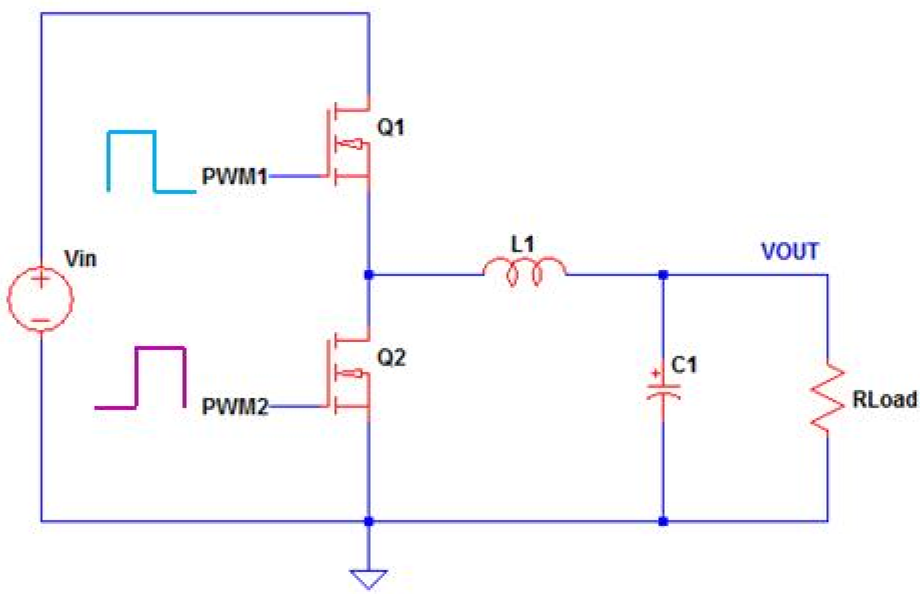
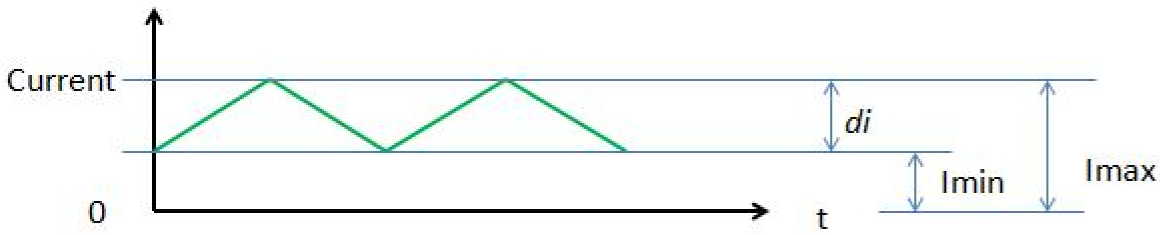
Synhronous Buck Converter Design



Derivations of Important Equations

Inductor Current Derivation



$I_{DC\_di} = \frac{di}{2}$

$I_{DC\_total} = Imin\_DC + I_{DC\_di}$

$Imin\_DC = \frac{1}{Tsw} \cdot \int_0^{Tsw} Imin\, dt \text{ simplify } \rightarrow Imin\_DC = Imin$

$Imin\_DC = Imin$

$di\_DC = \frac{1}{Tsw} \cdot \int_0^{Tsw} \frac{t}{Tsw} \cdot di\, dt \text{ simplify } \rightarrow di\_DC = \frac{di}{2}$

$di\_DC = \frac{di}{2}$

$I_{DC\_total} = Imin + \frac{di}{2}$

$I_{DC\_total} = Imax - di + \frac{di}{2} \text{ solve}, Imax \rightarrow I_{DC\_total} + \frac{di}{2}$

$Imax = I_{DC\_total} + \frac{di}{2}$

$Imax = Iload + \frac{di}{2}$ Note : The total DC current is equal to the DC of the load current

Inductor RMS Current

$$I_{RMS\_inductor} = I_{RMS\_di} + Imin\_RMS$$

$$I_{RMS\_di} = \sqrt{\frac{1}{T} \cdot \int_0^T \left(\frac{t}{T} \cdot di\right)^2 dt} \text{ simplify } \rightarrow I_{RMS\_di} = \frac{\sqrt{3} \cdot \sqrt{di^2}}{3}$$

$$I_{RMS\_di} = \frac{\sqrt{3} \cdot \sqrt{di^2}}{3}$$

$$I_{RMS\_di} = \frac{di}{\sqrt{3}}$$

$$Imin\_RMS = \sqrt{\frac{1}{T} \cdot \int_0^T Imin^2 \, dt} \text{ solve}, Imin\_RMS \rightarrow \sqrt{Imin^2}$$

$$Imin\_RMS = Imin$$

$$I_{RMS\_inductor} = \frac{di}{\sqrt{3}} + Imin$$

$$I_{RMS\_inductor} = \frac{di}{\sqrt{3}} + Imax - di$$

di Derivation (inductor ripple)

$$di = \int_{Ton}^{T} \frac{(Vout + V_D)}{L1} dt \text{ simplify } \rightarrow di = \frac{(T - Ton) \cdot (Vout + V_D)}{L1}$$

$$di = \frac{(T - Ton) \cdot (Vout + V_D)}{L1}$$

$$-(Ton - Tsw)\cdot\left(Vout + V_D\right) = -Ton\cdot(VQ1 - Vin + Vout) \text{ solve}, Vout \rightarrow \frac{V_D\cdot(Ton - Tsw) - Ton\cdot(VQ1 - Vin)}{Tsw}$$

$$Vout = \frac{V_D\cdot(Ton - Tsw) - Ton\cdot(VQ1 - Vin)}{Tsw}$$

$$Vout = \frac{V_D\cdot(Ton - Tsw) - Ton\cdot(VQ1 - Vin)}{Tsw} \text{ substitute}, Ton = D\cdot Tsw \rightarrow Vout = D\cdot Vin - D\cdot VQ1 - V_D + D\cdot V_D$$

$$Vout = D\cdot Vin - D\cdot VQ1 - V_D + D\cdot V_D$$

$$Vout = D\cdot Vin - D\cdot VQ1 - V_D + D\cdot V_D \text{ solve}, D \rightarrow \frac{Vout + V_D}{Vin - VQ1 + V_D}$$

$$D = \frac{Vout + V_D}{Vin - VQ1 + V_D} \text{ solve}, Vout \rightarrow D\cdot Vin - D\cdot VQ1 - V_D + D\cdot V_D$$

$$di = \int_0^{Ton} \frac{(Vin - VQ1 - Vout)}{L1}\, dt \text{ solve}, di \rightarrow -\frac{Ton\cdot(VQ1 - Vin + Vout)}{L1}$$

$$di = -\frac{Ton\cdot(VQ1 - Vin + Vout)}{L1} \text{ substitute}, Ton = D\cdot T \rightarrow di = -\frac{D\cdot T\cdot(VQ1 - Vin + Vout)}{L1}$$

$$di = -\frac{D\cdot T\cdot(VQ1 - Vin + Vout)}{L1}$$

$$Imin\_RMS = \sqrt{\frac{1}{Tsw}\left(\int_0^{Ton} Imin^2\, dt\right)} \text{ simplify} \rightarrow Imin\_RMS = \sqrt{\frac{Imin^2\cdot Ton}{Tsw}}$$

$$Imin\_RMS = \sqrt{\frac{Imin^2\cdot Ton}{Tsw}} \text{ substitute}, Ton = D\cdot Tsw \rightarrow Imin\_RMS = \sqrt{D\cdot Imin^2}$$

$$\int_{Ton}^{T} \frac{\left(Vout + V_D\right)}{L1}\,dt = \int_{0}^{Ton} \frac{(Vin - VQ1 - Vout)}{L1}\,dt$$

$$\frac{(T - Ton)\cdot\left(Vout + V_D\right)}{L1} = -\frac{Ton\cdot(VQ1 - Vin + Vout)}{L1}$$

