

Flyback Design (Continuous Mode)

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Definitions:

$$K \equiv 1000 \quad \mu s \equiv 10^{-6} s \quad \mu H \equiv 10^{-6} H \quad mH \equiv 10^{-3} H \quad \mu F \equiv 10^{-6} F$$

$$f := 200\text{KHz} \quad f_{\min} := f \cdot 0.8 \quad f_{\max} := f \cdot 1.2$$

$$V_{\text{in_min}} := 9V \quad V_{\text{rip_input}} := 0.5V \quad d_{\max} := 0.5$$

$$V_{\text{in_nom}} := 48V$$

$$V_{\text{in_max}} := 57V$$

Outputs:

$$V_{\text{out1}} := 56V \quad V_{\text{rip1}} := 0.36V$$

$$I_{\text{out1_min}} := 0.085A \quad R_{\text{load1_min}} := \frac{V_{\text{out1}}}{I_{\text{out1_min}}} \quad R_{\text{load1_min}} = 658.824 \Omega$$

$$I_{\text{out1_nom}} := 0.35A \quad R_{\text{load1_nom}} := \frac{V_{\text{out1}}}{I_{\text{out1_nom}}} \quad R_{\text{load1_nom}} = 160 \Omega$$

$$I_{\text{out1_max}} := 0.35A \quad R_{\text{load1_max}} := \frac{V_{\text{out1}}}{I_{\text{out1_max}}} \quad R_{\text{load1_max}} = 160 \Omega$$

$$V_{\text{out2}} := 12V \quad V_{\text{rip2}} := 0.12V$$

$$I_{\text{out2_min}} := 0.003A \quad R_{\text{load2_min}} := \frac{V_{\text{out2}}}{I_{\text{out2_min}}} \quad R_{\text{load2_min}} = 4 \times 10^3 \Omega$$

$$I_{\text{out2_nom}} := 0.01A \quad R_{\text{load2_nom}} := \frac{V_{\text{out2}}}{I_{\text{out2_nom}}} \quad R_{\text{load2_nom}} = 1.2 \times 10^3 \Omega$$

$$I_{\text{out2_max}} := 0.01A \quad R_{\text{load2_max}} := \frac{V_{\text{out2}}}{I_{\text{out2_max}}} \quad R_{\text{load2_max}} = 1.2 \times 10^3 \Omega$$

$$V_{\text{out3}} := 0V \quad V_{\text{rip3}} := 0.1V$$

$$I_{\text{out3_min}} := 0.001A \quad R_{\text{load3_min}} := \frac{V_{\text{out3}}}{I_{\text{out3_min}}} \quad R_{\text{load3_min}} = 0$$

$$I_{\text{out3_nom}} := 0.010A \quad R_{\text{load3_nom}} := \frac{V_{\text{out3}}}{I_{\text{out3_nom}}} \quad R_{\text{load3_nom}} = 0$$

$$I_{\text{out3_max}} := 0.00015A \quad R_{\text{load3_max}} := \frac{V_{\text{out3}}}{I_{\text{out3_max}}} \quad R_{\text{load3_max}} = 0$$

$$V_{out4} := 0.1V \quad V_{rip4} := 0.12V$$

$$I_{out4_min} := 0.0001A \quad R_{load4_min} := \frac{V_{out4}}{I_{out4_min}} \quad R_{load4_min} = 1 \times 10^3 \Omega$$

$$I_{out4_nom} := 0.001A \quad R_{load4_nom} := \frac{V_{out4}}{I_{out4_nom}} \quad R_{load4_nom} = 100 \Omega$$

$$I_{out4_max} := 0.00001A \quad R_{load4_max} := \frac{V_{out4}}{I_{out4_max}} \quad R_{load4_max} = 1 \times 10^4 \Omega$$

$$V_{out5} := 0.1V \quad V_{rip5} := 0.48V$$

$$I_{out5_min} := 0.0001A \quad R_{load5_min} := \frac{V_{out5}}{I_{out5_min}} \quad R_{load5_min} = 1 \times 10^3 \Omega$$

$$I_{out5_nom} := 0.001A \quad R_{load5_nom} := \frac{V_{out5}}{I_{out5_nom}} \quad R_{load5_nom} = 100 \Omega$$

$$I_{out5_max} := 0.00001A \quad R_{load5_max} := \frac{V_{out5}}{I_{out5_max}} \quad R_{load5_max} = 1 \times 10^4 \Omega$$

$$V_{out6} := 0.1V \quad V_{rip6} := 0.050V$$

$$I_{out6_min} := 0.001A \quad R_{load6_min} := \frac{V_{out6}}{I_{out6_min}} \quad R_{load6_min} = 100 \Omega$$

$$I_{out6_nom} := 0.002A \quad R_{load6_nom} := \frac{V_{out6}}{I_{out6_nom}} \quad R_{load6_nom} = 50 \Omega$$

$$I_{out6_max} := 0.00001A \quad R_{load6_max} := \frac{V_{out6}}{I_{out6_max}} \quad R_{load6_max} = 1 \times 10^4 \Omega$$

