3/11/25 JETSON/ IMX8/ PERIF Calcs.

JETSON Config:

* Each UV/OV Threshold will be the same because each load switch is before each switching regulator

a.) LTC4365: UV/OV Protection

- The $V_{os(uv)}$ is the max voltage deviation that you can get at the output. This is given by the highest leakage current at the $I_{(uv)}$ pin.

1.) Find $R_1 + R_2$

$$R_1 + R_2 = \frac{V_{os(uv)}}{I_{uv}}$$

$$R_1 + R_2 = \frac{3mV}{10nA}$$

$$R_1 + R_2 = 300k$$

Recommended Parameters:

$V_{os(uv)} = 3mV$
$I_{(uv)} = 10nA$

Set by me:

$OV_{TH} = 32V$

$UV_{TH} = 24V$

From LTC 4365 Datasheet (Pg. 11)

Procedure for Selecting UV/OV External Resistor Values

The following 3-step procedure helps select the resistor values for the resistive divider of Figure 4. This procedure minimizes UV and OV offset errors caused by leakage currents at the respective pins.

1. Choose maximum tolerable offset at the UV pin, $V_{OS(UV)}$. Divide by the worst case leakage current at the UV pin, I_{UV} (10nA). Set the sum of R1 + R2 equal to $V_{OS(UV)}$ divided by 10nA. Note that due to the presence of R3, the actual offset at UV will be slightly lower:

$$R1 + R2 = \frac{V_{OS(UV)}}{I_{UV}}$$

2. Select the desired V_{IN} UV trip threshold, UV_{TH}. Find the value of R3:

$$R3 = \frac{V_{OS(UV)}}{I_{UV}} \cdot \left(\frac{UV_{TH} - 0.5V}{0.5V}\right)$$

3. Select the desired V_{IN} OV trip threshold, OV_{TH}. Find the values of R1 and R2:

$$R1 = \frac{\left(\frac{V_{OS(UV)}}{I_{UV}}\right) + R3}{OV_{TH}} \cdot 0.5V$$

$$R2 = \frac{V_{OS(UV)}}{I_{UV}} - R1$$

The example of Figure 4 uses standard 1% resistor values. The following parameters were selected:

$V_{OS(UV)} = 3mV$
$I_{UV} = 10nA$
$UV_{TH} = 5V$
$OV_{TH} = 18V$

2.) Find R_3 using UV trip threshold

$$R_3 = \frac{V_{os(uv)}}{I_{(uv)}} \cdot \left(\frac{UV_{TH} - 0.5v}{0.5v}\right)$$

Let $UV_{TH} = 24V$

$$R_3 = \left(\frac{3mV}{10nA}\right) \cdot \left(\frac{24 - 0.5}{0.5}\right) = 14.1\,M\Omega$$

3.) Find R_1 using OV trip threshold

Let OV = 32v

$$R_1 = \frac{\left(\frac{V_{ov(uv)}}{I(uv)}\right) + R_3}{OV} \cdot 0.5v$$

$$R_1 = \frac{\left(\frac{3mV}{10nA}\right) + 14.1M\Omega}{32} (0.5v) = 225000\,\Omega$$

Let $OV_{TH} = 21v$

$$R_1 \approx 225\,k\Omega$$

4.) Find R_2

$$R_1 + R_2 = 300k$$

$R_1 = 260k$

$R_2 = 300k - 225k$
$R_2 = 75k$

For JETSON Load switch OV/UV

$R_1 = 225\,k\Omega$ $R_2 = 75k$

$R_3 = 300k\Omega$

JETSON Config: (Cont.) Switching Regulator

6.) LT8638SEV: Output Voltage, Default Switching Frequency and choke Inductor selection

FB Resistor Network:

Let $R_2 = 3k\Omega$
$V_{out} = 20v$

$$R_1 = R_2\left(\frac{V_{out}}{0.6v} - 1\right)$$

$$R_1 = 3k\left(\frac{20}{0.6v} - 1\right)$$

$$R_1 = 97000\,\Omega$$

$$R_1 \approx 100k$$

FB Resistor Network for $V_{out} = 20v$

$R_1 = 100k$, $R_2 = 3k$

From LT8638SEV Datasheet (P.g 17)

FB Resistor Network

The output voltage is programmed with a resistor divider between the output and the FB pin. Choose the resistor values according to E1.

$$R1 = R2\left(\frac{V_{OUT}}{0.6V} - 1\right) \quad (1)$$

Reference designators refer to the Block Diagram. 1% resistors are recommended to maintain output voltage accuracy.

When using large FB resistors, a 4.7pF to 47pF phase-lead capacitor should be connected from V_{OUT} to FB.

Default Switching Frequency RT calculations:

$$f_{sw(max)} = \frac{V_{out} + V_{sw}(BOT)}{t_{on(min)}\left(V_{in} - V_{in_{sw(TOP)}} + V_{sw(BOT)}\right)}$$

where V_{in} is the typical input voltage, V_{out} is the output voltage, $V_{sw\,Top} = \sim 0.2v$, $V_{sw\,BOT} = \sim 0.8v$, $t_{on(min)}$ is the minimum top switch on time

internal switch drops at max load

- The higher your switching frequency, the lower your input voltage can be and lower efficiency

Let:

$V_{sw(BOT)} = 0.8v$

$V_{sw}(TOP) = 0.2v$

$V_{out} = 20v$

$t_{on(min)} = 25\,ns$

from electrical characteristics

$$f_{sw(max)} = \frac{20v + 0.8v}{(25\times10^{-9})(28v - 0.2 + 0.8)}$$

$$= 29090909.09\ Hz$$

$$\approx 30\ mHz$$

Super high, so not a huge concern.