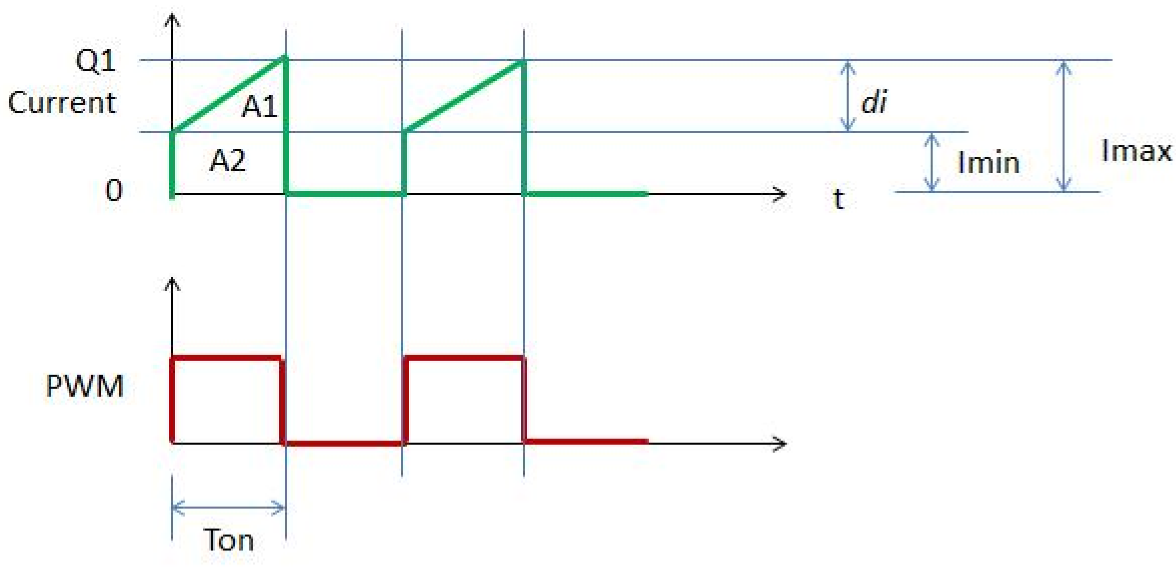
$$(T - Ton)\cdot\left(Vout + V_D\right) = -Ton\cdot(VQ1 - Vin + Vout)$$

$$-T\cdot(D - 1)\cdot\left(Vout + V_D\right) = -D\cdot T\cdot(VQ1 - Vin + Vout)$$

$$-T\cdot(D - 1)\cdot\left(Vout + V_D\right) = -D\cdot T\cdot(VQ1 - Vin + Vout) \text{ solve}, D \rightarrow \frac{Vout + V_D}{Vin - VQ1 + V_D}$$

$$D = \frac{Vout + V_D}{Vin - VQ1 + V_D} \qquad D = \frac{Vout}{Vin}$$

Q1 Current Derivation



The RMS current of the switch is the sum of the RMS of the area A1 and A2. A1 is a triangle while A2 is rectangle.

RMS of Area A1

$$I_{RMS\_A1} = \sqrt{\frac{1}{T}\int_0^{Ton}\left(\frac{di\cdot t}{Ton}\right)^2 dt} \text{ simplify } \rightarrow I_{RMS\_A1} = \frac{\sqrt{\frac{3\cdot Ton\cdot di^2}{T}}}{3}$$

$$I_{RMS\_A1} = \frac{\sqrt{\frac{3\cdot Ton\cdot di^2}{T}}}{3} \text{ substitute}, Ton = D\cdot T \rightarrow I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{D\cdot di^2}}{3}$$

$$I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{D\cdot di^2}}{3}$$

RMS of Area A2

$$I_{RMS\_A1} = di\cdot\sqrt{\frac{D}{3}}$$

$$I_{RMS\_A2} = \sqrt{\frac{1}{T}\int_0^{Ton} Imin^2\, dt} \text{ simplify } \rightarrow I_{RMS\_A2} = \sqrt{\frac{Imin^2\cdot Ton}{T}}$$

$$I_{RMS\_A2} = \sqrt{\frac{Imin^2\cdot Ton}{T}} \text{ substitute}, Ton = D\cdot T \rightarrow I_{RMS\_A2} = \sqrt{D\cdot Imin^2}$$

$$I_{RMS\_A2} = \sqrt{D\cdot Imin^2}$$

$$I_{RMS\_A2} = Imin\cdot\sqrt{D}$$

RMS of the Switch Current

$$I_{RMS\_Q1} = I_{RMS\_A1} + I_{RMS\_A2}$$

$$I_{RMS\_Q1} = di\cdot\sqrt{\frac{D}{3}} + (Imax - di)\cdot\sqrt{D}$$

$$I_{RMS\_Q1} = \sqrt{D}\cdot Imax - \sqrt{D}\cdot di + \frac{\sqrt{3}\cdot\sqrt{D}\cdot di}{3} \text{ solve}, Imax \rightarrow \frac{I_{RMS\_Q1} + \sqrt{D}\cdot di - \frac{\sqrt{3}\cdot\sqrt{D}\cdot di}{3}}{\sqrt{D}}$$

$$Imax = \frac{I_{RMS\_Q1} + \sqrt{D}\cdot di - \frac{\sqrt{3}\cdot\sqrt{D}\cdot di}{3}}{\sqrt{D}} \text{ simplify } \rightarrow Imax = di - \frac{\sqrt{3}\cdot di}{3} + \frac{I_{RMS\_Q1}}{\sqrt{D}}$$

$$Imax = di - \frac{\sqrt{3}\cdot di}{3} + \frac{I_{RMS\_Q1}}{\sqrt{D}}$$

$$I_{RMS\_Q1} = di\cdot\sqrt{\frac{D}{3}} + (Imax - di)\cdot\sqrt{D} \text{ simplify } \rightarrow I_{RMS\_Q1} = \sqrt{D}\cdot\left(Imax - di + \frac{\sqrt{3}\cdot di}{3}\right)$$

$$I_{RMS\_Q1} = di\cdot\sqrt{\frac{D}{3}} + \left(I_{Load} + \frac{di}{2} - di\right)\cdot\sqrt{D} \text{ simplify } \rightarrow I_{RMS\_Q1} = \sqrt{D}\cdot\left(I_{Load} - \frac{di}{2} + \frac{\sqrt{3}\cdot di}{3}\right)$$

Maximum Switch Current

$$Imax = di + Imin$$

Minimum Switch Current

$$Imin = Imax - di$$

Switch Average Current

$$I_{DC\_A1} = \frac{1}{Tsw}\cdot\int_0^{Ton} \frac{di\cdot t}{Ton}\, dt \text{ simplify } \rightarrow I_{DC\_A1} = \frac{Ton\cdot di}{2\cdot Tsw}$$

$$I_{DC\_A1} = \frac{Ton\cdot di}{2\cdot Tsw} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{DC\_A1} = \frac{D\cdot di}{2}$$

$$I_{DC\_A1} = \frac{D\cdot di}{2}$$

$$I_{DC\_A2} = \frac{1}{Tsw}\int_0^{Ton} Imin\,dt \text{ simplify } \rightarrow I_{DC\_A2} = \frac{Imin\cdot Ton}{Tsw}$$

$$I_{DC\_A2} = \frac{Imin\cdot Ton}{Tsw} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{DC\_A2} = D\cdot Imin$$

$$I_{DC\_A2} = D\cdot Imin$$

$$I_{DC\_A2} = D\cdot(Imax - di)$$

$$I_{DC\_total} = \frac{D\cdot di}{2} + D\cdot(Imax - di)$$

$$I_{DC\_total} = I_{DC\_A1} + I_{DC\_A2}$$

$$I_{DC\_total} = \frac{D\cdot di}{2} + D\cdot(Imax - di) \text{ simplify } \rightarrow I_{DC\_total} = -\frac{D\cdot(di - 2\cdot Imax)}{2}$$

