ECEN 5009 Power Electronics Project Lab

Prepared By: CHINMAY PATIL

Project: LED Driver

Last Updated: 8-Dec-2018

Description: PROJECT CALCULATIONS

Revision: 4

Power Stage Calculations

Given

Parameter	Min	Nom	Max	
Input Voltage	85	115	264	Vac
Input Voltage Frequency	45		65	Hz
No load input Power			1	W
LED Current	0		1200	mA
LED ripple current			1	% pk-pk
			1	mA pk-pk
No Load Output voltage			29	Vdc
Output Voltage	0		20	Vdc
Dimming Control Input Voltage	0		10	Vdc
Dimming Control Input Resistance	10			kΩ
Output Overcurrent threshold	1.3		1.5	A

General Calculations

Efficiency	0.8	%

Vac

Vac min	85	Vac
Vac max	264	Vac
Vac nom	115	Vac

Vbus

Vbus min	100	Vdc
Vbus peak	141.4213562	Vdc
Vbus max	373.3523805	Vdc

Vbus_m = Vac_m*sqrt(2)

Vaux

Vout_aux	20	V	Min. Vout_aux	12
Forward Voltage Drop_Vdiode_aux	1	V		
Vout_aux + Forward VoltageDrop_Vdiode_aux	21	V	Min. Vout_aux + Vdiode_aux	13

Power Calculations

Pout_max	24	W
Pbus_max	30	W

Frequency Calculations

Ride through time (T_rt)	17.5	ms	Frequency (50hz at 100Vdc input)
Fsw_tol	0.1	%	
Fsw_nom	67.5	kHz	
Fsw_max	75	kHz	
Fsw_min	60.75	kHz	
Tsw_nom	1.48148E-05	Secs	
Tsw_max	1.64609E-05	Secs	
Tsw_min	1.33333E-05	Secs	
T_idle_min	2.50E-07	secs	

Mosfet Calculations

Mosfet rating	9.00E+02	V
Mosfet max voltage (Vdrain_max)	7.00E+02	V

Clamp Diode

Forward recovery voltage of clamp diode (Vdiode_clamp)	25	V

Vout

Forward recovery voltage of main output diode (Vdiode)	1	V	Min. Vout	8
Vout+Vdiode	21	V	Min. Vout + Vdiode	9

Max_clamp & mosfet voltages

Vclamp_max	3.02E+02	V
Vmag	1.51E+02	V
V_Mosfet_max	377.4952376	V

Vds_max = Vds_rated - 200

Main Diode Voltage Rating

V_diode_max	73.33605435	V

Vout_d = Vbus_max*(Ns/Np)+Vout_max

Reset Calculations

Vreset	147	V	output voltage refelected to primary
Treset_max	5.2969E-06	Secs	worst case reset time
Ton_max	7.79E-06	Secs	
Ton_min	1.00E-06	Secs	

Vreset=Np/Ns*(Vout+V_diode)

Treset_max = (Tsw_min-Tidle_min)/(1+Vreset/Vbus_min)

Ton_max = Tsw_min - Treset_max - T_idle

Magnetizing inductance & Leakage Inductance

Lmag_max	0.000757858	757.8575625	uH	
Lmag_tol	0.2	%		
Lmag_nom	0.000631548	631.5479688	600	uH
Lmag_max	720	uH		
Lmag_min	480	uH		
L_leakage	12	uH		

Lm_Max=Vbus_min^2*Ton_max^2*Fsw_max/(2*Pbus_max)

LOW LINE, MAX LOAD

Permutations	Minimum Lmag,Min Fsw, Max pbus	Nom Lmag,Nom Fsw, Max pbus	Max Lmag,Max Fsw, Max pbus
Ipri_peak_||_max	1.434438276	1.217161239	[illegible]
Ton_||_max	6.8853E-06	7.30297E-06	[illegible]
Ipri_rms_||_max	0.535618946	0.493388536	[illegible]
Treset_||_max	4.68388E-06	4.96801E-06	[illegible]
Isec_peak_||max	10.04106793	8.520128672	[illegible]
Dreset_||_max	0.284545715	0.335340341	[illegible]
Isec_rms_||_max	3.092397426	2.848580043	[illegible]
Tidle_||_max	4.89172E-06	2.54384E-06	[illegible]
Fsw_min_||	60750	67500	75000

