Department of Electrical, Computer, and Software Engineering

ELECTENG 734

Technical Design Report

Group Number: 24

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Declaration of Originality

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Buck Conveter Design - Part I

Specifications

Parameter	Value	Unit
Nominal Vin(avg)	15.00	V
Max Iin(avg)	1.30	A
Max Vout(avg)	9.70	V
Max RL(max)	10.00	Ω
Min RL(min)	2.00	Ω
Design η	90.00	%
Operating fs	100.00	kHz

Evaluating Steady-State Operating Conditions

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.00	Ω	4.00	Ω	10.00	Ω
Pout	17.55	W (1)	17.55	W (1)	9.41	W (2)
Io=IL(avg)	2.96	A (3)	2.10	A (3)	1.33	A (3)
Iin(avg)=Is(avg)	1.30	A (4)	1.30	A (4)	0.70	A (4)
D	43.88	% (5)	62.07	% (5)	71.85	% (5)
Vout	5.92	V (6)	8.38	V (6)	9.70	V (6)

Evaluating Minimum Inductance

Parameter	Value	Unit (eq)
Vin(critical)	15.00	V
RL(critical)	10.00	Ω
D @ RL(critical)	71.85	%
Lmin	10.27	µH (7)

Selected Inductance

Parameter	Value	Unit (eq)
L(selected)	25.00	µH

Evaluating Steady-State Ripple and RMS Curents

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.00	Ω	4.00	Ω	10.00	Ω
ΔIL	1.33	A (8)	1.27	A (8)	1.09	A (8)
IL,pk	3.63	A (9)	2.74	A (9)	1.88	A (9)
IL,rms	2.98	A (10)	2.13	A (10)	1.37	A (10)
Iin,rms=Is,rms	1.98	A (11)	1.68	A (11)	1.16	A (11)
IC,rms	0.38	A (12)	0.37	A (12)	0.31	A (12)

Buck Conveter Design - Part II

Specifications

Parameter	Value	Unit
Selected L	25.00	µH
Max IL,pk	3.63	A
Max IL,rms	2.98	A
Operating fs	100.00	kHz
Design Bmax	0.25	T
Design Jmax	5.00	A/mm^2

Core, Former & Magnet Wire Details

Parameter	Value	Unit
Core type	EFD20	
Core material	N87	
Ae	31.00	mm^2
le	47.00	mm
Ve	1460.00	mm^3
AN	28.10	mm^2
ln	40.20	mm
Wire ρ	1.8E-08	Ωm
Wire µ0	1.3E-06	H/m
Achievable Kf	0.65	

Design Choices

Parameter	Value	Unit (eq)
Selected Air-gap (lg)	0.15	mm
Wire dcu	0.43	mm (13)

Evaluating Inductor Parameters

Parameter	Value	Unit (eq)
N	14 (13.64)	Turns (14)
Bc(max)	0.22	T (15)
Acu per strand	1.45E-07	m^2 (16)
Np	9	Strands (17)
Acu per bundle	1.31E-06	m^2 (18)
Jmax	2.27	A/mm^2 (19)
Bundle Rw(dc)	7.7	mΩ (20)

Evaluating Steady-State Inductor Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.0	Ω	4.0	Ω	10.0	Ω
IL,rms	2.98	A	2.13	A	1.37	A
ΔIL	1.33	A	1.27	A	1.09	A
Bac	40.30	mT (21)	38.48	mT (21)	33.03	mT (21)
Pcu	68.67	mW (22)	35.08	mW (22)	14.51	mW (22)
Pv	8.99	mW (23)	8.01	mW (23)	5.47	mW (23)
Ptotal	77.66	mW (24)	43.09	mW (24)	19.98	mW (24)

Buck Conveter Design - Part III

Specifications

Parameter	Value	Unit
Max Vc	9.70	V
Max IC,rms	0.38	A
Max ΔIC=ΔIL	1.33	A
Ripple fs	100.00	kHz
Design ΔVo	1.00	%

Minimum Capacitance to Meet ΔVo

Parameter	Value	Unit (eq)
Co(min)	17.14	µF (25)
ESR(max)	72.93	mΩ (26)

Selecting a Capacitor

Parameter	Value	Unit
Manufacturer	Panasonic	
Series	TP	
Voltage rating	35	V
Capacitance Co	330	µF
ESR	52	mΩ
IC,rms rating	1.1	A

Evaluating Steady-State Capacitor Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.0	Ω	4.0	Ω	10.0	Ω
IC,rms	0.38	A	0.37	A	0.31	A
PC	7.5	mW (27)	7.1	mW (27)	5.0	mW (27)

Buck Conveter Design - Part IV

Specifications

Parameter	Value	Unit
Max Vsw	15.00	V
Max Is,rms	1.98	A
Max Isw,pk	3.63	A
Switching fs	100.00	kHz
Ta	30.00	Degrees C

