

Design: SSR Flyback - FSL126MR - 10/24/2011

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Design Requirements

Requirements

Input Mode	AC
Min AC line voltage (rms)	85V
Max AC line voltage (rms)	265V
Min line frequency	50Hz
Number of Outputs	3

Main Output

Voltage (Vo1)	5V
Max current (Io1_max)	2A
Max power	10W
Forward voltage drop of main output diode (Vf1)	400mV

2nd Output

Target voltage (Vo2)	15V
Max current (Io2_max)	1A
Max power	15W
Forward voltage drop of 2 nd output diode (Vf2)	400mV

3rd Output

Target voltage (Vo3)	3.3V
Max current (Io3_max)	500mA
Max power	1.65W
Forward voltage drop of 3 rd output diode (Vf3)	400mV
Converter output-power rating	26.7W

Main Output (control-regulated)

Ripple voltage, max steady-state (peak-to-peak)	250mV
Worst-case load step ($\Delta Io1/Io1_max$)	50%
Peak transient voltage deviation (% of Vo1)	8%
Min transient output voltage	4.6V
Max transient output voltage	5.4V

2nd Output (cross-regulated)

Max steady-state ripple voltage (peak-to-peak)	750mV
Worst-case load step ($\Delta Io2/Io2_max$)	50%
Peak transient voltage deviation (% of Vo2)	15%

3rd Output (cross-regulated)

Max steady-state ripple voltage (peak-to-peak)	170mV
Worst-case load step ($\Delta Io3/Io3_max$)	50%
Peak transient voltage deviation (% of Vo3)	15%
Operating mode:	CCM

Efficiency

Converter efficiency estimate for min input voltage, full load	80%
Max ambient temperature	50°C

Input capacitor

Capacitance degradation factor	70%
DC link capacitor (Cdc)	95.2uF
Peak of min ac line voltage	120.2V
Droop at low line, full load (negative)	-39.9V

Min DC link voltage 80.3V

Max DC link voltage 375V

Controller Selection

MOSFET Overshoot factor (V_{os}/V_{ro})	1.3
MOSFET voltage derating factor (DF = % of BV_{dss})	80%
Main output voltage reflected to primary (V_{ro})	63.1V
Ripple factor (Krf)	0.30

Max peak drain current (I_{d_max}) for a:

650V MOSFET	1.23A
700V MOSFET	1.15A
Peak-current-limit derating factor	93%
Controller:	FSL126MR
Burst-mode inception	5.7W
Primary-to-main output turns ratio	11.69
Primary-side magnetizing inductance (L_m)	933uH
Max duty cycle	44%
Target controller bias voltage (V_{cc})	15V
V_{cc} supply current (avg)	4mA

MOSFET

Max peak drain current (I_{d_max})	1.23A
Max allowed drain voltage	520V
Max peak drain voltage (V_{ds})	520V
Min FPS junction-to-ambient thermal resistance (θ_{jc})	3°C/W
Junction-to-ambient thermal resistance for no heat sink & natural convection (θ_{ja} from datasheet)	62.5°C/W
Design junction-to-ambient thermal resistance	13.1°C/W
Worse case MOSFET dissipation	4.98W
Preliminary MOSFET junction temperature	115°C

Output Diode(s)

Reverse-voltage overshoot	15%
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Approximate peak reverse voltage for:

Main output diode	43V
2 nd output diode	122V
3 rd output diode	29V

Core & Turns

Max allowed flux density	300m T
Max core-window fill factor	0.18
Target current density for the primary winding	5A/mm ²
Target current density for the other windings	8A/mm ²
Min core area product (AeAw)	5600mm ⁴
	0.5600cm ⁴
Core part number	PC40RM10Z-12
Bobbin part number	B65814N1012D001

Main Output

Min turns before rounding	4.10
Turns (Nsec1)	5
Primary-winding turns	58

2nd Output

Turns (Nsec2)	14
Nominal output voltage	14.7V
Max transient voltage	16.9V

3rd Output

Turns (Nsec3)	3
Nominal output voltage	2.84V
Max transient voltage	3.27V

Auxiliary winding

Turns	15
Nominal output voltage (Vcc)	15.5V

Revised max converter output power 26.1W

Core air gap (lg)	419um
Max flux density in current limit	246m T
Half flux-density swing (Bm on loss curves)	46.2m T
	462G
Core loss density (kW/m ³ = mW/cm ³)	4.02kW/m ³
Core loss at low line, full load	17.3m W

Windings

Magnet wire sizes	AWG
Min wire copper diameter	200um
Skin depth	267um
Max wire copper diameter	533um
Total margin-tape width	0m