Isec_pk = (Np/Ns)*Ipri_pk

T_reset = (Ns/Np)*2*Lmag_nom*Isec_pk/(Vout+Vd)

Dreset = T_reset/Tsw_nom

RMS current in output capacitor

A_||_max	1.44	1.44	1.44
B_||_max	3.428571429	3.428571429	3.428571429
C_||_max	9.562921842	8.114408259	7.027283689
Icap_rms_||_max	2.752153777	2.475042794	2.244707611

Ic_rms = sqrt(Iout^2 - Iout*Isec_pk*Dreset+(1/3)*Isec_pk^2*Dreset)

HIGH LINE, MAX LOAD

[illegible]

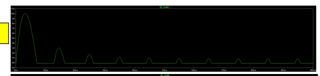
Icap_rms_||_max	2.752153777	A

Auxillary Current

Iaux_peak_||_max	0.03	A
Iaux_rms_||_max	0.010778001	A

Output Capacitor

C_out	3.9	mF	Looking at the datasheet to find rms current



Current through C_bulk before inrush resistor

Minimuim Output Power

Pbus_min_nom	15.6816	W
Pbus_min_max	21.78	W

Aux Diode Voltage Rating

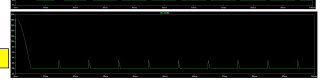
Vdiode_aux	73.33605435	V	
Derating Factor	25	V	
Total Vdiode_aux	98.33605435	V	Auxillary diode with minimuim reverse voltage rating of 100V to be selected

Aux Capacitor

C_Aux	1.13125E-05	F	22	uf

Cbulk Calculation

cbulk_min	105	uF			Cbulk Found through Simulations
cbulk_tol	0.2	%			
cbulk_nom_calc	131.25	uF	2.20E-04	F	Finally Selected



Current through C_bulk after inrush resistor

Inrush Limiter

12 ohms, 3A resistor

Next higher standard value capacitor with voltage rating of 450 V selected.

cbulk	220	uF	Icrms	0.598	A
Selected Capacitors from std list			Derated Icrms	0.8542857	A
			Approximation	1	A

Finding capacitor of this rms current

RCD Clamp Calculations

Vclamp_max	3.02E+02	V	
Power_clamp	1.462911071	W	
R_clamp	62198.78173	Ω	450 V rated components
C_clamp	2.38185E-10	F	C_clamp should be much much greater than this value.
	2.38185E-09	F	Hence multiplying by a factor of 20
C_Clamp_Final	4.7637E-09	F	

L_lkg = 0.02*Lmag_nom

Ipri_pk = sqrt(2*Pbus_max/(Lm_nom*Fsw_min))

Pclamp=Vclmp·Vclmp/(Vclmp-Vreset)*0.5*Llkg*Ipri_pk^2*Fsw

R_clamp = V_clamp^2/P_clamp

C_clamp >> Tsw_nom/R_clamp

Final Power Stage Design Values

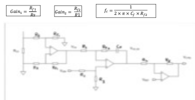
Component	Value		
Power Stage			
Cbulk_calculated	131.25	uF	
Standard Cbulk value	220	uF	
Lmag_nom	600	uH	
Turns ratio (Primary:Secondary)	7.182086179	7	
Turns ratio (Primary:Auxillary)	7	7	
Vdiode (With derating)	98.33605435	V	Diode with voltage rating of 130-150 V to be selected.
Cout	3.9	mF	16-0006-008
Caux	22	uF	
Aux Turns ratio	9	-	
Aux_Vdiode (With Derating)	98.33605435	V	

Feedback circuitory

Current Error Amplifier

Current Sense Resistor (Rcs)	1.00E-01	Ω	Assume
Voltage across Rcs	1.20E-01	V	
Max. Voltage output of first opamp	5.00E+00	V	
[illegible]			

$$Gain_1 = \frac{R_{f1}}{R_1}$$ $$Gain_2 = \frac{R_{f2}}{R_2}$$ $$f_c = \frac{1}{2\pi \times C_f \times R_f}$$



Taking into account current for safety

Current Error Opamp

Voltage Error Amplifier

Working Shown on Another Sheet

$$f_c = \frac{1}{2\pi \times C_f}$$

NCP1340

Feedback

C_FB	470	pF		
R_FB	3.06E+04	Ω	30.62200957	KΩ
V_lim_min	0.2	V		
V_lim_max	0.8	V		
V_FB_min	0.8	V		
V_FB_max	3.2	V		
I_FB	1.00E-04	A		
Resistor internal to FB Pin	4.00E+05	Ω		

