Output Inductor Selection for the AAT115X Series Buck Converter

Introduction
This Application Note summarizes the method for selecting the output inductor for AnalogicTech’s AAT115X series of DC/DC inductor-based buck converters. It presents the suggested method for determining the proper inductor value and confirming that the selected inductor ratings are not exceeded.

Inductor Value
AnalogicTech’s AAT115X switch mode buck converters require that the output inductor ripple current be limited to 30% to 40% of the rated current at the maximum input voltage (Eq. 1). This limits the peak switch current while still providing a good ramp slope for the PWM peak current mode comparator input. The AAT115X peak current mode control loop senses the current flowing through the high-side P-channel MOSFET and compares it to the output of the voltage loop error amplifier. Sufficient sensed current slope is important for good noise immunity and a wide duty cycle dynamic range. Moreover, this value guarantees that there is sufficient internal slope compensation which assures stability of the current mode loop for applications requiring greater than 50% duty cycle. With the inductor ripple current set to 40% of the rated current at the maximum input voltage, the converter is guaranteed to operate in continuous conduction mode (CCM) above 20% of full load for the full input voltage range.

\[
L = \frac{V_{\text{OUT}}}{I_o \cdot k \cdot F} \left(1 - \frac{V_o}{V_{\text{IN(MAX)}}}\right)
\]

\[
k = 40\%
\]

<table>
<thead>
<tr>
<th>Device</th>
<th>(I_o) (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAT1150/52</td>
<td>1.0</td>
</tr>
<tr>
<td>AAT1151/56</td>
<td>0.7</td>
</tr>
<tr>
<td>AAT1154/55</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Figure 1: Buck Converter.
Inductor Efficiency

Once an inductor has been selected, the DC resistance (DCR) must be examined. To reduce DCR, an inductor requires either more window area for the increased wire diameter or fewer turns to reduce the length of the copper winding. Fewer turns demands an inductor core with a larger cross-sectional area in order to maintain the same saturation characteristics. Either method of reducing the DCR requires a larger inductor. Consequently, the inductor size must always be considered when examining the inductor DCR. Since the ripple component of the inductor is a small percentage of the DC load, AC losses in the inductor core and winding do not typically contribute significantly to the total losses in the inductor.

Low noise shielded inductors use the minimum gap possible to limit the distance that magnetic fields can radiate from the inductor. This prevents the magnetic fields associated with the output inductor from interfering with nearby circuitry. Shielded inductors typically have a higher DCR and are less efficient than a similar sized non-shielded inductor. Table 1 shows how the efficiency of the output inductor varies with size and shielding. Moreover, the saturation characteristics and DC current ratings are examined.
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Table 1: Inductor Performance Comparison \((V_O = 0.8V; \ I_O = 0.7A; \ L = 2.2\mu H)\).

<table>
<thead>
<tr>
<th>Inductor 2.2\mu H</th>
<th>Dimensions W x L x H (mm)</th>
<th>DCR max (m\Omega)</th>
<th>PL (mW)</th>
<th>Inductor (I_{DC}) (A)</th>
<th>Inductor (I_{SAT}) (A) 20(^\circ)C</th>
<th>Inductor (I_{SAT}) (A) 100(^\circ)C</th>
<th>Inductor Efficiency (%) (V_O=0.8V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDRH4D18C-2R2 Sumida</td>
<td>5.1 x 5.1 x 2.0 Shielded</td>
<td>39</td>
<td>19</td>
<td>1.7(^1)</td>
<td>1.7(^1)</td>
<td>1.7(^1)</td>
<td>97</td>
</tr>
<tr>
<td>CDRH3D16-2R2 Sumida</td>
<td>4.0 x 4.0 x 1.8 Shielded</td>
<td>72</td>
<td>35</td>
<td>1.2(^2)</td>
<td>1.2(^2)</td>
<td>1.2(^2)</td>
<td>94</td>
</tr>
<tr>
<td>CDRH2D11-2R2 Sumida</td>
<td>3.2 x 3.2 x 1.2 Shielded</td>
<td>98</td>
<td>47</td>
<td>1.27</td>
<td>0.78</td>
<td>0.58</td>
<td>92</td>
</tr>
<tr>
<td>CDRH2D18/HP Sumida</td>
<td>3.2 x 3.2 x 2.0 Shielded</td>
<td>60</td>
<td>29</td>
<td>1.9</td>
<td>1.6</td>
<td>1.15</td>
<td>95</td>
</tr>
<tr>
<td>CDRH2D14 Sumida</td>
<td>3.2 x 3.2 x 1.55 Shielded</td>
<td>94</td>
<td>46</td>
<td>1.6</td>
<td>1.5</td>
<td>1.0</td>
<td>92</td>
</tr>
<tr>
<td>CDH53-2R2 Sumida</td>
<td>3.0 x 3.0 x 1.2 Non-Shielded</td>
<td>66</td>
<td>32</td>
<td>2.03(^2)</td>
<td>2.03(^2)</td>
<td>2.03(^2)</td>
<td>94</td>
</tr>
<tr>
<td>LQH32CN2R2M51 MuRata</td>
<td>3.2 x 2.5 x 1.55 Shielded</td>
<td>97</td>
<td>48</td>
<td>0.79</td>
<td>&gt;1.0</td>
<td></td>
<td>92</td>
</tr>
<tr>
<td>A914BYW-2R2M=P3</td>
<td>5.0 x 5.0 x 2.0</td>
<td>59</td>
<td>29</td>
<td>1.64</td>
<td>1.63</td>
<td></td>
<td>95</td>
</tr>
</tbody>
</table>