Primary Winding

Insulation type:	Heavy
Wire Size	26AWG
Wire outer diameter	462um
Number of layers	2.60
AC-to-DC resistance ratio	2.40
AC component of winding loss	247mW
DC component of winding loss	76.8mW

Max winding loss (low line, full load)	324mW
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Main Output

Insulation type:	Reinforced
Number of strands wound in parallel	2
Wire Size	24AWG
Wire outer diameter	777um
Number of layers	0.75
AC-to-DC resistance ratio	1.66
AC component of winding loss	66.4mW
DC component of winding loss	47.7mW

Total winding loss (low line, proportional full load)	114mW
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2nd Output

Insulation type:	Reinforced
Number of strands wound in parallel	2
Wire Size	27AWG
Wire outer diameter	615um
Number of layers	1.67
AC-to-DC resistance ratio	1.74
AC component of winding loss	98.0mW
DC component of winding loss	66.9mW

Total winding loss (low line, proportional full load)	165mW
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3rd Output

Insulation type:	Reinforced
Number of strands wound in parallel	1
Wire Size	27AWG
Wire outer diameter	615um
Number of layers	0.18
AC-to-DC resistance ratio	1.13
AC component of winding loss	6.80mW
DC component of winding loss	7.17mW

Total winding loss (low line, proportional full load)	14.0mW
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Auxiliary Winding

Insulation type:	Heavy
Wire Size	32AWG
Wire outer diameter	249um
Number of layers	0.36
AC-to-DC resistance ratio	1.01
AC component of winding loss	6.16uW
DC component of winding loss	7.25uW

Total winding loss (low line, proportional full load)	13.4uW
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Winding Summary

Max winding height	4.58mm
Layers of tape	9
Finished height of one tape layer	63um
Winding height reduction due to shared layer(s)	0m
Unfilled winding height	-249um
Copper loss at low line full load	617mW
Core loss	17.3mW

Total transformer loss at low line full load	634mW
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Power Semiconductors

Reverse-voltage derating factor	75%
Average-forward-current derating factor	85%

Main Output

Min peak-reverse-voltage rating (V _{rrm})	57.2V
Min average-forward-current rating (I _{f_av})	2.35A
Avg forward current during conduction	2.55A
Conduction loss at full output	800mW
Typical blocking voltage	28.3V
Junction capacitance at typical blocking voltage	85.9pF
Reverse recovery charge (Q _{rr})	0C

2nd Output

Min peak-reverse-voltage rating (V _{rrm})	161V
Min average-forward-current rating (I _{f_av})	1.18A
Avg forward current during conduction	1.28A
Conduction loss at full output	400mW
Typical blocking voltage	80.1V
Junction capacitance at typical blocking voltage	2pF
Reverse recovery charge (Q _{rr})	0C

3rd Output

Min peak-reverse-voltage rating (V _{rrm})	34.1V
Min average-forward-current rating (I _{f_av})	588mA
Avg forward current during conduction	638mA
Conduction loss at full output	200mW
Typical blocking voltage	16.8V
Junction capacitance at typical blocking voltage	18.9pF
Reverse recovery charge (Q _{rr})	0C

MOSFET Losses

Conduction losses	4.77W
Switching losses	188mW
Losses due to rectifier-diode reverse recovery	0W
MOSFET Capacitive Loss	22.8mW

Total MOSFET losses at low line full load	4.98W
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Conduction losses	755mW
Switching losses	400mW
Losses due to rectifier-diode reverse recovery	0W
MOSFET Capacitive Loss	213mW

Total MOSFET losses at high line full load	1.37W
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Worst case junction temperature	115°C
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Filters

Main Output

Capacitor voltage derating factor	70%
Capacitor ripple-current derating factor	50%
Min capacitor voltage rating	8V
Include 2 nd stage filter?	No
Initial quantity of capacitors (all stages)	2

Ratings of the selected capacitor:

ESR	70m Ω
Capacitance	270uF
Ripple current (rms)	2.99A
Worst-case output-voltage ripple (peak-to-peak)	215mV
High-frequency-noise capacitor (Co1_3)	100nF

2nd Output

Min capacitor voltage rating	25V
Include 2 nd stage filter?	No
Initial quantity of capacitors (all stages)	2

Ratings of the selected capacitor:

ESR	100m Ω
Capacitance	20uF
Ripple current (rms)	1.62A
Worst-case output-voltage ripple (peak-to-peak)	307mV
High-frequency-noise capacitor (Co2_3)	100nF

3rd Output

Min capacitor voltage rating	5V
Include 2 nd stage filter?	No
Initial quantity of capacitors (all stages)	1