Opto Coupler

Current through Opto Reciever	2.00E-04	A	For easier CTR estimation · 200 uA
CTR	5.00E-01		Look at the plot in datasheet to find out
Current through Opto Emitter	4.00E-04	A	

ZCD/OPP

V_OPP	-0.1	V		
V_ZCD_min	8	V		
R_ZCD/R_OPPL	0.375		Actual R_ZCD/R_oppl	0.5
(R_ZCD+R_OPPU)/R_OPPL	534.3605435			
R_ZCD	1000	Ω	1	KΩ
R_OPPU	1066721.087	Ω	1.066721087	MΩ
R_OPPL	2000	Ω	2	KΩ
Voltage Rating of D_ZCD	53.33605435	V		

Auxillary

Auxillary Diode	98.33605435	V	100 V rating Diode to be selected	
C_aux	1.13125E-05	F	11.3125	uF

Current Sensing

Rcs_primary	0.557709602	Ω

Stress Analysis Calculations

Diode/Mosfet Temperatures

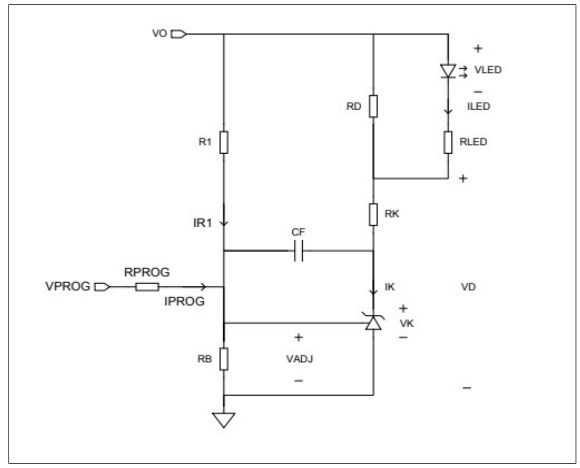
T_Ambient	30
Clamp Diode	
Forward Voltage	1.3
Forward Current	0.00487
Power dissipation	0.006331
Rth_JA	105
Junction Temperature	30.664755
HV Diodes	
Forward Voltage	1.3
Forward Current	0.02
Power dissipation	0.026
Rth_JA	105
Junction Temperature	32.73
Aux Diode	
Forward Voltage	0.95
Forward Current	0.03
Power dissipation	0.0285
Rth_JA	125
Junction Temperature	33.5625
Gate Driver Diode	
Forward Voltage	1.3
Forward Current	0.08
Power dissipation	0.104
Rth_JA	105
Junction Temperature	40.92
Output Diode	
Forward Voltage	0.95
Forward Current	3.09
Power dissipation	2.9355
Rth_JA	20
Junction Temperature	88.71
Output Diode	
Forward Voltage	1.1
Forward Current	0.53
Power dissipation	0.583
Rth_JA	60
Junction Temperature	64.98
SMT Mosfet	
RMS Current	0.535618946
Rds_ON	0.34
Power dissipation	0.097541803
Rth_JA	62
Junction Temperature	36.04759177

$$P_d = V_f * I_f$$

$$P_d = \frac{T_j - T_A}{R_{th_{ja}}}$$

TL431 Calculations

Vout_min	10	V
Vout_max	21	V
Vadj	2.495	V
I_BIAS	1.00E-03	A
Vprog_min	0.7	V
Vprog_max	4.406	V
Vk	2.5	V
V_diode_opto	0.9	V
V_acrossRK	6.6	V
Ik_min	1.00E-03	A
Ie_min	1.00E-03	A
I_opto_min	3.00E-05	A
I_opto_max	4.00E-04	A
Id_min	6.00E-04	A
Id_max	9.70E-04	A



A11	7.505	V	A11 = Vout_min - Vadj
A12	1.911	V	A12 = Vprog_max - Vadj
A21	18.505	V	A21 = Vout_max - Vadj
A22	-1.795	V	A22 = Vprog_min - Vadj