Selecting a N-Channel MOSFET

Parameter	Value	Unit
Manufacturer	Infineon	
Model no	IPP052N06L3	
Vdss	60	V
ID(max)	80	A
tr	5	ns
tf	12	ns
Crss @ Max Vsw/2	175	pF
Vgs(Io)	3.6	V
Rds,on	3.9	mΩ
RthJA - no heatsink	62	C/W

Gate Drive Details

Parameter	Value	Unit (eq)
Design Vgg	15.00	V
Design Igg	1.00	A
Rg	15.00	Ω (28)

Evaluating Steady-State Switch Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.00	Ω	4.0	Ω	10.0	Ω
IL,avg	2.96	A	2.10	A	1.33	A
Is,rms	1.98	A	1.68	A	1.16	A
ΔIL	1.33	A	1.27	A	1.09	A
Is @ on	2.30	A (29)	1.47	A (29)	0.79	A (29)
Is @ off	3.63	A (30)	2.74	A (30)	1.88	A (30)
tvf	3.45	ns (31)	3.45	ns (31)	3.45	ns (31)
trv	10.93	ns (32)	10.93	ns (32)	10.93	ns (32)
ts,on	8.45	ns (33)	8.45	ns (33)	8.45	ns (33)
ts,off	22.93	ns (34)	22.93	ns (34)	22.93	ns (34)
Pswitching	77.00	mW (35)	56.44	mW (35)	37.34	mW (35)
Pconduction	15.30	mW (36)	11.01	mW (36)	5.25	mW (36)
Ptotal	92.30	mw (37)	67.45	mw (37)	42.59	mw (37)

Evaluating Junction Temprature

Parameter	Value	Unit (eq)
Tj,max	35.72	C (38)

Buck Conveter Design - Part V

Specifications

Parameter	Value	Unit (eq)
Max Vd	15.00	V
Max Id,avg	1.66	A
Switching fs	100.00	kHz
Ta	30.00	Degrees C

Selecting a Diode

Parameter	Value	Unit
Manufacturer	Vishay	
Model no	VS-MBR1045-M3	
Vr(max)	45	V
IF(max) - dual	10	A
VF	0.57	V
RthJA - D2Pak	70	C/W

Assuming same thermal resistance as the other diodes with same case

Evaluating Steady-State Switch Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load RL	2.00	Ω	4.0	Ω	10.0	Ω
IL,avg	2.96	A	2.10	A	1.33	A
D	43.88	%	62.07	%	71.85	%
ID,avg	1.66	A (39)	0.80	A (39)	0.37	A (39)
Pconduction	0.94	W (40)	0.46	W (40)	0.21	W (40)
Prr	0.00	W (41)	0.00	W (41)	0.00	W (41)
Ptotal	0.94	W (42)	0.94	W (42)	0.94	W (42)

Evaluating Junction Temprature

Parameter	Value	Unit (eq)
Tj,max	95.80	C (43)

Buck Converter Design - Part VI

Specifications

Parameter	Value	Unit
Vout,nominal	9.70	V
Max Is,pk	3.63	A
Co	330.00	µF
ESR	52	mΩ
Switching fs	100.00	kHz
Max Td	5.00	%

Oscilator Setup

Parameter	Value	Unit (eq)
CT	1	nF
RT	18k	kΩ
Td	320	ns

Current Feedback Setup

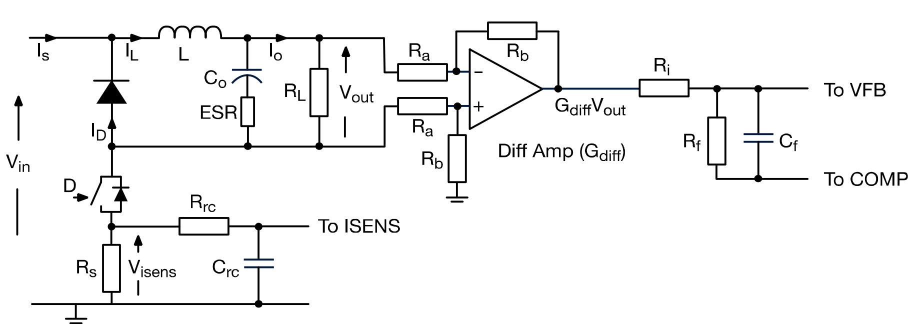
Parameter	Value	Unit (eq)
Rs	0.28	Ω (44)
RC filter - Rrc	100.00	Ω
RC filter - Crc	159.15	pF (45)

Voltage Feedback Setup

Parameter	Value	Unit (eq)
Tp(s) Pole fo @ 2Ω	241.14	Hz (46)
Tp(s) Zero fz @ 2Ω	9.27	kHz (47)
Tp(0) @ 2Ω	17.71	dB (48)
Design TOL(s) fcross	10.00	kHz
Tm(s)	1.00	
Required TOL(0) @ 2Ω	32.35	dB (49)
Required Tc(0)	14.63	dB (50)
Compensator Rf	22.00	kΩ
Compensator Cf	0.78	nF (51)
Compensator Ri	4.08	kΩ (52)
Diff Amp Gain Gdiff	0.26	Gain (53)

Hint:
It is strongly reccomended you plot the bode magnitude and phase response of the plant transfer function *Tp*(s) of the current controlled buck converter under the 2 Ω load condition using MATLAB prior to attempting the compensator design.