$$I_{DC\_total} = -\frac{D\cdot(di - 2\cdot Imax)}{2}$$

$$I_{DC\_total} = \frac{D\cdot(2\cdot Imax - di)}{2}$$

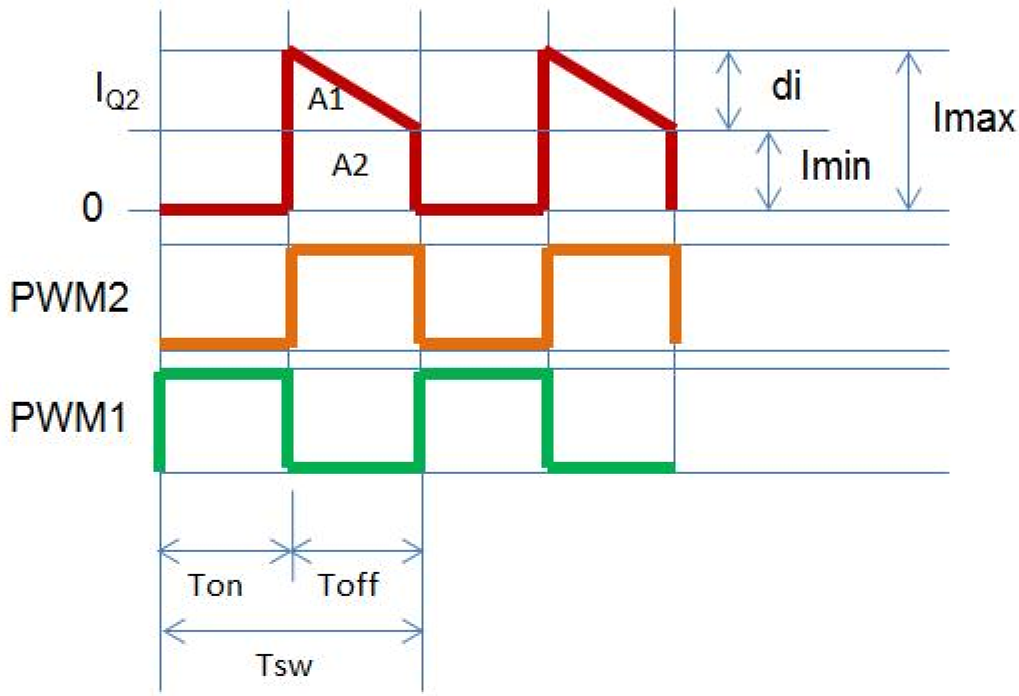
$$Imax = I_{load} + di - \frac{D\cdot di}{2}$$

from inductor current derivation

$$I_{DC\_total} = -\frac{D\cdot\left[di - 2\cdot\left(I_{load} + di - \frac{D\cdot di}{2}\right)\right]}{2} \text{ simplify } \rightarrow I_{DC\_total} = \frac{D\cdot\left(2\cdot I_{load} + di - D\cdot di\right)}{2}$$

$$I_{DC\_total} = \frac{D\cdot\left(2\cdot I_{load} + di - D\cdot di\right)}{2}$$

Q2 Current Derivation



Q2 RMS Current

Q2 will conduct only at Toff.

$$I_{RMS\_A1} = \sqrt{\frac{1}{Tsw}\cdot\int_{Ton}^{Tsw}\left(\frac{t-Ton}{Toff}\right)^2\cdot di^2\,dt} \text{ simplify } \rightarrow I_{RMS\_A1} = \frac{\sqrt{-\frac{3\cdot di^2\cdot(Ton-Tsw)^3}{Tsw\cdot Toff^2}}}{3}$$

$$I_{RMS\_A1} = \frac{\sqrt{\frac{3\cdot di^2\cdot(Tsw-Ton)^3}{Tsw\cdot Toff^2}}}{3} \text{ substitute}, Toff = Tsw - Ton \rightarrow I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{-\frac{di^2\cdot(Ton-Tsw)}{Tsw}}}{3}$$

$$I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{\frac{di^2\cdot(Tsw-Ton)}{Tsw}}}{3} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{-di^2\cdot(D-1)}}{3}$$

$$I_{RMS\_A1} = \frac{\sqrt{3}\cdot\sqrt{-di^{2}\cdot(D-1)}}{3}$$

$$I_{RMS\_A1} = di\cdot\sqrt{\frac{1-D}{3}}$$

$$I_{RMS\_A2} = \sqrt{\frac{1}{Tsw}\cdot\int_{Ton}^{Tsw} Imin^2\, dt} \text{ simplify } \rightarrow I_{RMS\_A2} = \sqrt{-\frac{Imin^2\cdot(Ton - Tsw)}{Tsw}}$$

$$I_{RMS\_A2} = \sqrt{-\frac{Imin^2\cdot(Ton - Tsw)}{Tsw}} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{RMS\_A2} = \sqrt{-Imin^2\cdot(D-1)}$$

$$I_{RMS\_A2} = Imin\cdot\sqrt{(1-D)}$$

$$I_{RMS\_Q2} = I_{RMS\_A1} + I_{RMS\_A2}$$

$$I_{RMS\_Q2} = di\cdot\sqrt{\frac{1-D}{3}} + (Imax - di)\cdot\sqrt{1-D}$$

$$Imax\_Q2 = I_{RMS\_Q2} + di\cdot\left(1 - \sqrt{\frac{1-D}{3}}\right)$$

$$I_{RMS\_Q2} = \sqrt{1-D}\cdot\left(Imax - di + \frac{\sqrt{3}\cdot di}{3}\right)$$

Q2 DC Current

$$I_{DC\_A1} = \frac{1}{Tsw}\cdot\int_{Ton}^{Tsw}\left(\frac{t - Ton}{Toff}\right)\cdot di\, dt \text{ simplify } \rightarrow I_{DC\_A1} = \frac{di\cdot(Ton - Tsw)^2}{2\cdot Tsw\cdot Toff}$$

$$I_{DC\_A1} = \frac{di\cdot(Tsw - Ton)^2}{2\cdot Tsw\cdot Toff} \text{ substitute}, Toff = Tsw - Ton \rightarrow I_{DC\_A1} = -\frac{Ton\cdot di - Tsw\cdot di}{2\cdot Tsw}$$

$$I_{DC\_A1} = \frac{Tsw\cdot di - Ton\cdot di}{2\cdot Tsw} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{DC\_A1} = -\frac{di\cdot(D-1)}{2}$$

$$I_{DC\_A1} = -\frac{di\cdot(D-1)}{2}$$

$$I_{DC\_A1} = \frac{di\cdot(1-D)}{2}$$

$$I_{DC\_A2} = \frac{1}{Tsw}\cdot\int_{Ton}^{Tsw} Imin\,dt \text{ simplify } \rightarrow I_{DC\_A2} = -\frac{Imin\cdot(Ton-Tsw)}{Tsw}$$

$$I_{DC\_A2} = -\frac{Imin\cdot(Ton-Tsw)}{Tsw} \text{ substitute}, Ton = D\cdot Tsw \rightarrow I_{DC\_A2} = -Imin\cdot(D-1)$$

$$I_{DC\_A2} = Imin\cdot(1-D)$$

$$I_{DC\_A2} = (Imax-di)\cdot(1-D)$$

$$I_{DC\_Q2} = \frac{di\cdot(1-D)}{2} + (Imax-di)\cdot(1-D)$$

MOSFETs Drain-Source Voltage

$$VQ1\_Vinmax = Vin\_max$$

$$VQ1\_Vinmin = Vin\_min$$

$$VQ2\_Vinmax = Vin\_max$$

$$VQ2\_Vinmin = Vin\_min$$

Calculations with Values

This section computes the currents of Q1, Q2 and L1. The resulting currents are total currents on the individual location. For instance, there are more than one MOSFETs used the Q1 slot, the current will be divided to how many MOSFETs on this slot.