$$\eta := 0.90 \quad (\text{assume BSC160N10NS3G})$$

$$I_{pk_est} := 5.31A$$

$$R_{ds} := 0.015 \cdot 1.5\text{ohm}$$

$$R_{sense_act} := 0.015\text{ohm} \quad (\text{No I sense xfmr})$$

$$V_{fet} := R_{ds} \cdot I_{pk_est}$$

$$V_{rsense} := R_{sense_act} \cdot \left(\frac{I_{pk_est}}{1} \right)$$

$$V_{fet} = 0.119V$$

$$V_{rsense} = 0.08V$$

$$V_{rsense_pri} := \frac{V_{rsense}}{1}$$

(Estimate peak Pri current - Enter Ip in Ipk_est above)

$$I_p := \frac{20W}{\eta \cdot V_{in_min}} \cdot 2.5 \quad I_p = 6.173A$$

$$P_{out} := V_{out1} \cdot I_{out1_max} + V_{out2} \cdot I_{out2_max} + V_{out3} \cdot I_{out3_max} + V_{out4} \cdot I_{out4_max} + V_{out5} \cdot I_{out5_max}$$

$$P_{out} = 19.72 \text{ W} \quad (\text{Max power})$$

$$P_{out_min} := V_{out1} \cdot I_{out1_min} + V_{out2} \cdot I_{out2_min} + V_{out3} \cdot I_{out3_min} + V_{out4} \cdot I_{out4_min}$$

$$P_{out_min} = 4.796 \text{ W} \quad (\text{Min power})$$

Use this worksheet to determine the MAX FET Vds voltage to pick.

Transformer turns ratio (primary to secondary 1)

$$V_{diode1} := 0.65 \text{ V} \quad V_{diode4} := 0.75 \text{ V}$$

$$V_{diode2} := 0.7 \text{ V} \quad V_{diode5} := 0.6 \text{ V}$$

$$V_{diode3} := 0.7 \text{ V} \quad V_{diode6} := 0.7 \text{ V}$$

$$V_{diode1} = 0.65 \text{ V} \quad \text{Output 1 diode drop or Sync FET Vdson voltage}$$

$$D_{max} := 0.569 \quad \text{Pick max duty cycle to stay discontinuous}$$

$$T_{dead} := 0.01 \quad \text{Pick dead time as a percent of period to ensure discontinuous operation}$$

$$N_{p_s1_max} := \frac{V_{in_min} - V_{fet} - V_{rsense_pri}}{V_{out1} + V_{diode1}} \cdot \frac{D_{max}}{1 - D_{max} + T_{dead}} \quad N_{p_s1_max} = 0.2$$

$$N_{p_s1} := 0.2 \quad \text{Pick actual primary to secondary 1 turns ratio}$$

Power FET drain to source voltage

$$V_{ds} := (V_{out1} + V_{diode1}) \cdot N_{p_s1} + V_{in_max}$$

$$V_{ds} = 68.33 \cdot \text{V}$$

Pick FET max voltage and spiking: $N1 := 1$

$$V_{ds_max} := 68.33 \text{ V} \quad \text{Set both:} \quad N_{ps_act} := 0.2$$

$$V_{pivD1} := V_{out1} + \frac{V_{in_max}}{N_{ps_act}}$$

$$V_{pivD1} = 341 \text{ V}$$

$$I_{d1} := \frac{I_{out1_max}}{1 - D_{max}}$$

$$I_{d1} = 0.812 \text{ A}$$

Calc transformer turns ratio:

$$(1) \quad N_{p_s1} := \frac{V_{ds_max} - V_{in_max}}{V_{out1} + V_{diode1}} \quad N_{p_s1} = 0.2$$

$$(2) \quad N_{2_1} := \frac{V_{out2} + V_{diode2}}{V_{out1} + V_{diode1}} \quad N_{2_1} = 0.224 \quad \text{Set: } N_{2_1_act} := 0.226$$

(OR)

$$N_{p_s2} := \frac{V_{ds_max} - V_{in_max}}{V_{out2} + V_{diode2}} \quad N_{p_s2} = 0.892 \quad \text{Set: } N_{ps2_act} := 0.885$$

$$V_{out2_act} := (V_{out1} + V_{diode1}) \cdot N_{2_1_act} - V_{diode2} \quad V_{out2_act} = 12.103 \text{ V}$$

For stacked windings:

$$N_{2_1s} := \frac{V_{out2} + V_{diode2} - V_{out1} - V_{diode1}}{V_{out1} + V_{diode1}} \quad N_{2_1s} = -0.776$$

$$N_2 := N_1 \cdot \frac{V_{out2} + V_{diode2} - V_{out1} - V_{diode1}}{V_{out1} + V_{diode1}} \quad N_2 = -0.776$$

$$(3) \quad N_{3_1} := \frac{V_{out3} + V_{diode3}}{V_{out1} + V_{diode1}} \quad N_{3_1} = 0.012 \quad \text{Set: } N_{3_1_act} := 0.019$$

$$N_{p_s3} := \frac{V_{ds_max} - V_{in_max}}{V_{out3} + V_{diode3}} \quad N_{p_s3} = 16.186 \quad \text{Set: } N_{ps3_act} := 34$$

$$V_{out3_act} := (V_{out1} + V_{diode1}) \cdot N_{3_1_act} - V_{diode3} \quad V_{out3_act} = 0.376 \text{ V}$$

