2/12/24 Switch Regulator Calcs

Jetson Switch Regulator:

- FB Resistor Network

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

Let $R_2 = 3k\Omega$

$V_{out} = 20v$

$$R_1 = R_2\left(\frac{20v}{0.6v} - 1\right)$$

$$R_1 = R_2(33.\overline{333} - 1)$$

$$R_1 = R_2(32.\overline{333})$$

$$R_1 = 3k(32.333) = 96,999\ \Omega$$

$R_1 \approx 100k\Omega$

$R_2 \approx 3k\Omega$

- Max Switching Frequency and RT calculation

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

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:

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

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

$V_{out} = 20v$

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

from electrical characteristics

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

$= 29090909.09$ Hz

≈ 30 mHz

Super high, not a huge concern.

Pick avg. value on table,

$\boxed{400\text{ khz} \rightarrow RT = 105k\Omega}$

6 Inductor Selection and maximum output Current

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.

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

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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.

$I_{Load\,max}\approx 8A$

1. First find L_{min} due to

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

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

$$L_{min}=\frac{28\left(\left(2\cdot\frac{20}{28}\right)-1\right)}{5\cdot 4000000}$$

$=6\times10^{-6}=6\mu H$

2.) Find the PP ripple current

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

$$\Delta I_L=\left(\frac{20}{(6\times10^{-6})(400000)}\right)\left(1-\frac{20v}{28v}\right)$$

$\Delta I_L=2.38095\,A$

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

$DC=0.714$ so $I_L\approx 15A$

$I_{out\,max}$ is max output current

$$I_{out\,max}=I_{lim}-\frac{I\Delta_L}{2}$$

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

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

$I_{L(peak)}=I_{load(max)}+\frac{1}{2}\Delta I_L$

$I_{L(peak)}=13.809525+\frac{1}{2}(2.38095)$

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

$I_{Load(max)}=13.809525A$

$\Delta I_L=2.38095A$

5.) Finalize L value

$$L=\frac{V_{out}+SW(Bot)}{f_{sw}}\cdot 0.2 \quad \leftarrow f_{sw}\text{ in MHz}$$

$$L=\frac{20+0.8}{0.4}\cdot 0.2$$

$L=10.4\,\mu H$

So in conclusion, $L\geq 10.4\mu H$ with $I_{RMS}\geq 15A$ for Jetson

OBC Switching Regulator:

- FB Resistor Network

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

Let $R_2 = 5k$

$V_{out} = 12v$

$$R_1 = R_2\left(\frac{12v}{0.6v} - 1\right)$$

$$R_1 = R_2(20 - 1)$$

$$R_1 = R_2(19)$$

$$R_1 = 5k(19) = 95k\Omega$$

$$R_1 = 95k\Omega,\ R_2 = 5k$$

- Frequency will be the same for all

Inductor Selection:

1.) First find Lmin due to $\frac{V_o}{V_{in}} > 0.5$

$$\frac{12v}{28v} = 0.428v \approx 0.5$$

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

$$L_{min} = \frac{28v\left(2 \cdot \frac{12}{28} - 1\right)}{5 \cdot 400\,000)} = 8\times10^{-6}\ H$$

$$L_{min} = 8\mu H$$

2.) Find ΔI_L ripple current for peak RMS

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

$$\Delta I_L = \left(\frac{12}{(8\times10^{-6})(400000)}\right)\left(1 - \frac{12}{28v}\right)$$

$$\Delta I_L = 2.142\ A$$

3.) Calculate Iout max

$I_{Lim} \approx 15A$

$$I_{out_{max}} = I_{Lim} - \frac{I_{\Delta L}}{2}$$

$$I_{out_{max}} = 15 - \frac{2.142}{2} = 13.92\ A$$

4.) Peak RMS of 13/15A

5.) Calculate inductor value

$$L = \frac{V_{out} + V_{SW}(BOT)}{0.400} \times 0.2 = \frac{12 + 0.8}{0.400} \times 0.2 = 6.4\mu H$$

FPGA Switching Regulator (5v Peripheral is identical due to having same input/output reqs)

- FB Resistor Network

$R_1 = R_2\left(\frac{5}{0.6v} - 1\right)$

$R_1 = R_2(8.\overline{333} - 1)$

$R_1 = R_2(7.\overline{333})$ Let $R_2 = 3k$

$R_1 = 3k(7.\overline{333})$

$R_1 = 21.\overline{999}\,k\Omega \approx 22k\Omega$

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

1.) Because $\frac{V_o}{V_{in}} << 0.5$, L_{min} is not a concern

2.) $L = \frac{V_{out} + V_{SW(Bot)}}{0.400} \times 0.2 = \frac{5 + 0.8}{0.400} \times 0.2 = 2.9\mu H$

$\boxed{\text{Round up to } 3\mu H}$

3.) Peak I_{RMS} of about 7A