Notes:
1. Specified as the current where either the inductance is 35% lower than its initial value in DC saturation characteristics or temperature rise is 30\(^\circ\)C above ambient \((T_A=20\(^\circ\)C)\).
2. Specified as the current where either the inductance is 10% lower than its initial value in DC saturation characteristics or temperature rise is 40\(^\circ\)C above ambient \((T_A=20\(^\circ\)C)\).

Saturation Current

The saturation current is specified as the current at which the inductance drops a specific percentage from the nominal value. Except for short-circuit or other fault conditions, the peak current must always be less than the saturation current specified by the manufacturer. The buck peak current is the maximum load current plus one half of the inductor ripple current at the maximum input voltage (Eq. 2). Load and/or line transients can cause the peak current to exceed this level for short durations. Maintaining the peak current below the inductor saturation specification keeps the inductor ripple current and the output voltage ripple under control. In many cases, graphs are available which display the actual inductance and saturation characteristics vs. applied inductor current. The saturation characteristics of the inductor can vary significantly with core temperature. Therefore, the core and ambient temperatures must be considered when examining the core saturation characteristics.

\[
\text{Eq. 2: } \Delta I = \frac{V_O}{L \cdot F} \cdot \left(1 - \frac{V_O}{V_{IN}}\right)
\]

\[
l_{PK} = l_{OUT} + \frac{\Delta I}{2}
\]
DC Current Rating

The RMS or DC current rating is associated with losses in the copper windings and the resulting temperature rise of the inductor. For a buck converter, the inductor RMS current can be approximated to be equal to the load current. The maximum DC output current must be less than the inductor DC current rating. It is not uncommon for an inductor with the DCR necessary for good efficiency to have saturation and DC current ratings well beyond the levels seen in the application.

Design Example

\( I_O = 0.7A \)

\( V_O = 0.8V \) (AAT1156)

\( V_IN = 3.6V \) to 4.2V

1. Select inductor value for 40% ripple.

\[
\text{Eq. 3:} \quad L = \frac{V_O}{I_O \cdot k \cdot F} \cdot \left( 1 - \frac{V_O}{V_{IN(MAX)}} \right) = \left( \frac{0.8V}{0.7A \cdot 0.4 \cdot 1.0MHz} \right) \left( 1 - \frac{0.8V}{4.2V} \right) = 2.3\mu H
\]

The Sumida CDRH3D16 2.2\( \mu H \) 72m\( \Omega \) inductor is selected.

\( I_{MAX} = 1.2A \) (specified as the current where either the inductance is 35% lower than the nominal value or temperature rise is 30°C above ambient).

2. Examine the efficiency of the selected inductor.

\[
\text{Eq. 4:} \quad P = I_O^2 \cdot \text{DCR} = (0.7A)^2 \cdot 72m\Omega = 35.3mW
\]

\[
\eta = \frac{I_O \cdot V_O}{I_O \cdot V_O + P_{\text{INDUCTOR}}} = \frac{0.7A \cdot 0.8V}{0.7A \cdot 0.8V + 35.3mW} = 94\%
\]

3. Confirm that the peak current is within the inductor current saturation specification.

\[
\text{Eq. 5:} \quad \Delta I = \frac{V_O}{L \cdot F} \cdot \left( 1 - \frac{V_O}{V_{IN}} \right) = \frac{0.8V}{2.2\mu H \cdot 1.0MHz} \left( 1 - \frac{0.8V}{4.2V} \right) = 294mA
\]

\[
l_{PK} = l_{OUT} + \frac{\Delta I}{2} = 0.7A + 0.147A = 0.847A < 1.2A
\]

4. Confirm that the inductor rated DC current is less than the maximum load current.

\[
\text{Eq. 6:} \quad l_{OUT} < \text{Inductor Rated Current}
\]

\[ 0.7A < 1.2A \]
Pulse Frequency Modulation Efficiency

The efficiency curves below display the AAT1151 efficiency vs. load current for various output voltages using recommended inductor values.

**AAT1151 Efficiency vs. Load Current**

- *(V_o = 1.0V; V_in = 3.6V)*
- *(V_o = 1.2V; V_in = 3.6V)*
- *(V_o = 1.5V; V_in = 3.6V)*
- *(V_o = 1.8V; V_in = 3.6V)*
- *(V_o = 2.5V; V_in = 3.6V)*
- *(V_o = 3.3V; V_in = 3.6V)*
Summary

The process of selecting the inductor for the AnalogicTech AA115X buck converter is simple. Select an inductor value that limits the inductor ripple current to 30% to 40% of the maximum load current at the maximum input voltage. Then examine the efficiency, along with the peak and DC current ratings, of the inductor.