Application Report
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Power Budget of an LED Backlight Driver

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ABSTRACT

This application report discusses the Power Budget of an LED backlight driver. It provides experimental and theoretical methods of calculating different losses associated with LED backlight drivers. It also provides an analytical discussion on behavior of different losses vs brightness levels.

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1 Introduction

Today as the demand for more and more efficient LED Backlight drivers is on rise, this exhaustive analysis details the profound impact of different losses on the overall efficiency of the Backlight Drivers and thereby methods to make it more power efficient.

2 Logic Power and LDO losses

Today most of the LED Backlight drivers have separate logic supply and boost input voltage. This logic voltage is either regulated via an LDO to get a clean stepped down voltage or given directly to the logic circuitry. Apart from this it is generally used to drive internal oscillator and driving the gate of switching FET.

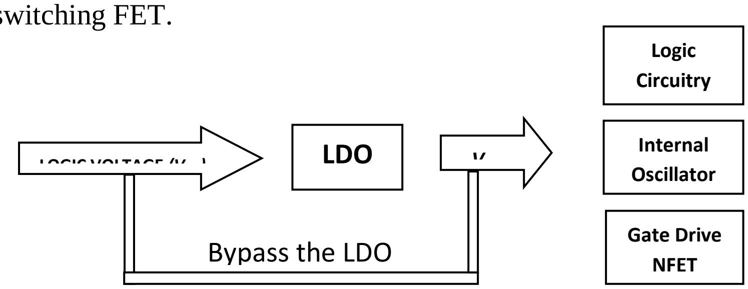

Figure 1.Logic Voltage Tree

<u>Power dissipation in the LDO:</u>

$$P_{LDO} = (V_{DD} - V_{LDO}) \bullet I_{DD} \quad (1)$$

Where V_{DD} is the Input voltage to the LDO, V_{LDO} is the output voltage of the LDO, I_{DD} is the Input current for the V_{DD} power supply.

<u>Total Power dissipation (**LDO + Oscillator +Gate Drive + Logic Circuitry**):</u>

$$P_{DD} = V_{DD} \bullet I_{DD} \quad (2)$$

3 Inductor Losses

Before we get in power dissipated by Inductor, presented below is a model of a loss Inductor, where R_{AC} represents the effective AC resistance, R_{DC} the DC resistance, R_C the effective core losses resistance and L, the actual Inductance.

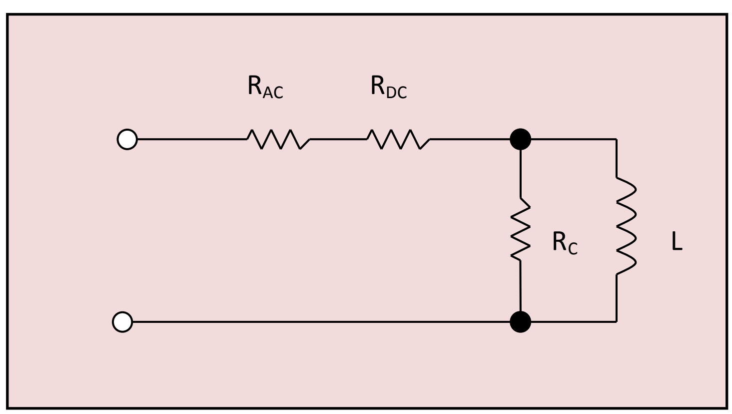

Figure 2. Inductor's Equivalent Loss Model

Inductor Core Losses

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 Fig.3. *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 cause power loss in the inductor core.

