple current filter effect can be got, while result in more efficiency loss.



Some Equations

$$V_{Co} = V_{DS} + V_{LED} = V_{DG} + V_{C}$$

$$V_{C} = V_{GS} + V_{LED}$$

$$V_{DS} = V_{DG} + V_{GS}$$

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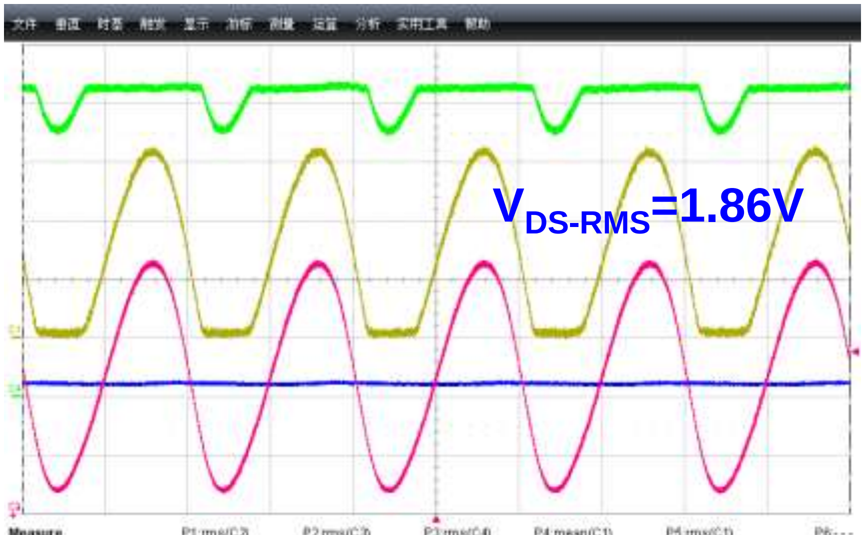
AL1692/7 Dimming Auxiliary Circuit Design

➢ Output Ripple Suppressor Circuit

V_{DS}	V_{Co}	V_C	I_{LED}

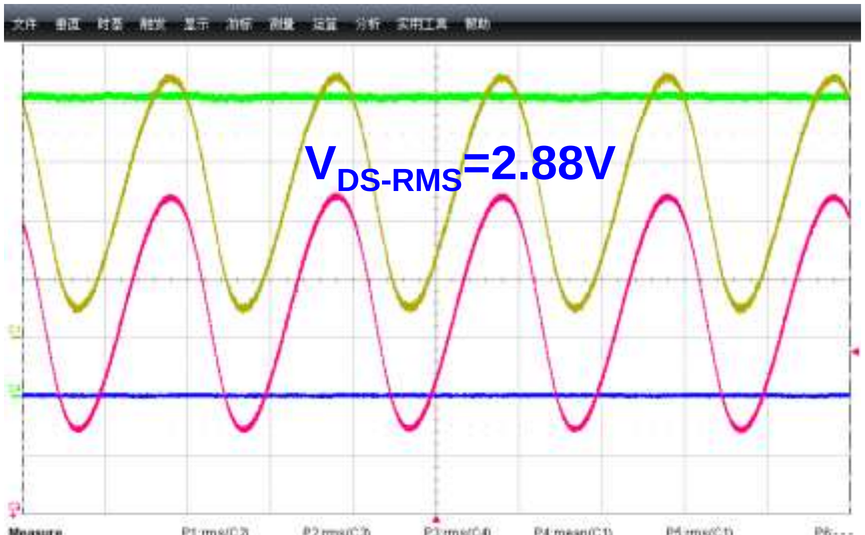
To obtain good ripple suppressor effect, first step is to fix the maximum output capacitor can be used, then consider the ripple current and efficiency affect to choose the suitable D3 zener voltage.

Example: AL1697-230Vac, 63V/103mA



Small Co and D3, Q1 exists saturation work area, result in lager ripple current.

Co=68uF, D3=3.0V, I_{LED}=103mA



Increase D3 voltage to get smaller ripple current

Co=68uF, D3=4.7V, I_{LED}=103mA

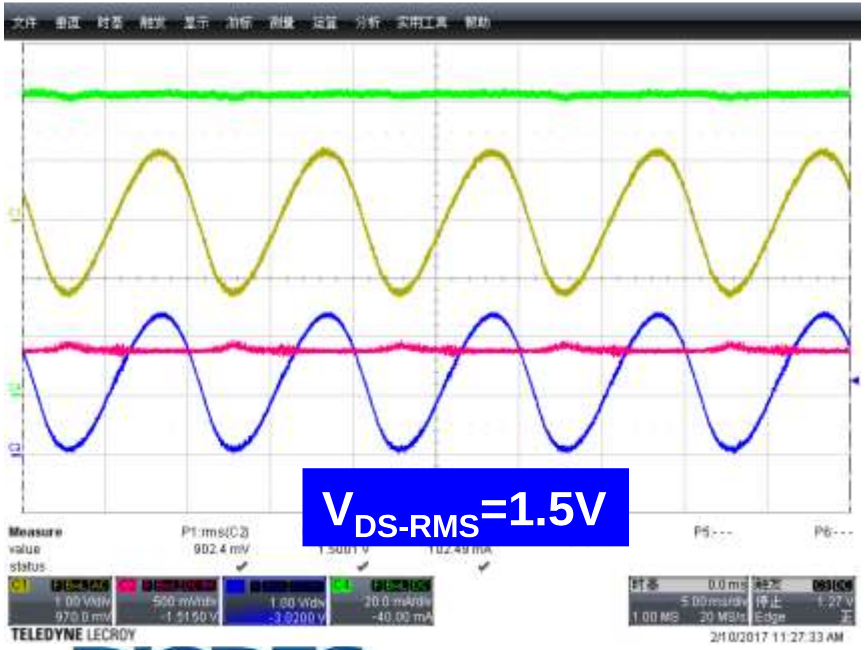
AL1692/7 Dimming Auxiliary Circuit Design

➢ Output Ripple Suppressor Circuit

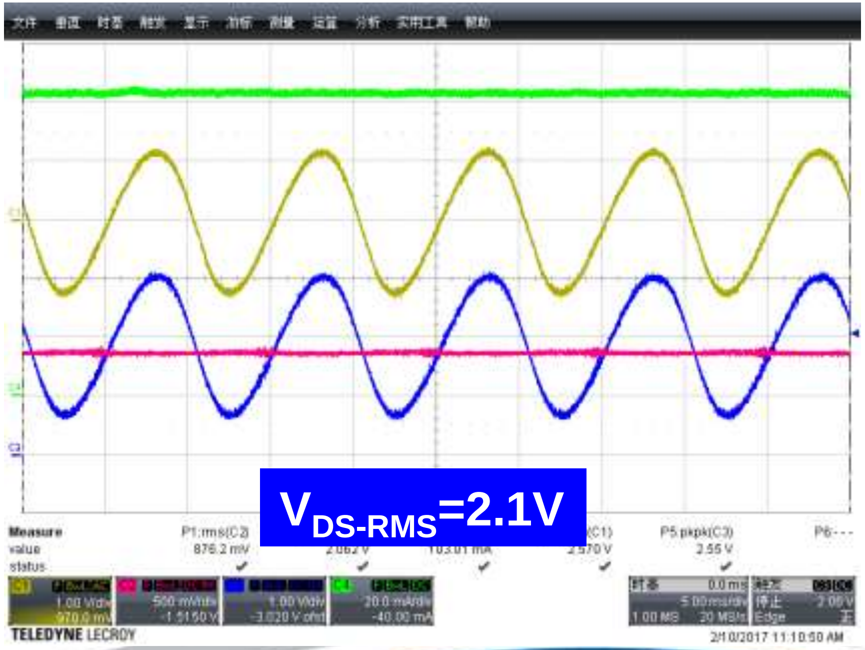
V_{Co-AC} | V_{GS} | V_{DS} | I_{LED}

If Co is used 120uF, basing on same D3 zener voltage, smaller Co ripple voltage and better ripple suppress effect can be obtained, also reduced V_{DS} RMS voltage and efficiency loss.

Example: AL1697-230Vac, 63V/103mA



Co=120uF, D3=3.0V, I_{LED}=103mA



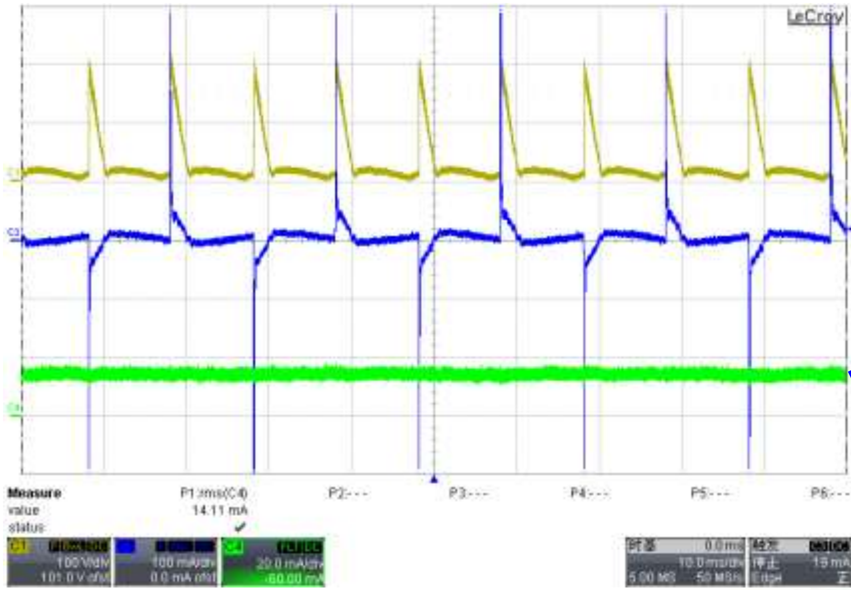
Co=120uF, D3=4.7V, I_{LED}=103mA

AL1692/7 Dimming Auxiliary Circuit Design

➢ Output Ripple Suppressor Circuit

V_{BUS} I_{IN} I_{LED}

LED current ripple suppression solved shimmer or flicker issue at small conduction angle caused by distorted and dirty mains input or asymmetrical waveform after dimmer effectively.