A	7.505	1.911
	18.505	-1.795

A^-1	0.03675678	0.039132
	0.37893269	-0.15368

I_BIAS	1.00E-03
	1.00E-03

Formula

| G1 GPROG | = | A^-1 | X | I_BIAS I_BIAS |

G1	7.5889E-05
GPROG	2.25E-04

R1	1.32E+04	Ω				
RPROG	4.44E+03	Ω				
RD	9.28E+02	Ω	RD = V_diode/Id_max			
RK	6.60E+03	Ω	RK = V_acrossRK/Ik_min			
RB	2.50E+03	Ω	RB = Vadj/Ibias			
Cf	10	nF	Fz = 1/(2∏Cf)	Fz	166	Hz

FLYBACK XFMR DESIGN

DATA INPUT		RESULTS	
Peak output power (Wpk)	24	Peak pri current =	1.2
Min dc input voltage (on Cbulk)	100	Primary rms current =	0.562849891
Efficiency estimate (dec. #)	0.8	Primary L (uH) =	617.2839506
Switching freq (kHz) (set to 45 kHz for QR design)	67.5	Primary turns =	38.98635478
		Min secondary turns =	4.016775947
Core area (Ae in sq cm)	0.76		
Max core flux (kilogauss)	2.5	Approx core gap-inches =	0.01122807
Output voltage	20		
Duty Cycle max. (set to 0.6 for QR design)	0.66		

= Enter Data

= Calculated Data

$$I_{mag} = I_{Pri\_Peak}$$

$$\Delta i_m = I_{mag}$$

$$L_{mag} = \frac{V_g D T_s}{2\Delta i_m}$$

$$I_p = I_{p\_rms\_max}$$

$$I_s = I_{s\_rms\_max}$$

$$I_{aux} = I_{aux\_rms\_max}$$

$$l_g = \frac{\mu_0 L_{mag} {I_{pri\_pk}}^2}{{B_{max}}^2 A_C}$$

$$I_{tot} = I_p + \frac{N_s}{N_p}(I_s) + \frac{N_{aux}}{N_p}(I_{aux})$$

$$K_g \geq \frac{\rho {L_{mag}}^2 {I_{tot}}^2 I_{pri\_pk}}{{B_{max}}^2 P_{Cu} K_u}$$

XFMR DESIGN — Primary:Secondary

Given

Vbus_min	100		
V_out	20		
I_out	1.2		
Output Load	16.66666667		
Fsw_nom	67500		
Tsw_nom	1.48148E-05		
Np/Ns	7.182086179	~	7
Dmax	0.387217673		
Ipri_peak	1.434438276		

ρ	1.72E-06		2.30E-06
Bmax	0.25		
P_Cu	1		
Ku	0.5		
μ0	1.25664E-06	A	
Np	28		Approximated
Ns	4		Approximated

Calculation

Imag	1.434438276	A	
Delta_Imag	1.434438276	A	
Lmag	617.2839506	uH	6.00E-04
I_primary	0.535618946		
I_secondary	3.092397426		
I_tot	0.978929721		

ETD34 CORE	
Kg	0.193
Ac	0.97
WA	1.23
MLT	6
lm	7.86

Core Geometry

kg	0.003907038

Air Gap Length

lg	0.000255902

Fill Areas

α1	0.547147496
α2	0.451279649

XFMR DESIGN — Primary:Auxillary

Given

Vbus_min	100		
V_out	20		
I_out	5.00E-03		
Output Load	4000		
Fsw_nom	67500		
Tsw_nom	1.48148E-05		
Np/Na	7	~	7
Dmax	0.387217673		
Ipri_peak	1.434438276		

ρ	1.72E-06	
Bmax	0.25	
P_Cu	1	
Ku	0.5	
μ0	1.25664E-05	
Np	49	Approximated
Na	7	Approximated

Calculation

Imag	1.434438276	
Delta_Imag	1.434438276	
Lmag	617.2839506	6.00E-04
I_primary	0.535618946	
I_aux	0.010778001	
I_tot	0.978929721	

ETD34 CORE	
Kg	0.193
Ac	0.97
WA	1.23
MLT	6
lm	7.86

Core Geometry

kg	0.003907038

Air Gap Length

lg	0.002559017

Fill Areas

α1	0.547147496
α2	0.001572855

Main Calculation

AWG

ratio	2		2	Lecture
delta_25	0.254057762	mm	0.293786722	delta_100
	0.01000228	in	0.011566413	
AWG	24.04137605		22.78824267	
AWG_min	24		22	
AWG_max	25		23	Lecture