Ratings of the selected capacitor:

ESR	80m Ω
Capacitance	140uF
Ripple current (rms)	1.36A
Worst-case output-voltage ripple (peak-to-peak)	127mV
High-frequency-noise capacitor (Co3_3)	100nF

Controller Setup

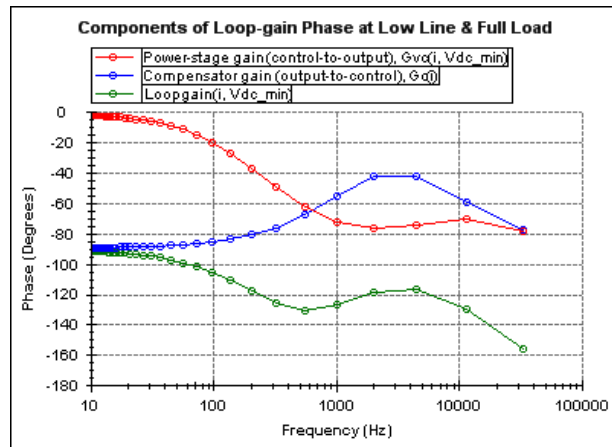
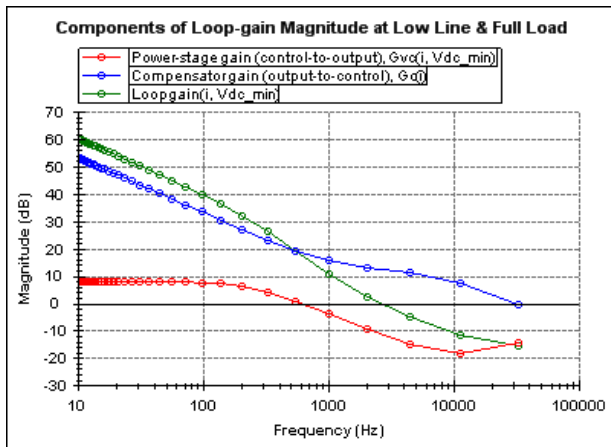
Power Stage Characteristics

Bode plot start frequency	10Hz
Bode plot end frequency	33.5kHz
Equivalent output capacitor ESR zero	8.42kHz
Right half plane zero	15.8kHz
Power stage dominant pole	265Hz

Feedback Compensation

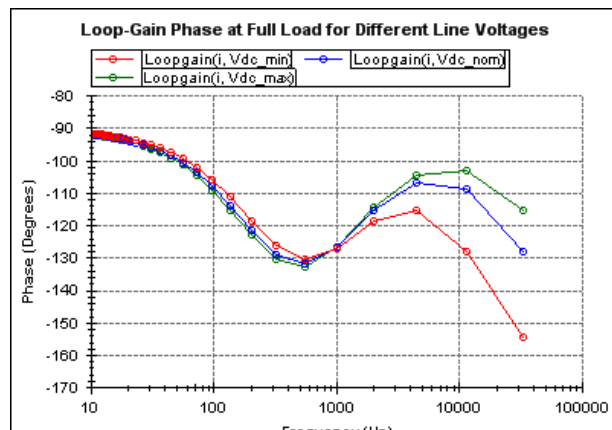
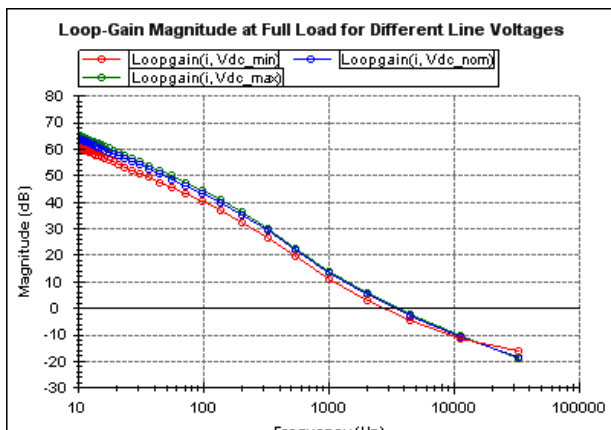
Opto diode forward voltage drop	1V
Opto collector-to-emitter parasitic capacitance (Copto)	1nF
Reference voltage of adjustable shunt regulator	2.5V
Opto-coupler current transfer ratio	1
Output voltage feedback divider resistor (Rs_top)	2.50kΩ
Output voltage feedback divider resistor (Rs_bot)	2.50kΩ
Opto and adjustable shunt regulator bias voltage	5V
Opto coupler diode resistor (Rd)	1.50kΩ
Shunt regulator bias resistor (Rbias)	1.00kΩ
Current-limit resistor (Ripk)	2.85MegΩ
Final peak-current-limit derating factor	93%
FB pin input resistance (Rb)	5.94kΩ
Target loop gain crossover frequency	2.64kHz
Compensator pole	8.42kHz
Estimated shutdown delay time	2.23ms
Target loop gain phase margin (optional)	60°
Compensator zero	1.30kHz
Desired compensator integrator ("DC") gain	4.52kHz
Compensator capacitor (Cf)	55.7nF
Feedback pin capacitor (Cb)	2.18nF
Compensator resistor (Rf)	1mΩ
Effective compensator integrator ("DC") gain	4.52kHz
Effective compensator pole	8.42kHz
Effective compensator zero	1.14kHz