Pick avg. value on table,

Switching Frequency @ 400 khz Resistor

400 khz → RT = 105 kΩ

From LT8638SEV Datasheet (Pg. 18)

APPLICATIONS INFORMATION

table showing the necessary R_T value for a desired switching frequency is in Table 1.

The R_T resistor required for a desired switching frequency can be calculated using Equation 2.

$$R_T = \frac{44.8}{f_{SW}} - 5.9 \quad (2)$$

where R_T is in kΩ and f_{SW} is the desired switching frequency in MHz.

Table 1. SW Frequency vs R_T Value

f_{SW} (MHz)	R_T (kΩ)
0.2	226
0.3	143
0.4	105
0.5	82.5
0.6	66.5
0.7	56.2
0.8	48.7
1.0	38.3
1.2	31.6
1.4	26.1
1.6	22.1
1.8	19.1
2.0	16.9
2.2	15.4
3.0	10.5

Operating Frequency Selection and Trade-Offs

Selection of the operating frequency is a trade-off between efficiency, component size, and input voltage range. The advantage of high frequency operation is that smaller inductor and capacitor values may be used. The disadvantages are lower efficiency and a smaller input voltage range.

The highest switching frequency ($f_{SW(MAX)}$) for a given application can be calculated as follows:

$$f_{SW(MAX)} = \frac{V_{OUT} + V_{SW(BOT)}}{t_{ON(MIN)}\left(V_{IN} - V_{SW(TOP)} + V_{SW(BOT)}\right)} \quad (3)$$

where V_{IN} is the typical input voltage, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load) and $t_{ON(MIN)}$ is the minimum top switch on-time (see the Electrical Characteristics). Equation 3 shows that a slower switching frequency is necessary to accommodate a high V_{IN}/V_{OUT} ratio.

For transient operation, V_{IN} may go as high as the absolute maximum rating of 42V regardless of the R_T value, however the LT8638S will reduce switching frequency as necessary to maintain control of inductor current to assure safe operation.

The LT8638S is capable of a maximum duty cycle of approximately 99%, and the V_{IN}-to-V_{OUT} dropout is limited by the $R_{DS(ON)}$ of the top switch. In this mode the LT8638S skips switch cycles, resulting in a lower switching frequency than programmed by RT.

For applications that cannot allow deviation from the programmed switching frequency at low V_{IN}/V_{OUT} ratios use Equation 4 to set switching frequency.

$$V_{IN(MIN)} = \frac{V_{OUT} + V_{SW(BOT)}}{1 - f_{SW} \bullet t_{OFF(MIN)}} - V_{SW(BOT)} + V_{SW(TOP)} \quad (4)$$

where $V_{IN(MIN)}$ is the minimum input voltage without skipped cycles, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load), f_{SW} is the switching frequency (set by R_T), and $t_{OFF(MIN)}$ is the minimum switch off-time. Note that higher switching frequency will increase the minimum input voltage below which cycles will be dropped to achieve higher duty cycle.

JETSON CONFIG: (cont.)

Inductor Selection and Maximum Output Current:

Due to power requirements, $I_{Load\,max} \approx 8A$

1.) First Find L_{min} due to $\frac{V_o}{V_{in}} \geq 0.5$

$$\frac{V_o}{V_{min}} > 0.5 \qquad f_{sw} = 400\,kHz$$

$$L_{min} = \frac{V_{in}\left(2 \cdot \frac{V_o}{V_{in}} - 1\right)}{5 \cdot f_{sw}}$$

$$L_{min} = \frac{28\left(\left(2 \cdot \frac{20}{28}\right) - 1\right)}{5 \cdot 4\,000\,000}$$

$$= 6 \times 10^{-6} = 6\,\mu H$$

2.) Find the Peak-to-Peak ripple current

$$\Delta I_L = \frac{V_{out}}{L \cdot f_{sw}} \cdot \left(1 - \frac{V_{out}}{V_{in(max)}}\right)$$

$$\Delta I_L = \left(\frac{20}{(6 \times 10^{-6})(400000)}\right)\left(1 - \frac{20v}{28v}\right)$$

$$\Delta I_L = 2.38095\,A$$

3.) Calculate $I_{out(max)}$

Duty Cycle Ratio

$DC = 0.714$

so $I_L \approx 15A$ at $DC \approx 0.8$

$$I_{out\,max} = I_{Lim} - \frac{|\Delta_L|}{2}$$

* $I_{out(max)}$ is max output current

$$I_{out\,max} = 15A - \frac{2.38095A}{2} = 13.809525\,A$$

same

4.) Find $I_{L(max)}$ to pick inductor with high enough RMS

$$I_{L(peak)} = I_{load(max)} + \frac{1}{2}\Delta I_L \qquad I_{Load(max)} = 13.809525\,A$$

$$I_{L(peak)} = 13.809525 + \frac{1}{2}(2.38095) \qquad \Delta I_L = 2.38095\,A$$

$$I_{L(peak)} = 15A$$

LT8638SEV Datasheet (P.g. 19)

Inductor Selection and Maximum Output Current

The LT8638S is designed to minimize solution size by allowing the inductor to be chosen based on the output load requirements of the application. During overload or short-circuit conditions the LT8638S safely tolerates operation with a saturated inductor through the use of a high speed peak-current mode architecture.