Given Values

The maximum input power is 400W. The target efficiency is 95%. So, the output power will be

$Pin := 400W$

$Eff := 95\%$

$Pout := Pin \cdot Eff$

$Pout = 380\ W$

With a 1 ohm resitor, the equivalent load current and voltage will be

$RLoad := 1\Omega$ Given load resistance used in the evaluation

$$I\_Load := \sqrt{\frac{Pout}{RLoad}}$$

$I\_Load = 19.494\ A$ This is the computed load current

The output voltage is therefore

$Vout := I\_Load \cdot RLoad$

$Vout = 19.494\ V$ This is the coputed output voltage of the converter

$Vin\_max := 100V$ This is the maximum input voltage

$Vin\_min := 60V$ Minimum input voltage

$Fsw := 140kHz$ Switching frequency of operation

$L1 := 10\mu H$ Selected inductance value

$Cout := 880\mu F$ Minimum output capacitance used

$VQ1 := 0.2V$

$VQ2 := 0.2V$

VQ1 and VQ2, approximated individual voltage drop of MOSFET in Q1 and Q2 slots

Equations Used

Maximum Input Voltage

$$Tsw := \frac{1}{Fsw}$$

$$D\_Vinmax := \frac{Vout + VQ2}{Vin\_max - VQ1 + VQ2}$$

$$di\_Vinmax := -\frac{D\_Vinmax \cdot Tsw \cdot (VQ1 - Vin\_max + Vout)}{L1}$$

$$Imax\_Vinmax := I\_Load + \frac{di\_Vinmax}{2}$$

$$Imin\_Vinmax := Imax\_Vinmax - di\_Vinmax$$

$$I_{DC\_Q2\_Vinmax} := \frac{di\_Vinmax \cdot (1 - D\_Vinmax)}{2} + (Imax\_Vinmax - di\_Vinmax) \cdot (1 - D\_Vinmax)$$

$$I_{RMS\_Q2\_Vinmax} := \sqrt{1 - D\_Vinmax} \cdot \left(Imax\_Vinmax - di\_Vinmax + \frac{\sqrt{3} \cdot di\_Vinmax}{3} \right)$$

$$I_{DC\_Q1\_Vinmax} := \frac{D\_Vinmax \cdot di\_Vinmax}{2} + D\_Vinmax \cdot (Imax\_Vinmax - di\_Vinmax)$$

$$I_{RMS\_Q1\_Vinmax} := di\_Vinmax \cdot \sqrt{\frac{D\_Vinmax}{3}} + (Imax\_Vinmax - di\_Vinmax) \cdot \sqrt{D\_Vinmax}$$

$$I_{RMS\_L1\_Vinmax} := \frac{di\_Vinmax}{\sqrt{3}} + Imax\_Vinmax - di\_Vinmax$$

$$Vripple\_Vinmax := di\_Vinmax \cdot \frac{\frac{1}{Fsw}}{Cout}$$

$$OperationMode\_Vinmax := \begin{cases} \text{"CCM"} & \text{if } Imin\_Vinmax > 0 \\ \text{"Boundary"} & \text{if } Imin\_Vinmax = 0 \\ \text{""DCM"} & \text{otherwise} \end{cases}$$

$$Irip\_outcap\_Vinmax := \sqrt{{I_{RMS\_L1\_Vinmax}}^2 - I\_Load^2}$$

Minimum Input Voltage

$$D\_Vinmin := \frac{Vout + VQ2}{Vin\_min - VQ1 + VQ2}$$

$$di\_Vinmin := -\frac{D\_Vinmin \cdot Tsw \cdot (VQ1 - Vin\_min + Vout)}{L1}$$

$$Imax\_Vinmin := I\_Load + \frac{di\_Vinmin}{2}$$

$$Imin\_Vinmin := Imax\_Vinmin - di\_Vinmin$$

$$I_{DC\_Q2\_Vinmin} := \frac{di\_Vinmin \cdot (1 - D\_Vinmin)}{2} + (Imax\_Vinmin - di\_Vinmin) \cdot (1 - D\_Vinmin)$$

$$I_{RMS\_Q2\_Vinmin} := \sqrt{1 - D\_Vinmin} \cdot \left(Imax\_Vinmin - di\_Vinmin + \frac{\sqrt{3} \cdot di\_Vinmin}{3} \right)$$

$$I_{DC\_Q1\_Vinmin} := \frac{D\_Vinmin \cdot di\_Vinmin}{2} + D\_Vinmin \cdot (Imax\_Vinmin - di\_Vinmin)$$

$$I_{RMS\_Q1\_Vinmin} := di\_Vinmin \cdot \sqrt{\frac{D\_Vinmin}{3}} + (Imax\_Vinmin - di\_Vinmin) \cdot \sqrt{D\_Vinmin}$$

$$I_{RMS\_L1\_Vinmin} := \frac{di\_Vinmin}{\sqrt{3}} + Imax\_Vinmin - di\_Vinmin$$

$$Vripple\_Vinmin := di\_Vinmin \cdot \frac{\frac{1}{Fsw}}{Cout}$$

$$OperationMode\_Vinmin := \begin{cases} \text{"CCM"} & \text{if } Imin\_Vinmin > 0 \\ \text{"Boundary"} & \text{if } Imin\_Vinmin = 0 \\ \text{""DCM"} & \text{otherwise} \end{cases}$$

$$VQ1\_Vinmax := Vin\_max$$

$$VQ1\_Vinmin := Vin\_min$$

$$VQ2\_Vinmax := Vin\_max$$

$$VQ2\_Vinmin := Vin\_min$$

$$Irip\_outcap\_Vinmin := \sqrt{{I_{RMS\_L1\_Vinmin}}^2 - I\_Load^2}$$

Computed Results

Maximum Input Voltage

OperationMode_Vinmax = "CCM"

Tsw = 7.143·µs

D_Vinmax = 19.694·% — Duty cycle

di_Vinmax = 11.297·A — Inductor ripple current

Imin_Vinmax = 13.845·A — Minimum inductor current

Imax_Vinmax = 25.142 A — Repetitive peak current of inductor, diode and switch/controller

$I_{DC\_Q2\_Vinmax}$ = 15.655 A — diode DC current

$I_{RMS\_Q2\_Vinmax}$ = 18.252 A — RMS current of the diode

$I_{DC\_Q1\_Vinmax}$ = 3.839 A — Switch DC current

$I_{RMS\_Q1\_Vinmax}$ = 9.039 A — RMS current of the switch/controller

$I_{RMS\_L1\_Vinmax}$ = 20.367 A — Inductor RMS current

Vripple_Vinmax = 91.693·mV — Output ripple voltage

Irip_outcap_Vinmax = 5.902 A — This is the total ripple current on the output capacitors. This will be divided by the number of output capacitor used.

Minimum Input Voltage

OperationMode_Vinmin = "CCM"

Tsw = 7.143·µs

D_Vinmin = 32.823·% — Duty cycle

di_Vinmin = 9.45·A — Inductor ripple current

Imin_Vinmin = 14.769·A — Minimum inductor current

Imax_Vinmin = 24.218 A — Repetitive peak current of inductor, diode and switch/controller

$I_{DC\_Q2\_Vinmin}$ = 13.095 A — diode DC current

$I_{RMS\_Q2\_Vinmin}$ = 16.576 A — RMS current of the diode

$I_{DC\_Q1\_Vinmin}$ = 6.398 A — Switch DC current

$I_{RMS\_Q1\_Vinmin}$ = 11.587 A — RMS current of the switch/controller

$I_{RMS\_L1\_Vinmin}$ = 20.225 A — Inductor RMS current

Vripple_Vinmin = 0.077·V — Output ripple voltage

Irip_outcap_Vinmin = 5.388 A — This is the total ripple current on the output capacitors. This will be divided by the number of output capacitor used.

