ABSTRACT

This application report discusses a way to increase the efficiency of the boost converter in a backlight driver by reducing conduction and AC losses in the inductor, thereby increasing the overall efficiency of the backlight driver at higher loads.

1 Introduction

Today backlight drivers are commonly powered by single-cell-based electronic equipment. However, the efficiency of the boost converters they employ drops continuously with decreasing input voltage (increasing input current) because of more losses in Inductor. A new method of putting two inductors in parallel, doubling the original inductance value, has shown improvement in the efficiency of the converter at higher loads, thus increasing the overall efficiency of the backlight driver.

2 Inductor Operation

Before discussing different inductor losses, here is a review of the operation of a power inductor in a boost converter. Turning on the primary switch applies a source voltage $V_{\text{IN}}$ across the inductor, causing the current to increase as:

$$\frac{di(t)}{dt} = \frac{V_{\text{IN}}}{L}$$  \hspace{1cm} (1)

This changing current $di(t)/dt$, induces a changing magnetic field in the core material according to Ampere’s Law:

$$\frac{dH(t)}{dt} = \frac{n}{l_E} \frac{di(t)}{dt}$$  \hspace{1cm} (2)

where: $H(t)$ is magnetic-field strength, $l_E$ is effective length of the core, $n$ is the number of wire turns around the inductor core and $i(t)$ is the inductor current.

In turn, magnetic flux through the inductor's core increases as:

$$\frac{d\phi(t)}{dt} = \frac{n}{R} \frac{di(t)}{dt}$$  \hspace{1cm} (3)

Where $\phi(t)$ is the magnetic flux in the inductor core, and $R$ is the reluctance.

The increase can be rewritten in terms of magnetic-field density:

$$\frac{dB(t)}{dt} = \frac{n}{A \cdot R} \frac{di(t)}{dt}$$  \hspace{1cm} (4)

The primary switch opens during the off time and removes $V_{\text{IN}}$, causing the magnetic field to collapse. In response, a decreasing $d\phi(t)/dt$ in the inductor’s core induces (according to Faraday’s Law) a voltage $-n d\phi(t)/dt$ across the inductor.

A graph of $B(t)$ as a function of $H(t)$ for a sinusoidal input voltage produces the hysteresis loop shown in bold lines in Figure 1. $B(t)$ is measured as $H(t)$ is increased. The response of $B(t)$ versus $H(t)$ is nonlinear and exhibits hysteresis, hence the name hysteresis loop. Hysteresis is one of the core-material characteristics that causes power loss in the inductor core.
3 Power Loss in Inductor Core

3.1 Hysteresis Losses

Energy loss due to the changing magnetic energy in the core during a switching cycle equals the difference between magnetic energy put into the core during the on time and the magnetic energy extracted from the core during the off time. Total energy ($E_T$) into the inductor over one switching period $T$ is:

$$E(t) = \int_0^T V(t) \cdot I(t) \, dt$$  \hspace{1cm} (5)

Using Ampere’s Law $n \cdot \frac{H(t) \cdot I_E}{n} = I(t)$ and Faraday’s Law $n \cdot A \cdot \frac{dB(t)}{dt} = V(t)$, the equation for $E(t)$ can be rewritten as:

$$E(t) = A \cdot I_E \int_0^T H(t) \cdot dB(t)$$  \hspace{1cm} (6)

Thus, the total energy put into the core over one switching period is the area of the shaded region within the $B$-$H$ loop of Figure 1 multiplied by the volume of the core. The magnetic field decreases as inductor current ramps down, tracing a different path (following the direction of the arrows in Figure 1) for magnetic flux density. Most of the energy goes to the load, but the difference between stored energy and delivered energy equals the energy loss.

Energy loss in the core is the area traced out by the $B$-$H$ loop multiplied by the core’s volume, and the power loss is this energy ($E_T$) multiplied by the switching frequency.

Hysteresis loss varies as a function of $\Delta B^p$, where (for most ferrites) “$p$” lies in the range 1 to 3. This expression applies on the conditions that the core is not driven into saturation, and the switching frequency lies in the intended operating range.

The shaded area in Figure 1, which occupies the first quadrant of the $B$-$H$ loop, represents the operating region for positive flux-density excursions, because typical boost converters operate with positive inductor currents.

$$\Delta B = \mu \cdot \Delta H$$  \hspace{1cm} (7)
Using Ampere’s Law:
\[ \Delta H = n \frac{\Delta I}{I_e} \]  
(8)

Using Faraday’s Law \( \frac{dI(t)}{dt} = \frac{V_{in}}{L} \):
\[ \Delta H = n \frac{V_{in}}{L} \cdot T_{on} \]  
(9)

Magnetic flux density can be given as:
\[ \Delta B = K \left( \frac{V_{in}}{L} \cdot T_{on} \right) \]  
(10)

Where \( K = \mu \cdot N \).

Thus, the Hysteresis CORE LOSSES can be written as:
\[ P_c = \lambda \left( \frac{V_{in}}{L} \cdot T_{on} \right)^p \]  
(11)

Where \( \lambda \) is a constant.