For stacked windings:

$$N_{3_12s} := \frac{V_{out3} + V_{diode3} - V_{out2} - V_{diode2}}{V_{out2} + V_{diode2}} \quad N_{3_12s} = -0.945$$

$$N_3 := (N_1 + N_2) \cdot \frac{V_{out3} + V_{diode3} - V_{out2} - V_{diode2}}{V_{out2} + V_{diode2}} \quad N_3 = -0.212$$

$$(4) \quad N4_1 := \frac{Vout4 + Vdiode4}{Vout1 + Vdiode1} \quad N4_1 = 0.015 \quad \text{Set:} \quad N4_1_act := 0.007$$

$$Np_s4 := \frac{Vds_max - Vin_max}{Vout4 + Vdiode4} \quad Np_s4 = 13.329 \quad \text{Set:} \quad Nps4_act := 0.25$$

$$Vout4_act := (Vout1 + Vdiode1) \cdot N4_1_act - Vdiode4 \quad Vout4_act = -0.353 \text{ V}$$

For stacked windings:

$$N4_123s := \frac{Vout4 + Vdiode4 - Vout3 - Vdiode3}{Vout3 + Vdiode3} \quad N4_123s = 0.214$$

$$N4 := (N1 + N2 + N3) \cdot \frac{Vout4 + Vdiode4 - Vout3 - Vdiode3}{Vout3 + Vdiode3} \quad N4 = 2.648 \times 10^{-3}$$

$$(5) \quad N5_1 := \frac{Vout5 + Vdiode5}{Vout1 + Vdiode1} \quad N5_1 = 0.012 \quad \text{Set:} \quad N5_1_act := 0.006$$

$$Np_s5 := \frac{Vds_max - Vin_max}{Vout5 + Vdiode5} \quad Np_s5 = 16.186 \quad \text{Set:} \quad Nps5_act := 0.25$$

$$Vout5_act := (Vout1 + Vdiode1) \cdot N5_1_act - Vdiode5 \quad Vout5_act = -0.26 \text{ V}$$

For stacked windings:

$$N5_1234s := \frac{Vout5 + Vdiode5 - Vout4 - Vdiode4}{Vout4 + Vdiode4} \quad N5_1234s = -0.176$$

$$N5 := (N1 + N2 + N3 + N4) \cdot \frac{Vout5 + Vdiode5 - Vout4 - Vdiode4}{Vout4 + Vdiode4} \quad N5 = -2.648 \times 10^{-3}$$

$$(6) \quad N6_1 := \frac{Vout6 + Vdiode6}{Vout1 + Vdiode1} \quad N6_1 = 0.014 \quad \text{Set:} \quad N6_1_act := 0.007$$

$$Np_s6 := \frac{Vds_max - Vin_max}{Vout6 + Vdiode6} \quad Np_s6 = 14.162 \quad \text{Set:} \quad Nps6_act := 0.25$$

$$Vout6_act := (Vout1 + Vdiode1) \cdot N6_1_act - Vdiode6 \quad Vout6_act = -0.303 \text{ V}$$

Calc max on-time to remain discontinuous:

$$\text{SET: } \text{ton_max_act} := \frac{D_{\max}}{f_{\max}} \quad \text{ton_max_act} = 2.371 \times 10^{-6} \text{ s}$$

Calc MIN Primary Inductance:

$$L_{\text{pri_min}} := \frac{[(V_{\text{in_min}} - V_{\text{fet}} - V_{\text{rsense_pri}}) \cdot \text{ton_max_act}]^2 \cdot \eta}{\frac{2}{f_{\max}} \cdot P_{\text{out_min}}} \quad L_{\text{pri_min}} = 9.804 \cdot \mu\text{H}$$

Set: $L_{\text{pri_act}} := 10 \mu\text{H}$

Calc Actual duty cycle (f = nom):

$$d_{\max} := \frac{N_{\text{ps_act}} \cdot V_{\text{out1}}}{(V_{\text{in_min}} - V_{\text{fet}} - V_{\text{rsense}}) + N_{\text{ps_act}} \cdot V_{\text{out1}}} \quad d_{\max} = 0.56$$

$$d_{\min} := \frac{N_{\text{ps_act}} \cdot V_{\text{out1}}}{V_{\text{in_max}} + N_{\text{ps_act}} \cdot V_{\text{out1}}} \quad d_{\min} = 0.164$$

Calc Primary MAX Peak current:

$V_{\text{in min}}$:

$$I_{\text{cpr}} := \frac{\frac{I_{\text{out1_max}}}{N_{\text{ps_act}}} + \frac{I_{\text{out2_max}}}{N_{\text{ps2_act}}} + \frac{I_{\text{out3_max}}}{N_{\text{ps3_act}}} + \frac{I_{\text{out4_max}}}{N_{\text{ps4_act}}} + \frac{I_{\text{out5_max}}}{N_{\text{ps5_act}}} + \frac{I_{\text{out6_max}}}{N_{\text{ps6_act}}}}{1 - D_{\max}}$$

$$I_{\text{cpr}} = 4.087 \text{ A}$$

$$I_{\text{ripple_pp}} := \frac{2 \cdot P_{\text{out_min}}}{\eta \cdot V_{\text{in_min}} \cdot D_{\max}} \quad I_{\text{ripple_pp}} = 2.081 \text{ A}$$

$$I_{\text{pk_max}} := I_{\text{cpr}} + \frac{I_{\text{ripple_pp}}}{2} \quad I_{\text{pk_max}} = 5.127 \text{ A}$$

$$I_{\text{pri_rms}} := \sqrt{D_{\max} \cdot \left(I_{\text{cpr}}^2 + \frac{I_{\text{ripple_pp}}^2}{12} \right)} \quad I_{\text{pri_rms}} = 3.116 \text{ A}$$

Vin max:

$$I_{cpr2} := \frac{\frac{I_{out1_max}}{N_{ps_act}} + \frac{I_{out2_max}}{N_{ps2_act}} + \frac{I_{out3_max}}{N_{ps3_act}} + \frac{I_{out4_max}}{N_{ps4_act}} + \frac{I_{out5_max}}{N_{ps5_act}} + \frac{I_{out6_max}}{N_{ps6_act}}}{1 - d_{min}}$$

$$I_{cpr2} = 2.108 \text{ A}$$

$$I_{ripple_pp2} := \frac{2 \cdot P_{out_min}}{\eta \cdot V_{in_max} \cdot d_{min}}$$

$$I_{ripple_pp2} = 1.139 \text{ A}$$

$$I_{pk_max2} := I_{cpr2} + \frac{I_{ripple_pp2}}{2}$$

$$I_{pk_max2} = 2.677 \text{ A}$$

$$I_{pri_rms2} := \sqrt{d_{min} \cdot \left(I_{cpr2}^2 + \frac{I_{ripple_pp2}^2}{12} \right)}$$

$$I_{pri_rms2} = 0.864 \text{ A}$$

Calc Rsense:

Calc Level shift for Rsense:

$$V_{ref} := 5 \text{ V} \quad R_{top} := 10000 \text{ K}\Omega$$

$$R_{bot} := 2 \text{ K}\Omega$$

$$V_{shift_dc} := V_{ref} \cdot \left(\frac{R_{bot}}{R_{top} + R_{bot}} \right)$$

$$V_{shift_dc} = 9.998 \times 10^{-4} \text{ V}$$

Calc Rsense:

$$R_{sense} := \frac{0.12 \text{ V} - V_{shift_dc}}{\left(\frac{I_{pk_max}}{1} \right)}$$

$$R_{sense} = 0.023 \Omega$$

$$R_{sense_act} = 0.015 \Omega$$

$$I_{pk_act} := \frac{(0.15 \text{ V} - V_{shift_dc}) \cdot 1}{R_{sense_act}}$$

$$I_{pk_act} = 9.933 \text{ A}$$

(Peak current at current limit)

$$P_{Rsense} := \left(\frac{I_{pri_rms}}{1} \right)^2 \cdot R_{sense_act}$$

$$P_{Rsense} = 0.146 \text{ W}$$

Calc FET:

FET: BSC160N10NS3G

$$V_{ds_max} := V_{in_max} + (V_{out1} + V_{diode1}) \cdot N_{ps_act}$$

$$V_{ds_max} = 68.33 \text{ V}$$

$$Q_{fet} := 16 \cdot 10^{-9} \text{ C}$$

$$R_{ds} = 0.023 \Omega$$

$$V_{ds_min} := V_{in_min} + (V_{out1} + V_{diode1}) \cdot N_{ps_act}$$

$$V_{ds_min} = 20.33 \text{ V}$$

Vin min losses

$$P_{cond1} := I_{pri_rms}^2 \cdot R_{ds} \quad P_{cond1} = 0.218 \text{ W}$$

$$P_{sw1} := 0.25 \cdot f \cdot (50 \cdot 10^{-9} \text{ s}) \cdot I_{pk_max} \cdot V_{ds_min} \quad P_{sw1} = 0.261 \text{ W}$$

$$P_{coss1} := 0.125 \text{ W} \quad (\text{from Coss spreadsheet, } V_{in_min}, \text{ estimated})$$

$$P_{fet_tot1} := P_{cond1} + P_{sw1} + P_{coss1} \quad P_{fet_tot1} = 0.604 \text{ W}$$

Vin max losses

$$P_{cond2} := I_{pri_rms2}^2 \cdot R_{ds} \quad P_{cond2} = 0.017 \text{ W}$$

$$P_{sw2} := 0.25 \cdot f \cdot (50 \cdot 10^{-9} \text{ s}) \cdot I_{pk_max2} \cdot V_{ds_max} \quad P_{sw2} = 0.457 \text{ W}$$

$$P_{coss2} := 0.125 \text{ W} \quad (\text{from Coss spreadsheet, } V_{in_max}, \text{ estimated})$$

$$P_{fet_tot2} := P_{cond2} + P_{sw2} + P_{coss2} \quad P_{fet_tot2} = 0.599 \text{ W}$$