A good first choice for the inductor value is given by Equation 5.

$$L = \left(\frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}}\right) \bullet 0.2 \qquad (5)$$

Rev. A

where f_{SW} is the switching frequency in MHz, V_{OUT} is the output voltage, $V_{SW(BOT)}$ is the bottom switch drop (~0.08V) and L is the inductor value in µH.

To avoid overheating and poor efficiency, an inductor must be chosen with an RMS current rating that is greater than the maximum expected output load of the application. In addition, the saturation current (typically labeled I_{SAT}) rating of the inductor must be higher than the load current plus 1/2 of in inductor ripple current (Equation 6)

$$I_{L(PEAK)} = I_{LOAD(MAX)} + \frac{1}{2}\Delta I_L \qquad (6)$$

where ΔI_L is the inductor ripple current as calculated in Equation 8 and $I_{LOAD(MAX)}$ is the maximum output load for a given application.

As a quick example, an application requiring 3A output should use an inductor with an RMS rating of greater than 3A and an I_{SAT} of greater than 4A. During long duration overload or short-circuit conditions, the inductor RMS rating requirement is greater to avoid overheating of the inductor. To keep the efficiency high, the series resistance (DCR) should be less than 8mΩ, and the core material should be intended for high frequency applications.

The LT8638S limits the peak switch current in order to protect the switches and the system from overload faults. The top switch current limit (I_{LIM}) is 20A at low duty cycles and decreases linearly to 15A at DC = 0.8. The inductor value must then be sufficient to supply the desired maximum output current ($I_{OUT(MAX)}$), which is a function of the switch current limit (I_{LIM}) and the ripple current (Equation 7).

$$I_{OUT(MAX)} = I_{LIM} - \frac{\Delta I_L}{2} \qquad (7)$$

The peak-to-peak ripple current in the inductor can be calculated using Equation 8.

$$\Delta I_L = \frac{V_{OUT}}{L \bullet f_{SW}} \bullet \left(1 - \frac{V_{OUT}}{V_{IN(MAX)}}\right) \qquad (8)$$

where f_{SW} is the switching frequency of the LT8638S, and L is the value of the inductor. Therefore, the maximum output current that the LT8638S will deliver depends on the switch current limit, the inductor value, and the input and output voltages. The inductor value may have to be increased if the inductor ripple current does not allow sufficient maximum output current ($I_{OUT(MAX)}$) given the switching frequency, and maximum input voltage used in the desired application.

In order to achieve higher light load efficiency, more energy must be delivered to the output during the single small pulses in Burst Mode operation such that the LT8638S can stay in sleep mode longer between each pulse. This can be achieved by using a larger value inductor (i.e., 4.7µH), and should be considered independent of switching frequency when choosing an inductor. For example, while a lower inductor value would typically be used for a high switching frequency application, if high light load efficiency is desired, a higher inductor value should be chosen. See curve in Typical Performance Characteristics.

The optimum inductor for a given application may differ from the one indicated by this design guide. A larger value inductor provides a higher maximum load current and reduces the output voltage ripple. For applications requiring smaller load currents, the value of the inductor may be lower and the LT8638S may operate with higher ripple current. This allows use of a physically smaller inductor, or one with a lower DCR resulting in higher efficiency. Be aware that low inductance may result in discontinuous mode operation, which further reduces maximum load current.

For more information about maximum output current and discontinuous operation, see Analog Devices' Application Note 44.

For duty cycles greater than 50% ($V_{OUT}/V_{IN} > 0.5$), a minimum inductance is required to avoid subharmonic oscillation (Equation 9). See Application Note 19 for more details.

$$L_{MIN} = \frac{V_{IN}(2 \bullet DC - 1)}{5 \bullet f_{SW}} \qquad (9)$$

$\frac{V_o}{V_{in}} = \frac{20}{28} = 0.714$

where DC is the duty cycle ratio (V_{OUT}/V_{IN}) and f_{SW} is the switching frequency.

* Due to $\frac{V_o}{V_{in}} \geq 0.5$, a minimum inductance value must be calculated

5.) Finalize L value

$$L = \frac{V_{out} + SW(Bot)}{f_{sw}} \cdot 0.2$$

f_{sw} in MHz

$$L = \left(\frac{20 + 0.8}{0.4}\right) \cdot 0.2$$

$$\boxed{L = 10.4\,\mu H}$$

* can use $10\,\mu H$

OBC Config:

a.) LTC4365: UV/OV Protection

- The $V_{OS(UV)}$ is the max voltage deviation that you can get at the output. This is given by the highest leakage current at the $I(UV)$ pin.

1.) Find $R_1 + R_2$

$$R_1 + R_2 = \frac{V_{OS(UV)}}{I_{UV}}$$

$$R_1 + R_2 = \frac{3mV}{10nA}$$

$$R_1 + R_2 = 300k$$

Recommended Parameters:

$V_{OS(UV)} = 3mV$
$I(UV) = 10nA$

Set by me:

$OV_{TH} = 32V$

$UV_{TH} = 24V$

From LTC 4365 Datasheet (Pg. 11)

Procedure for Selecting UV/OV External Resistor Values

The following 3-step procedure helps select the resistor values for the resistive divider of Figure 4. This procedure minimizes UV and OV offset errors caused by leakage currents at the respective pins.