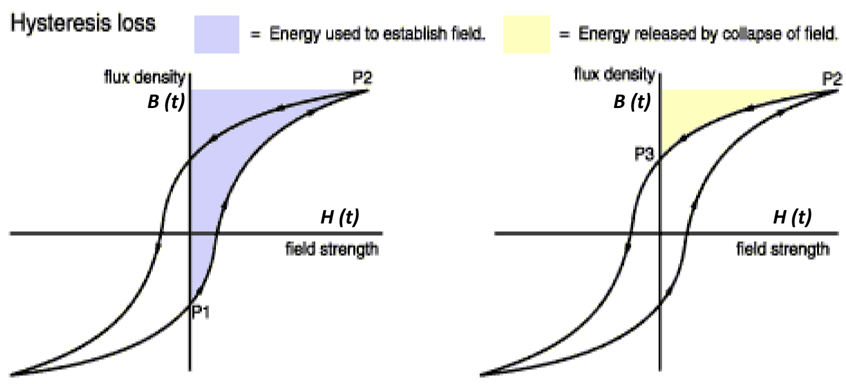

Figure 3. B(t) as a function of H(t) for a sinusoidal input

<u>Hysteresis Losses</u>

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:

$$E(t) = \int_0^T V(t) \bullet I(t)dt \qquad (3)$$

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:

$$E(t) = A \bullet l_E \int_0^T H(t) \bullet dB(t) \qquad (4)$$

where A is the area of the core and l_E is the length of the inductor winding.
Thus, the total energy put into the core over one switching period is the area of the shaded region with-in the *B-H* loop of **Fig. 3** multiplied by the volume of the core. The magnetic field decreases as inductor current ramps down, tracing a different path (following the path traced by ramping down of the arrows in **Fig. 3**) 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 (difference in blue and yellow region in **Fig. 3**) multiplied by the core's volume and the power loss is this energy (E_T) multiplied by the switching frequency(F_{SW}).

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 **Fig. 3**, 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.

$$\Delta B = \mu \bullet \Delta H \qquad (5)$$

Using Ampere's Law
$$\Delta H = n \bullet \frac{\Delta I}{l_E} \qquad (6)$$

Using Faraday's Law $di(t)/dt = Vin/L$

$$\Delta H = n \bullet \frac{Vin}{L} \bullet Ton \qquad (7)$$

Magnetic flux density can be given as

$$\Delta B = K \bullet (\frac{Vin}{L} \bullet Ton) \qquad (8)$$

where $K = \mu \bullet n$

So the Hysteresis CORE LOSSES can be written as

$$Pc = \lambda \bullet \left(\frac{Vin}{L} \bullet Ton \right)^p \qquad (9)$$

where λ is a constant

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

$$Pe = \frac{Vin^2}{Rc} \bullet \frac{Ton}{Tp} \qquad (10)$$

Where: *Vin* is the input voltage to the inductor, *Rc* Inductor core loss resistance, *Ton* is the duty cycle on time and *Tp* is the total time period.

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

Power dissipation in Inductor Windings

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}). ($I_{DC}^2 R_{DC}$).

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

$$I_{RMS} = \Delta I/12 \qquad (11)$$

$$P_{AC} = I_{RMS}^2 \cdot R_{AC} \qquad (12)$$

4 Switching N-FET Losses

Power Dissipation in R_{dson}

As the N-FET operates in the linear region it has a R_{dson} associated with. It's value depends on the process technology used, bias current (indirectly on gate drive voltage).

In the linear region N-FET operates as per the given equation:

$$I_D = K_N^{'} \bullet \left(\frac{W}{L}\right) \bullet \left((V_{GS} - V_T) \bullet V_{DS} - 0.5 \bullet V_{DS}^2\right) \quad (13)$$

Where I_D is the drain current, $K_N^{'} = \mu \bullet C_{OX}$ (μ is the mobility and C_{OX} is the oxide capacitance) V_{GS} is the gate-source voltage, V_T is the channel threshold voltage, V_{DS} is the drain-source voltage.

As V_{DS} is generally very small, so V^2_{DS} can be neglected.

Hence,

$$I_D = K_N^{'} \bullet \left(\frac{W}{L}\right) \bullet (V_{GS} - V_T) \bullet V_{DS} \quad (14)$$

$$R_{dson} = \frac{dV_{DS}}{dI} = \frac{1}{K_N^{'} \bullet \left(\frac{W}{L}\right) \bullet (V_{GS} - V_T)}$$

$$P_{FET\text{-}DC} = I_{FET-DC} \bullet R_{DSON}^2 \quad (15)$$

So, more is the Gate drive voltage (V_{GS}) lesser is the R_{dson} , lesser are the losses in the FET DC resistance. But more is the Gate Drive voltage generally also means more switching losses in driving the gate. So It is a trade-off that needs to be worked with.

$$I_{FET-DC} = I_{IN} - I_{OUT} = \frac{I_{OUT} \bullet D}{1 - D} \quad (16)$$

Where $I_{FET\text{-}DC}$ is the net DC current flowing through N-FET, I_{IN} is the net input current flowing through the boost input voltage and I_{OUT} is the net current flowing through the boost.