Schematic of Controller



Buck Converter Design Equations

Eq. #	Equation
(1)	$I_{OUT(MAX)} = \sqrt{\frac{V_{IN} I_{IN} \eta}{R_{LOAD}}}$ $V_{OUT} = I \times R_{LOAD}$ $P_{OUT} = \frac{{V_{OUT}}^2}{R_{LOAD}}$
(2)	$P_{OUT} = \frac{{V_{OUT(MAX)}}^2}{R_{LOAD}}$
(3)	$I_{OUT} = \frac{V_{OUT}}{R_{LOAD}}$
(4)	$D = \frac{V_{OUT}}{V_{IN} \times \eta}$ $R_{IN} = \frac{1}{D^2} \times R_{OUT}$ $I_{IN} = \frac{V_{IN}}{R_{IN}}$
(5)	$D = \frac{V_{OUT}}{V_{IN} \times \eta}$
(6)	$V_{OUT} = I_{OUT} \times R_{OUT}$ (I_{OUT} is limited by $I_{OUT(MAX)}$ OR $V_{OUT(MAX)}$)
(7)	$L_{min} = \frac{V_{OUT(MAX)}(1 - D)T_S}{\Delta I_L}$ Where: $\Delta I_L = 2 I_{L(AVG)}$
(8)	$\Delta I_L = \frac{V_{OUT}(1 - D)T_S}{L}$
(9)	$I_{L(peak)} = \frac{1}{2} \Delta I_L \times I_{L(AVG)}$
(10)	$I_{L(RMS)} = \sqrt{I_{L(AVG)} + \frac{\Delta I_L^2}{12}}$
(11)	$I_{S(RMS)} = \sqrt{\left(D \left[I_{L(AVG)}^2 + \frac{\Delta I_L^2}{12}\right]\right)}$

(12)	$I_{C(RMS)} = \frac{\Delta I_L}{\sqrt{(12)}}$
(13)	$d_{cu} \leq 2\delta$ $\delta = \sqrt{\frac{\rho}{\pi \mu_0 \mu_r f}}$
(14)	$N = \sqrt{\frac{2 l_g L}{A_e \mu_0}}$
(15)	$B_{C(MAX)} = \frac{N \mu_0 I_{MAX}}{2 l_g}$
(16)	$A_{CU(STRAND)} = \pi \frac{d_{cu}^2}{4}$
(17)	$N_{CU} = \frac{K_f \cdot A_N}{N \cdot A_{CU}}$
(18)	$A_{CU(BUNDLE)} = N_P \times A_{CU(STRAND)}$
(19)	$J_{MAX} = \frac{I_{RMS(MAX)}}{A_{CU(STRAND)} \times 10^6}$ (In Amm^{-2})
(20)	$R_{W(BUNDLE,\ DC)} = \frac{\rho \cdot N \cdot I_n}{A_{CU(BUNDLE)}}$
(21)	$B_{ac} = \frac{B_{MAX}}{I_{L(MAX)}} \times \frac{\Delta I_L}{2}$
(22)	$R_{w(DC)} = \frac{\rho N I_n}{A_{CU(BUNDLE)}}$ $P_{CU} = R_{w(DC)} \times I_{L(RMS)}^2$
(23)	$P_V = k \cdot f^a \cdot {B_{ac}}^b$ Where: $k = 1.5 \cdot 10^{-6}$ $a = 1.3$ $b = 2.5$ $P_{LOSS(AC)} = P_V \times V_e$ Results given in mW
(24)	$P_{TOTAL} = P_{cu} + P_{LOSS(AC)}$
(25)	$C_{O(MIN)} \geq \frac{\Delta I_L T_s}{8 \Delta V_o}$

