Introduction
The LYTSwitch™-3 family is ideal for single-stage power factor corrected constant current LED drivers for bulbs and recessed lighting up to 20 W. Each device combines a high-voltage power MOSFET, variable frequency and on-time control engine, fast start-up with soft-finish, selectable dimming curves with load shutdown at deep dimming and protection functions including instantaneous line over-voltage shutdown, output short-circuit auto-restart, output overvoltage latch-off and thermal-foldback with over-temperature-shutdown into a single package, thus greatly reducing component count. Its internal feedback controller is capable of indirect and direct output current sensing that can be set via external programming resistor, thus eliminating the need for optocoupler, especially with isolated design applications.

The integrated 725 V power MOSFET provides a large Drain voltage margin in high-line input AC applications, thus increasing reliability. A 625 V power MOSFET option is also offered to reduce cost in applications where the voltage stress on the power MOSFET is low.

Topology neutral LYTSwitch-3 operates in discontinuous conduction mode (DCM) for tight tolerance output current regulation over line input range and operating temperature, high power factor with significantly low harmonic currents via its internal control algorithm. The combination of a low-side switching topology, cooling via electronically quiet SOURCE pins, frequency jitter and DCM operation which inherently eliminates reverse current from the output diode when the power MOSFET is in OFF-state reducing high frequency noise allow the use of a simple and small input pi filter yet produces low EMI and audible noise during dimming (e.g. low input capacitance reduces THD and increases PF).

All LYTSwitch-3 ICs have a built-in TRIAC detector that discriminates accurately between leading-edge and trailing-edge type dimmers. This capability together with load monitoring circuitry regulates bleeder current during each AC line half-cycle. The controller disables the bleeder circuit completely if no dimmer is detected, significantly increasing efficiency.

Output Power Table

<table>
<thead>
<tr>
<th>Product</th>
<th>Output Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>LYT3x4D</td>
<td>5.7 W</td>
</tr>
<tr>
<td>LYT3x5D</td>
<td>8.8 W</td>
</tr>
<tr>
<td>LYT3x6D</td>
<td>12.6 W</td>
</tr>
<tr>
<td>LYT3x8D</td>
<td>20.4 W</td>
</tr>
</tbody>
</table>

Table 1. LYTSwitch-3 Output Power Table.
Typical Circuit Configuration

The LYTSwitch-3 device family is topology neutral and can be used in any switching configuration such as buck (tapped-buck), buck-boost (tapped buck-boost), boost and flyback (isolated and non-isolated) making it broadly applicable to any design requirement regardless of LED voltage string. The high level integration of LYTSwitch-3 family enables ease of design optimization both in converter side and bleeder circuit resulting in shortened development time.

Circuit in Figures 1 and 2 show a typical low component count TRIAC dimmable LED driver using LYTSwitch-3 in Buck and Buck-Boost configuration respectively.

Figure 1. Low Component Count Typical Circuit Dimmable Low-Line Buck Topology with LYTSwitch-3 (30 External Components; $R_{OUT}$ is Optional Component).

Figure 2. Low Component Count Typical Circuit Dimmable High-Line Buck-Boost Topology with LYTSwitch-3 (31 external components; $R_{OUT}$ and $R_L$ are Optional Components).
Notice some minor differences in the bleeder circuit configuration between the low-line driver circuit – Figure 1 and the high-line driver circuit – Figure 2. Other than topology, using two resistors ($R_L$ and $R_{L1}$) for the LINE-SENSE pin to handle higher voltage stress if using 1/4 W resistor (one is sufficient if 1/2 W is to be used) and two bleeder resistors ($R_B$ and $R_{B1}$) to increase thermal handling capacity at high-line, the main difference is that a passive RC bleeder ($R_P$ and $C_P$) was employed for stronger damping capability because there is much higher energy ringing can be generated at high-line when the TRIAC dimmer turns on, while the low-line design did not have the RC bleeder, the ringing energy is much less. However, it employed a blocking diode (D1) to keep the energy stored in the input filter from discharging current through the active bleeder which could consequently pull less current from the dimmer making the TRIAC turn-off prematurely, especially at low conduction angle.

**Scope**

This application note is intended for users designing an AC-DC LED driver using LYTSwitch-3 family devices. A simplified step-by-step instruction will guide the user in selecting key components, especially in designing the magnetics necessary to quickly jump start the design process and come up with a sound prototype design. This application note refers directly to the PXIs design spreadsheet that is a part of the PI Expert™ design software suite (https://piexpertonline.power.com/site/login).

In this application note the user may also find product Reference Design Kits (RDK) and Design Engineering References (DER) useful. These contain a prototype board, a link to an engineering report that contains complete design information including gerber for the printed circuit-board (PCB) and test data and product samples. Further details on downloading PI Expert, RDKs and updates to this document can be found at Power Integrations’ website www.power.com.