Loop Gain



Normal ac line voltage

175V



Frequency (Hz)

Frequency (Hz)

Loop gain crossover frequency at low line full load	2.58kHz
Loop gain phase margin at low line full load	62.7 deg

Controller Setup

HV startup resistor (Rstr)	75.0k Ω
Vcc bulk capacitor (Cvcc_bk)	47 μ F
Vcc high frequency capacitor (Cvcc_hf)	220nF
Vcc zener (optional part) (Dzvcc)	20V
Zener series resistor (optional part) (Rdvcc)	50 Ω

Snubbers

Primary side leakage inductance (Llk)	15.5 μ H
Maximum Voltage of snubber capacitor (Vsn)	144V
Power loss in primary snubber resistor	1.39W
Snubber resistor (Rsn)	15.0k Ω
Max voltage of Csn	144V
Max snubber ripple voltage (peak-to-peak%)	10%
Snubber capacitor (Csn)	9.98nF
Δ Vsn_max based on selected Rsn and Csn	100mV
Max voltage stress on MOSFET	504V

Main Output

Use secondary snubber (main diode)?	No
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2nd Output

Use secondary snubber (2 nd diode)?	No
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3rd Output

Use secondary snubber (3 rd diode)?	No
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AC Input Circuit

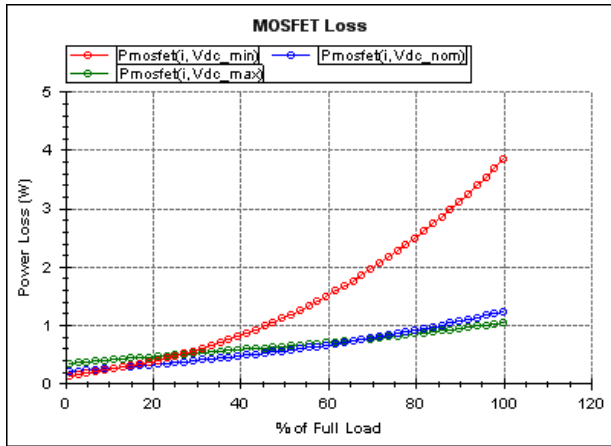
Bridge-rectifier forward voltage drop per diode (Din1, Din2, Din3, Din4)	800mV
Bridge rectifier average forward current per diode	207mA
Bridge rectifier total power loss	664mW
Common-mode choke (Lin)	20mH
First X-capacitor (Cin1)	220nF
Discharge resistor (Rin1)	1.50Meg Ω
Second X-capacitor (Cin2)	150nF
Y-capacitor (across transformer)	4.7nF
Input NTC (NTC)	1

Protection Devices

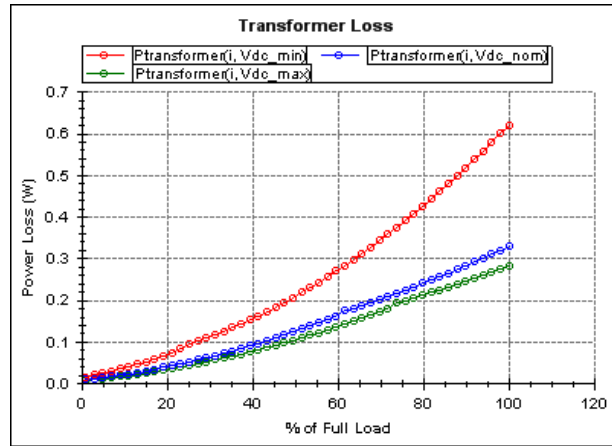
Input fuse (Fuse)	1 Ω
Clamp 2 nd output voltage?	No
Clamp 3 rd output voltage?	No