(26)	$R_{ESR(MAX)} = \frac{\Delta V_o}{\Delta I_L}$
(27)	$P_C = I_{C(RMS)}^2 \times R_{ESR}$
(28)	$R_g = \frac{V_{gg}}{I_{gg}}$
(29)	$I_{S(ON)} = I_{L(AVG)} - \frac{\Delta I_L}{2}$
(30)	$I_{S(OFF)} = I_{L(AVG)} + \frac{\Delta I_L}{2}$
(31)	$t_{fv} = \left(V_{ds(OFF)} - R_{DS(ON)} I_{S(ON)}\right) \times \frac{R_g C_{rss(Vsoff/2)}}{V_{gg} - V_{gs(I_o)}}$
(32)	$t_{rv} = \left(V_{ds(OFF)} - R_{DS(ON)} I_{S(OFF)}\right) \times \frac{R_g C_{rss(Vsoff/2)}}{V_{gs(I_o)}}$
(33)	$T_{S(ON)} = t_r + t_{fv}$
(34)	$T_{S(OFF)} = t_f + t_{rv}$
(35)	$P_{SWITCHING} = \frac{V_{S(OFF)} f_s}{2} \times \left[I_{S(ON)} t_{S(ON)} + I_{S(OFF)} t_{S(OFF)}\right]$
(36)	$P_{CONDUCTION} = I_{S(RMS)}^2 \times R_{DS(ON)}$
(37)	$P_{TOTAL} = P_{CONDUCTION} + P_{SWITCHING}$
(38)	$T_{j(MAX)} = T_a + P_T \times R_{\theta ja}$
(39)	$I_{D(AVG)} = I_{L(AVG)}(1 - D)$
(40)	$P_{CONDUCTION} = I_{D(AVG)} \cdot V_F$
(41)	$P_{rr} = V_R Q_{rr} f_s$
(42)	$P_{TOTAL} = P_{CONDUCTION} + P_{SWITCHING}$
(43)	$T_{j(MAX)} = T_a + P_T \times R_{\theta ja}$
(44)	$R_S = \frac{1}{I_{S(MAX)}}$
(45)	$C_{rc} = \frac{1}{2\pi R_c f_{cutoff}}$
(46)	$T_p(s) = \frac{R_L}{R_S} \times \frac{s C_{out} r_{esr} + 1}{s C_{out} R_L + 1}$
(47)	$f_p = \frac{1}{2\pi C_o R_L}$

(48)	$$f_z = \frac{1}{2\pi C_o R_c}$$
(49)	$$T_c(0) = log\left[\frac{f_{cross}}{f_p}\right] \times 20 - \mathrm{T_p}(0)$$ $$T_p(0) = \frac{R_L}{R_s}$$ $$T_{OL}(0) = T_p(0) \cdot T_c(0) \cdot T_m(0)$$
(50)	$$T_c(0) = log\left[\frac{f_{cross}}{f_p}\right] \times 20 - \mathrm{T_p}(0)$$
(51)	$$C_f = \frac{1}{2\pi f_p R_f}$$ Where: f_p *is set to cancel plant zero*
(52)	$$R_i = \frac{R_f}{10^{\frac{T_c(0)}{20}}}$$ Where: $T_c(0)$ is gain in dB
(53)	$$G_{DIFF} = \frac{2.5}{V_{OUT(NOMINAL)}}$$

Pick-up Converter Design - Part I

Specifications

Parameter	Value	Unit
Nominal Vout(avg)	15.00	V
Isc(rms)	1.17	A
Voc(rms)	7.12	V
Winding L2	25.00	µH
Track f0	38.40	kHz

Evaluating Steady-State Operating Conditions

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load	10.00	Ω	15.00	Ω	25.00	Ω
Io	1.29	A (1)	1.00	A (2)	0.60	A (2)
Vout	12.87	V (3)	15.00	V (3)	15.00	V (3)
Po	16.56	W (4)	15.00	W (4)	9.00	W (4)
D	0.00	% (5)	22.30	% (5)	53.38	% (5)
Qmax	1.99	(6)	2.32	(6)	2.32	(6)
Qavg	1.99	(7)	1.80	(7)	1.08	(7)

Evaluating Compensation Capacitor

Parameter	Value	Unit (eq)
C2	0.67	µF (8)
Max V2	16.50	V (9)
Max IC2	2.67	A (10)

Pick-up Converter Design - Part II

Specifications

Parameter	Value	Unit
Max fs	1000.00	Hz
Nominal Vout	15.00	V
Max Iout	1.29	A
Design ΔVo	1.00	V,peak to peak

Minimum Capacitance to Meet ΔVo

Parameter	Value	Unit (eq)
C(min)	324.89	µF (11)

Selecting a Capacitor

Parameter	Value	Unit
Manufacturer	Panasonic	
Series	TP	
Voltage rating	25	V
Capacitance	470	µF
ESR	130	mΩ
IC,rms rating	1.1	A

Evaluating Steady-State Capacitor Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load	10.0	Ω	15.0	Ω	25.0	Ω
fs	0.0	Hz (12)	479.1	Hz (12)	688.1	Hz (12)
IC,rms	0.0	A (13)	0.5	A (13)	0.6	A (13)
PC	0.0	mW (14)	37.3	mW (14)	53.8	mW (14)