Power Dissipation in Switching Losses

Now to quantize switching losses in N-FET we need to know the net capacitance at the drain of the N-FET. We can get these specification from the datasheet.

To experimentally calculate the value, we can do so by observing the rise time of switch node and average inductor current flowing during that short span of time(which comes out to be actually the **peak current** through the Inductor).

$$I = C \bullet \frac{dV}{dT} \quad (17)$$

I_{Peak}=860 mA

Using Information from the Figure-4 of switch Node dV =17.4volts and dt=3.76nsec.

C=150pf

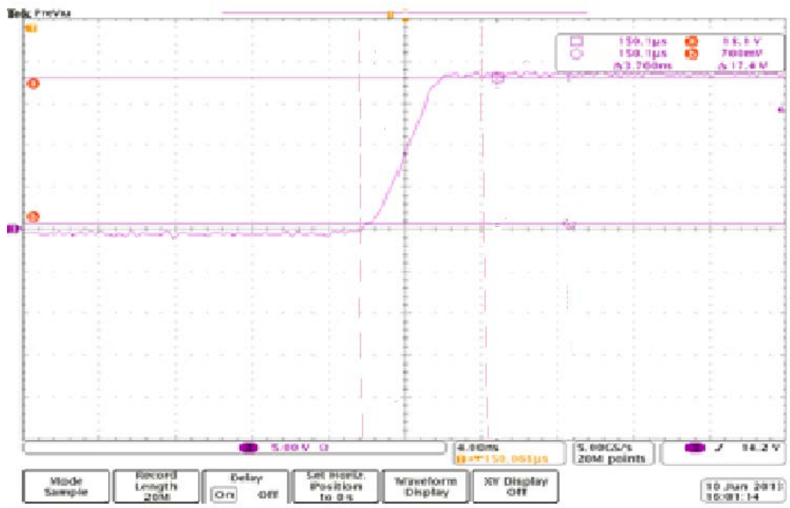

Figure 4. Rising Edge of Switch Node

$$P_{FET-SW} = \frac{1}{2} \bullet C_{DRAIN} \bullet V_{SW}{}^{2} \bullet F_{SW} \quad (18)$$

Where P_{SW} is the switching power loss, C_{DRAIN} is the net capacitance seen at the drain of the FET, F_{SW} is the switching frequency and V_{SW} is net drain to source voltage.

5 Diode Losses:

A lossy diode can be represented by a constant voltage source of 0.7volts in series with a resistance (R_{DIODE}) and parallel with a capacitor .

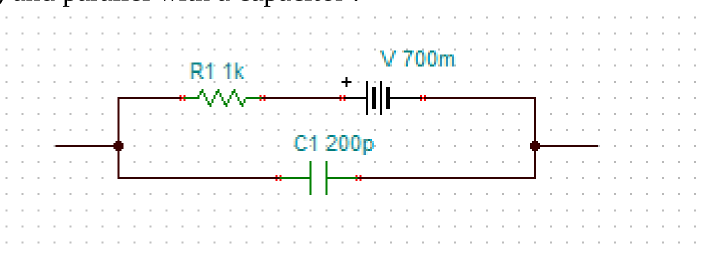

Figure 5. Diode's Equivalent Loss Model

<u>DC Power Dissipation in the Diode</u>

Total power dissipated in the diode is both the sum of power dissipation across resistor and across the threshold voltage (0.7votls).

$$P_{DIODE-DC} = I^{2}_{DC} \bullet R_{DC} + V_{DC} \bullet I_{DC} \quad (19)$$

Where P_{DC} is the DC power dissipated in the diode, I_{DC} is the DC current flowing through the diode, R_{DC} is the DC resistance of the diode and V_{DC} is the constant drop of 0.7volts

<u>Switching Power Dissipation in the Diode</u>

The switching losses in diode are generally a very small part of the total power dissipated for LED Backlight Drivers used for laptops, tablets and mobile phone applications , hence can be neglected.