Efficiency

Typical full-load fraction of max winding loads	1
Main output full load condition	100%
Main output max power	10W
2 nd output full load condition	100%
2 nd output max power	14.7W
3 rd output full load condition	100%
3 rd output max power	1.42W
Load Sum	26.1W
MOSFET Loss	

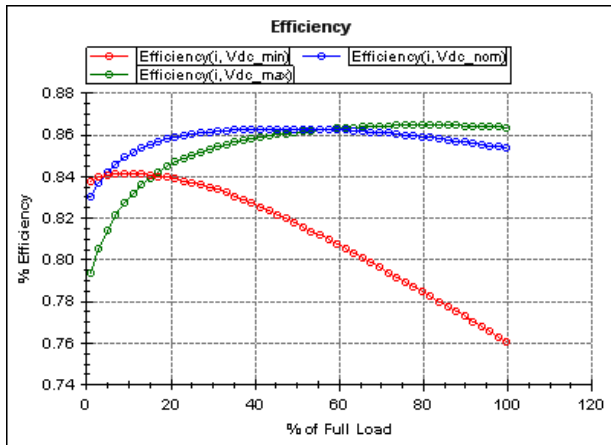


Transformer Loss

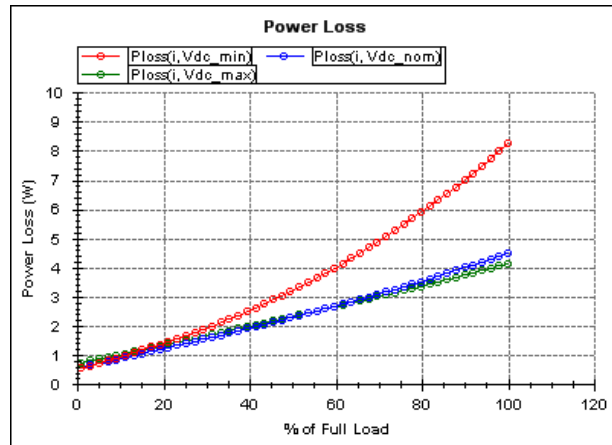


CCM-DCM boundary load(%) at Vin_min	32.5%
CCM-DCM boundary load(%) at Vin_nom	63.7%
CCM-DCM boundary load(%) at Vin_max	75.6%

Efficiency

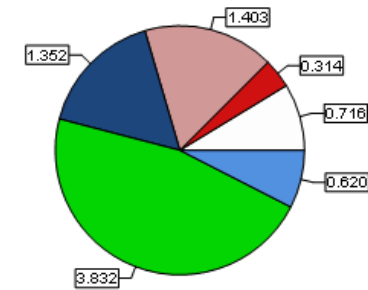


Power loss



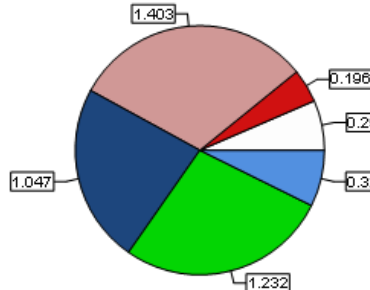
Loss summary at low line & full load (W)

Loss summary at low line



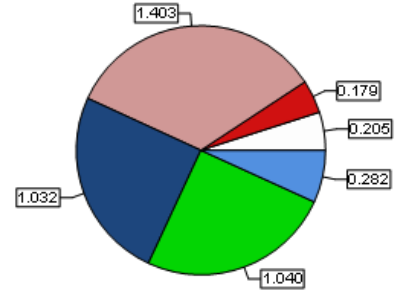
Loss summary at Nominal line & full load (W)

Loss summary at Nominal line



Loss summary at high line & full load (W)