Component Selection

For better matching, the upper and lower MOSFET must be of the same type. Below computations are individual losses in each MOSFET used in the Q1 and Q2 slots.

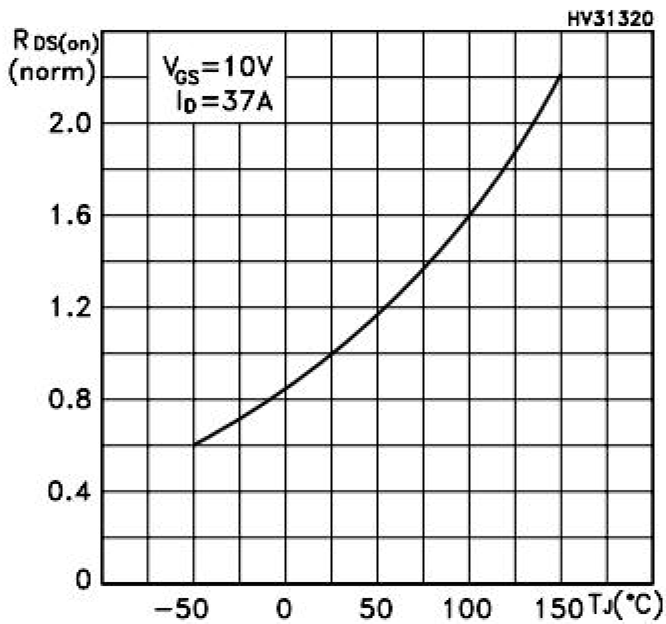
Q1 and Q2 Slot

1. The maximum voltage at least typical without considering the ringing for Q1 and Q2 slots is 100V which is the maximum input voltage. Based on experienced, ringing is can be as high as 70%, so a 200V MOSFET is a good choice.
2. The MOSFET RDSon should be minimum so that the efficiency target of 95% is attainable
3. The dynamic paramers are must be small as well for efficiency reason

MOSFET Parameters (From the Datasheet)

$RDSon := 0.034\Omega$ — This is the drain to source on state resistance of the MOSFET. Multiplied this witht the normalized value if only typical is provided.

$RDSon\_norm := 1.6$ — This is the normalized RDSon of the MOSFET. Use the value at 100'C.



$Qgtotal := 84nC$ — Maximum total gate charge of the MOSFET

Table 5. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$g_{fs}^{(1)}$	Forward transconductance	V_{DS} = 15V, I_D= 37A		40		S
C_{iss} C_{oss} C_{rss}	Input capacitance Output capacitance Reverse Transfer Capacitance	V_{DS} = 25V, f = 1 MHz, V_{GS} =0		3260 640 110		pF pF pF
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	V_{DD}= 160V, I_D=75A, V_{GS}= 10V *(see Figure 16)*		84 18 34		nC nC nC

Coss := 640pF Output capacitance of the MOSFET

Table 5. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$g_{fs}^{(1)}$	Forward transconductance	V_{DS} = 15V, I_D= 37A		40		S
C_{iss} C_{oss} C_{rss}	Input capacitance Output capacitance Reverse Transfer Capacitance	V_{DS} = 25V, f = 1 MHz, V_{GS} =0		3260 640 110		pF pF pF
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	V_{DD}= 160V, I_D=75A, V_{GS}= 10V *(see Figure 16)*		84 18 34		nC nC nC

Vdrive := 10V Drive voltage applied to the MOSFET gate. This is the regulation of the small buck converter.

trise := 33ns Rise time of the MOSFET

tfall := 29ns Fall time of the MOSFET

Table 6. Switching times

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$	Turn-on delay time	V_{DD} = 100V, I_D = 37A R_G= 4.7Ω, V_{GS}= 10V, *(see Figure 15)*		53		ns
t_r	Rise time			33		ns
$t_{d(off)}$	Turn-off delay time			75		ns
t_f	Fall time			29		ns

Inductor Parameter

In selecting inductors, the RMS and peak current are useful parameters. Select and inductor that has higher RMS current rating than the computed RMS current above. The saturation current of the inductor must be higher than the peak or maximum current computed above.

$RDC := 0.00286\Omega$ maximum DC resistance of the inductor

Part number[1]	Inductance[2] ±10% (µH)	DCR[3] (mOhms)		SRF typ[4] (MHz)	Isat (A)[5]			Irms (A)[6]	
		nom	max		10% drop	20% drop	30% drop	20°C rise	40°C rise
SER2915L-152KL	1.5	1.50	1.65	60	100	>100	>100	20	30
SER2915H-222KL	2.2	1.86	2.05	40	100	>100	>100	20	30
SER2915L-222KL	2.2	1.50	1.65	50	82.0	84.0	84.8	20	30
SER2918H-332KL	3.3	2.60	2.86	40	91.0	92.5	93.6	20	28
SER2915H-332KL	3.3	1.86	2.05	30	62.0	66.9	68.4	20	30
SER2915L-332KL	3.3	1.50	1.65	40	48.0	54.0	57.0	20	30
SER2918H-472KL	4.7	2.60	2.86	30	59.0	61.2	62.4	20	28
SER2915H-472KL	4.7	1.86	2.05	25	42.0	48.0	50.1	20	30
SER2915L-472KL	4.7	1.50	1.65	30	33.0	36.9	39.0	20	30
SER2918H-682KL	6.8	2.60	2.86	25	42.0	45.0	45.9	20	28
SER2915H-682KL	6.8	1.86	2.05	20	30.0	34.5	36.2	20	30
SER2915L-682KL	6.8	1.50	1.65	25	22.0	26.0	27.8	20	30
SER2918H-103KL	10	2.60	2.86	20	28.0	31.2	32.1	20	28
SER2915H-103KL	10	1.86	2.05	15	18.0	21.5	23.4	20	30
SER2915L-103KL	10	1.50	1.65	20	13.0	16.2	17.6	20	30
SER2918H-153KL	15	2.60	2.86	16	18.0	21.2	21.9	20	28
SER2915H-153KL	15	1.86	2.05	12	11.5	14.0	15.2	20	30
SER2915L-153KL	15	1.50	1.65	15	7.5	9.8	11.0	20	30
SER2918H-223KL	22	2.60	2.86	15	12.0	14.0	15.0	20	28
SER2915H-223KL	22	1.86	2.05	10	7.0	8.6	9.6	20	30
SER2915L-223KL	22	1.50	1.65	10	4.5	6.0	6.8	20	30
SER2918H-333KL	33	2.60	2.86	10	7.0	8.7	9.6	20	28
SER2915H-333KL	33	1.86	2.05	8	4.0	5.1	5.9	20	30
SER2915L-333KL	33	1.50	1.65	7	2.0	2.6	3.3	20	30

Output Capacitor Stress

In selecting output capacitors, the ripple current and voltage must be considered. The computed ripple current above is the total ripple current. That will be divided by the number of parallel output capacitors used.

$Cout\_parallel := 4$

$Iripple\_capability := 1.6A$

$$Ioutcap\_Vinmax\_stress := \frac{\dfrac{Irip\_outcap\_Vinmax}{Cout\_parallel}}{Iripple\_capability}$$

$Ioutcap\_Vinmax\_stress = 92.214 \cdot \%$

$$Ioutcap\_Vinmin\_stress := \frac{\dfrac{Irip\_outcap\_Vinmin}{Cout\_parallel}}{Iripple\_capability}$$

$Ioutcap\_Vinmin\_stress = 84.189 \cdot \%$

MOSFET Power Loss and Stress Calculation

Q1 MOSFET

Maximum Input Voltage

$Q1\_parallel := 2$

This is the numbe of MOSFETs used in the Q1 slot. If only one MOSFET is used, put here 1.

$$Idrain\_Q1\_Vinmax := \frac{I_{RMS\_Q1\_Vinmax}}{Q1\_parallel}$$

This is the computed drain current from above derivations. If you are going to use several MOSFETs in Q1 slot, divide this by the number of MOSFETs you use.