6 Backlight Driver Losses

DC Power Dissipation in Backlight Driver

$$P_{DC-DRIVER} = I^2_{OUT/CHANNEL} \bullet R_{DC} \bullet N \qquad (20)$$

Where $I_{OUT/CHANNEL}$ is the DC current flowing per channel, R_{DC} is the DC resistance of the Backlight Driver and N are the number of channels.

Switching Losses in Backlight Driver

Switching losses in the backlight driver take place only when the device enters into PWM dimming control. Generally for a LED Backlight Driver the device into PWM dimming control below 25% brightness.

$$P_{SW-DRIVER} = \frac{1}{2} \bullet C \bullet V^2 \bullet F_{PWM-FREQ} \qquad (21)$$

Where $P_{SW\text{-}DRIVER}$ is the switching loss in the driver and V is the total change in the voltage at drain of the driver and C is the net capacitance at the drain and $F_{PWM\text{-}FREQ}$.

Generally these losses are very small because the $F_{PWM\text{-}FREQ}$ is the order of few Khz but still their proportion can increase at lower brightness.

7 Miscellaneous Losses:

Apart from the major losses mentioned above, the power dissipation will also take place in the ESR of the output capacitances, Di-electric of the capacitance, resistance of traces, AC loss in the Diode and AC loss in the Mosfet ,etc .But the proportional share of all these added together as compare to the losses mentioned above is negligible.

8 Comparison of losses in PWM and PFM mode

Losses	PWM Mode	PFM Mode
NFET DC Power Loss	$P_{DC\_PWM} = R_{FET-DC} \bullet \left(\frac{I_{OUT}}{1-D}\right)^2 \bullet (D)^2$ $= V_{FET-ON} \bullet \left(\frac{I_{OUT}}{1-D}\right) \bullet (D)$	$P_{DC\_PFM} = R_{FET-DC} \bullet \left(\frac{I_{OUT}}{1-D}\right)^2 \bullet (D)^2$ $= V_{FET-ON} \bullet \left(\frac{I_{OUT}}{1-D}\right) \bullet (D)$
NFET Switching Loss	$P_{SW\_PWM} = \left(\frac{C_{DRAIN} \bullet V^2_{SW}}{2}\right) \bullet F_{SW}$	$P_{SW\_PFM} = \left(\frac{C_{DRAIN} \bullet V^2_{SW}}{2}\right) \bullet F_{SW} \bullet \left(\frac{\lambda}{K}\right)$
Inductor DC Power Loss	$P_{DC\_PWM} = R_{DC} \bullet \left(\frac{I_{OUT}}{1-D}\right)^2$	$P_{DC\_PFM} = R_{DC} \bullet \left(\frac{I_{OUT}}{1-D}\right)^2$
Inductor AC Power Loss	$P_{AC\_PWM} = R_{AC} \bullet (\Delta I)^2$	$P_{AC\_PFM} = R_{AC} \bullet (\Delta I_{PFM})^2 \bullet \left(\frac{\lambda}{K}\right)$
Inductor Core Loss	$P_{C\_PWM} = k \bullet (\Delta B)$	$P_{C\_PFM} = k \bullet (\Delta B_{PFM}) \bullet \left(\frac{\lambda}{K}\right)$

Diode Switching Losses	$P_{DSW\_PWM} = \left(\frac{C_D \bullet V_{OUT}^2}{2} \right) \bullet F_{SW}$	$P_{DSW\_PFM} = \left(\frac{C_D \bullet V_{OUT}^2}{2} \right) \bullet F_{SW} \bullet \frac{\lambda}{k}$
Diode DC Loss	$P_{DIODE-DC\_PWM} = R_D \bullet (I_{OUT})^2 + V_{DC} \bullet I_{DC}$	$P_{DIODE-DC\_PFM} = R_D \bullet (I_{OUT})^2 + V_{DC} \bullet I_{DC}$
Driver DC Losses	$P_{DRIVER-DC\_PWM} = I_{OUT/CHANNEL}^2 \bullet R_{DC} \bullet N$	$P_{DRIVER-DC\_PFM} = I_{OUT/CHANNEL}^2 \bullet R_{DC} \bullet N$

Where λ is the repeated number of switching cycles occurring in a given time in PFM mode and k are the actual number of switching cycles that would have occurred in the given time.