Calc primary FET voltage clamp (snubber):

$$R_{snub} := 5 \text{ K}\Omega \quad (\text{SET})$$

$$V_{capsnub} := V_{out1} \cdot (1.5) \cdot N_{ps_act}$$

$$V_{capsnub} = 16.8 \text{ V} \quad (\text{SET 1.5 factor to account for ringing})$$

$$P_{snub} := \frac{V_{capsnub}^2}{R_{snub}}$$

$$P_{snub} = 0.056 \text{ W}$$

Calc main output cap:

$$I_{pksec1} := \frac{I_{out1_max}}{1 - D_{max}}$$

$$I_{pksec1} = 0.812 \text{ A}$$

5x ceramics

$$C_{out1_act} := 4 \mu\text{F}$$

$$R_{esr1_act} := 0.001 \text{ ohm}$$

$$C_{out1} := I_{out1_max} \cdot \frac{D_{max}}{f \cdot V_{rip1}}$$

$$C_{out1} = 2.766 \mu\text{F}$$

$$I_{rms_out1} := I_{out1_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}} \quad I_{rms_out1} = 0.402 \text{ A}$$

$$R_{esr1} := \frac{V_{rip1}}{I_{pksec1}} \quad R_{esr1} = 0.443 \Omega$$

$$V_{rip_act} := \frac{I_{out1_max} \cdot D_{max}}{C_{out1_act} \cdot f} \quad V_{rip_act} = 0.249 \text{ V}$$

(if secondary L-C filter needed)

Calc Vout2 output cap:

Use xxx

$$I_{pksec2} := \frac{I_{out2_max}}{1 - D_{max}} \quad I_{pksec2} = 0.023 \text{ A}$$

$$C_{out2_act} := 0.1 \mu\text{F}$$

$$R_{esr2_act} := 0.01 \text{ ohm}$$

$$I_{rip_sec2} := \frac{V_{out2} + V_{diode2}}{\left(\frac{1}{N_{ps2_act}}\right)^2 \cdot L_{pri_act}} \cdot \frac{1 - D_{max}}{f} \quad I_{rip_sec2} = 2.144 \text{ A}$$

$$C_{out2} := I_{out2_max} \cdot \frac{D_{max}}{f \cdot V_{rip2}} \quad C_{out2} = 0.237 \cdot \mu\text{F}$$

$$I_{rms_out2} := I_{out2_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}} \quad I_{rms_out2} = 0.011 \text{ A}$$

$$R_{esr2} := \frac{V_{rip2}}{\frac{I_{out2_max}}{1 - D_{max}} + \frac{I_{rip_sec2}}{2}} \quad R_{esr2} = 0.11 \Omega$$

Calc Vout3 output cap:

Use xxx

$$I_{pksec3} := \frac{I_{out3_max}}{1 - D_{max}} \quad I_{pksec3} = 3.48 \times 10^{-4} \text{ A} \quad C_{out3_act} := 0.00001 \mu\text{F}$$

$$R_{esr3_act} := 0.3 \text{ ohm}$$

$$I_{rip_sec3} := \frac{V_{out3} + V_{diode3}}{\left(\frac{1}{N_{ps3_act}}\right)^2 \cdot L_{pri_act}} \cdot \frac{1 - D_{max}}{f} \quad I_{rip_sec3} = 174.383 \text{ A}$$

$$C_{out3} := I_{out3_max} \cdot \frac{D_{max}}{f \cdot V_{rip3}} \quad C_{out3} = 4.267 \times 10^{-3} \cdot \mu\text{F}$$

$$I_{rms_out3} := I_{out3_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}} \quad I_{rms_out3} = 1.723 \times 10^{-4} \text{ A}$$

$$R_{esr3} := \frac{V_{rip3}}{\frac{I_{out3_max}}{1 - D_{max}} + \frac{I_{rip_sec3}}{2}} \quad R_{esr3} = 1.147 \times 10^{-3} \Omega$$

Calc Vout4 output cap:

Use xxx

$$I_{pksec4} := \frac{I_{out4_max}}{1 - D_{max}} \quad I_{pksec4} = 2.32 \times 10^{-5} \text{ A} \quad C_{out4_act} := 0.0001 \mu\text{F}$$

$$R_{esr4_act} := 0.016 \text{ ohm}$$

$$I_{rip_sec4} := \frac{V_{out4} + V_{diode4}}{\left(\frac{1}{N_{ps4_act}}\right)^2 \cdot L_{pri_act}} \cdot \frac{1 - D_{max}}{f} \quad I_{rip_sec4} = 0.011 \text{ A}$$

$$C_{out4} := I_{out4_max} \cdot \frac{D_{max}}{f \cdot V_{rip4}} \quad C_{out4} = 2.371 \times 10^{-4} \cdot \mu\text{F}$$

$$I_{rms_out4} := I_{out4_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}} \quad I_{rms_out4} = 1.149 \times 10^{-5} \text{ A}$$

$$R_{esr4} := \frac{V_{rip4}}{\frac{I_{out4_max}}{1 - D_{max}} + \frac{I_{rip_sec4}}{2}} \quad R_{esr4} = 20.879 \Omega$$