Evaluating Feedback Resistor Network

Parameter	Value	Unit	
Vref	4.00	V	E12 Series Values used in slides
Vo,opamp	15.00	V	
Selected Rb	10.00	kΩ	
Ra	14.33	kΩ (15)	
Rf	214.95	kΩ (16)	

Pick-up Converter Design - Part III

Specifications

Parameter	Value	Unit
Max IL(Avg)	1.29	A
Ripple fs	38.40	kHz
Design Bmax	0.25	T
Design Jmax	5.00	A/mm^2

Core & Magnet Wire Details

Parameter	Value	Unit
Core type	Drum15	
Al	0.052	µH
Ae	28.30	mm^2
AN	36.00	mm^2
ln	31.50	mm
Wire ρ	1.8E-08	Ωm
Wire µ0	1.3E-06	H/m
Achievable Kf	0.70	

Design Choices

Parameter	Value	Unit (eq)
Selected L	200.00	µH
Selected dcu	0.56	mm

Evaluating Inductor Parameters

Parameter	Value	Unit (eq)
N	63	Turns (17)
Bc(max)	0.14	T (18)
Acu (1 strand)	2.46E-01	mm^2 (19)
Used Winding Area	22.17	mm^2 (20)
Jmax	5.24	A/mm^2 (21)
Bundle Rw(dc)	145.0	mΩ (22)

Evaluating Steady-State Inductor Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load	10.0	Ω	15.0	Ω	25.0	Ω
IL,rms	1.3	A	1.3	A	1.3	A
Pcu	241.34	mW (23)	241.34	mW (23)	241.34	mW (23)

Pick-up Conveter Design - Part IV

Specifications

Parameter	Value	Unit
Max Vsw	15.00	V
Max Is,rms	1.29	A
Ta	30.00	Degrees C

Selecting a N-Channel MOSFET

Parameter	Value	Unit
Manufacturer	infineon	
Model no	IPP052N06L3	
Vdss	60	V
ID(max)	80	A
tr	5	ns
tf	12	ns
Crss @ Max Vsw/2	47	pF
Vgs(Io)	4.5	V
Rds,on	5	mΩ
RthJA - no heatsink	62	C/W

Gate Drive Details

Parameter	Value	Unit (eq)
Design Vgg	15.00	V
Design Igg	0.10	A
Rg	150.00	Ω (24)

Evaluating Steady-State Switch Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load	10.00	Ω	15.0	Ω	25.0	Ω
fs	0.00	Hz	479.09	Hz	688.09	Hz
Is,rms	0.00	A	0.61	A	0.94	A
Is @ on	0.00	A (25)	0.66	A (25)	0.39	A (25)
Is @ off	0.00	A (25)	1.91	A (25)	2.18	A (25)
tfv	10.07	ns (26)	10.07	ns (26)	10.07	ns (26)
trv	23.49	ns (27)	23.49	ns (27)	23.49	ns (27)
ts,on	15.07	ns (28)	15.07	ns (28)	15.07	ns (28)
ts,off	35.49	ns (29)	35.49	ns (29)	35.49	ns (29)
Pswitching	0.00	mW (30)	0.28	mW (30)	0.43	mW (30)
Pconduction	0.00	mw (31)	1.85	mw (31)	4.42	mw (31)
Ptotal	0.00	mw (32)	2.13	mw (32)	4.85	mw (32)

Evaluating Junction Temperature

Parameter	Value	Unit (eq)
Tj,max	30.30	C (33)

Pick-up Converter Design - Part V

Specifications

Parameter	Value	Unit (eq)
Max Vd	15.00	V
Max Id,avg	1.29	A
Ta	30.00	Degrees C

Selecting a Diode

Parameter	Value	Unit
Manufacturer	Vishay	
Model no	VS-MBR1045-M3	
Vr(max)	45	V
IF(max) - dual	10	A
VF	0.57	V
RthJA - D2Pak	n/a	C/W

Evaluating Steady-State Switch Losses

Parameter	Value	Unit (eq)	Value	Unit (eq)	Value	Unit (eq)
Load	10.00	Ω	15.0	Ω	25.0	Ω
D	0.00	%	22.30	%	53.38	%
ID,avg	1.29	A (34)	1.00	A (34)	0.60	A (34)
Pconduction	0.73	W (35)	0.57	W (35)	0.34	W (35)
Prr	0.00	W (36)	0.00	W (36)	0.00	W (36)
Ptotal	0.73	W (37)	0.57	W (37)	0.34	W (37)

Evaluating Junction Temperature

Parameter	Value	Unit (eq)	
Tj,max	75.00	C (38)	Approximation assuming similar RthJA to MOSFET