Example: Let the switching frequency of device be 500Khz (2usec), the device enters into PFM mode and is now switching at a rate of 10 cycles in 30usec.whereas if it would have entered into PWM mode it would have 15 switching cycles in 30usec.So the value of λ is 10 and value of k is 15.
Thereby you can calculate the change in the different losses with the device entering the PFM mode.

9 To validate the above assertions and to calculate the share of different losses under a given set of conditions the following test setup was used.

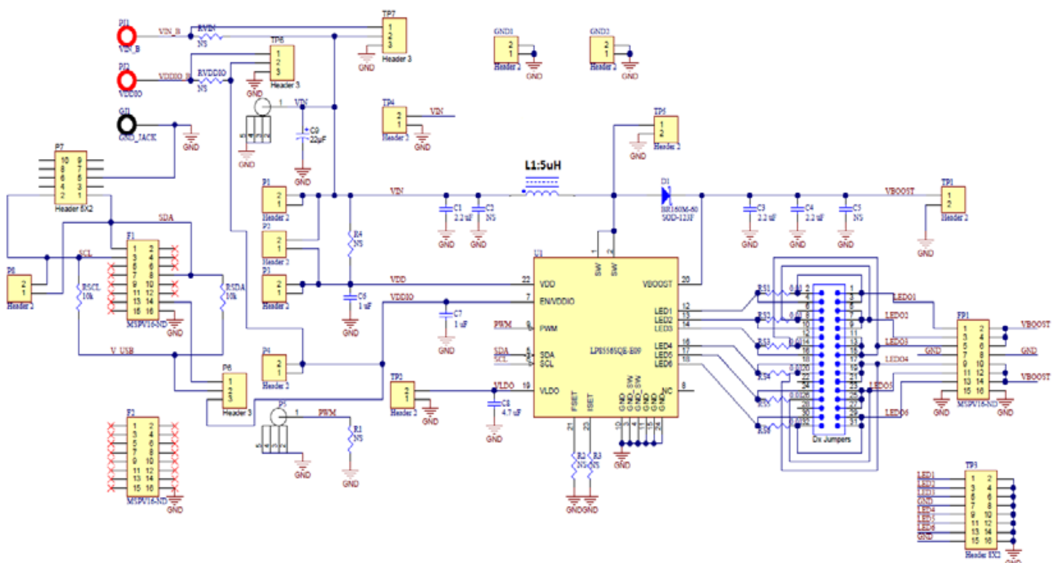

Figure 6:LP8556 EVM schematic

- The Inductor belongs to IHLP-2020BZ-01 series from Vishay

10 Specifications used for the above test case:

Input Voltage	3.8Volts
Output Voltage	17.2Volts
Switching Frequency	1.246Mhz
Dimming Control	Adaptive
Switch Point	25%
Load	6s/6p
PWM output Frequency after 25% switch point	10Khz

PWM Input Frequency	20Khz
Full load current	0.135 Amperes

11 Variation in different Losses with Brightness

Brightness	100%	75%	50%	25%	20%	10%
Logic Power +Gat Loss	0.01635	0.01635	0.01389	0.01062	0.00995	0.00877
LDO Power Loss	0.00244	0.00244	0.00207	0.00159	0.00149	0.00131
Inductor DC Power Loss	0.09674	0.04842	0.02086	0.00501	0.00296	0.00108
Inductor AC Power Loss	0.06013	0.06077	0.06341	0.04555	0.03241	0.01639
Inductor Core Loss	0.03453	0.03585	0.03760	0.02572	0.01783	0.00850
Diode DC Loss	0.11558	0.08088	0.05201	0.02454	0.01894	0.01015
Mosfet DC Loss	0.09030	0.04015	0.01745	0.00792	0.00581	0.00309
Mosfet Switching Loss	0.02600	0.02600	0.02600	0.02000	0.00803	0.00603
Driver DC Losses	0.07187	0.05447	0.03469	0.01750	0.01390	0.00745
Miscellaneous Losses	0.00370	0.00221	0.00181	0.00072	0.00272	0.00359
Total Losses	0.51765	0.36754	0.26979	0.15916	0.11405	0.06635