Steady output LED current.

With leading-edge dimmer at small conduction angle@220V mains input

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

AL1692 120Vac Mains Dimmer Compatibility Optimization Summary			
Item	**Common Incompatible Issues**	**Reason Analysis**	**Solution**
1	Shimmer or flicker at low conduction angle	Asymmetrical voltage of different AC cycle after dimmer	1)Increase output capacitor; 2)Increase dummy load current; 3)Add comp deep dimming circuit; 4)Adopt output ripple suppressor.
2	Flicker caused by inadequate latching current or misfire by ringing current	Inadequate latching current or ringing current casued triac misfire	1)Adjust RC latching parameter; 2)Increase AC damping resistor
3	Flicker at start-up when power on/off dimmer quickly	Output capacitor can't be discharged completely	Increase dummy load current
4	Flicker at low end caused by inadequate VCC supply	Can't provide enough ICC current at low angle and pull down VCC	1)Decrease start-up resistor and increase VCC capacitor; 2)Decrease start-up and VCC supply resistor.

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

1) Shimmer or flicker at low conduction angle caused by asymmetrical waveform after dimmer

Solutions:

- ➢ Increase Output Capacitor;--Considering PCB size and housing dimension to choose the larger capacitor can be accepted;
- ➢ Increase Dummy Load Current;--Increase dummy load current to around 2~3mA, need to consider the power loss of dummy load resistor.
- ➢ Add Comp Deep Dimming Circuit;--Improve the dimming depth at low angle, well used in most of 120Vac applications.
- ➢ Adopt Output Ripple Suppressor.--Can be used in some high voltage output application (such as filament, size limitation for Co).

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

1) Shimmer or flicker at low conduction angle caused by asymmetrical waveform after dimmer

V_{IN-AC} | I_{IN} | I_{LED}

No Comp Deep Dimming

Add Comp Deep Dimming

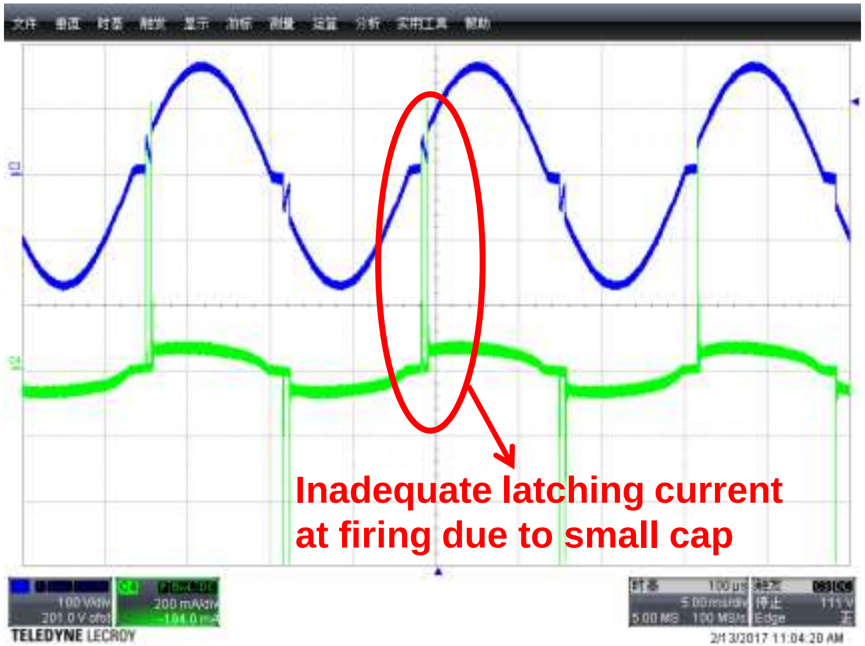
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

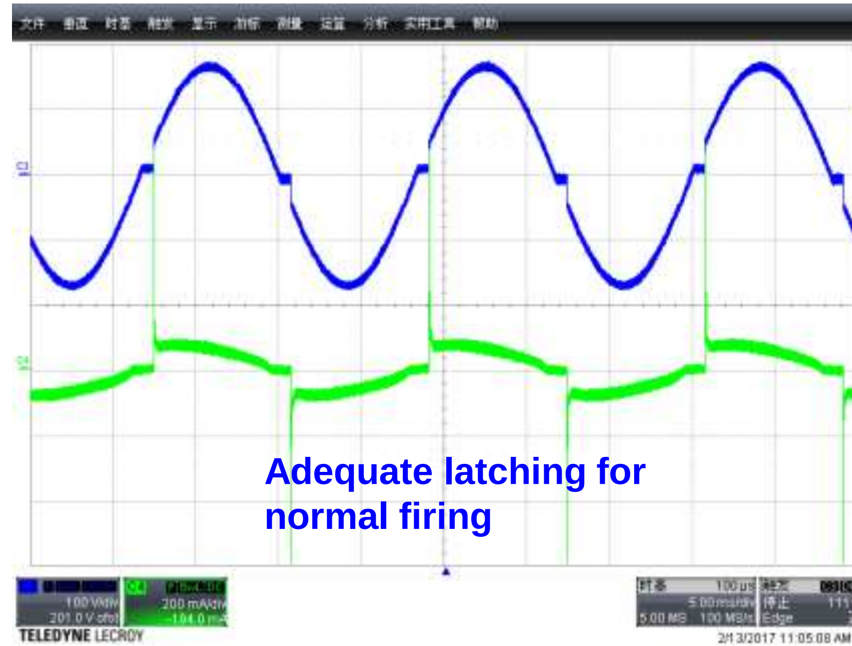
V_{IN-AC} I_{IN}

2) Flicker caused by inadequate latching current or misfire by ringing current

Solutions: Adjust RC latching parameter.



Too small latching Cap



Increase latching cap to 220nF

Suggested RC latching parameters for 120Vac: C--150~220nF, R-330~560R

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

V_{IN-AC} | I_{IN}

2) Flicker caused by inadequate latching current or misfire by ringing current

Solutions: Increase AC damping resistor.

Inadequate AC Damping

Increase AC Damping

Suggested AC Damping Resistor for 120Vac mains: R--20~100ohm

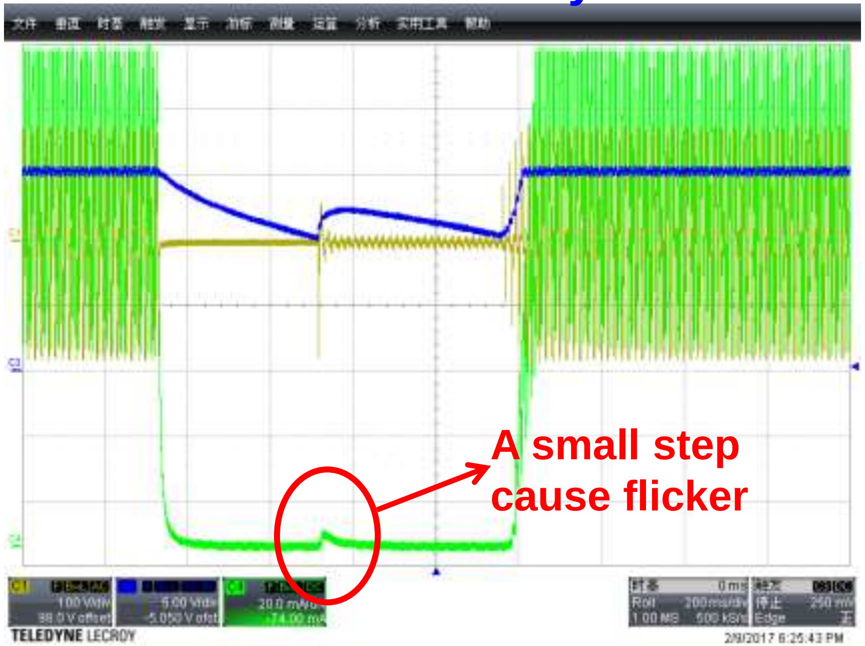
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

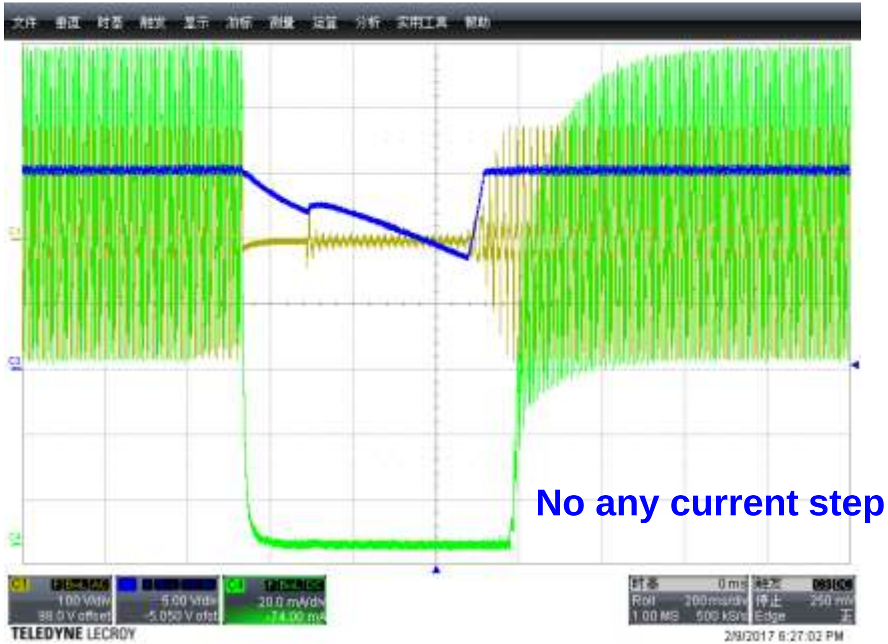
3) Flicker at start-up when power on/off dimmer quickly

Solutions: Increase dummy load current.