Loss summary at high line

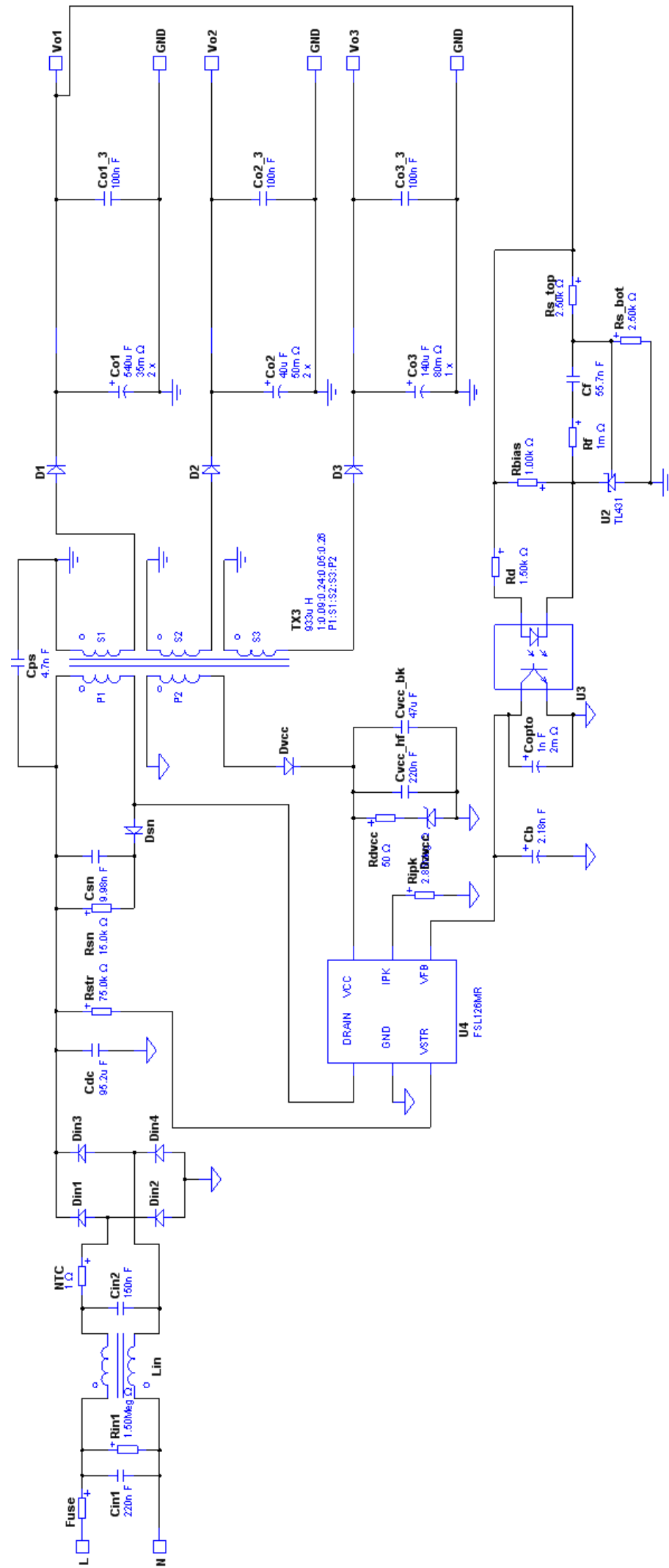


- Transformer loss
- MOSFET loss
- Snubber loss
- Secondary diode loss
- Output capacitor ESR loss
- Misc. loss - FPS IC, gate drive, input bridge

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Schematic



Bill Of Materials

Subcircuits	Quantity	Part Number	Additional Parameters
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U3, U4, U2 3

Capacitors	Quantity	Capacitance	Additional Parameters
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Co1	2	540uF	
Co2	2	40uF	
Co3	1	140uF	
Cvcc_bk	1	47uF	
Cb	1	2.18nF	
Cf	1	55.7nF	
Cin2	1	150nF	
Cdc	1	95.2uF	
Csn	1	9.98nF	
Cps	1	4.7nF	
Copto	1	1nF	
Cin1, Cvcc_hf	2	220nF	
Co2_3, Co3_3, Co1_3	3	100nF	

Resistors	Quantity	Resistance	Additional Parameters
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Rf	1	1m Ω	
Rstr	1	75.0k Ω	
Rd	1	1.50k Ω	
Rbias	1	1.00k Ω	
Ripk	1	2.85Meg Ω	
Rin1	1	1.50Meg Ω	
Rsn	1	15.0k Ω	
Rdvcc	1	50 Ω	
Fuse, NTC	2	1 Ω	
Rs_bot, Rs_top	2	2.50k Ω	

Diodes	Quantity	Part Number	Additional Parameters
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Dzvcc 1

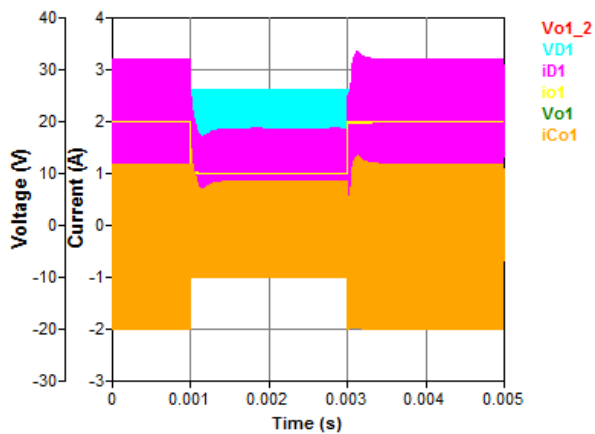
Others	Quantity	Description	Additional Parameters
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Lin 1