Calc Vout5 output cap:

Use xxx

$$C_{out5_act} := 0.0001 \mu\text{F}$$

$$I_{pksec5} := \frac{I_{out5_max}}{1 - D_{max}}$$

$$I_{pksec5} = 2.32 \times 10^{-5} \text{ A}$$

$$Resr5_act := 0.016 \text{ ohm}$$

$$I_{rip_sec5} := \frac{V_{out5} + V_{diode5}}{\left(\frac{1}{N_{ps5_act}}\right)^2 \cdot L_{pri_act}} \cdot \frac{1 - D_{max}}{f}$$

$$I_{rip_sec5} = 9.428 \times 10^{-3} \text{ A}$$

$$C_{out5} := I_{out5_max} \cdot \frac{D_{max}}{f \cdot V_{rip5}}$$

$$C_{out5} = 5.927 \times 10^{-5} \cdot \mu\text{F}$$

$$I_{rms_out5} := I_{out5_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}}$$

$$I_{rms_out5} = 1.149 \times 10^{-5} \text{ A}$$

$$Resr5 := \frac{V_{rip5}}{\frac{I_{out5_max}}{1 - D_{max}} + \frac{I_{rip_sec5}}{2}}$$

$$Resr5 = 101.324 \Omega$$

Calc Vout6 output cap:

Use xxx

$$I_{pksec6} := \frac{I_{out6_max}}{1 - D_{max}}$$

$$I_{pksec6} = 2.32 \times 10^{-5} \text{ A}$$

$$C_{out6_act} := 0.0001 \mu\text{F}$$

$$Resr6_act := 0.016 \text{ ohm}$$

$$I_{rip_sec6} := \frac{V_{out6} + V_{diode6}}{\left(\frac{1}{N_{ps6_act}}\right)^2 \cdot L_{pri_act}} \cdot \frac{1 - D_{max}}{f}$$

$$I_{rip_sec6} = 0.011 \text{ A}$$

$$C_{out6} := I_{out6_max} \cdot \frac{D_{max}}{f \cdot V_{rip6}}$$

$$C_{out6} = 5.69 \times 10^{-4} \cdot \mu\text{F}$$

$$I_{rms_out6} := I_{out6_max} \cdot \sqrt{\frac{D_{max}}{1 - D_{max}}}$$

$$I_{rms_out6} = 1.149 \times 10^{-5} \text{ A}$$

$$Resr6 := \frac{V_{rip6}}{\frac{I_{out6_max}}{1 - D_{max}} + \frac{I_{rip_sec6}}{2}}$$

$$Resr6 = 9.241 \Omega$$

Calc input cap:

Calc charge on input cap:

From Above:

$$V_{rip_input} = 0.5 \text{ V}$$

Use 1x 390uF, 100V

$$Resr_in := 0.044 \text{ ohm}$$

$$Q := \frac{I_{pk_max} \cdot d_{max}}{2 \cdot f_{min}}$$

$$Q = 8.973 \times 10^{-6} \text{ C}$$

$$C_{in} := \frac{Q}{V_{rip_input}}$$

$$C_{in} = 17.945 \cdot \mu\text{F}$$

$$Resr_input := \frac{V_{rip_input}}{I_{pk_max}}$$

$$Resr_input = 0.098 \Omega$$

$$I_{Cin_rms} := I_{cpr} \cdot \sqrt{D_{max} \cdot (1 - D_{max})}$$

$$I_{Cin_rms} = 2.024 \text{ A}$$

$$P_{Cin} := I_{pri_rms}^2 \cdot Resr_in \quad P_{Cin} = 0.427 \text{ W}$$

Calc Lpri losses:

$$R_{pri_act} := 0.015 \cdot \text{ohm} \quad R_{sec1_act} := 0.19 \cdot \text{ohm} \quad R_{sec2_act} := 0.185 \cdot \text{ohm}$$

$$R_{sec3_act} := 0.53 \cdot \text{ohm} \quad R_{sec4_act} := 0.25 \cdot \text{ohm}$$