V_{IN-AC} | V_{CC} | I_{LED}



Large dummy load resistor



Using smaller dummy load resistor

According to output voltage/power loss to use proper dummy load resistor.

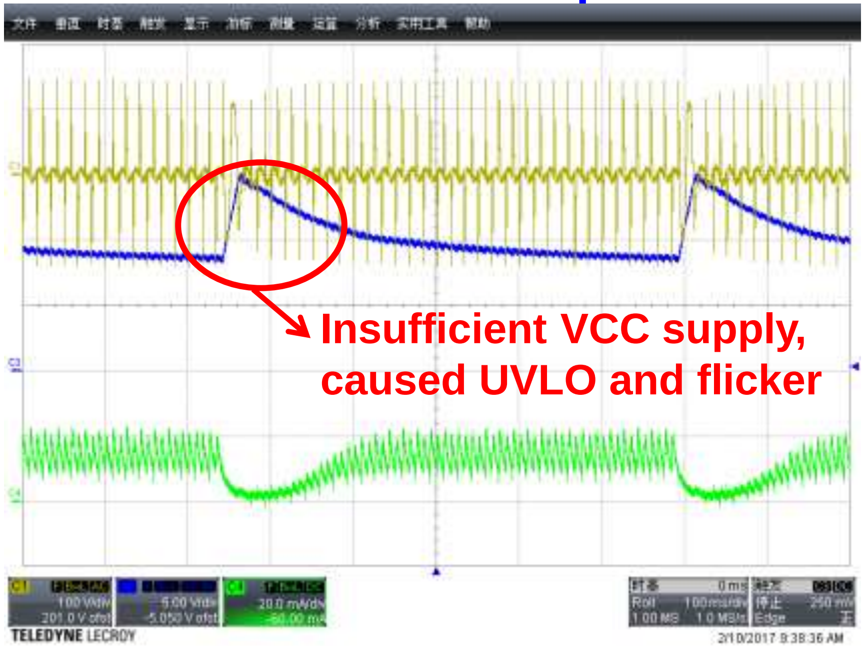
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

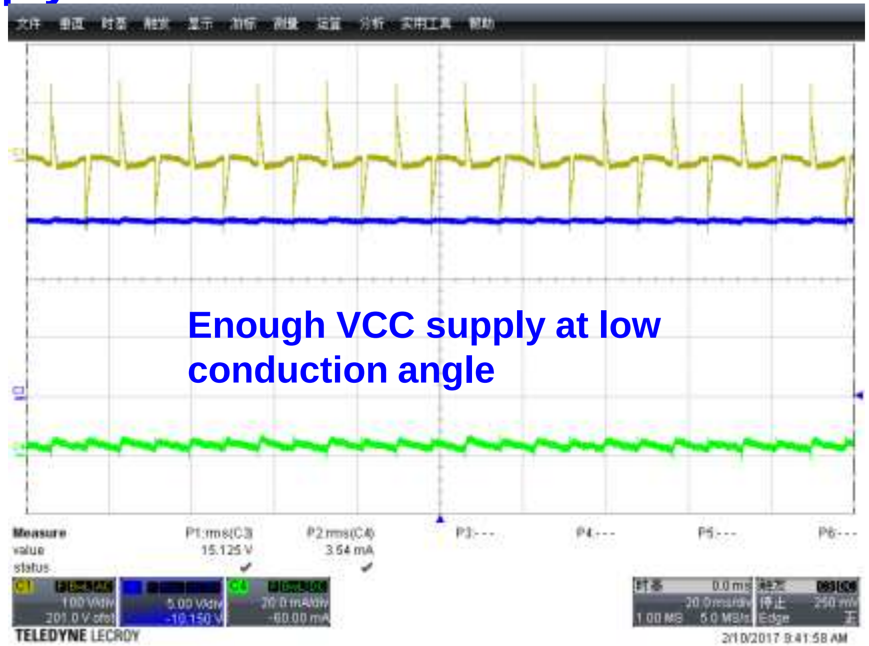
➢ 120Vac Mains Dimmer Compatibility Debug Experience

4) Flicker at low end caused by inadequate VCC supply

Solutions: Decrease start-up and VCC supply resistor.

V_{IN-AC} | V_{CC} | I_{LED}





Large start-up or VCC supply resistor

Reduce start-up or VCC supply resistor

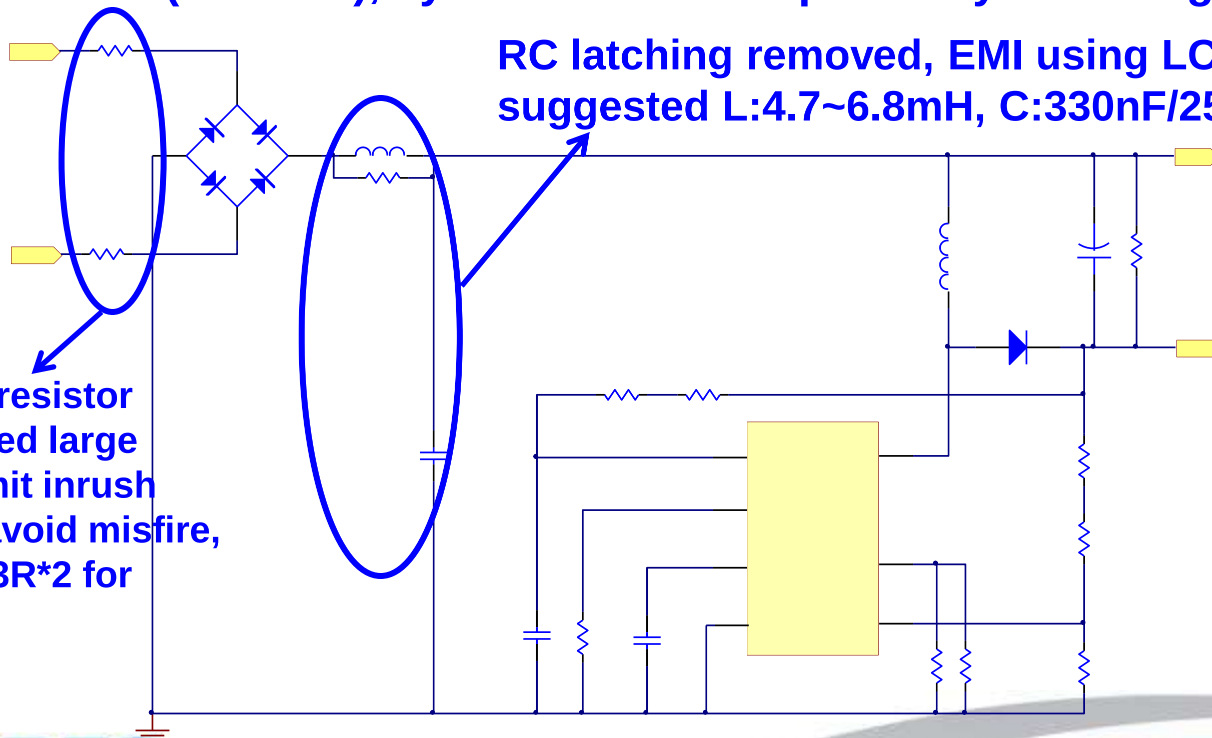
If occurs VCC UVLO at low angle, decrease start-up or VCC supply resistor.

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmable Solution Simplification(Remove RC Latching)

To reduce BOM cost and improve advantage for competition, or for some application has size limitation(filament), system can be simplified by removing RC latching.

RC latching removed, EMI using LC filter, suggested L:4.7~6.8mH, C:330nF/250V



AC damping resistor should be used large enough to limit inrush current and avoid misfire, Here using 33R*2 for 10W driver.