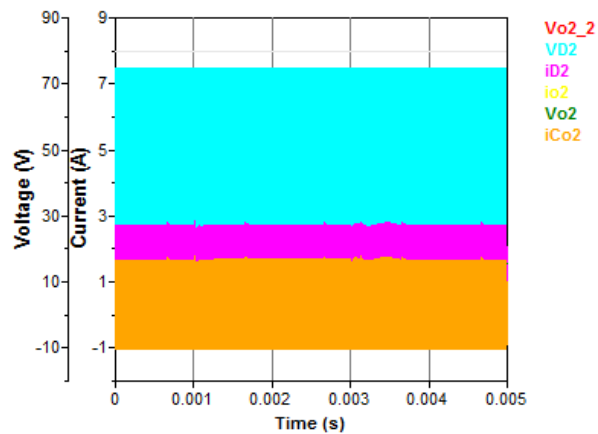
Simulation Results

Transient Results

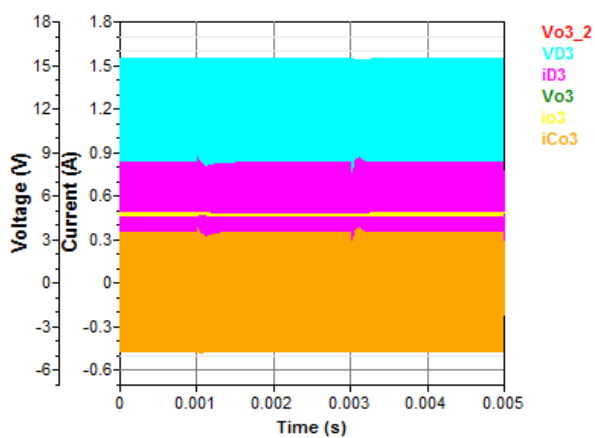
Output 1



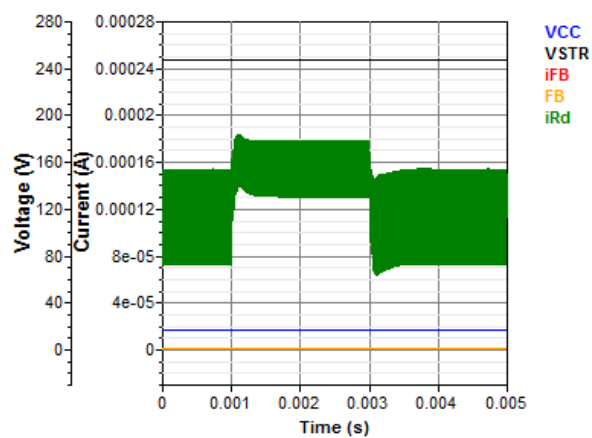
Output 2



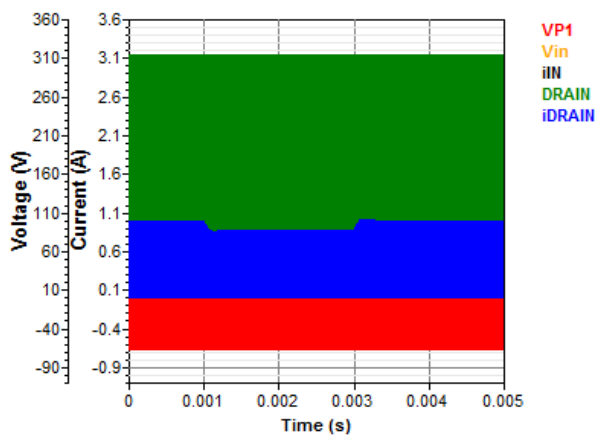
Output 3



Control

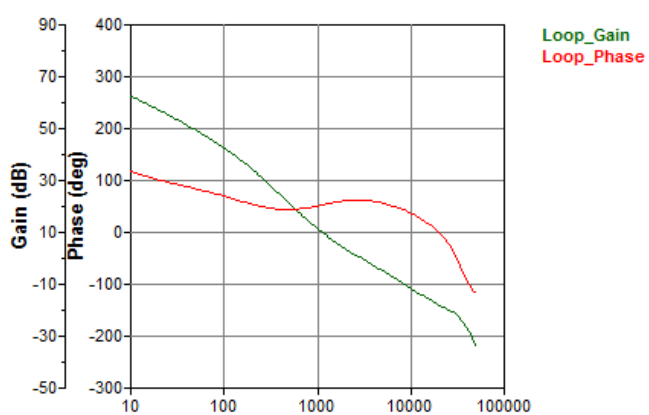


Power Train



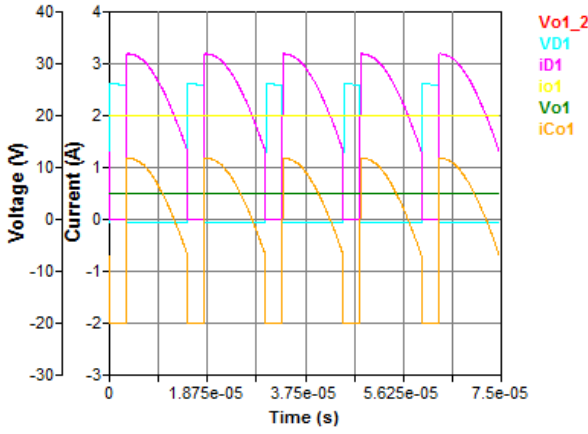