### Choosing Switching Topology

The LYTSwitch-3 device family can be used in any switching topology configuration such as buck (tapped-buck), buck-boost (tapped buck-boost), boost and flyback (isolated and non-isolated) making it broadly applicable to any design requirement regardless of LED voltage string. Choosing the right topology to use can be challenging at times, however using LYTSwitch-3 the designer only needs to know is the output voltage and efficiency merit in choosing the suitable topology to use. Table 2 shows a quick selection guide.

<table>
<thead>
<tr>
<th>Output Voltage (V)</th>
<th>Recommended Topology</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low-Line</strong></td>
<td><strong>High-Line</strong></td>
<td>Tapped-Buck</td>
</tr>
<tr>
<td>&lt; 12</td>
<td>&lt; 25</td>
<td>✓</td>
</tr>
<tr>
<td>13 – 60</td>
<td>27 - 100</td>
<td></td>
</tr>
<tr>
<td>&gt; 24</td>
<td>&gt; 48</td>
<td></td>
</tr>
<tr>
<td>$V_{out} &gt; V_{in}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any Voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum Efficiency Estimate</td>
<td>&gt;80</td>
<td>&gt;87</td>
</tr>
</tbody>
</table>

*Table 2. Recommended Topology Selection Guide.*
Design Example

Design an 8 W TRIAC dimmable non-isolated LED driver using a LYTSwitch-3 device and having an output voltage of 72 V, output current of 115 mA, ±5% regulation tolerance with an input voltage range of 195 VAC to 265 VAC and 85% minimum efficiency. Output current should shutdown at low conduction angle to avoid light output shimmer. (Refer to DER-524 for complete report through this link https://led-driver.power.com/design-support/reference-designs/design-examples/der-524-8-w-triac-dimmable-high/)

Step-by-Step Design Procedure

For this particular specification a buck-boost topology is suitable, hence the corresponding PIXls designer spreadsheet will be used. Visit https://piexpertonline.power.com/site/login

Step 1- Enter Application Variables

<table>
<thead>
<tr>
<th></th>
<th>ENTER APPLICATION VARIABLES</th>
<th>Design Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>VACMIN</td>
<td>195.0 Volts RMS Minimum AC line voltage.</td>
</tr>
<tr>
<td>4</td>
<td>VACNOM</td>
<td>230.0 Volts RMS Nominal AC line voltage.</td>
</tr>
<tr>
<td>5</td>
<td>VACMAX</td>
<td>265.0 Volts RMS Maximum AC line voltage.</td>
</tr>
<tr>
<td>6</td>
<td>FL</td>
<td>50 Hertz AC line frequency.</td>
</tr>
<tr>
<td>7</td>
<td>VO_MIN</td>
<td>64.8 Volts DC Guaranteed minimum VO that maintains output regulation.</td>
</tr>
<tr>
<td>8</td>
<td>VO</td>
<td>72.0 Volts DC Worst case normal operating output voltage.</td>
</tr>
<tr>
<td>9</td>
<td>VO_OVP_MIN</td>
<td>85.4 Volts DC Minimum Voltage at which output voltage protection may be activated.</td>
</tr>
<tr>
<td>10</td>
<td>IO</td>
<td>115.0 m-Amperes Average output current specification.</td>
</tr>
<tr>
<td>11</td>
<td>EFFICIENCY</td>
<td>0.87 Dimensionless Total power supply efficiency.</td>
</tr>
<tr>
<td>12</td>
<td>Z</td>
<td>0.50 Dimensionless Loss allocation factor.</td>
</tr>
<tr>
<td>13</td>
<td>PO</td>
<td>8.28 Watts Output power.</td>
</tr>
</tbody>
</table>

\[
PO = \int IO(t) \times VO(t) dt
\]

LYTSwitch-3 ICs have built-in latching output overvoltage protection (OVP). Once the current exceeds the \( I_{OVP} \) threshold via the OUTPUT COMPENSATION pin the IC will trigger a latch to disable switching thus preventing the output from rising further. Recycling the AC supply is needed to reset this protection mode from latch-off state. The minimum voltage at which output voltage protection may be activated is calculated in cell VO_OVP_MIN [E9].

\[
VO_{OVP\_MIN} = \left( R_{OC} \times I_{OVP} + V_{OC} \right) \times \frac{N_S}{N_B}
\]

Where:
- \( R_{OC} \) is the feedback resistor connected to OUTPUT COMPENSATION pin from the bias supply. Typical resistance value set at 100 \( \mu \)A \( I_{OC} \) current for nominal output voltage and output current.

Enter Input Voltage and Line Frequency: VACMIN [C3], VACNOM [C4], VACMAX [C5], FL [C6]

LYTSwitch-3 devices are intended for single range input voltages applications. Optimum electrical performance, dimmer compatibility and cost are best achieved with a single input voltage range as opposed to wide input voltage range which will require bigger components for both converter and bleeder circuits.