$$I_{sec1_rms} := \sqrt{(1 - d_{max}) \cdot (I_{pksec1})^2}$$

$$I_{sec1_rms} = 0.539 \text{ A}$$

$$I_{sec2_rms} := \sqrt{(1 - d_{max}) \cdot (I_{pksec2})^2}$$

$$I_{sec2_rms} = 0.015 \text{ A}$$

$$I_{sec3_rms} := \sqrt{(1 - d_{max}) \cdot (I_{pksec3})^2}$$

$$I_{sec3_rms} = 2.309 \times 10^{-4} \text{ A}$$

$$I_{sec4_rms} := \sqrt{(1 - d_{max}) \cdot (I_{pksec4})^2}$$

$$I_{sec4_rms} = 1.539 \times 10^{-5} \text{ A}$$

$$\begin{aligned}
P_{pri} &:= I_{pri_rms}^2 \cdot R_{pri_act} & P_{pri} &= 0.146 \text{ W} \\
P_{sec1} &:= I_{sec1_rms}^2 \cdot R_{sec1_act} & P_{sec1} &= 0.055 \text{ W} \\
P_{sec2} &:= I_{sec2_rms}^2 \cdot R_{sec2_act} & P_{sec2} &= 4.382 \times 10^{-5} \text{ W} \\
P_{sec3} &:= I_{sec3_rms}^2 \cdot R_{sec3_act} & P_{sec3} &= 2.825 \times 10^{-8} \text{ W} \\
P_{sec4} &:= I_{sec4_rms}^2 \cdot R_{sec4_act} & P_{sec4} &= 5.922 \times 10^{-11} \text{ W} \\
P_{sec} &:= P_{sec1} + P_{sec2} + P_{sec3} + P_{sec4} & P_{sec} &= 0.055 \text{ W} \\
P_{core} &:= P_{pri} + P_{sec} & P_{core} &= 0.201 \text{ W} \\
P_{xfmr} &:= P_{pri} + P_{sec} + P_{core} & P_{xfmr} &= 0.402 \text{ W}
\end{aligned}$$

Calc Vout1 output diode:

Use MURS260, 2A, 600V

$$V_{diode1} = 0.65 \text{ V}$$

$$V_{piv1} := V_{out1} + \frac{V_{in_max}}{N_{ps_act}} \quad V_{piv1} = 341 \text{ V}$$

$$P_{diode1} := (I_{pksec1}) \cdot V_{diode1} \cdot (1 - D_{max}) \quad P_{diode1} = 0.228 \text{ W}$$

Calc Vout1 output syncfet (instead of Diode1 - Sync FET NOT USED):

FET: Si7884DP

Enter sync drive winding voltage

$$\begin{aligned}
N_{ps_sd} &:= N_{ps2_act} & V_{out_sd} &:= V_{out2} & V_{d_sd} &:= V_{diode2} \\
R_{dson_sync} &:= 0.007 \cdot 1.35 \Omega & Q_{sync} &:= 28 \cdot 10^{-9} \text{ coul} & V_{gate_sync} &:= 8.2 \text{ V}
\end{aligned}$$

Calc sync FET gate-source "on" voltage:

$$V_{gate_on} := (V_{out_sd} + V_{d_sd}) - (V_{out1} + V_{diode1}) \quad V_{gate_on} = -43.95 \text{ V}$$

FET must turn on with this

Calc sync FET gate-source "off" voltage:

negative swing on xfmr winding, main output

$$V_{\text{sec_neg1}} := \frac{-V_{\text{in_max}}}{N_{\text{ps_act}}} \quad V_{\text{sec_neg1}} = -285 \text{ V}$$

negative swing on xfmr winding, sync output

$$V_{\text{sec_neg2}} := \frac{-V_{\text{in_max}}}{N_{\text{ps_sd}}} \quad V_{\text{sec_neg2}} = -64.407 \text{ V}$$

Make sure FET can withstand

$$V_{\text{sync_dr_neg}} := V_{\text{sec_neg2}} - V_{\text{sec_neg1}} \quad V_{\text{sync_dr_neg}} = 220.593 \text{ V}$$

$$I_{\text{pksec1}} = 0.812 \text{ A}$$

$$I_{\text{sec1_rms}} := I_{\text{pksec1}} \cdot \sqrt{1 - D_{\text{max}}} \quad I_{\text{sec1_rms}} = 0.533 \text{ A}$$

$$P_{\text{cond}} := I_{\text{sec1_rms}}^2 \cdot R_{\text{dson_sync}} \quad P_{\text{cond}} = 2.686 \times 10^{-3} \text{ W}$$

$$P_{\text{gate_sync}} := Q_{\text{sync}} \cdot V_{\text{gate_sync}} \cdot f \quad P_{\text{gate_sync}} = 0.046 \text{ W}$$

$$P_{\text{syncfet}} := P_{\text{cond}} + P_{\text{gate_sync}} \quad P_{\text{syncfet}} = 0.049 \text{ W}$$

Calc Vout2 output diode:

Use BAS20, 0.2A, 200V

$$V_{\text{diode2}} = 0.7 \text{ V}$$

$$V_{\text{piv2}} := V_{\text{out2}} + \frac{V_{\text{in_max}}}{\frac{N_{\text{ps_act}}}{N_{2_1_act}}} \quad V_{\text{piv2}} = 76.41 \text{ V}$$

$$P_{\text{diode2}} := (I_{\text{pksec2}}) \cdot V_{\text{diode2}} \cdot (1 - D_{\text{max}}) \quad P_{\text{diode2}} = 7 \times 10^{-3} \text{ W}$$

Calc Vout3 output diode:

Use BAS16, 0.2A, 75V

$$V_{\text{diode3}} = 0.7 \text{ V}$$

$$V_{piv3} := V_{out3} + \frac{V_{in_max}}{\frac{N_{ps_act}}{N3_1_act}} \quad V_{piv3} = 5.415 \text{ V}$$

$$P_{diode3} := (I_{pksec3}) \cdot V_{diode3} \cdot (1 - D_{max}) \quad P_{diode3} = 1.05 \times 10^{-4} \text{ W}$$