AC Results

Bode Plot

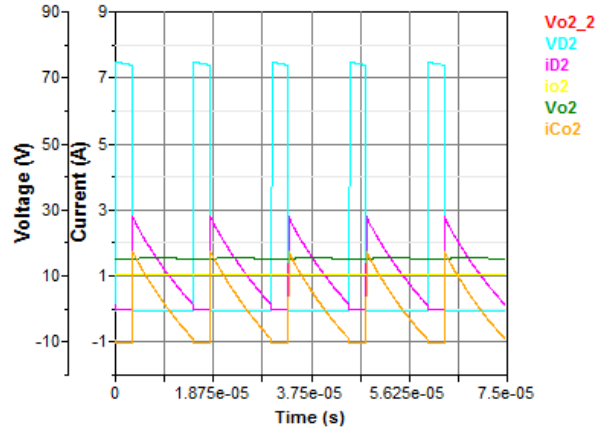


Steady State Results

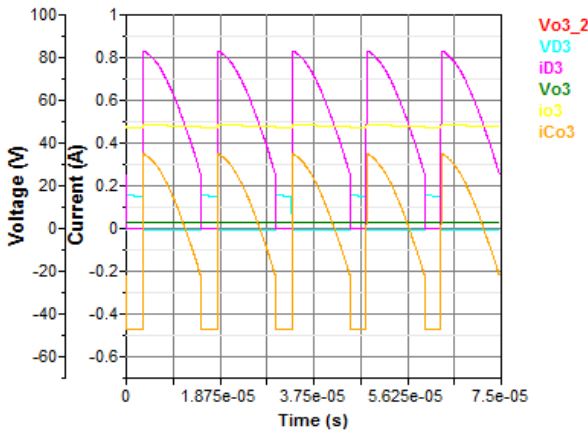
Output 1



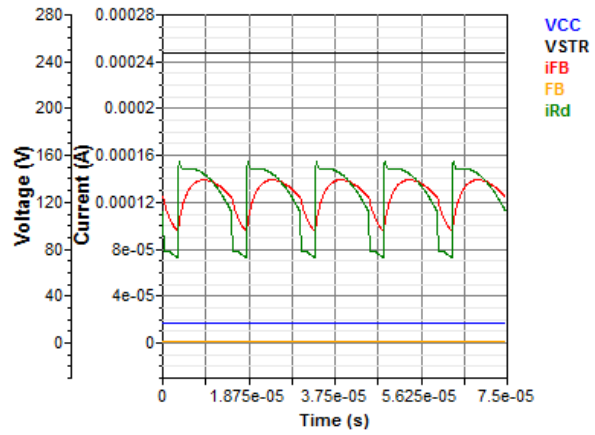
Output 2



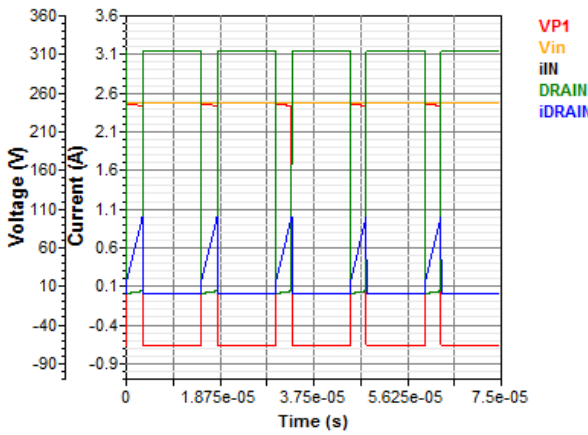
Output 3



Control



Power Train



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