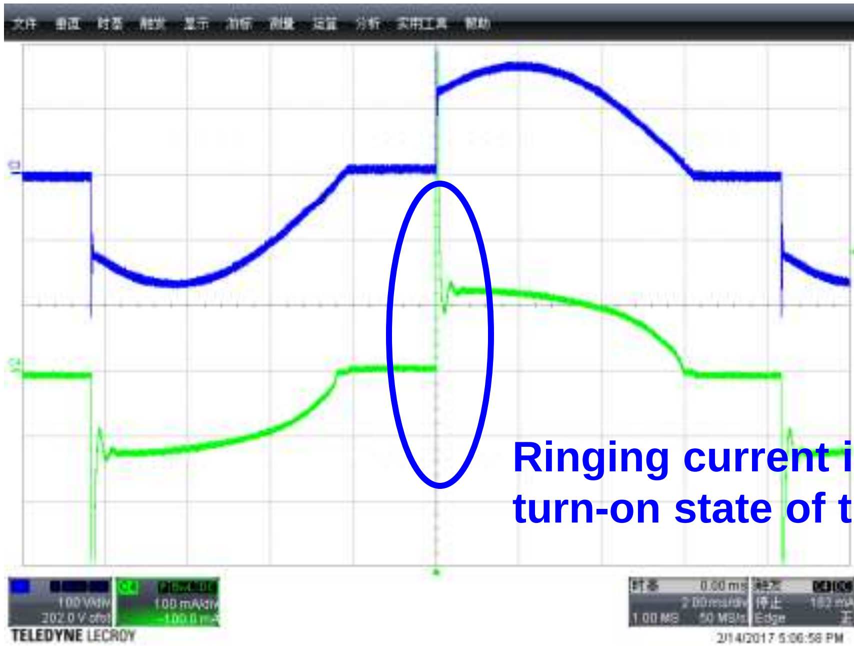
AL1692-30B-120Vac, 45V/185mA

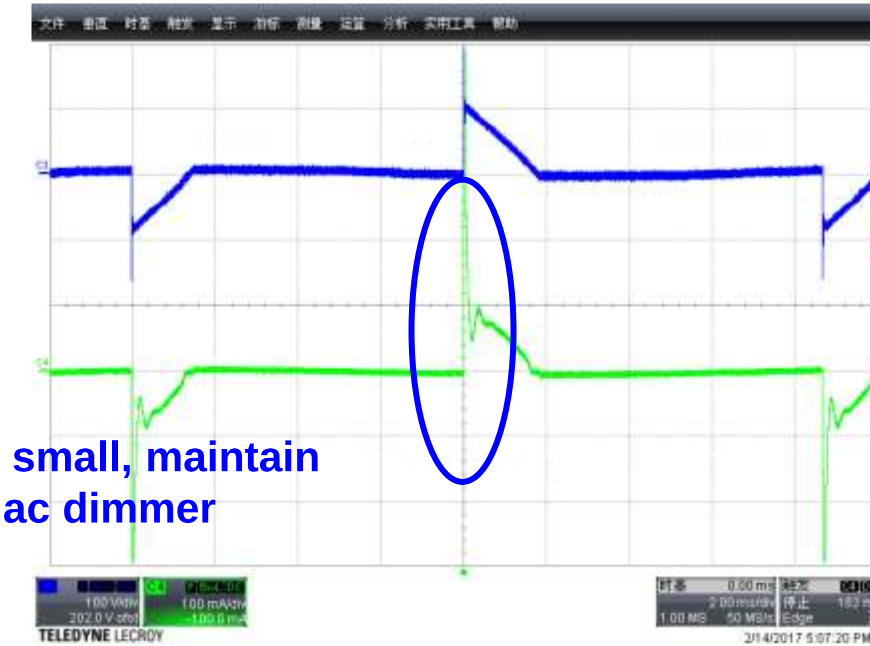
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmable Solution Simplification(Remove RC Latching)

Remove RC latching also can get good dimmer compatibility.

V_{IN-AC}	I_{IN}





Ringing current is small, maintain turn-on state of triac dimmer

Large Conduction Angle

Small Conduction Angle

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmer Compatibility Debug Experience

AL1692/7 230Vac Mains Dimmer Compatibility Optimization Summary			
Item	**Common Incompatible Issues**	**Reason Analysis**	**Solution**
1	Shimmer or flicker at low conduction angle for distorted or dirty 220/230Vac mains input	Distorted or dirty mains input waveform cause asymmetrical input current	1)Increase dummy load current; 2)Adopt output ripple suppressor.
2	Flicker at high angle caused by severe distorted mains voltage	Severe distorted mains cause input current lower than holding current	1) Adjust input EMI CBB capacitor; 2) Increase AC damping resistor; 3) Adjust RT resistor.
3	Flicker caused by inadequate latching current or misfire by ringing current	Inadequate latching current or ringing current caused triac misfire	1)Adjust RC latching parameter; 2)Increase AC damping resistor or inductor
4	Flicker at low angle caused by inadequate VCC supply	Can't provide enough ICC current at low angle and pull down VCC	1)Decrease start-up resistor and increase VCC capacitor; 2)Decrease start-up and VCC supply resistor.
5	Flicker at high angle for partial trailing edge or universal dimmer	Large filter capacitor after bridge	Decrease filter capacitor after bridge properly.

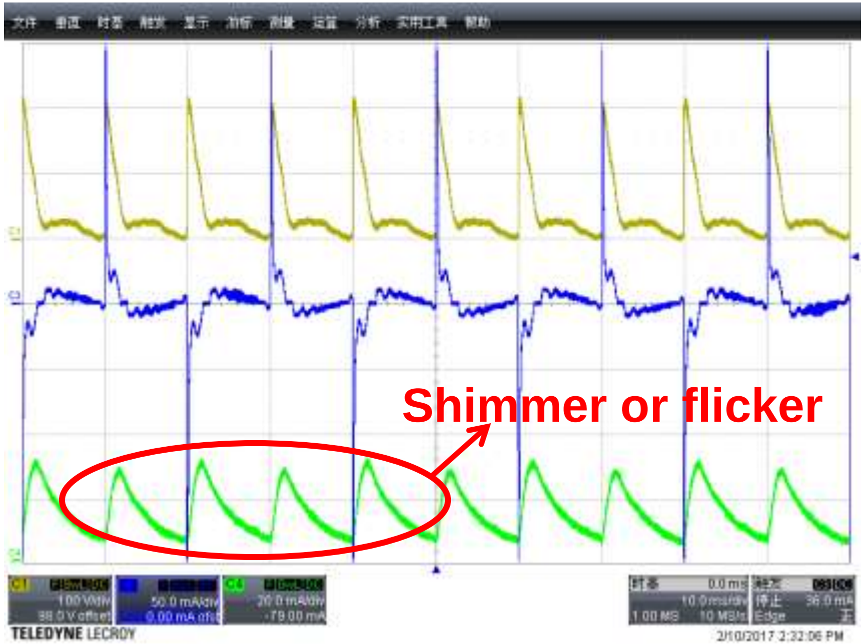
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmer Compatibility Debug Experience

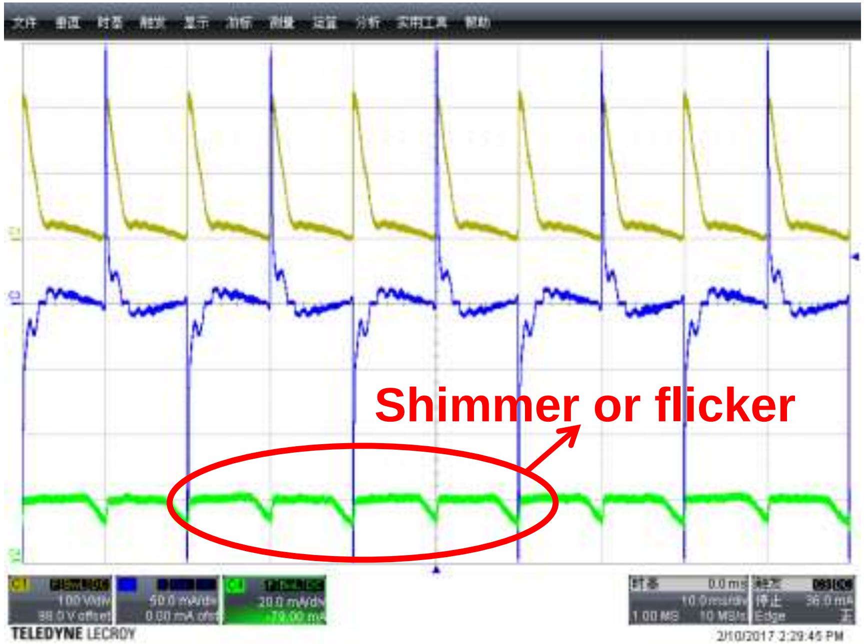
1) Shimmer or flicker at low conduction angle for distorted and dirty 220/230Vac mains input.

Solutions: Adopt and adjust output ripple suppressor

V_{BUS} | I_{IN} | I_{LED}



No output ripple suppressor



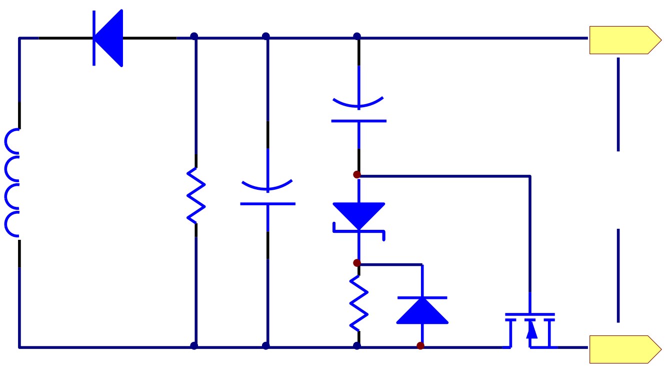
Poor ripple suppress effect

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

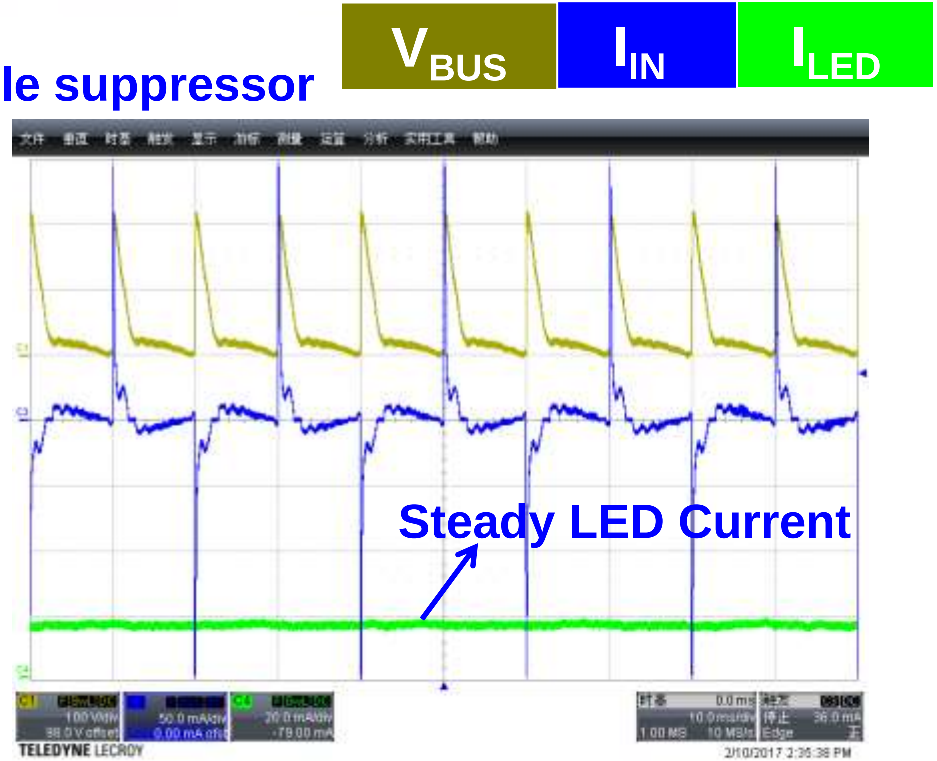
➢ 230Vac Mains Dimmer Compatibility Debug Experience