1. Choose maximum tolerable offset at the UV pin, $V_{OS(UV)}$. Divide by the worst case leakage current at the UV pin, I_{UV} (10nA). Set the sum of R1 + R2 equal to $V_{OS(UV)}$ divided by 10nA. Note that due to the presence of R3, the actual offset at UV will be slightly lower:

$$R1 + R2 = \frac{V_{OS(UV)}}{I_{UV}}$$

2. Select the desired V_{IN} UV trip threshold, UV_{TH}. Find the value of R3:

$$R3 = \frac{V_{OS(UV)}}{I_{UV}} \cdot \left(\frac{UV_{TH} - 0.5V}{0.5V}\right)$$

3. Select the desired V_{IN} OV trip threshold, OV_{TH}. Find the values of R1 and R2:

$$R1 = \frac{\left(\frac{V_{OS(UV)}}{I_{UV}}\right) + R3}{OV_{TH}} \cdot 0.5V$$

$$R2 = \frac{V_{OS(UV)}}{I_{UV}} - R1$$

The example of Figure 4 uses standard 1% resistor values. The following parameters were selected:

$V_{OS(UV)} = 3mV$
$I_{UV} = 10nA$
$UV_{TH} = 5V$
$OV_{TH} = 18V$

2.) Find R_3 using UV trip threshold

$$R_3 = \frac{V_{OS(UV)}}{I(UV)} \cdot \left(\frac{UV_{TH} - 0.5v}{0.5v}\right)$$

Let $UV_{TH} = 24V$

$$R_3 = \left(\frac{3mV}{10nA}\right) \cdot \left(\frac{24 - 0.5}{0.5}\right) = 14.1\,M\Omega$$

3.) Find R_1 using OV trip threshold

Let $OV = 32v$

$$R_1 = \frac{\left(\frac{V_{OV(UV)}}{I(UV)}\right) + R_3}{OV} \cdot 0.5v$$

$$R_1 = \frac{\left(\frac{3mV}{10nA}\right) + 14.1M\Omega}{32} \left(0.5v\right) = 225000\,\Omega$$

For OBC Load switch OV/UV

$$\boxed{R_1 = 225\,k\Omega \quad R_2 = 75k \quad R_3 = 300k\Omega}$$

*Each UV/OV Threshold will be the same because each load switch is before each switching regulator

Let $OV_{TH} = 21v$

$$R_1 \approx 225\,k\Omega$$

4.) Find R_2

$$R_1 + R_2 = 300k$$

$R_1 = 260k$

$R_2 = 300k - 225k$
$R_2 = 75k$

OBC Config: (Cont.) Switching Regulator

6.) LT8638SEV: Output Voltage, Default Switching Frequency and choke Inductor selection

FB Resistor Network:

Let $R_2 = 5.5k$

$V_{out} = 3.3v$

$$R_1 = R_2\left(\frac{V_{out}}{0.6v} - 1\right)$$

$$R_1 = 5.5k\left(\frac{3.3}{0.6v} - 1\right)$$

$$R_1 = 24750$$

$$R_1 \approx 25k$$

FB Resistor Network for $V_{out} = 3.3v$

$R_1 = 25k$, $R_2 = 5.5k$

From LT8638SEV Datasheet (P.g 17)

FB Resistor Network

The output voltage is programmed with a resistor divider between the output and the FB pin. Choose the resistor values according to E1.

$$R1 = R2\left(\frac{V_{OUT}}{0.6V} - 1\right) \quad (1)$$

Reference designators refer to the Block Diagram. 1% resistors are recommended to maintain output voltage accuracy.

When using large FB resistors, a 4.7pF to 47pF phase-lead capacitor should be connected from V_{OUT} to FB.

Default Switching Frequency RT calculations:

$$f_{sw(max)} = \frac{V_{out} + V_{sw}(BOT)}{t_{on(min)}\left(V_{in} - V_{in_{sw(TOP)}} + V_{sw(BOT)}\right)}$$

where V_{in} is the typical input voltage, V_{out} is the output voltage, $V_{sw\,Top} = \sim 0.2v$, $V_{sw\,BOT} = \sim 0.8v$, $t_{on}(min)$ is the minimum top switch on time

internal switch drops at max load

- The higher your switching frequency, the lower your input voltage can be and lower efficiency

Let:

$V_{sw(BOT)} = 0.8v$

$V_{sw}(TOP) = 0.2v$

$V_{out} = 3.3v$

$t_{on(min)} = 25\,ns$

from electrical characteristics

$$f_{sw(max)} = \frac{3.3v + 0.8v}{(25\times10^{-9})(28v - 0.2 + 0.8)}$$

$$= 5734265.734\ Hz$$

$$\approx 5.7\,MHz$$

Super high, so not a huge concern. Pick avg. value on table,

Switching Frequency @ 400 khz Resistor

400 khz → RT = 105 kΩ

From LT8638SEV Datasheet (Pg. 18)

APPLICATIONS INFORMATION

table showing the necessary R_T value for a desired switching frequency is in Table 1.