Calc Vout4 output diode:

Use BAS16, 0.2A, 75V

$$V_{diode4} = 0.75 \text{ V}$$

$$V_{piv4} := V_{out4} + \frac{V_{in_max}}{\frac{N_{ps_act}}{N4_1_act}} \quad V_{piv4} = 2.095 \text{ V}$$

$$P_{diode4} := (I_{pksec4}) \cdot V_{diode4} \cdot (1 - D_{max}) \quad P_{diode4} = 7.5 \times 10^{-6} \text{ W}$$

Calc Vout5 output diode:

Use xxx, 1A, xxV

$$V_{diode5} = 0.6 \text{ V}$$

$$V_{piv5} := V_{out5} + \frac{V_{in_max}}{\frac{N_{ps_act}}{N5_1_act}} \quad V_{piv5} = 1.81 \text{ V}$$

$$P_{diode5} := (I_{pksec5}) \cdot V_{diode5} \cdot (1 - D_{max}) \quad P_{diode5} = 6 \times 10^{-6} \text{ W}$$

Calc controller power required:

If using UCC3809 Controller

Calc gate drive power:

$$V_{bias} := 12 \text{ V}$$

$$I_{gate} := Q_{fet} \cdot f_{max}$$

$$I_{gate} = 3.84 \times 10^{-3} \text{ A}$$

$$P_{gate} := f \cdot Q_{fet} \cdot V_{bias}$$

$$P_{gate} = 0.038 \text{ W}$$

$$P_{controller} := P_{gate} + 0.9 \cdot 10^{-3} \text{ A} \cdot V_{bias}$$

$$P_{controller} = 0.049 \text{ W}$$

Calc oscillator res and cap (UCC3809):

$$RT1 := 28 \text{ K}\Omega \quad RT2 := 10 \text{ K}\Omega \quad CT := 150 \cdot 10^{-12} \text{ F}$$

$$F_{osc} := \left[0.74 \cdot \left(CT + 27 \cdot 10^{-12} \text{ F} \right) \cdot (RT1 + RT2) \right]^{-1} \quad F_{osc} = 200.915 \cdot \text{KHz}$$

$$D_{\max_cont} := 0.74 \cdot RT1 \cdot (CT + 27 \cdot 10^{-12} \text{F}) \cdot F_{osc} \quad D_{\max_cont} = 0.737$$

Calc oscillator res and cap (UCC3813):

$$RT := 15 \text{K}\Omega \quad CT := 330 \cdot 10^{-12} \text{F}$$

$$F_{osc} := \frac{1}{RT \cdot CT} \quad F_{osc} = 202.02 \cdot \text{KHz}$$

$$f_{switching} := \frac{F_{osc}}{2} \quad f_{switching} = 101.01 \cdot \text{KHz} \quad (\text{for } -1, -4 \text{ and } -5 \text{ parts only})$$

Calc start up resistor and cap:

Use UCC3809-2
Controller

$$V_{\text{startup_hys}} := 6.2 \text{V}$$

$$V_{\text{startup_max}} := 15.6 \text{V}$$

$$t_{\text{startup}} := 0.005 \text{s}$$

$$I_{\text{vdd_start}} := 250 \cdot 10^{-6} \text{A}$$

(100uA to IC + 150uA
to charge the cap)

$$R_{\text{startup_max}} := \frac{V_{\text{in_min}} - V_{\text{startup_max}}}{I_{\text{vdd_start}}}$$

$$R_{\text{startup_max}} = -26.4 \cdot \text{k}\Omega$$

$$R_{\text{start_act}} := 1000000 \text{K}\Omega$$

$$PR_{\text{startup_max}} := \frac{(V_{\text{in_max}} - V_{\text{out2}})^2}{R_{\text{start_act}}}$$

$$PR_{\text{startup_max}} = 2.025 \times 10^{-6} \text{W}$$

$$C_{\text{startup}} := \frac{I_{\text{out3_max}} \cdot t_{\text{startup}}}{V_{\text{startup_hys}}}$$

$$C_{\text{startup}} = 0.121 \cdot \mu\text{F}$$

$$C_{\text{startup_act}} := 22 \mu\text{F}$$

$$t_{\text{delay}} := -R_{\text{start_act}} \cdot C_{\text{startup_act}} \cdot \ln \left[1 - \left(\frac{V_{\text{startup_max}}}{V_{\text{in_nom}}} \right) \right]$$

$$t_{\text{delay}} = 8.647 \times 10^3 \text{s}$$

Calc efficiency (Select either Pdiode1 or Psyncfet):

$$P_{\text{loss}} := P_{\text{xfmr}} + P_{\text{Rsense}} + P_{\text{fet_tot1}} + P_{\text{Cin}} + P_{\text{diode1}} + P_{\text{diode2}} + P_{\text{controller}} + PR_{\text{startup_max}}$$

$$P_{\text{loss}} = 1.862 \text{W}$$

$$\text{Eff} := \left(\frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{loss}}} \right) \cdot 100$$

$$\text{Eff} = 91.372$$