1) Shimmer or flicker at low conduction angle for distorted and dirty 220/230Vac mains input.

Solutions: Adopt and adjust output ripple suppressor



Suggested ripple suppressor



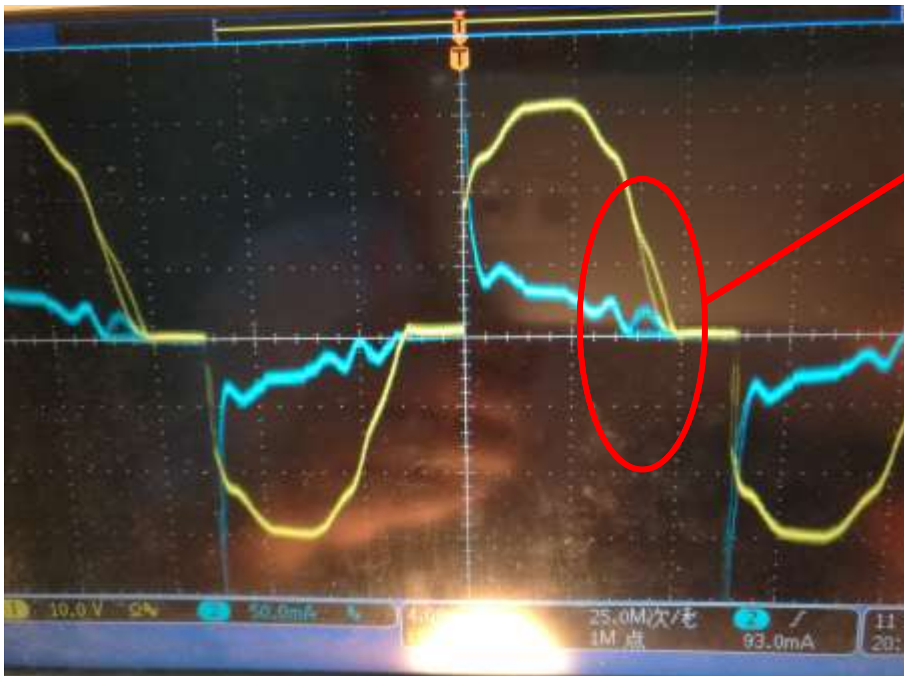
Adjust ripple suppressor and get good effect

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmer Compatibility Debug Experience

2) Flicker at high conduction angle for severe distorted and dirty 220/230Vac mains input.

V_{IN-AC} I_{IN}



Severe distorted mains voltage cause input current may be lower than holding current

Solutions:

- Adjust input EMI CBB capacitor;
- Increase AC damping resistor;
- Adjust RT resistor.

Severe distorted mains voltage

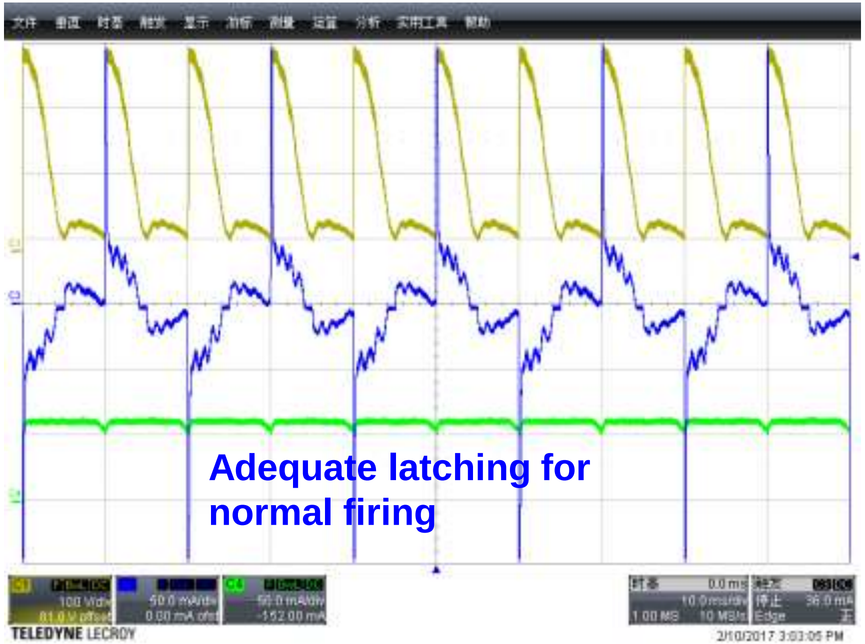
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmer Compatibility Debug Experience

V_{BUS} I_{IN} I_{LED}

3) Flicker caused by inadequate latching current or misfire by ringing current

Solutions: Adjust RC latching parameter



Too small latching Cap (100nF+470R)

Increase latching cap to 150nF (150nF+470R)

Suggested RC latching parameters for 230Vac: C--100~150nF, R-390~560R

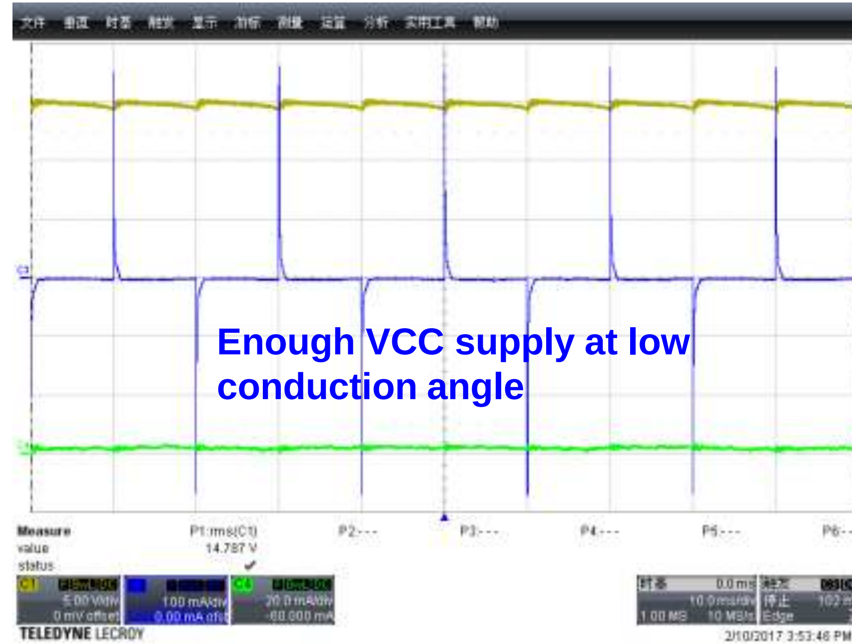
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

4) Flicker at low angle caused by inadequate VCC suppl

Solutions: Decrease start-up and VCC supply resistor.

V_{CC}	I_{IN}	I_{LED}



Large start-up or VCC supply resistor	Reduce start-up or VCC supply resistor

If occurs VCC UVLO at low angle, decrease start-up or VCC supply resistor.