$Idrain\_Q1\_Vinmax = 4.519\,A$

$$Pconduction\_Q1\_Vinmax := Idrain\_Q1\_Vinmax^2 \cdot RDSon \cdot RDSon\_norm$$

$Pconduction\_Q1\_Vinmax = 1.111\,W$

This is the individual conduction loss or the RDSon loss of the MOSFETs in Q1 slot

$$Ploss\_Qgtotal\_Q1\_Vinmax := \frac{1}{2} Qgtotal \cdot Vdrive \cdot Fsw$$

$Ploss\_Qgtotal\_Q1\_Vinmax = 0.059\,W$

This is the loss on individual MOSFETs on Q1 slot due to the total gate charge

$$Ploss\_Coss\_Q1\_Vinmax := \frac{1}{2} \cdot Coss \cdot VQ1\_Vinmax^2 \cdot Fsw$$

$Ploss\_Coss\_Q1\_Vinmax = 0.448\,W$

This is the individual loss on the MOSFETs in Q1 slot due to output capacitance

$$Ploss\_trise\_tfall\_Q1\_Vinmax := \frac{1}{2} \cdot (trise + tfall) \cdot Idrain\_Q1\_Vinmax \cdot Vdrive \cdot Fsw$$

$Ploss\_trise\_tfall\_Q1\_Vinmax = 0.196\,W$

This is the individual loss on the MOSFETs in the Q1 slot due to the rise and fall time delays

$$Ploss\_total\_Q1\_Vinmax := Pconduction\_Q1\_Vinmax + Ploss\_Qgtotal\_Q1\_Vinmax \ldots + Ploss\_Coss\_Q1\_Vinmax + Ploss\_trise\_tfall\_Q1\_Vinmax$$

$Ploss\_total\_Q1\_Vinmax = 1.814\,W$

This is the total power loss or power dissipation of each MOSFETs in the Q1 slot.

Minimum Input Voltage

$$Idrain\_Q1\_Vinmin := \frac{I_{RMS\_Q1\_Vinmin}}{Q1\_parallel}$$

This is the computed drain current from above derivations. If you are going to use several MOSFETs in Q1 slot, divide this by the number of MOSFETs you use.

$Idrain\_Q1\_Vinmin = 5.793\,A$

$$Pconduction\_Q1\_Vinmin := Idrain\_Q1\_Vinmin^2 \cdot RDSon \cdot RDSon\_norm$$

$Pconduction\_Q1\_Vinmin = 1.826\,W$

This is the individual conduction loss or the RDSon loss of the MOSFETs in Q1 slot

$$Ploss\_Qgtotal\_Q1\_Vinmin := \frac{1}{2} Qgtotal \cdot Vdrive \cdot Fsw$$

$Ploss\_Qgtotal\_Q1\_Vinmin = 0.059\,W$

This is the loss on individual MOSFETs on Q1 slot due to the total gate charge

$$Ploss\_Coss\_Q1\_Vinmin := \frac{1}{2} \cdot Coss \cdot VQ1\_Vinmin^{2} \cdot Fsw$$

$Ploss\_Coss\_Q1\_Vinmin = 0.161\,W$

This is the individual loss on the MOSFETs in Q1 slot due to output capacitance

$$Ploss\_trise\_tfall\_Q1\_Vinmin := \frac{1}{2} \cdot (trise + tfall) \cdot Idrain\_Q1\_Vinmin \cdot Vdrive \cdot Fsw$$

$Ploss\_trise\_tfall\_Q1\_Vinmin = 0.251\,W$

This is the individual loss on the MOSFETs in the Q1 slot due to the rise and fall time delays

$$Ploss\_total\_Q1\_Vinmin := Pconduction\_Q1\_Vinmin + Ploss\_Qgtotal\_Q1\_Vinmin \ldots + Ploss\_Coss\_Q1\_Vinmin + Ploss\_trise\_tfall\_Q1\_Vinmin$$

$Ploss\_total\_Q1\_Vinmin = 2.297\,W$

This is the total power loss or power dissipation of each MOSFETs in the Q1 slot.

Q2 MOSFET

Maximum Input Voltage

$Q2\_parallel := 3$

This is the numbe of MOSFETs used in the Q1 slot. If only one MOSFET is used, put here 1.

$$Idrain\_Q2\_Vinmax := \frac{I_{RMS\_Q2\_Vinmax}}{Q2\_parallel}$$

This is the computed drain current from above derivations. If you are going to use several MOSFETs in Q1 slot, divide this by the number of MOSFETs you use.

$Idrain\_Q2\_Vinmax = 6.084\,A$

$$Pconduction\_Q2\_Vinmax := Idrain\_Q2\_Vinmax^{2} \cdot RDSon \cdot RDSon\_norm$$

$Pconduction\_Q2\_Vinmax = 2.014\,W$

This is the individual conduction loss or the RDSon loss of the MOSFETs in Q1 slot

$$Ploss\_Qgtotal\_Q2\_Vinmax := \frac{1}{2} Qgtotal \cdot Vdrive \cdot Fsw$$

$Ploss\_Qgtotal\_Q2\_Vinmax = 0.059\,W$

This is the loss on individual MOSFETs on Q1 slot due to the total gate charge

$$\text{Ploss\_Coss\_Q2\_Vinmax} := \frac{1}{2}\cdot\text{Coss}\cdot\text{VQ2\_Vinmax}^2\cdot\text{Fsw}$$

$\text{Ploss\_Coss\_Q2\_Vinmax} = 0.448\,\text{W}$

This is the individual loss on the MOSFETs in Q1 slot due to output capacitance

$$\text{Ploss\_trise\_tfall\_Q2\_Vinmax} := \frac{1}{2}\cdot(\text{trise} + \text{tfall})\cdot\text{Idrain\_Q2\_Vinmax}\cdot\text{Vdrive}\cdot\text{Fsw}$$

$\text{Ploss\_trise\_tfall\_Q2\_Vinmax} = 0.264\,\text{W}$

This is the individual loss on the MOSFETs in the Q1 slot due to the rise and fall time delays

$$\text{Ploss\_total\_Q2\_Vinmax} := \text{Pconduction\_Q2\_Vinmax} + \text{Ploss\_Qgtotal\_Q2\_Vinmax} \ldots + \text{Ploss\_Coss\_Q2\_Vinmax} + \text{Ploss\_trise\_tfall\_Q2\_Vinmax}$$

$\text{Ploss\_total\_Q2\_Vinmax} = 2.784\,\text{W}$

This is the total power loss or power dissipation of each MOSFETs in the Q1 slot.

Minimum Input Voltage

$$\text{Idrain\_Q2\_Vinmin} := \frac{I_{\text{RMS\_Q2\_Vinmin}}}{\text{Q2\_parallel}}$$

This is the computed drain current from above derivations. If you are going to use several MOSFETs in Q1 slot, divide this by the number of MOSFETs you use.