The R_T resistor required for a desired switching frequency can be calculated using Equation 2.

$$R_T = \frac{44.8}{f_{SW}} - 5.9 \quad (2)$$

where R_T is in kΩ and f_{SW} is the desired switching frequency in MHz.

Table 1. SW Frequency vs R_T Value

f_{SW} (MHz)	R_T (kΩ)
0.2	226
0.3	143
0.4	105
0.5	82.5
0.6	66.5
0.7	56.2
0.8	48.7
1.0	38.3
1.2	31.6
1.4	26.1
1.6	22.1
1.8	19.1
2.0	16.9
2.2	15.4
3.0	10.5

Operating Frequency Selection and Trade-Offs

Selection of the operating frequency is a trade-off between efficiency, component size, and input voltage range. The advantage of high frequency operation is that smaller inductor and capacitor values may be used. The disadvantages are lower efficiency and a smaller input voltage range.

The highest switching frequency ($f_{SW(MAX)}$) for a given application can be calculated as follows:

$$f_{SW(MAX)} = \frac{V_{OUT} + V_{SW(BOT)}}{t_{ON(MIN)}\left(V_{IN} - V_{SW(TOP)} + V_{SW(BOT)}\right)} \quad (3)$$

where V_{IN} is the typical input voltage, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load) and $t_{ON(MIN)}$ is the minimum top switch on-time (see the Electrical Characteristics). Equation 3 shows that a slower switching frequency is necessary to accommodate a high V_{IN}/V_{OUT} ratio.

For transient operation, V_{IN} may go as high as the absolute maximum rating of 42V regardless of the R_T value, however the LT8638S will reduce switching frequency as necessary to maintain control of inductor current to assure safe operation.

The LT8638S is capable of a maximum duty cycle of approximately 99%, and the V_{IN}-to-V_{OUT} dropout is limited by the $R_{DS(ON)}$ of the top switch. In this mode the LT8638S skips switch cycles, resulting in a lower switching frequency than programmed by RT.

For applications that cannot allow deviation from the programmed switching frequency at low V_{IN}/V_{OUT} ratios use Equation 4 to set switching frequency.

$$V_{IN(MIN)} = \frac{V_{OUT} + V_{SW(BOT)}}{1 - f_{SW} \bullet t_{OFF(MIN)}} - V_{SW(BOT)} + V_{SW(TOP)} \quad (4)$$

where $V_{IN(MIN)}$ is the minimum input voltage without skipped cycles, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load), f_{SW} is the switching frequency (set by R_T), and $t_{OFF(MIN)}$ is the minimum switch off-time. Note that higher switching frequency will increase the minimum input voltage below which cycles will be dropped to achieve higher duty cycle.

OBC config: (cont.) Choke inductor selection LT8638 Datasheet (Pg. 17)

1. Choose appropriate first choice inductor

$$L = \frac{V_{out} + V_{SW(BOT)}}{f_{sw}} \cdot 0.2$$

Given:

$V_{SW(BOT)} = 0.08V$

L is in μH

$V_{out} = 3.3$

$f_{sw} = 400khz$

$$L = \frac{3.3v + 0.8}{400\,000} \cdot 0.2$$

$$= \boxed{2.05\mu H}$$

Inductor Selection and Maximum Output Current

The LT8638S is designed to minimize solution size by allowing the inductor to be chosen based on the output load requirements of the application. During overload or short-circuit conditions the LT8638S safely tolerates operation with a saturated inductor through the use of a high speed peak-current mode architecture.

A good first choice for the inductor value is given by Equation 5.

$$L = \left(\frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}}\right) \bullet 0.2 \qquad (5)$$

Rev. A

2. Check duty cycle ratio for minimum inductance rating

$$\frac{V_{out}}{V_{in}} = \frac{3.3v}{28v} = 0.117 < 0.5$$

No minimum inductance necessary

For duty cycles greater than 50% ($V_{OUT}/V_{IN} > 0.5$), a minimum inductance is required to avoid subharmonic oscillation (Equation 9). See Application Note 19 for more details.

$$L_{MIN} = \frac{V_{IN}(2 \bullet DC - 1)}{5 \bullet f_{SW}} \qquad (9)$$

where DC is the duty cycle ratio (V_{OUT}/V_{IN}) and f_{SW} is the switching frequency.

3.) Confirm inductor value can support max current (3A) for IMX8

a.) First find the ripple current ΔI_L

$$\Delta I_L = \frac{V_{out}}{L \cdot f_{sw}} \cdot \left(1 - \frac{V_{out}}{V_{in(max)}}\right)$$

$$\Delta L = \left(\frac{3.3v}{2.05\mu H \cdot 400khz}\right)\left(1 - \frac{3.3v}{28v}\right) = 3.55\text{ A}$$

$I_{Lim} = 15A$

$$I_{out(max)} = I_{Lim} - \frac{\Delta I_L}{2}$$

$$I_{out_{max}} = 15A - \frac{3.55}{2} = 13.255\text{ A}$$

we only need 3A for this component, so our max Iout is more than enough

So in conclusion:

$$\boxed{L = 2.05\mu H}$$

Peripheral Board (5v conn.)

a.) LTC4365: UV/OV Protection

- The $V_{os(UV)}$ is the max voltage deviation that you can get at the output. This is given by the highest leakage current at the $I_{(UV)}$ pin.