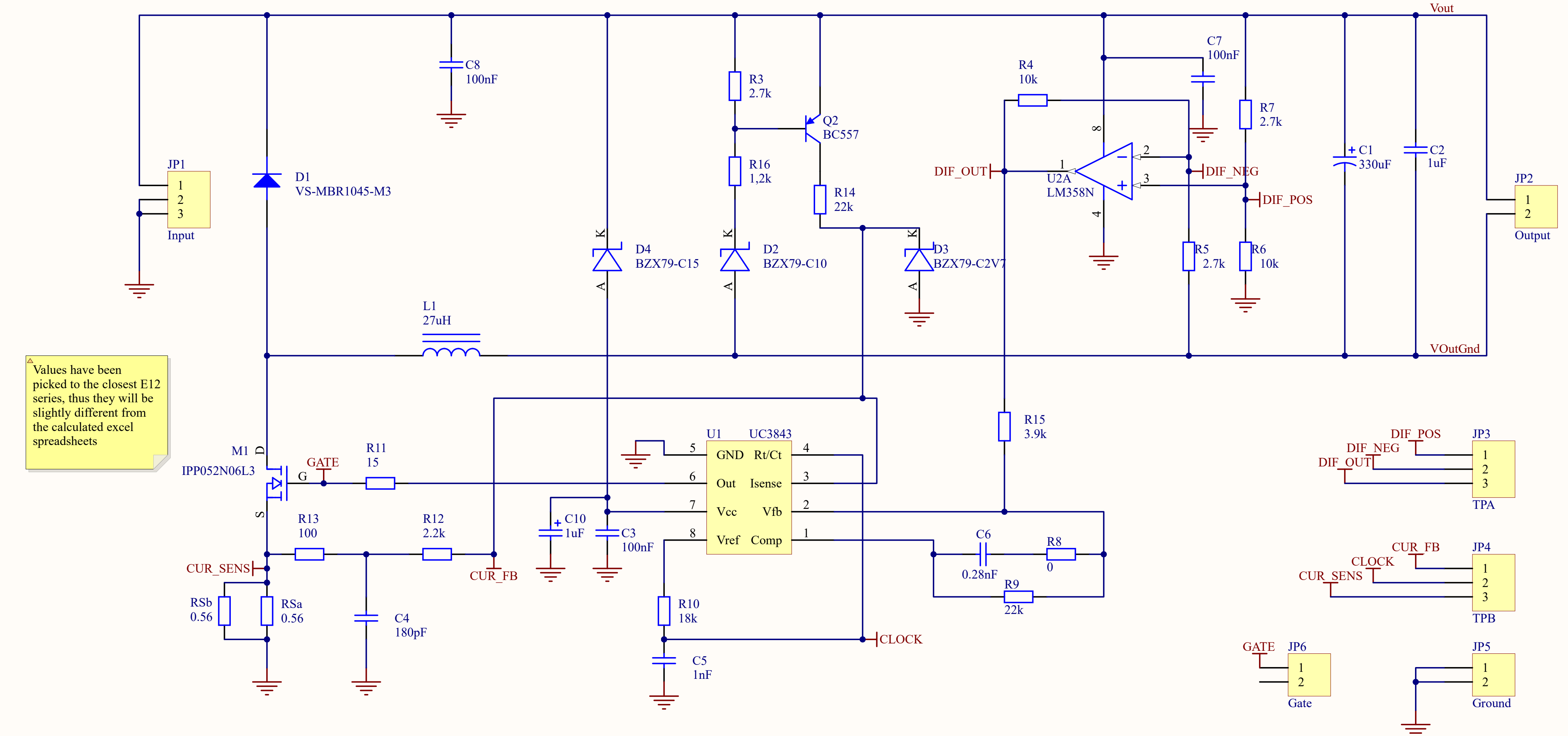
IPT Pick-up Design Equations

Eq. #	Equation
(1)	Io (for $R_L < 11.66\Omega$) is the largest current possible: $$I_{out} = 1.1 I_{sc} \approx 1.29$$
(2)	Io (for $R_L \geq 11.66\Omega$): $$I_{out} = \frac{V_{out(nominal)}}{R_{Load}}$$
(3)	Vout: $$V_{out} = I_{out} R_{Load}$$
(4)	Pout: $$P_{out} = \frac{V_{out}^2}{R_{Load}} = I_{out}^2 R_{Load} = V_{out} I_{out}$$
(5)	Duty Cycle (D): $$P_{out} = P_{max}(1 - D)$$ $$D = 1 - \frac{P_{out}}{P_{max}}$$ Where Pmax is given by: $$P_{max} = \left(1.1 I_{sc} \times V_{out(nominal)}\right)$$
(6)	Qmax: $$Q_{max} = \frac{1.1\, V_{out}}{V_{oc}}$$
(7)	Qavg: $$Q_{avg} = \frac{P_{out}}{S_u} = \frac{V_{out} I_{out}}{V_{oc} I_{sc}}$$
(8)	C2 Compensation Capacitor: Impedance matching to increase overall power: $$j\omega L_2 = -\frac{1}{j\omega C_2}$$ Rearranging and solving, we are able to find C2: $$C_2 = \left\| \frac{1}{(j\omega)^2 L_2} \right\|$$
(9)	Max V2: We know that VC2 is the voltage before the rectifier stage and due to parallel compensation: $$V_{out,nominal} = \frac{V_2}{1.1}$$ Rearranging and solving we are able to find V2:

	$$V_2 = 1.1 \cdot V_{out,nominal}$$
(10)	Max IC2: $$I_{c_2,max} = \frac{V_2}{Z_{C_2}} = \lvert j2\pi f_0 \cdot C_2 \cdot V_2 \rvert$$
(11)	Cmin can be found with the following formula: $$C_{min} = C_{dc} > \frac{\pi I_{sc}}{8\sqrt{2} f_{s,max} \Delta V_{out}}$$
(12)	fs (for $R \geq 11.66\Omega$): $$f_s \approx \frac{\pi I_{sc}}{8\sqrt{2}\, C_{dc} \Delta V_{out}}$$ fs (for $R < 11.66\Omega, \text{i. e. not sufficient to begin switching}$): $$f_s = 0$$
(13)	IC,rms: Given the two states of IC,rms when the switch is on and off: $$I_{C,RMS} = \sqrt{\frac{1}{T_s}\int_0^{DT_s} -I_{out}^2\, dt + \int_{DT_s}^{T_s} (I_{dc} - I_{out})^2}$$
(14)	Capacitor power loss ($P_{loss,C_{dc}}$): $$P_{loss,C_{dc}} = I_{rms,C_{dc}}^2 \cdot R_{esr,C_{dc}}$$
(15)	Evaluating feedback resistor network: 1. $\Delta V_{out} = V_{op} \frac{R_a}{R_f}$ 2. $V_{out,avg} = V_{ref} \frac{R_a R_b + R_f (R_a + R_b)}{R_f R_b} - V_{op} \frac{R_a}{2R_f}$ Rearranging both equations for Rf and equating we get the following equation: $$V_{op} \frac{R_a}{\Delta V_{out}} = \frac{-V_{op} R_a R_b + 2V_{ref} R_a R_b}{2V_{out,avg} R_b + 2V_{ref} R_a + +2V_{ref} R_b}$$ Subbing in chosen $R_b = 10k\Omega$ and solving for Ra.
(16)	Rf can be found by using ‘1.’ from above solution: $$R_f = V_{op} \frac{R_a}{\Delta V_{out}}$$
(17)	N: $$L = A_L \cdot N_i^2$$ $$N = \sqrt{\frac{L}{A_L}}$$

(18)	Bc(max): $$B_{c[max]} = \frac{LI_{L,avg}}{NA_e}$$
(19)	Single strand copper cross sectional area (Acu): $$A_{cu} = \frac{\pi\, d_{cu}^2}{4}$$
(20)	Used winding area: $$K_f = \frac{NA_{cu}}{A_N} \le 1$$ $$A_N = \frac{NA_{cu}}{K_f}$$
(21)	Jmax: $$J_{max} = \frac{I_{RMS(max)}}{A_{cu}}$$
(22)	Bundle Rw (dc): $$R_{\omega(dc)} = \frac{\rho N l_n}{A_{cu}}$$
(23)	Steady-state wire losses (Pcu): $$P_{cu} = R_{\omega(dc)} \cdot I_{L,RMS}^2$$
(24)	Gate driver resistance (Rg): $$R_g = \frac{V_{gg}}{I_{gg}}$$
(25)	Is @ on: $$I_{s,on} = I_{L,avg} - \frac{\Delta I_L}{2}$$ Is @ off: $$I_{s,on} = I_{L,avg} + \frac{\Delta I_L}{2}$$ Where ΔI_L is given by: $$\Delta I_L = \frac{8\,\Delta V_{out} Cdc}{T_s}$$
(26)	tvf: $$t_{vf} = \left(V_{sw} - R_{ds,ON} \cdot I_{s,ON}\right) \frac{R_g C_{rss,V_{sw}/2}}{V_{gg} - V_{gs(io)}}$$
(27)	tvr:

	$$t_{vr} = \left(V_{sw} - R_{ds,ON} \cdot I_{s,OFF}\right) \frac{R_g C_{rss,V_{sw}/2}}{V_{gs(io)}}$$
(28)	ts,on: $$t_{s,on} = t_{ir} + t_{vf}$$ Where t_{ir} = current rise time and t_{vf} = voltage fall time.
(29)	ts,off: $$t_{s,off} = t_{if} + t_{vr}$$ Where t_{if} = current fall time and t_{vr} = voltage rise time.
(30)	Pswitching: $$P_{switching} = \frac{V_{s,off} f_s}{2}\left[I_{s,on} t_{s,on} + I_{s,off} t_{s,off}\right]$$
(31)	Pconduction: $$P_{conduction} = \frac{1}{T_s}\int_0^{T_{s,on}} V_s\, I_s dt = I_{s,RMS}^2 \cdot R_{ds,on}$$
(32)	Ptotal: $$P_{total} = P_{switching} + P_{conduction}$$
(33)	Tj,max: $$T_j = T_a + P_T R_{\theta ja}$$
(34)	ID,avg: $$I_{D,avg} = (1-D) I_{D,avg[MAX]}$$
(35)	Pconduction loss: $$P_{conduction} = (1-D) V_F I_{L,avg}$$
(36)	Reverse recovery loss (Prr): $$P_{rr} \approx V_R Q_{rr} f_s$$ Where $Q_{rr} = I_{rr}\frac{t_{rr}}{2}$ However, due to the Schottky diode's physical make-up: $$P_{rr(schottky)} = 0W$$
(37)	Ptotal: $$P_{total} = P_{conduction} + P_{rr}$$
(38)	Tj,max: Similar to (33): $$T_j = T_a + P_T R_{\theta ja}$$



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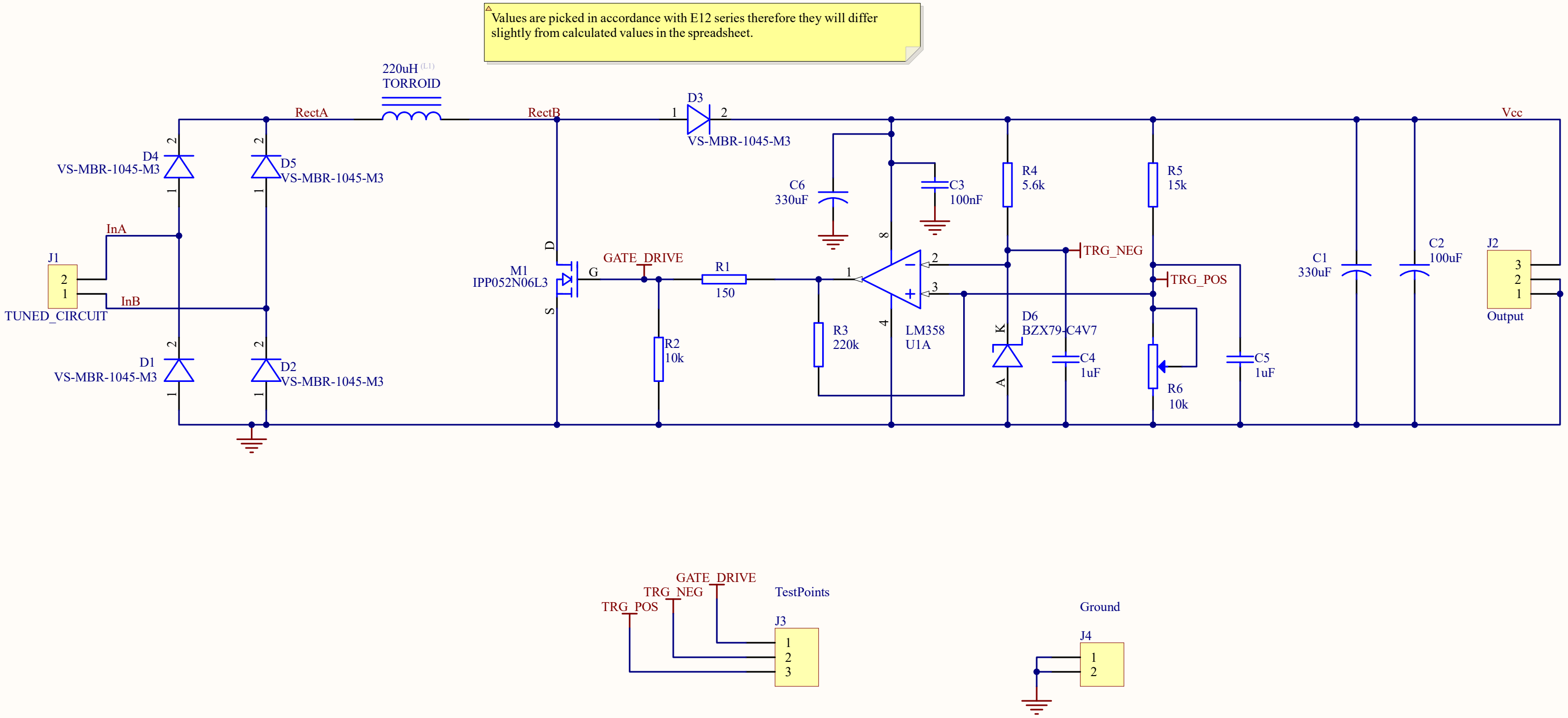

Title	IPT Pickup Controller		
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