$\text{Idrain\_Q2\_Vinmin} = 5.525\,\text{A}$

$$\text{Pconduction\_Q2\_Vinmin} := \text{Idrain\_Q2\_Vinmin}^2\cdot\text{RDSon}\cdot\text{RDSon\_norm}$$

$\text{Pconduction\_Q2\_Vinmin} = 1.661\,\text{W}$

This is the individual conduction loss or the RDSon loss of the MOSFETs in Q1 slot

$$\text{Ploss\_Qgtotal\_Q2\_Vinmin} := \frac{1}{2}\text{Qgtotal}\cdot\text{Vdrive}\cdot\text{Fsw}$$

$\text{Ploss\_Qgtotal\_Q2\_Vinmin} = 0.059\,\text{W}$

This is the loss on individual MOSFETs on Q1 slot due to the total gate charge

$$Ploss\_Coss\_Q2\_Vinmin := \frac{1}{2} \cdot Coss \cdot VQ2\_Vinmin^2 \cdot Fsw$$

$Ploss\_Coss\_Q2\_Vinmin = 0.161\,W$

This is the individual loss on the MOSFETs in Q1 slot due to output capacitance

$$Ploss\_trise\_tfall\_Q2\_Vinmin := \frac{1}{2} \cdot (trise + tfall) \cdot Idrain\_Q2\_Vinmin \cdot Vdrive \cdot Fsw$$

$Ploss\_trise\_tfall\_Q2\_Vinmin = 0.24\,W$

This is the individual loss on the MOSFETs in the Q1 slot due to the rise and fall time delays

$$Ploss\_total\_Q2\_Vinmin := Pconduction\_Q2\_Vinmin + Ploss\_Qgtotal\_Q2\_Vinmin \ldots + Ploss\_Coss\_Q2\_Vinmin + Ploss\_trise\_tfall\_Q2\_Vinmin$$

$Ploss\_total\_Q2\_Vinmin = 2.121\,W$

This is the total power loss or power dissipation of each MOSFETs in the Q1 slot.

Heat Sink Sizing

Equation to Use

$$Pdiss = \frac{Tj\_max - Tcase\_max}{Rthjc + Rthchs}$$

Where ;
Pdiss is the computed power dissipation of the MOSFET
Tj_max is the maximum ambient temperature
Tcase_max is the maximum case temperature setting
Rthjc is the thermal resistance from junction to case
Rthchs is the thermal resistance from case to heat sink

Solve for heat sink thermal resistance

$$Pdiss = \frac{Tj\_max - Tcase\_max}{Rthjc + Rthchs} \text{ solve}, Rthchs \rightarrow \frac{Tj\_max - Tcase\_max}{Pdiss} - Rthjc$$

$Tcase\_max := 100\Delta{}^{\circ}C$

This is a good case temperature regulation for the MOSFETs. Usually MOSFETs are operated with this case temp. Although some cases that MOSFETs are allowwd to go to 120'C, but here let us consider 100'C only for enough margin.

$$Rthjc := 0.66 \frac{\Delta°C}{W}$$

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.50	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	40	

$$Rthchs\_Q1\_Vinmax := -Rthjc - \frac{Tcase\_max - 175 \cdot \Delta°C}{Ploss\_total\_Q1\_Vinmax}$$

$$Rthchs\_Q1\_Vinmax = 40.685 \frac{1}{W} \cdot \Delta°C$$

This should be the maximum thermal resistance of the heat sink for each MOSFET on Q1 slot when maximum input voltage is used

$$Rthchs\_Q1\_Vinmin := -Rthjc - \frac{Tcase\_max - 175 \cdot \Delta°C}{Ploss\_total\_Q1\_Vinmin}$$

$$Rthchs\_Q1\_Vinmin = 31.986 \frac{1}{W} \cdot \Delta°C$$

This should be the maximum thermal resistance of the heat sink for each MOSFET on Q1 slot when minimum input voltage is used

$$Rthchs\_Q2\_Vinmax := -Rthjc - \frac{Tcase\_max - 175 \cdot \Delta°C}{Ploss\_total\_Q2\_Vinmax}$$

$$Rthchs\_Q2\_Vinmax = 26.275 \frac{1}{W} \cdot \Delta°C$$

This should be the maximum thermal resistance of the heat sink for each MOSFET on Q2 slot when maximum input voltage is used

$$Rthchs\_Q2\_Vinmin := -Rthjc - \frac{Tcase\_max - 175 \cdot \Delta°C}{Ploss\_total\_Q2\_Vinmin}$$

$$Rthchs\_Q2\_Vinmin = 34.705 \frac{1}{W} \cdot \Delta°C$$

This should be the maximum thermal resistance of the heat sink for each MOSFET on Q2 slot when minimum input voltage is used

The thermal resistance of the heat sink needed for maximum input voltage and minimum input voltage cannot co-exist. So, need to consider the smallest value. The heat sink to use must have a thermal resistance less than the computed smallest thermal resistance between Vinmax and Vinmin.

The computed minimum thermal resistance is 40.7'C/W. For more margin, we can use a heat sink with thermal resistance below 26 'C/W.

$Rthchs := 8 \frac{\Delta°C}{W}$

This is the target maximum thermal resistance of the heat sink. The lower is the better.

Note: A heat sink with smaller thermal resistance has a larger surface area.

MOSFET Power Capability

In this analysis, the MOSFETs are mounted on aa PCB without using a heat sink. There is a form of heat sink but only limited by the PCB trace/pads. To minimize the thermal resistance from junction to ambient, the pad area must be large enough. This analysis is more applicable to SMD MOSFETs.

$Tj\_max := 150\Delta°C$

This is the maximum junction temperature the MOSFET can operate

$$Pcapability\_MOSFET := \frac{Tj\_max - Tcase\_max}{Rthjc + Rthchs}$$

$Pcapability\_MOSFET = 5.774\,W$

This is the maximum power capability of the selected MOSFET given the above parameters

$$Pstress\_Q1\_Vinmax := \frac{Ploss\_total\_Q1\_Vinmax}{Pcapability\_MOSFET}$$

$Pstress\_Q1\_Vinmax = 31.418 \cdot \%$

This is the power stress of each of the MOSFETs in Q1 slot at maximum input voltage

$$Pstress\_Q1\_Vinmin := \frac{Ploss\_total\_Q1\_Vinmin}{Pcapability\_MOSFET}$$

$Pstress\_Q1\_Vinmin = 39.791 \cdot \%$

This is the power stress of each of the MOSFETs in Q1 slot at minimum input voltage

$$Pstress\_Q2\_Vinmax := \frac{Ploss\_total\_Q2\_Vinmax}{Pcapability\_MOSFET}$$

$Pstress\_Q2\_Vinmax = 48.227 \cdot \%$

This is the power stress of each of the MOSFETs in Q2 slot at maximum input voltage

$$Pstress\_Q2\_Vinmin := \frac{Ploss\_total\_Q2\_Vinmin}{Pcapability\_MOSFET}$$

$Pstress\_Q2\_Vinmin = 36.732 \cdot \%$

This is the power stress of each of the MOSFETs in Q2 slot at minimum input voltage

Inductor Power Loss

Inductor power loss is composed of DC and AC components. DC loss is due to the DC resistance while AC loss is due to the core losses (hysterisis and eddy current loss). In most cases, the DC and AC losses are almost in the same magnitude for switching frequency of 100 kHz to 200kHz so whatever the computed DC loss is can be multiplied by two to get the total loss. A margin is can be added as well.

$$Ploss\_L1\_Vinmax := I_{RMS\_L1\_Vinmax}^{\;2} \cdot RDC$$

$Ploss\_L1\_Vinmax = 1.186\,W$

$$Ploss\_L1\_Vinmin := I_{RMS\_L1\_Vinmin}^{\;2} \cdot RDC$$

$Ploss\_L1\_Vinmin = 1.17\,W$

Total Inductor Loss

$$Ploss\_L1\_Vinmax\_total := 3 \cdot Ploss\_L1\_Vinmax$$

$Ploss\_L1\_Vinmax\_total = 3.559\,W$

In this analysis, the switching frequency is set to 650kHz. It is expected that the AC loss is high, so it is approximated as twice the DC loss.

$$Ploss\_L1\_Vinmin\_total := 3 \cdot Ploss\_L1\_Vinmin$$

$Ploss\_L1\_Vinmin\_total = 3.509\,W$

Efficiency Computations

$$\text{Efficiency} = \frac{\text{Pout}}{\text{Pin}} = \frac{\text{Pout}}{\text{Pout} + \text{Ploss}} = \frac{\text{Pin} - \text{Ploss}}{\text{Pin}}$$

Below equation is to used in the computations of efficiency because the input power is the one being regulated.