1.) Find $R_1 + R_2$

$$R_1 + R_2 = \frac{V_{os(UV)}}{I_{UV}}$$

$$R_1 + R_2 = \frac{3mV}{10nA}$$

$$R_1 + R_2 = 300K$$

Recommended Parameters:

$V_{os(UV)} = 3mV$
$I_{(UV)} = 10nA$

Set by me:

$OV_{TH} = 32V$

$UV_{TH} = 24V$

From LTC 4365 Datasheet (Pg. 11)

Procedure for Selecting UV/OV External Resistor Values

The following 3-step procedure helps select the resistor values for the resistive divider of Figure 4. This procedure minimizes UV and OV offset errors caused by leakage currents at the respective pins.

1. Choose maximum tolerable offset at the UV pin, $V_{OS(UV)}$. Divide by the worst case leakage current at the UV pin, I_{UV} (10nA). Set the sum of R1 + R2 equal to $V_{OS(UV)}$ divided by 10nA. Note that due to the presence of R3, the actual offset at UV will be slightly lower:

$$R1 + R2 = \frac{V_{OS(UV)}}{I_{UV}}$$

2. Select the desired V_{IN} UV trip threshold, UV_{TH}. Find the value of R3:

$$R3 = \frac{V_{OS(UV)}}{I_{UV}} \bullet \left(\frac{UV_{TH} - 0.5V}{0.5V}\right)$$

3. Select the desired V_{IN} OV trip threshold, OV_{TH}. Find the values of R1 and R2:

$$R1 = \frac{\left(\frac{V_{OS(UV)}}{I_{UV}}\right) + R3}{OV_{TH}} \bullet 0.5V$$

$$R2 = \frac{V_{OS(UV)}}{I_{UV}} - R1$$

The example of Figure 4 uses standard 1% resistor values. The following parameters were selected:

$V_{OS(UV)} = 3mV$
$I_{UV} = 10nA$
$UV_{TH} = 5V$
$OV_{TH} = 18V$

2.) Find R_3 using UV trip threshold

$$R_3 = \frac{V_{os(UV)}}{I_{(UV)}} \cdot \left(\frac{UV_{TH} - 0.5v}{0.5v}\right)$$

Let $UV_{TH} = 24V$

$$R_3 = \left(\frac{3mV}{10nA}\right) \cdot \left(\frac{24 - 0.5}{0.5}\right) = 14.1\ M\Omega$$

3.) Find R_1 using OV trip threshold

Let OV = 32v

$$R_1 = \frac{\left(\frac{V_{ov(UV)}}{I_{(UV)}}\right) + R_3}{OV} \cdot 0.5v$$

$$R_1 = \frac{\left(\frac{3mV}{10nA}\right) + 14.1M\Omega}{32} \left(0.5v\right) = 225000\ \Omega$$

Let $OV_{TH} = 21v$

$$R_1 \cong 225\ k\Omega$$

4.) Find R_2

$$R_1 + R_2 = 300k$$

$R_1 = 260k$

$R_2 = 300k - 225k$
$R_2 = 75k$

For PERIF Load switch OV/UV

$$\boxed{R_1 = 225\ k\Omega \quad R_2 = 75k \quad R_3 = 300k\Omega}$$

Peripheral Config: (Cont.) Switching Regulator

6.) **LT8638SEV**: Output Voltage, Default Switching Frequency and choke Inductor selection

FB Resistor Network:

Let $R_2 = 3k\Omega$
$V_{out} = 5v$

$$R_1 = R_2\left(\frac{V_{out}}{0.6v} - 1\right)$$

$$R_1 = 3k\left(\frac{5}{0.6v} - 1\right)$$

$$R_1 = 22000$$

$$R_1 \approx 22k$$

FB Resistor Network for $V_{out} = 5v$

$R_1 = 22k$, $R_2 = 3k$

From LT8638SEV Datasheet (P.g 17)

FB Resistor Network

The output voltage is programmed with a resistor divider between the output and the FB pin. Choose the resistor values according to E1.

$$R1 = R2\left(\frac{V_{OUT}}{0.6V} - 1\right) \quad (1)$$

Reference designators refer to the Block Diagram. 1% resistors are recommended to maintain output voltage accuracy.

When using large FB resistors, a 4.7pF to 47pF phase-lead capacitor should be connected from V_{OUT} to FB.

Default Switching Frequency RT calculations:

$$f_{sw(max)} = \frac{V_{out} + V_{sw}(BOT)}{t_{on(min)}\left(V_{in} - V_{in_{sw(TOP)}} + V_{sw(BOT)}\right)}$$

where V_{in} is the typical input voltage, V_{out} is the output voltage, $V_{sw\,Top} = \sim 0.2v$, $V_{sw\,BOT} = \sim 0.8v$, $t_{on(min)}$ is the minimum top switch on time

internal switch drops at max load

- The higher your switching frequency, the lower your input voltage can be and lower efficiency

Let:

$V_{sw(BOT)} = 0.8v$

$V_{sw}(TOP) = 0.2v$

$V_{out} = 5v$

$t_{on(min)} = 25ns$

from electrical characteristics

$$f_{sw(max)} = \frac{5v + 0.8v}{(25\times10^{-9})(28v - 0.2 + 0.8)}$$

$$= 8.1\ MHz$$

Super high, so not a huge concern.