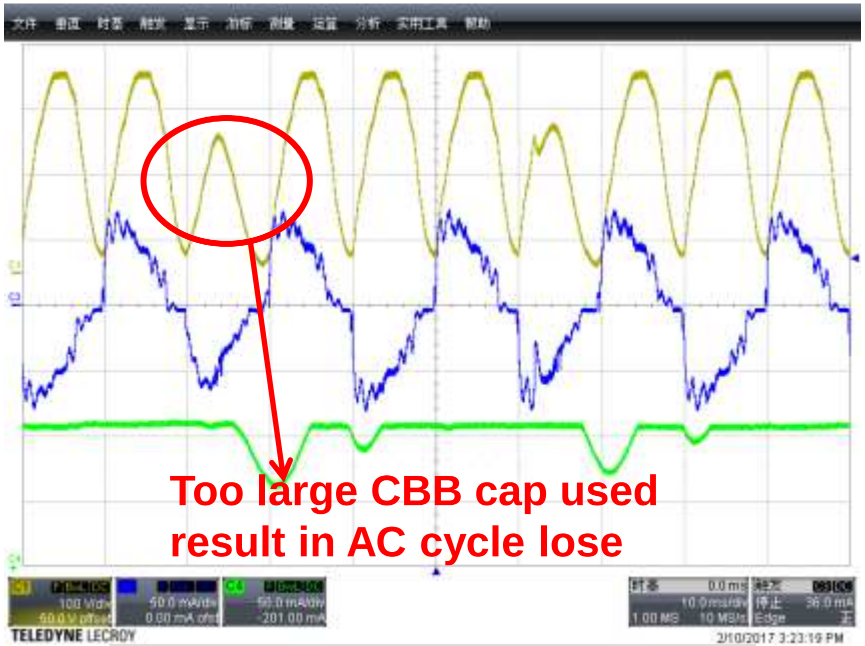
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 120Vac Mains Dimmer Compatibility Debug Experience

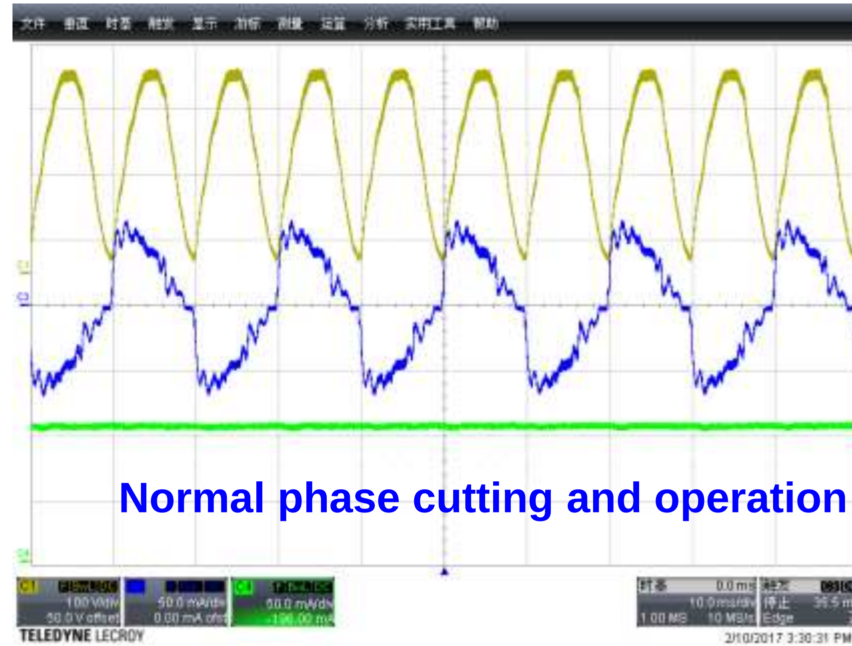
V_{BUS} I_{IN} I_{LED}

4) Flicker or restart at high angle for partial trailing or universal dimmer

Solutions: Decrease EMI filter capacitor properly



Large total CBB cap used



Reduce EMI filter cap

Trailing or universal dimmer requires not too large input filter cap for quick discharge in each phase cutting cycle.

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

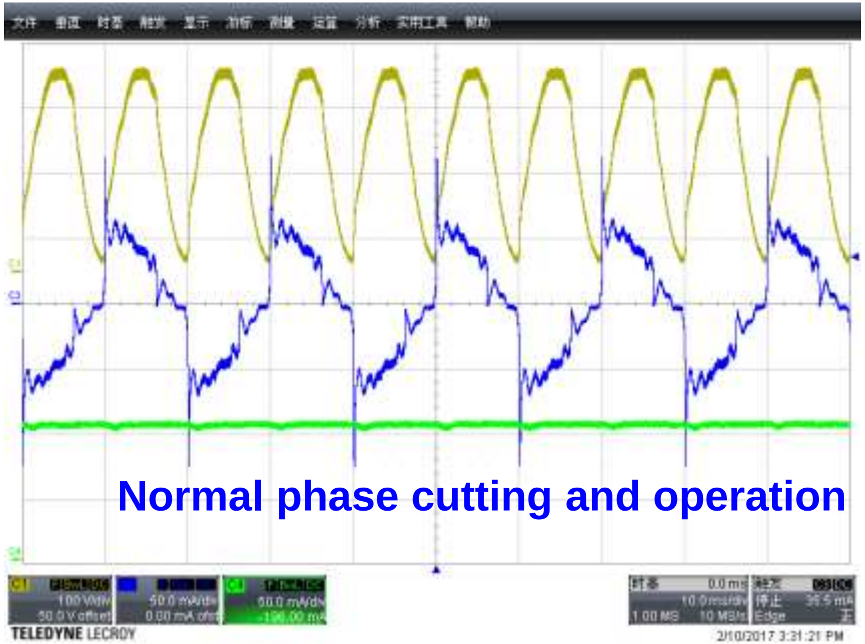
VBUS IIN ILED

➢ 120Vac Mains Dimmer Compatibility Debug Experience

4) Flicker or restart at high angle for partial trailing or universal dimmer

Solutions: Decrease EMI filter capacitor properly

Large total CBB cap used



Reduce EMI filter cap

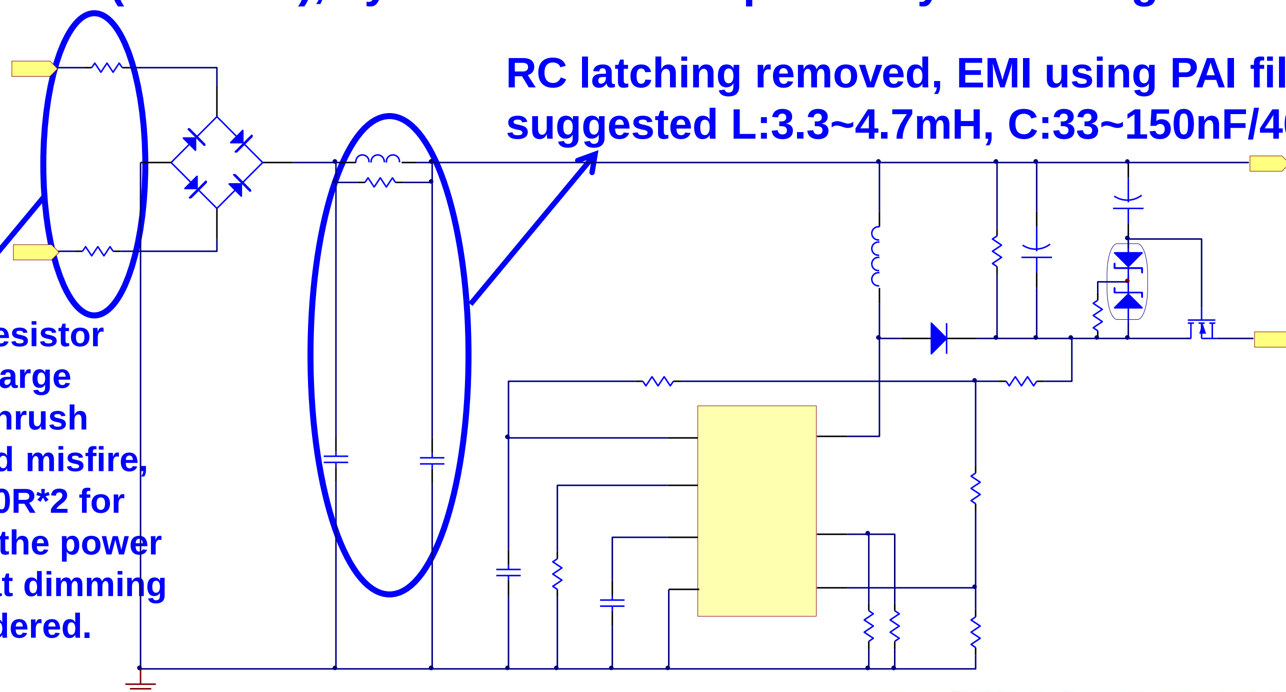
Trailing or universal dimmer requires not too large input filter cap for quick discharge in each phase cutting cycle.

AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmable Solution Simplification(Remove RC Latching)

To reduce BOM cost and improve advantage for competition, or for some application has size limitation(filament), system can be simplified by removing RC latching.

RC latching removed, EMI using PAI filter, suggested L:3.3~4.7mH, C:33~150nF/400V



1) AC damping resistor should be used large enough to limit inrush current and avoid misfire,
2) Here using 120R*2 for 10W driver, also the power loss of resistor at dimming should be considered.

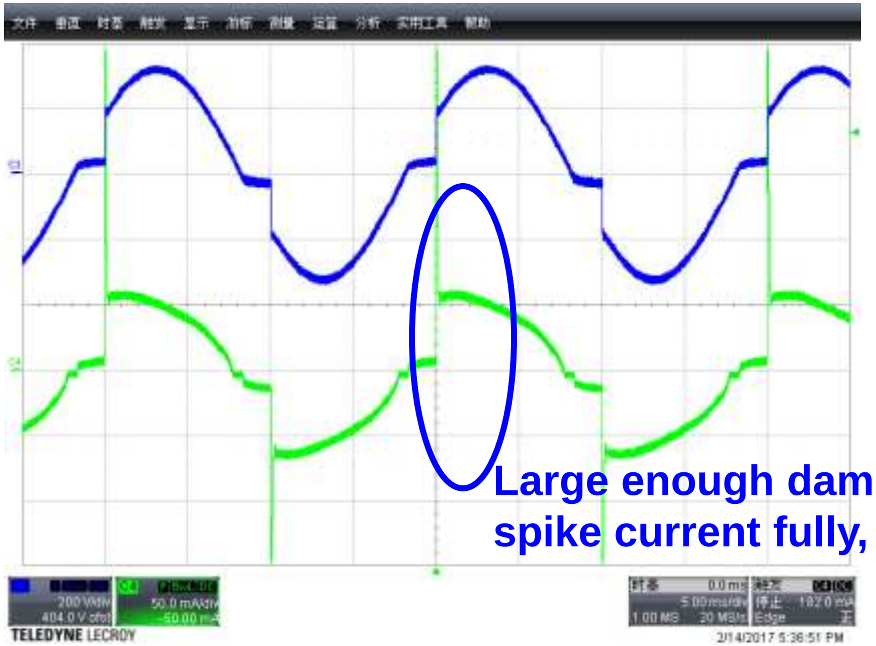
AL1692-10E A75 Filament-230Vac,160V/50mA

