TEXAS INSTRUMENTS

Application Report

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Increasing Full Load Efficiency of a Backlight Driver

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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_{IN} across the inductor, causing the current to increase as:

$$di(t) / dt = Vin / L \tag{1}$$

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

$$\frac{dH(t)}{dt} = \frac{n}{l_E} \bullet \frac{di(t)}{dt} \tag{2}$$

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:

$$\frac{d\o(t)}{dt} = \frac{n}{\Re} \bullet \frac{di(t)}{dt} \tag{3}$$

Where *ø(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:

$$\frac{dB(t)}{dt} = \frac{n}{A \bullet \Re} \bullet \frac{di(t)}{dt} \tag{4}$$

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

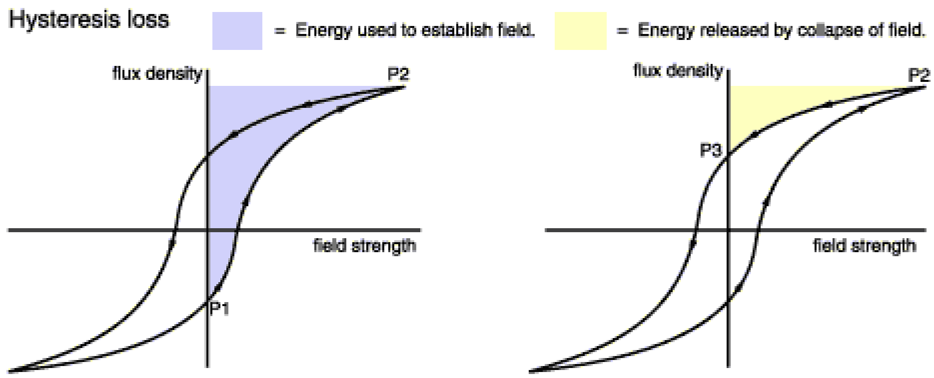

Figure 1. ***B(t)*** **as a Function of** ***H(t)*** **for a Sinusoidal Input Voltage**

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:

$$E(t) = \int_0^T V(t) \bullet I(t) dt \tag{5}$$

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

$$E(t) = A \bullet l_E \int_0^T H(t) \bullet dB(t) \tag{6}$$

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 ΔB^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.

$$\Delta B = \mu \bullet \Delta H \tag{7}$$

Using Ampere's Law:

$$\Delta H = n \bullet \frac{\Delta I}{l_E} \tag{8}$$

Using Faraday's Law $di(t)/dt = V_{IN}/L$:

$$\Delta H = n \bullet \frac{Vin}{L} \bullet Ton \tag{9}$$

Magnetic flux density can be given as:

$$\Delta B = K \bullet \left(\frac{Vin}{L} \bullet Ton \right) \tag{10}$$

Where $K = \mu * N$.

Thus, the Hysteresis CORE LOSSES can be written as:

$$P_c = \lambda \bullet \left(\frac{Vin}{L} \bullet Ton \right)^p \tag{11}$$

Where λ 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 *dø/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 I^2R or V^2/R power loss.

The power loss in the core due to eddy currents is:

$$Pe = \frac{Vin^2}{Rc} \bullet \frac{Ton}{Tp} \tag{12}$$

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:

$$I_{RMS} = \Delta I / 12 \tag{13}$$

$$Pac = I_{RMS}{}^2 \bullet R_{AC} \tag{14}$$

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).

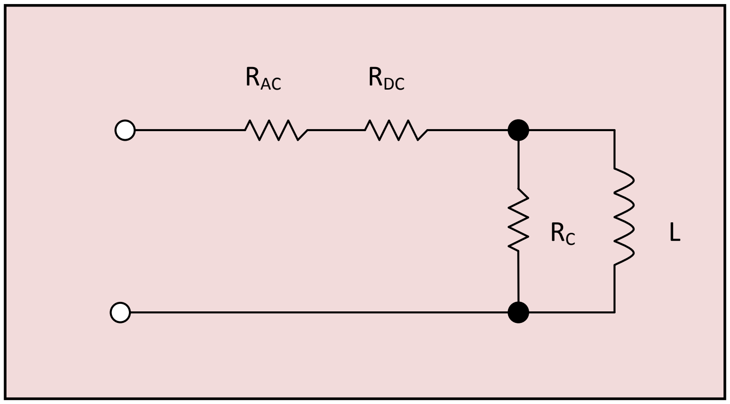

Figure 2. Inductor's Equivalent Loss Model

5 Reducing the AC and Conduction Losses

The conduction losses depends on the DC current flowing through the inductor and therefore by replacing 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 loss depends 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:

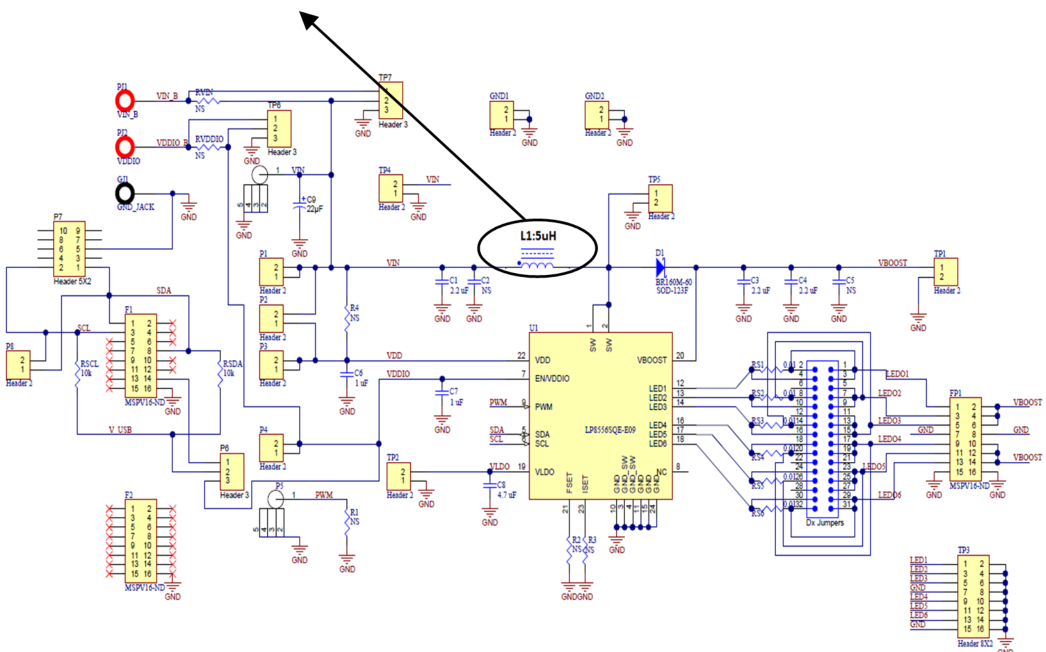

Figure 3. LP8556EVM Schematic with 5 µH Inductor

2. Two Inductors of 10 µH each - Double the needed value (5 µH) are placed in parallel:

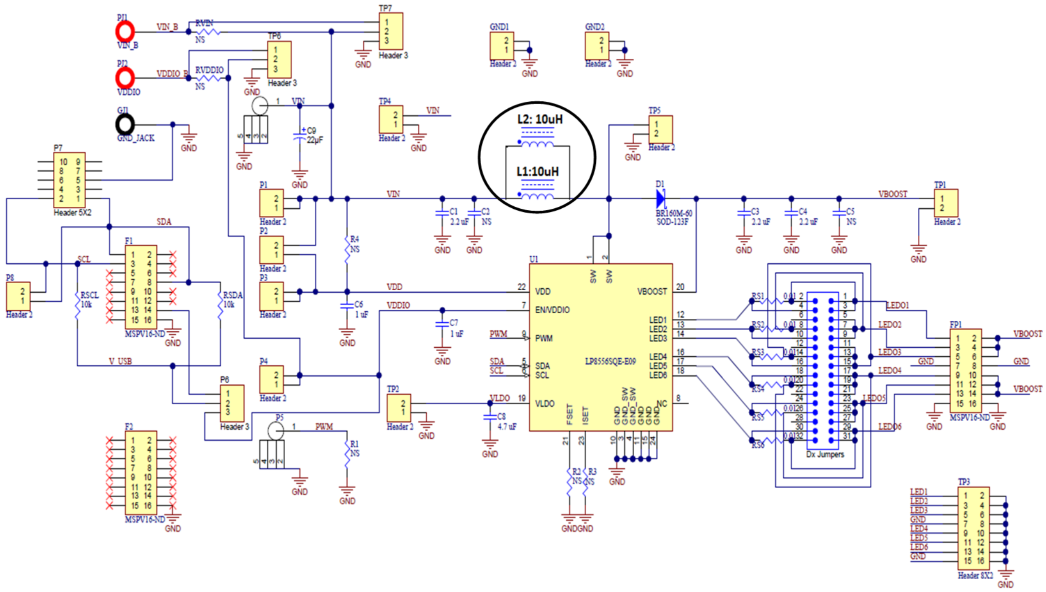

Figure 4. LP8556EVM Schematic with 10µH || 10µH {5µH} Inductors

> **NOTE:** All the three Inductors belongs to IHLP-2020BZ-01 series from Vishay

6 Theoretical Power Dissipation Calculations for Two Test Cases

<table>
<tr><td>Inductance Value</td><td>5 µH</td><td>10µH || 10µH so the core losses remain the same even with putting two inductors</td></tr>
<tr><td>Core Losses
$P_c = K1 \bullet \left(\frac{Vin}{L} \bullet Ton\right)^p$ p=1,for these inductors</td><td>Pc</td><td>Pc/2+Pc/2=Pc.</td></tr>
<tr><td>Value of DC Resistance</td><td>R_{DC}</td><td>{(3/2) * R_{DC} }|| { (3/2) * R_{DC}}</td></tr>
<tr><td>Value of DC current</td><td>I_{DC}</td><td>IDC /2 through each resistance</td></tr>
<tr><td>Conduction Power Loss</td><td>$P_{DC} = I_{DC}^2 R_{DC}$</td><td>(3/4) * P_{DC}</td></tr>
<tr><td>AC Resistance</td><td>R_{AC}</td><td>(3/2) * R_{AC}</td></tr>
<tr><td>Value of RMS</td><td>I_{RMS}</td><td>$I_{RMS}/2$</td></tr>
<tr><td>AC resistance Loss</td><td>P_{AC}</td><td>(3/4)* P_{AC}</td></tr>
</table>

> **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(1)

Input Voltage	3.4 Volts
Output Voltage	31 Volts
Switching Frequency	1.246 Mhz
Full-load Current	0.136A
Input Current	1.72A
Input Power	**5.84 watts**

(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: $\{Power\ Saved \div Input\ Power\} * 100 = 2.3\%$

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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- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

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