Pick avg. value on table,

Switching Frequency @ 400 khz Resistor

400 khz → RT = 105kΩ

From LT8638SEV Datasheet (Pg. 18)

APPLICATIONS INFORMATION

table showing the necessary R_T value for a desired switching frequency is in Table 1.

The R_T resistor required for a desired switching frequency can be calculated using Equation 2.

$$R_T = \frac{44.8}{f_{SW}} - 5.9 \quad (2)$$

where R_T is in kΩ and f_{SW} is the desired switching frequency in MHz.

Table 1. SW Frequency vs R_T Value

f_{SW} (MHz)	R_T (kΩ)
0.2	226
0.3	143
0.4	105
0.5	82.5
0.6	66.5
0.7	56.2
0.8	48.7
1.0	38.3
1.2	31.6
1.4	26.1
1.6	22.1
1.8	19.1
2.0	16.9
2.2	15.4
3.0	10.5

Operating Frequency Selection and Trade-Offs

Selection of the operating frequency is a trade-off between efficiency, component size, and input voltage range. The advantage of high frequency operation is that smaller inductor and capacitor values may be used. The disadvantages are lower efficiency and a smaller input voltage range.

The highest switching frequency ($f_{SW(MAX)}$) for a given application can be calculated as follows:

$$f_{SW(MAX)} = \frac{V_{OUT} + V_{SW(BOT)}}{t_{ON(MIN)}\left(V_{IN} - V_{SW(TOP)} + V_{SW(BOT)}\right)} \quad (3)$$

where V_{IN} is the typical input voltage, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load) and $t_{ON(MIN)}$ is the minimum top switch on-time (see the Electrical Characteristics). Equation 3 shows that a slower switching frequency is necessary to accommodate a high V_{IN}/V_{OUT} ratio.

For transient operation, V_{IN} may go as high as the absolute maximum rating of 42V regardless of the R_T value, however the LT8638S will reduce switching frequency as necessary to maintain control of inductor current to assure safe operation.

The LT8638S is capable of a maximum duty cycle of approximately 99%, and the V_{IN}-to-V_{OUT} dropout is limited by the $R_{DS(ON)}$ of the top switch. In this mode the LT8638S skips switch cycles, resulting in a lower switching frequency than programmed by RT.

For applications that cannot allow deviation from the programmed switching frequency at low V_{IN}/V_{OUT} ratios use Equation 4 to set switching frequency.

$$V_{IN(MIN)} = \frac{V_{OUT} + V_{SW(BOT)}}{1 - f_{SW} \bullet t_{OFF(MIN)}} - V_{SW(BOT)} + V_{SW(TOP)} \quad (4)$$

where $V_{IN(MIN)}$ is the minimum input voltage without skipped cycles, V_{OUT} is the output voltage, $V_{SW(TOP)}$ and $V_{SW(BOT)}$ are the internal switch drops (~0.2V, ~0.08V, respectively at maximum load), f_{SW} is the switching frequency (set by R_T), and $t_{OFF(MIN)}$ is the minimum switch off-time. Note that higher switching frequency will increase the minimum input voltage below which cycles will be dropped to achieve higher duty cycle.

Perif config: (cont.) **Choke inductor selection** **LT8638 Datasheet (Pg. 14)**

1. Choose appropriate first choice inductor

$$L = \frac{V_{out} + V_{SW(BOT)}}{f_{SW}} \cdot 0.2$$

$$L = \frac{5v + 0.8}{400\,000} \cdot 0.2$$

$= 2.9 \times 10^{-6}\,H = 2.9\,\mu H$

Given:

$V_{SW(BOT)} = 0.08V$

L is in μH

$V_{out} = 5$

$f_{SW} = 400\,khz$

Inductor Selection and Maximum Output Current

The LT8638S is designed to minimize solution size by allowing the inductor to be chosen based on the output load requirements of the application. During overload or short-circuit conditions the LT8638S safely tolerates operation with a saturated inductor through the use of a high speed peak-current mode architecture.

A good first choice for the inductor value is given by Equation 5.

$$L = \left(\frac{V_{OUT} + V_{SW(BOT)}}{f_{SW}}\right) \cdot 0.2 \quad (5)$$

Rev. A

2. Check duty cycle ratio for minimum inductance rating

$$\frac{V_{out}}{V_{in}} = \frac{5v}{28v} = 0.17 < 0.5$$

No minimum inductance necessary

For duty cycles greater than 50% ($V_{OUT}/V_{IN} > 0.5$), a minimum inductance is required to avoid subharmonic oscillation (Equation 9). See Application Note 19 for more details.

$$L_{MIN} = \frac{V_{IN}(2 \cdot DC - 1)}{5 \cdot f_{SW}} \quad (9)$$

where DC is the duty cycle ratio (V_{OUT}/V_{IN}) and f_{SW} is the switching frequency.