12 Variation in Output power with Brightness

Brightness	100%	75%	50%	25%	20%	10%
Output Power	2.33103	1.73029	1.15013	0.56091	0.44502	0.23835

13 Brightness vs Inductor Losses

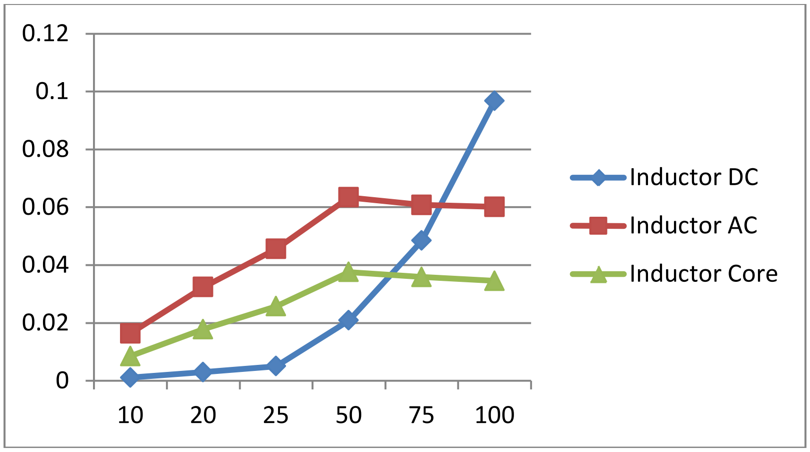

Figure 7: Variation of Inductor Losses with Brightness

14. Brightness vs Mosfet DC+ Diode Losses

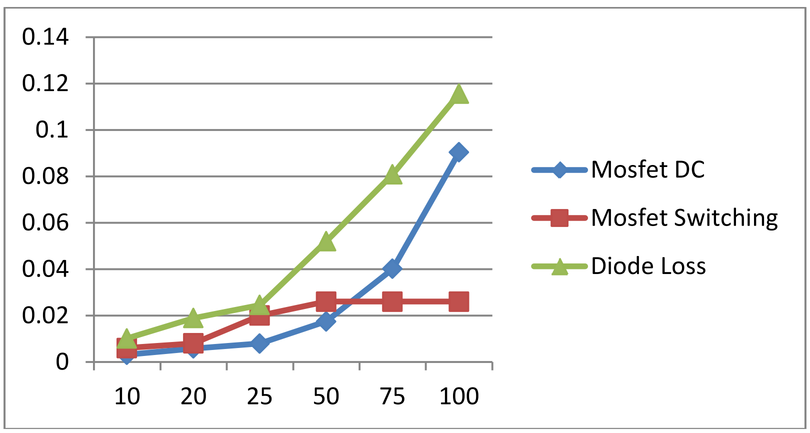

Figure 8: Variation of Mosfet DC+ Diode Losses with Brightness

15. Brightness vs Remaining Losses

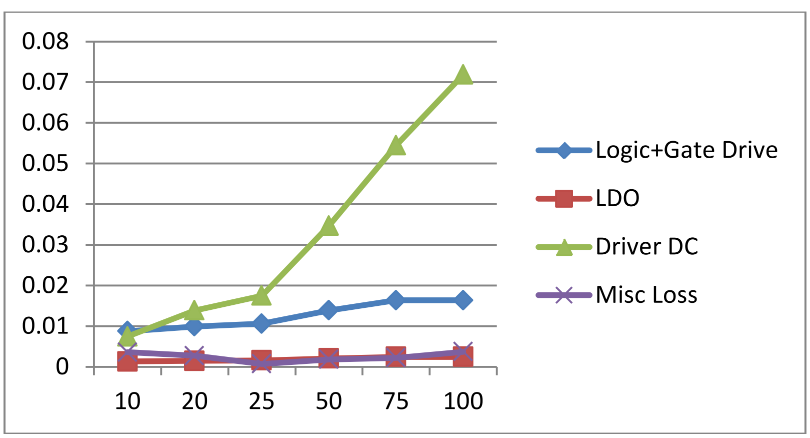

Figure 9: Variation of Mosfet DC+ Diode Losses with Brightness

14 Full Load Comparison: Different Losses and Output Power

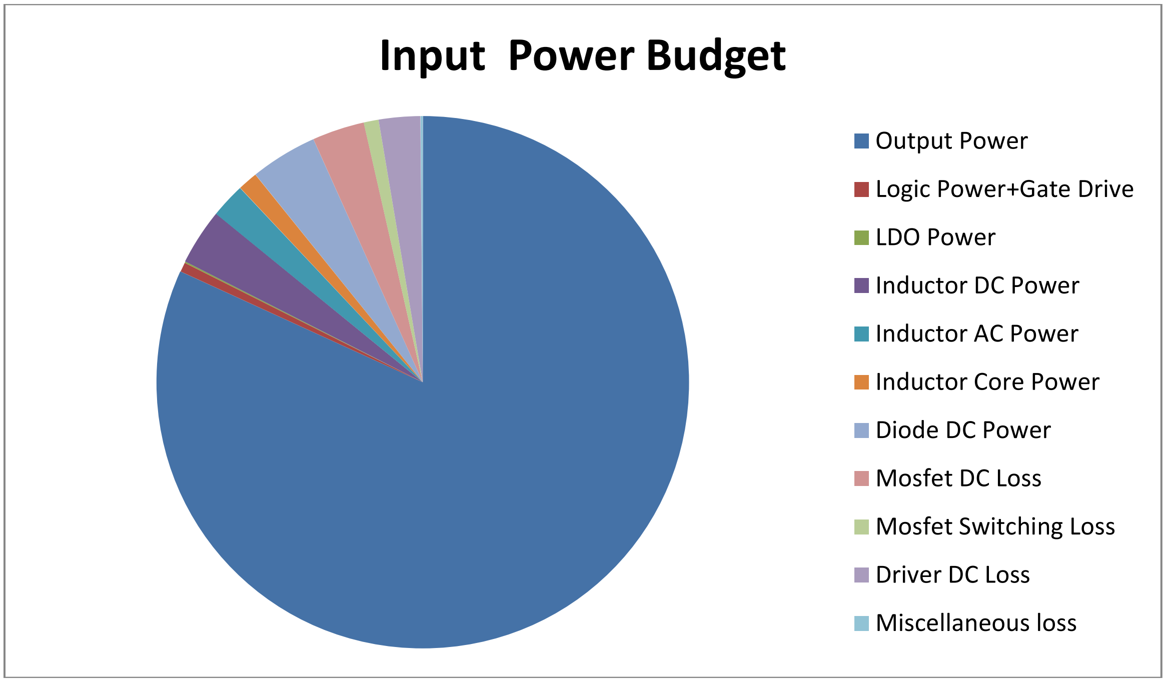

Figure 10: Input Power Budget

15 Conclusion

This application report analyzes different LED Backlight related power losses and calculations for each part of the power loss. The Effects of PFM mode entry are discussed and solutions are provided for the same.

Once we have a clear understanding of the above losses faced in the Backlight drivers, we can look up the reasons for the loss in efficiency and trade-offs concerning these Losses.

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   This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

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FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *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.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d’usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

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http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

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1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry’s Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けていないものがあります。 技術適合証明を受けていないもののご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。

1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。 日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿６丁目２４番１号
西新宿三井ビル

3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page
電力線搬送波通信についての開発キットをお使いになる際の注意事項については、次のところをご覧ください。http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_02.page

4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

5. *Accuracy of Information:* To the extent TI provides information on the availability and function of EVMs, TI attempts to be as accurate as possible. However, TI does not warrant the accuracy of EVM descriptions, EVM availability or other information on its websites as accurate, complete, reliable, current, or error-free.