3.2 Eddy Current Losses

The second type of core loss is due to eddy currents, which are induced in the core material by a time-varying flux \( \frac{d\Phi}{dt} \). According to Lenz’s Law, a changing flux induces a current that itself induces a flux in opposition to the initial flux.

This eddy current flows in the conductive core material and produces an \( fR \) or \( V^2/R \) power loss.

The power loss in the core due to eddy currents is:
\[ P_e = \frac{V_{in}^2}{R_c} \cdot \frac{T_{on}}{T_p} \]  
(12)

Where \( V_{in} \) is the input voltage to the inductor, \( R_c \) Inductor core loss resistance, \( T_{on} \) is the duty cycle on time.

Because the core material has high resistance, losses due to eddy currents in the core are usually much less than those due to hysteresis.

4 Power Loss in Inductor Windings

4.1 DC Power Loss

The preceding discussion presented losses in the inductor core, but losses also occur in the inductor windings. Power loss in the windings at dc is due to the windings’ DC resistance \( (R_{dc}) \); \( (I_{dc}^2R_{dc}) \).

4.2 AC Power Loss

With increasing frequency, the winding resistance increases due to a phenomenon called skin effect, caused by a changing \( I(t) \) within the conductor. This increase in resistance with frequency is donated in the form of AC resistance \( (R_{AC}) \) in which power loss occurs only because of the ripple current and is given as:
\[ I_{RMS} = \frac{\Delta I}{12} \]  
(13)
\[ P_{ac} = I_{RMS}^2 \cdot R_{AC} \]  
(14)

An equivalent loss model for a power inductor includes terms representing the ac- and dc-dependent winding losses \( (R_{AC} \) and \( R_{DC} \)) and the core losses \( (R_c) \).
5 Reducing the AC and Conduction Losses

The conduction losses depend on the DC current flowing through the inductor and therefore by replacing a single inductor with two inductors in parallel of double the original value, we are dividing the current equally between them and hence the conduction losses can be reduced, similarly the AC resistance losses depend upon the inverse square of the value of inductance so they should be get reduced by half.

To prove the above assertions made we are using two TEST CASES:

1. One Inductor of the required value L = 5 µH:

2. Two Inductors of 10 µH each - Double the needed value (5 µH) are placed in parallel:
### Theoretical Power Dissipation Calculations for Two Test Cases

| Inductance Value | 5 µH | 10µH || 10µH (5µH) Inductors |
|------------------|------|----------------------------------|
| Core Losses      | $P_c$ | $P_c/2 + P_c/2 = P_c$.          |
| $P_c = KI \cdot \left( \frac{\text{Vin}}{L} \cdot \text{Ton} \right)^p$ | for these inductors. | |
| Value of DC Resistance | $R_{DC}$ | $(3/2) \cdot R_{DC}$ || $(3/2) \cdot R_{DC}$ |
| Value of DC current | $I_{DC}$ | $I_{DC}/2$ through each resistance |
| Conduction Power Loss | $P_{DC} = I_{DC}^2 R_{DC}$ | $(3/4) \cdot P_{DC}$ |
| AC Resistance    | $R_{AC}$ | $(3/2) \cdot R_{AC}$ |
| Value of RMS      | $I_{RMS}$ | $I_{RMS}/2$ |
| AC resistance Loss | $P_{AC}$ | $(3/4) \cdot P_{AC}$ |

**NOTE:** The Conduction losses reduces by almost 1/4th which could save us as high as 100 mW at full load and lower input voltages. AC Losses reduce by 1/4th which could save around 20 to 30 mW.
## Table 1. Specifications Used for Two Test Cases

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<th>Value</th>
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<tr>
<td>Output Voltage</td>
<td>31 Volts</td>
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<td>Switching Frequency</td>
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<tr>
<td>Input Current</td>
<td>1.72A</td>
</tr>
<tr>
<td>Input Power</td>
<td>5.84 watts</td>
</tr>
</tbody>
</table>

(1) Calculated from the datasheet and information on site for two test cases. 0.130 watts saved at full load.

## Table 2. Actual Power Dissipation Values

| Inductance Value | 5 µH | 10 µH || 10 µH | Power Save |
|------------------|------|------|-------|-----------|
| Core losses      | 0.047 watts | 0.023 + 0.023 = 0.046 watts | 0.001 watts |
| DC Resistance losses | 0.325 watts | 0.235 watts | 0.090 watts |
| AC Resistance losses | 0.097 watts | 0.060 watts | 0.037 watts |
| Total Losses     | 0.469 watts | 0.341 watts | 0.130 watts |

**Efficiency Increase:** \( \frac{\text{Power Saved}}{\text{Input Power}} \times 100 = 2.3\% \)

**NOTE:** So one can save anywhere between 2 to 3 percent in the boost efficiency, depending upon the load conditions.

## 7 Conclusion

The efficiency for the boost, and hence the LED backlight driver, can be increased by putting two inductors in parallel. **The two-parallel-inductor solution provides benefits to efficiency, solution height, and doubling the saturation current limit for both inductors by trading off solution area.** This is a good compromise in applications where height and efficiency for the inductor are critical, but board area is available.
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