3.) Confirm inductor value can support max current (3A) for IMX8

a.) First find the ripple current ΔI_L

$$\Delta I_L = \frac{V_{out}}{L \cdot f_{SW}} \cdot \left(1 - \frac{V_{out}}{V_{in(max)}}\right)$$

$$\Delta L = \left(\frac{5v}{2.9\,\mu H \cdot 400kHz}\right)\left(1 - \frac{5v}{28v}\right) = 3.54A$$

$I_{Lim} = 15A$

$$I_{out(max)} = I_{Lim} - \frac{\Delta I_L}{2}$$

$$I_{out_{max}} = 15A - \frac{3.54}{2} = 13.23$$

we only need 3A for this component, so our max Iout is more than enough

So in conclusion:

$$\boxed{L = 2.90\,\mu H}$$

LTC 6902 Clock:

Frequency setting / Phase set / SSFM select

LTC6902 Datasheet (Pg.5)

By selecting the multiphase mode, a division parameter M is also chosen:

2-Phase: Connect PH Pin to GND   M = 1
3-Phase: Leave PH Open   M = 3
4-Phase: Connect PH Pin to V+   M = 4

Step 1:
Selecting the phase:

3-phase → 3 components

Leave PH open, M = 3

For SSFM →

DIVIDER SETTING		FREQUENCY RANGE ($f_{OUT} \bullet M$)
N = 1	Connect DIV Pin to GND	2MHz to 20MHz
N = 10	Leave DIV Open	200kHz to 2MHz
N = 100	Connect DIV Pin to V+	<200kHz

Note: The frequency range numbers are for a 5V supply where a 20MHz output is the maximum frequency supported. For low supply applications ($2.7V \le V^+ \le 4V$), the maximum rated output frequency is 10MHz and all of the above numbers should be halved.

Step 2: Frequency range

Let desired freq be 400 khz,
based on datasheet this is at 200khz < f < 2mHz

$$f_{OUT} = \frac{10MHz}{N \bullet M} \bullet \left(\frac{20k\Omega}{R_{SET}}\right); \; 5kHz \le f_{OUT} \le 20MHz$$

$$\text{Spreading Percentage} = 20 \bullet \frac{R_{SET}}{R_{MOD}}$$

So N = 10, leave div open

Step 3: Define Rset (For SSFM)

$$R_{set} = 20k\Omega \left(\frac{10MHz}{N \cdot M \cdot f_{out}}\right)$$

$$f_{out} = \frac{10MHz}{N \cdot M} \cdot \left(\frac{20k\Omega}{R_{set}}\right)$$

|| in SSFM is f_{max}

$$R_{set} = 20k\left(\frac{10MHz}{3 \cdot 10 \cdot (400kHz)}\right) = 16.\overline{666}\ k\Omega$$

Step 4: Define Rmod

$$R_{mod} = 20 \cdot \frac{R_{set}}{\text{spreading percentage}}$$

where spreading percentage $= 100\left(\frac{f_{max} - f_{min}}{f_{max}}\right)$

$$= 100\left(\frac{400khz - 300khz}{400khz}\right)$$

= 25% spreading

$$R_{mod} = 20 \cdot \left(\frac{16.666\ k\Omega}{25}\right) = 13.332\ k\Omega$$

LTC6902 Config:

SSFM with 25% spreading

$R_{set} = 16.\overline{666}\ k\Omega$ → Set   PH Open → M = 3

$R_{mod} = 13.\overline{333}\ k\Omega$ → mod   Div Open → N = 10

All LT8638SEV Soft-Start Calculations

For OBC

- Shortest SS

SS formula:

$$T_{ss} = \frac{0.8V \times C_{ss}}{2mA}$$

let $C_{ss_{OBC}} = 100nF$

$$T_{SS} = \frac{0.8 \times 10nF}{2mA}$$

$$\boxed{= 4ms}$$

For Peripherals

- 2nd Shortest SS

$$T_{ss} = \frac{0.8 \times 20nF}{2\mu A}$$

$$\boxed{= 8ms}$$

let $C_{ss_{prf}} = 20nF$

For JETSON

- Longest SS

$$T_{SS} = \frac{0.8 \times 100nF}{2mA}$$

$$\boxed{= 40ms}$$

let $C_{ss_{Jetson}} = 100nF$

LT8638SEV Datasheet (Pg. 22)

Output Voltage Tracking and Soft-Start

The LT8638S allows the user to program its output voltage ramp rate by means of the SS pin. An internal 2μA pulls up the SS pin to $INTV_{CC}$. Putting an external capacitor on SS enables soft starting the output to prevent current surge on the input supply. During the soft-start ramp the output voltage will proportionally track the SS pin voltage. For output tracking applications, SS can be externally driven by another voltage source. From 0V to 1V, the SS voltage will override the internal 0.6V reference input to the error amplifier, thus regulating the FB pin voltage to a function of the SS pin. See plot in the Typical Performance Characteristics section. When SS is above 1V, tracking is disabled and the feedback voltage will regulate to the internal reference voltage. The SS pin may be left floating if the function is not needed.

An active pull-down circuit is connected to the SS pin which will discharge the external soft-start capacitor in the case of fault conditions and restart the ramp when the faults are cleared. Fault conditions that clear the soft-start capacitor are the EN/UV pin transitioning low, V_{IN} voltage falling too low, or thermal shutdown.

Checklist for Calcs:

JETSON:
- Load Switch
  - OV/UV ✓
- Switching reg.
  - RT ✓
  - Inductor ✓
  - SS ✓

OBC:
- Load Switch
  - OV/UV ✓
- Switching reg.
  - RT ✓
  - Inductor ✓
  - SS ✓

Perif:
- Load Switch
  - OV/UV ✓
- Switching reg.
  - RT ✓
  - Inductor ✓
  - SS ✓

Clock:
- SSFM ✓
- fmax ✓
- # of phases ✓