6. *Disclaimers:*

   6.1 EXCEPT AS SET FORTH ABOVE, EVMS AND ANY WRITTEN DESIGN MATERIALS PROVIDED WITH THE EVM (AND THE DESIGN OF THE EVM ITSELF) ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." TI DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING SUCH ITEMS, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF ANY THIRD PARTY PATENTS, COPYRIGHTS, TRADE SECRETS OR OTHER INTELLECTUAL PROPERTY RIGHTS.

   6.2 EXCEPT FOR THE LIMITED RIGHT TO USE THE EVM SET FORTH HEREIN, NOTHING IN THESE TERMS AND CONDITIONS SHALL BE CONSTRUED AS GRANTING OR CONFERRING ANY RIGHTS BY LICENSE, PATENT, OR ANY OTHER INDUSTRIAL OR INTELLECTUAL PROPERTY RIGHT OF TI, ITS SUPPLIERS/LICENSORS OR ANY OTHER THIRD PARTY, TO USE THE EVM IN ANY FINISHED END-USER OR READY-TO-USE FINAL PRODUCT, OR FOR ANY INVENTION, DISCOVERY OR IMPROVEMENT MADE, CONCEIVED OR ACQUIRED PRIOR TO OR AFTER DELIVERY OF THE EVM.

7. *USER'S INDEMNITY OBLIGATIONS AND REPRESENTATIONS.* USER WILL DEFEND, INDEMNIFY AND HOLD TI, ITS LICENSORS AND THEIR REPRESENTATIVES HARMLESS FROM AND AGAINST ANY AND ALL CLAIMS, DAMAGES, LOSSES, EXPENSES, COSTS AND LIABILITIES (COLLECTIVELY, "CLAIMS") ARISING OUT OF OR IN CONNECTION WITH ANY HANDLING OR USE OF THE EVM THAT IS NOT IN ACCORDANCE WITH THESE TERMS AND CONDITIONS. THIS OBLIGATION SHALL APPLY WHETHER CLAIMS ARISE UNDER STATUTE, REGULATION, OR THE LAW OF TORT, CONTRACT OR ANY OTHER LEGAL THEORY, AND EVEN IF THE EVM FAILS TO PERFORM AS DESCRIBED OR EXPECTED.

8. *Limitations on Damages and Liability:*

   8.1 *General Limitations*. IN NO EVENT SHALL TI BE LIABLE FOR ANY SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL, OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THESE TERMS ANDCONDITIONS OR THE USE OF THE EVMS PROVIDED HEREUNDER, REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. EXCLUDED DAMAGES INCLUDE, BUT ARE NOT LIMITED TO, COST OF REMOVAL OR REINSTALLATION, ANCILLARY COSTS TO THE PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES, RETESTING, OUTSIDE COMPUTER TIME, LABOR COSTS, LOSS OF GOODWILL, LOSS OF PROFITS, LOSS OF SAVINGS, LOSS OF USE, LOSS OF DATA, OR BUSINESS INTERRUPTION. NO CLAIM, SUIT OR ACTION SHALL BE BROUGHT AGAINST TI MORE THAN ONE YEAR AFTER THE RELATED CAUSE OF ACTION HAS OCCURRED.

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9. *Return Policy.* Except as otherwise provided, TI does not offer any refunds, returns, or exchanges. Furthermore, no return of EVM(s) will be accepted if the package has been opened and no return of the EVM(s) will be accepted if they are damaged or otherwise not in a resalable condition. If User feels it has been incorrectly charged for the EVM(s) it ordered or that delivery violates the applicable order, User should contact TI. All refunds will be made in full within thirty (30) working days from the return of the components(s), excluding any postage or packaging costs.

10. *Governing Law:* These terms and conditions shall be governed by and interpreted in accordance with the laws of the State of Texas, without reference to conflict-of-laws principles. User agrees that non-exclusive jurisdiction for any dispute arising out of or relating to these terms and conditions lies within courts located in the State of Texas and consents to venue in Dallas County, Texas. Notwithstanding the foregoing, any judgment may be enforced in any United States or foreign court, and TI may seek injunctive relief in any United States or foreign court.

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