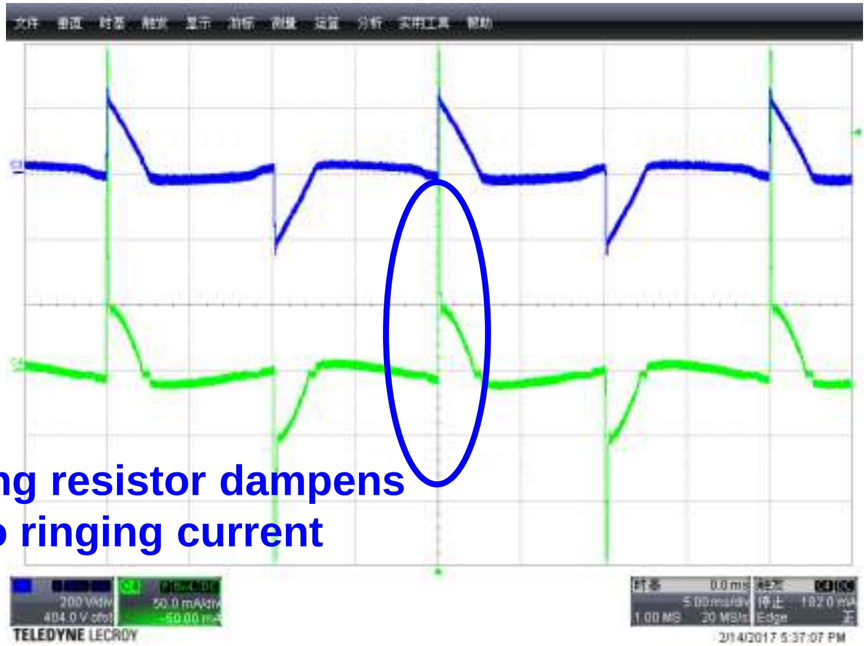
AL1692/7 Dimmer Compatibility Optimization & Debug Experience

➢ 230Vac Mains Dimmable Solution Simplification(Remove RC Latching)

Remove RC latching also can get good dimmer compatibility.

V_{IN-AC} I_{IN}





Large enough damping resistor dampens spike current fully, no ringing current

Large Conduction Angle

Small Conduction Angle

AL1692/7 EMI and Audible Noise Optimization

➢ AL1692/7 EMI Optimization

AL1692/7 operates in BCM mode for easy EMI/EMC design.

1) EMI Conduction

120Vac mains EMI filter suggested

- **PAI(CLC) Filter:** L inductance used 2.2~6.8mH; two CBB capacitance used 22nF~220nF/250V, according to output power to select suitable cap.
- **LC Filter:** Used for some small power or low cost application, L,C should be larger(4.7mH, 6.8mH), C(220nF, 330nF)

230Vac mains EMI filter suggested

- **PAI(CLC) Filter:** L inductance used 2.2~6.8mH; two CBB capacitance used 22nF~220nF/400V, according to output power to select suitable cap.
- **L+PAI(CLC) Filter:** Consider trailing dimmer compatibility, PAI filter capacitance is limited(10~47nF), so need one more inductor before bridge to pass EMI conduction.

AL1692/7 EMI and Audible Noise Optimization

➢ AL1692/7 EMI Optimization

AL1692/7 operates in BCM mode for easy EMI/EMC design.

2) EMI Radiation

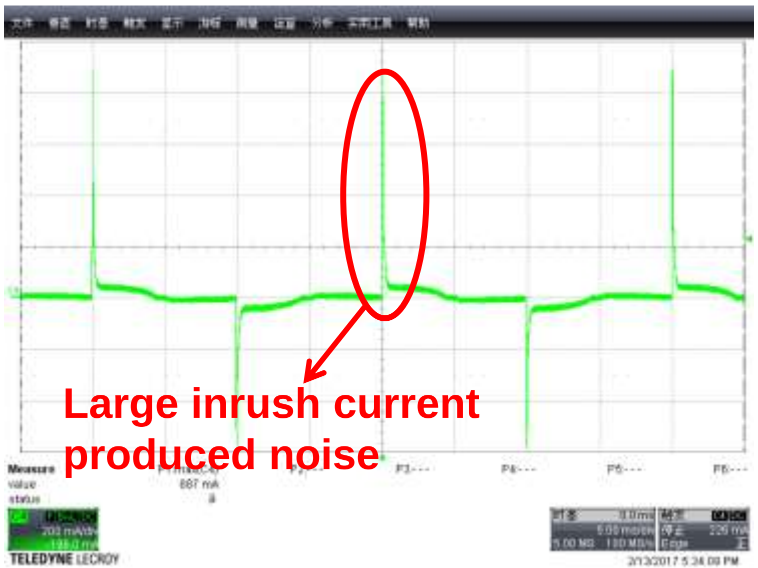
EMI radiation relates to PCB layout, power Mos/diode switching speed, switching frequency etc. Some useful methods for radiation improve are listed.

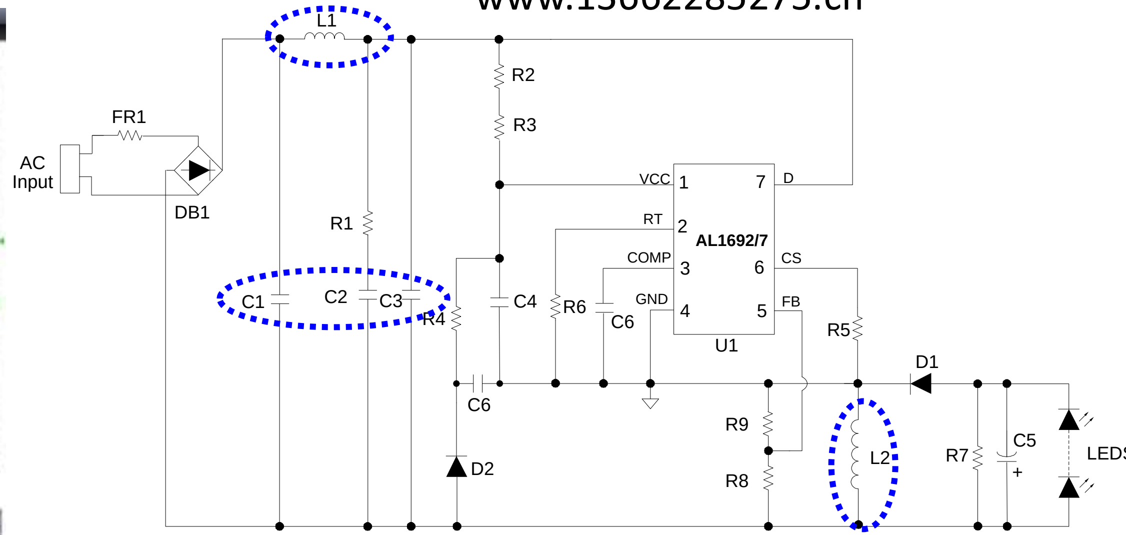
- ✓ Optimize PCB layout, minimize two power loop as small as possible, reduce switching node cooper area;
- ✓ Using relative slow output diode(US1J) or parallel RC snubber with diode;
- ✓ Reduce switching frequency, 50~60kHz is preferred;
- ✓ Add “Y” cap(1nF~10nF) between LED+ and GND for low side, LED- and V_{BUS} for high side;
- ✓ Series bead in switching power Mos/diode, or before bridge;
- ✓ For isolated application, optimize transformer winding structure, increase shielding winding, connect core to GND, etc.

AL1692/7 EMI and Audible Noise Optimization

➢ AL1692/7 Audible Noise Optimization

When connected with leading-edge dimmer, large inrush current occurs during phase cutting, result in obvious audible noise. The major noise source consists of 3 kinds of component: Differential Inductor, CBB/CL21 filter cap and Power Inductor/Transformer.





3 kinds of noise source

AL1692/7 EMI and Audible Noise Optimization

➢ AL1692/7 Audible Noise Optimization

Some solutions to reduce noise are listed as below.