Strands

Current Density	400		Primary RMS current	0.535
Wire Area	2.63E-03		Secondary RMS current	3.02
Wire Current Capacity	1.05E+00		Auxiliary RMS current	1.00E-02

Primary	0.51	=	1
Secondary	2.88	=	3
Auxiliary	0.01	=	1

Fill Area

Primary	0.12
Secondary	0.05
Auxiliary	0.02

$$\delta_{25} = \sqrt{\frac{\rho_{25}}{\pi \cdot \mu_0 \cdot F_{SW}}}$$

$$\delta_{100} = \sqrt{\frac{\rho_{100}}{\pi \cdot \mu_0 \cdot F_{SW}}}$$

$$AWG_{25} = -39 \cdot \log\left(\frac{Ratio\ \delta_{25}}{0.005\ in}, .92\right) + 36$$

$$AWG_{100} = -39 \cdot \log\left(\frac{Ratio\ \delta_{100}}{0.005\ in}, .92\right) + 36$$

Wire Current Capacity = Current Density * Wire Area

Number of Strands = RMS Current/Wire Current Capacity

$$A_{w\_pri} = \frac{\alpha_{Pri} K_u W_A}{N_p}$$

$$A_{w\_sec} = \frac{\alpha_{Sec} K_u W_A}{N_s}$$

$$A_{w\_aux} = \frac{\alpha_{Aux} K_u W_A}{N_a}$$

Transformer Testing

AirGap Length (Each Side)	0.005614035	blue
Magnetizing Inductance	547	Uh
Leakage Inductance	5	uH

Secondary Magnetizing Inductance	14.342	uH
Auxilliary Magnetizing Inductance	14.504	uH

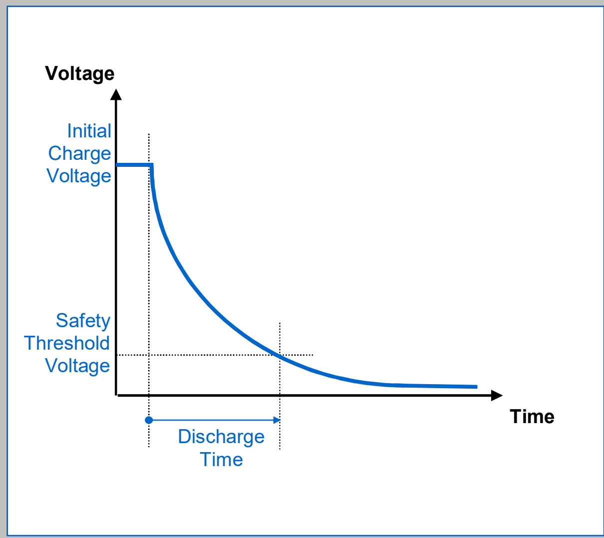
AirGap Length (Each Side)	0.004	tan
Magnetizing Inductance	628.53	uH
Leakage Inductance	5.477	uH

Polarity Testing		
Primary Winding Voltage	266	mV
Secondary Winding Voltage	39.2	mV
Auxillary Winding Voltage	39.2	mV
Turns Ratio (PandS)	6.785714286	
Turns Ratio (PandA)	6.785714286	

Test Conditions	
Function generator voltage	1.41 V, 67 kHz

Bleeder Resistance Calculator

ENTER: Capacitor Value (uF)	150	
ENTER: Initial Charge Voltage (V)	374	
ENTER: Safety Threshold Voltage (V)	30	
EITHER		
ENTER: Resistance Value (ohms)	50	
A bleed resistar at this ohmic value		
will ensure safe discharge within	0.01892294	s
The initial power in the resistor is	2797.52	W
and the time constant of the discharge is	0.0075	s
The total energy discharged is	10.4907	J
OR		
ENTER: Discharge Time (s)	60	
To ensure safe discharge within this time		
the bleed resistor should be at or below	158,537.7	ohms
The initial power in the resistor is	0.8822883	W
and the time constant of the discharge is	23.78	s
The total energy discharged is	10.4907	J



In theory, total discharge through a bleed resistor is never achieved, but in practice a safe discharge can be achieved. The time taken for this is proportional to the ohmic value chosen.