$$\text{Efficiency} = \frac{\text{Pin} - \text{Ploss}}{\text{Pin}}$$

$$\text{Ploss\_total\_Vinmax} := \text{Q1\_parallel} \cdot \text{Ploss\_total\_Q1\_Vinmax} + \text{Q2\_parallel} \cdot \text{Ploss\_total\_Q2\_Vinmax} \ldots + \text{Ploss\_L1\_Vinmax\_total}$$

$$\text{Ploss\_total\_Vinmax} = 15.541\ \text{W}$$

$$\text{Ploss\_total\_Vinmin} := \text{Q1\_parallel} \cdot \text{Ploss\_total\_Q1\_Vinmin} + \text{Q2\_parallel} \cdot \text{Ploss\_total\_Q2\_Vinmin} \ldots + \text{Ploss\_L1\_Vinmin\_total}$$

$$\text{Ploss\_total\_Vinmin} = 14.467\ \text{W}$$

$$\text{Efficiency\_Vinmax} := \frac{\text{Pin} - \text{Ploss\_total\_Vinmax}}{\text{Pin}}$$

$\text{Efficiency\_Vinmax} = 96.115 \cdot \%$ This is the efficiency of the power section at max Vin

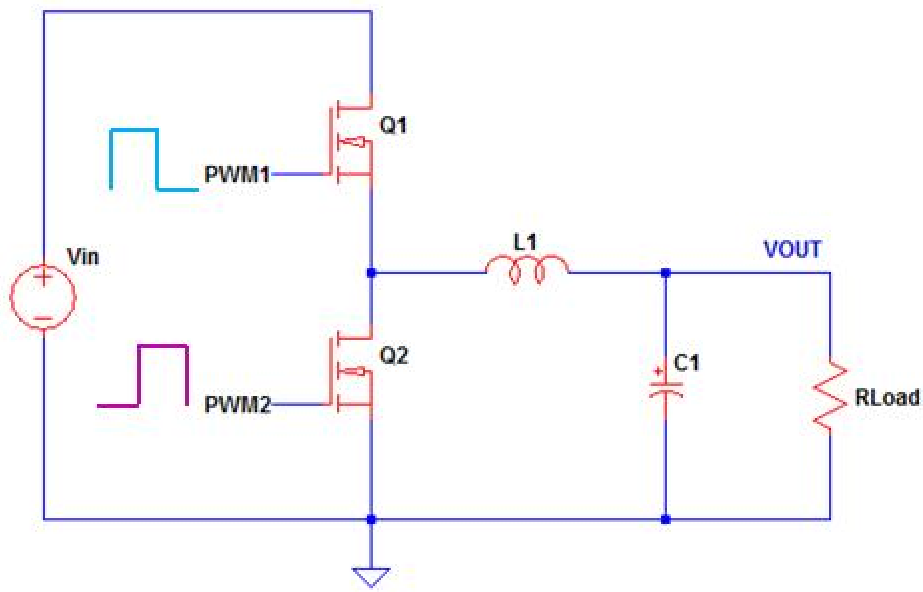
$$\text{Efficiency\_Vinmin} := \frac{\text{Pin} - \text{Ploss\_total\_Vinmin}}{\text{Pin}}$$

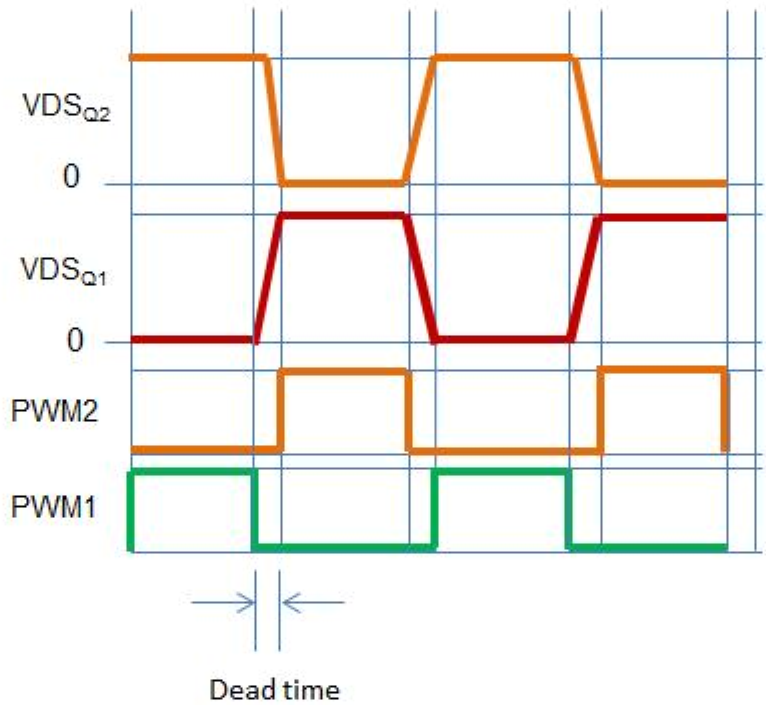
$\text{Efficiency\_Vinmin} = 96.383 \cdot \%$ This is the efficiency of the power section at min Vin

Dead Time Calculation

Q2 Should turn ON only after Q1 is fully turned OFF. The same scenario, Q1 should turn ON only after Q2 is fully turn OFF.

The total turn OFF delay of Q1 will be the sum of controller execution delay (from code to pin realization), driver propagation delay and Ciss discharge plus others as specified in the datasheet.
The total delay to turn OFF Q2 is the same with Q1 considering the same MOSFET to use.





CISS Discharge

$$VGS\_Q1 = VGS\_Q1\_initial \cdot e^{\frac{-tdecay\_Q1gate}{(RgQ1+RgDriver) \cdot CISS\_Q1}}$$

$$tdecay\_Q1gate = -CISS\_Q1 \cdot \ln\left(\frac{VGS\_Q1}{VGS\_Q1\_initial}\right) \cdot (RgQ1 + RgDriver)$$

Where;

VGS_Q1_initial - is the applied VGS when Q1 is running ON
$tdecay\_Q1gate$ - is the time delay when the charge voltage in the CISS is below the minimum VGS threshold of O1
$RgQ1$ - is the gate resistance of Q1. This is the sum of the external gate resistance and the internal. resistance on the IC
$RgDriver$ - gate pull down resistance of the driver
$CISS\_Q1$ - input capacitance of Q1

$VGS\_Q1\_initial := Vdrive$

$CISS\_Q1 := 3260pF$

$Cstray := 10nF$ Estimated stray capacitance

$VGS_{Threshold\_min} := 2V$

$VGS\_Q1 := VGS_{Threshold\_min}$

$RgQ1 := 5\Omega$

$RgDriver := 2.5\Omega$

$$tdecay\_Q1gate := -(CISS\_Q1 + Cstray)\cdot \ln\left(\frac{VGS\_Q1}{VGS\_Q1\_initial}\right)\cdot(RgQ1 + RgDriver)$$

$tdecay\_Q1gate = 160.059\cdot ns$

The MOSFET datasheet specifies a turn off delay. There is no information if this is already convering the CISS discharge, so we just add this to the computed value above.

Total Turn OFF Delay of Q1

$MCUdelay := 100ns$ MCU delay from code to pin realization

$driver\_delay := 45ns$ Driver propagation delay

$toffQ1 := 75ns$ Specified turn off delay of Q1 in the datasheet

$toff\_delay\_Q1\_total := MCUdelay + driver\_delay + tdecay\_Q1gate + toffQ1$

$toff\_delay\_Q1\_total = 380.059\cdot ns$ This is the computed dead time with estimated stray capacitance

Dead Time

$margin := 30\%$

$deadtime := (1 + margin)toff\_delay\_Q1\_total$

$deadtime = 494.076 \cdot ns$

Starting dead time. For verification in actual unit since the stray capacitances are difficult to estimate.