1) Select differential inductor with well-shielding(show as below) and large saturation current;

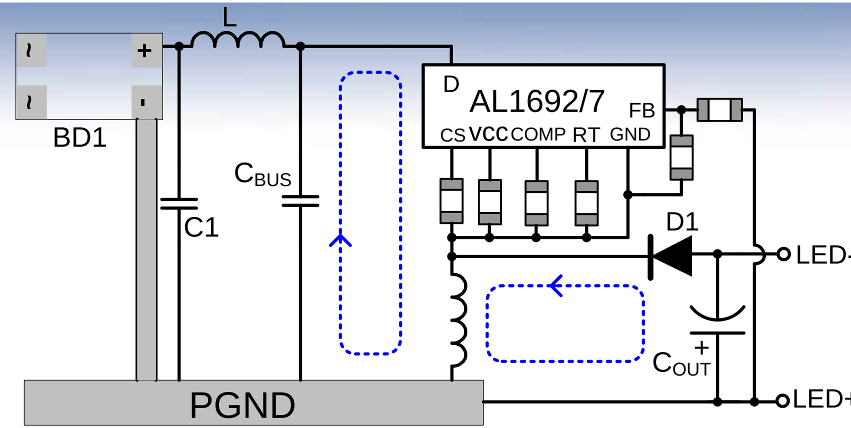
Inductor with shielding

X-cap

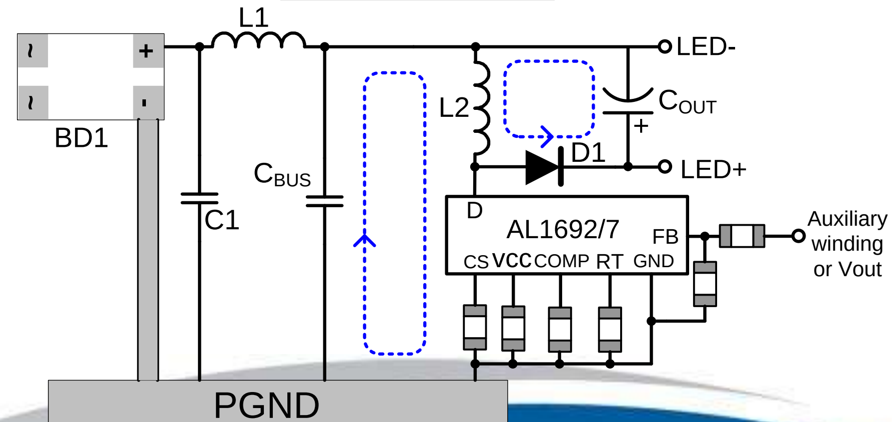
2) Select low noise EMI filter cap from vender, X-cap also can be used for better noise reduction;
3) Varnish the power inductor/transformer winding completely and potting with magnetic core;
4) Increase AC damping resistor, decrease RT resistor(limit $T_{on\text{-}max}$), using LC filter instead of PAI filter, to lower the inrush current during phase cutting.
5) Separate the EMI inductor, CBB cap and power inductor on the PCB.

Suggestion for AL1692/7 PCB Layout

1) Keep the two power loop(blue circle) area as small as possible;
2) Place VCC/COMP capacitor and RT/FB resistor as close as possible to VCC, COMP, RT, FB pin and GND pin respectively, and keep COMP/RT/FB resistor and track far away from high voltage and switching signal;
3) Place FB upper divider resistor sensing track as close to output E-cap positive node;
4) IC GND for high side and Drain for low side are switching nodes, do not use large area cooper for these nodes.



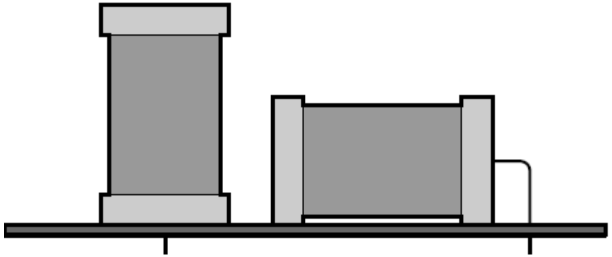
High Side



Low Side

Suggestion for AL1692/7 PCB Layout

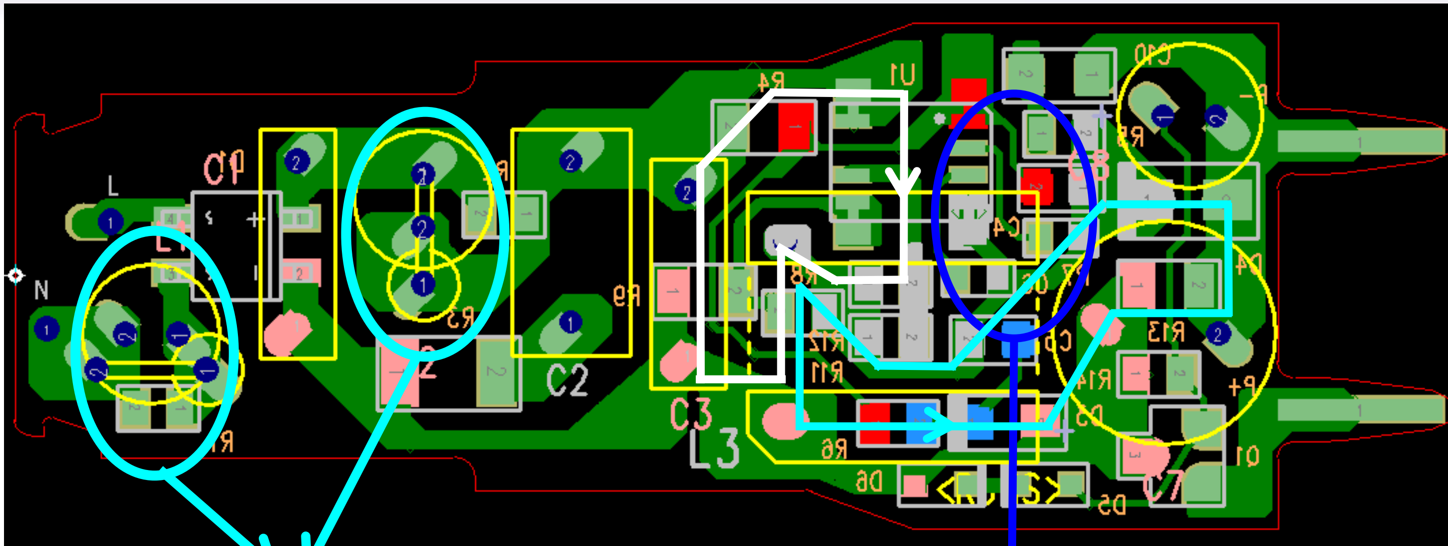
5) For some applications using two EMI inductor, separate the two EMI inductors, if PCB size is limited, suggest to use below inductor mounting on PCB, keep the distance between EMI inductor and power inductor/transformer to reduce the coupling as much as possible;



6) For high power bulb with narrow housing, to solve IC or E-Cap thermal issue, need to place IC or E-Cap on the input side of PCB.

Suggestion for AL1692/7 PCB Layout

Layout Example 1: AL1697-20C, A60 lamp, 230Vac, 55V/125mA



Separate two inductors

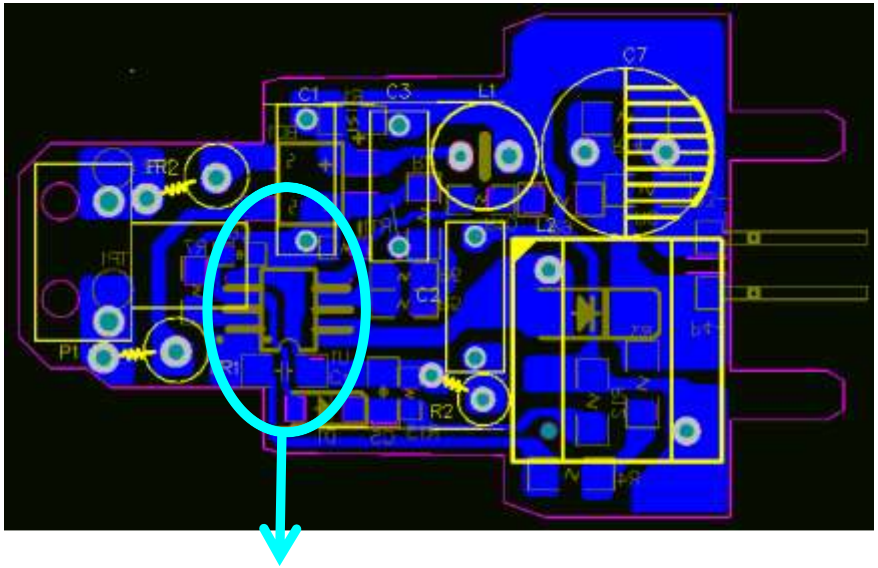
VCC, Comp cap and RT resistor close to IC pin

- Mos turns on power loop, white cycle;
- Mos turns off power loop, green cycle.

Suggestion for AL1692/7 PCB Layout

Layout Example2:

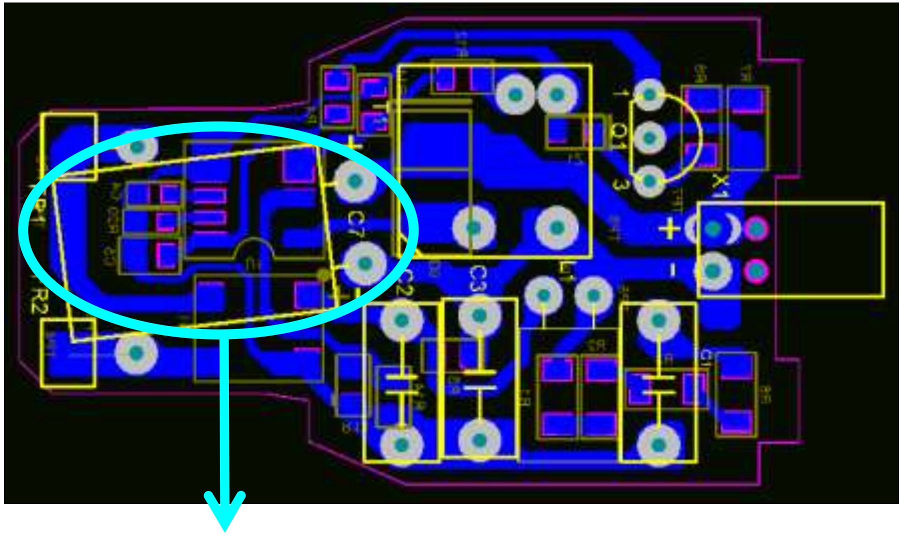
AL1692-30B,A800, 120Vac, 108V/75mA



IC placed in front of PCB for thermal consideration

Layout Example3:

AL1697-20C,Bulb, 230Vac, 48V/162mA



IC and E-cap placed in front of PCB for thermal consideration