Enter Output Parameters: VO [C8], IO [C10], Efficiency [C11], Z [C12]

In a high power factor single-stage LED driver, the output will have significantly large low frequency ripple with twice the frequency of the input line, it is recommended to use a power meter when measuring the output power for accuracy. \( P_o \) [E13] is calculated based on the integral product of \( V_o \) [C8] and \( I_o \) [C10], which is used to choose device size.

\[
R_{OC} = \frac{V_{BIAS} - V_{OC}}{100 \ \mu A}
\]

\( I_{OVP} \): Latching overvoltage current threshold. Minimum limit - 127 \( \mu \)A.
\( V_{OC} \): OUTPUT COMPENSATION pin voltage. Typical - 2.25 V.
NS: Output winding turns.
NB: Bias winding turns.

The output overvoltage is detected through the bias supply which is calculated in the PIXls. The accuracy actual overvoltage trigger point will be dependent on the magnetic coupling between bias and output winding.

For direct output voltage sensing, NS/NB = 1. Or for PIXls calculation, enter VBIAS [E76] = VO [C8].

Efficiency [C11], \( \eta \)

Use efficiency estimate in Table 2. Once the actual unit is available enter the measured efficiency for fine tuning the output current.

\[
\eta = \frac{PO}{P_{IN}}
\]

Loss Allocation Factor, Z [E12]

Allocation factor is the ratio of output and total loss. It is used in the efficiency of the DC-DC section of the converter for calculating the input power and drain current as seen by LYTSwitch-3 IC. Typical value is 0.5.

\[
Z = \frac{Secondary \ Losses}{Total \ Losses}
\]

Table 4. Standard Worldwide Input Line Voltages and Line Frequencies.
Step 2 - LYTSwitch-3 Design Variables

The ACTUAL DEVICE [C20] will be automatically selected based on the output power calculated and input voltage. In the BREAKDOWN VOLTAGE [C18] cell, a 725 V part is automatically chosen for high-line input, while 650 V for low-line input. However, the user can override the default selection dependent on the requirement and choose a 650 V part, if the actual measured stress voltage on the power MOSFET is much less than 650 V and / or choose a device with smaller power MOSFET, if the thermal condition is not critical.

The corresponding data sheet current limit specifications (ILIMITMIN [E21], ILIMITTYP [E22], and ILIMITMAX [E23]) of the selected device are displayed, which are needed for calculating other design magnetic parameters.

MOSFET Peak Current, IP_MOSFET [E24]

To ensure DCM operation, the theoretical highest operating peak current should not exceed device minimum current limit of device.

Minimum "ON" Time, TONMIN [E25]

The minimum on-time operation is based on the minimum output voltage VO_MIN [E7] to ensure tight output current regulation.

Maximum Duty Cycle, DC_MAX [E26]

The maximum operating duty cycle (DC_MAX) is based on the maximum tolerance of output voltage (assumed to be 110%) to ensure tight output current regulation.

Device MOSFET Average and RMS Currents, IAVG_MOSFET [E27], IRMS_MOSFET [E28]

MOSFET average current (IAVG_MOSFET) and RMS current (IRMS_MOSFET) are given to estimate the conduction loss of device MOSFET.

Ripple to Peak Current Ratio, KDP [E29]

KDP > 1 is maintained up to 110° conduction angle in the dimming curve to ensure discontinuous conduction mode of operation (Figure 4).

MOSFET Drain to Source Voltage Stress, VDRAIN [E30]

Drain to Source voltage stress (VDRAIN) is calculated based on maximum input voltage and 120% of VO to account for overvoltage condition.

Figure 4. LYTSwitch-3 Design Variables Section of PIXis Design Spreadsheet.

Figure 5. Inductor Current Illustration. KDP of > 1 Ensures Discontinuous Conduction Mode (DCM) of Operation.

Figure 6. Graph shows Maximum Dimming Curve with RBS = 6 kΩ and Minimum Dimming Curve with RBS = 12 kΩ Dimming Curve Programming Resistor. KDP > 1 is Maintained up to the Knee of the Dimming Curve as Shown in the Graph.

Figure 7. Minimum Dimming Curve with RBS = 12 kΩ Dimming Curve Programming Resistor with Load Shut Down (LSD).
Step 3 – Device Programming Parameters

### Dimming Curve Selection RBS [C35]
LYTSwitch-3 device dimming is a closed loop function with respect to conduction angle in which dimming is achieved by adjusting the internal feedback voltage reference (VFB) of the IC in the same direction as the TRIAC conduction angle, which is measured from the input bus via a resistor to the LINE-SENSE (L) pin. As the TRIAC conduction angle decreases or increases, the FEEDBACK (FB) pin voltage (VFB) proportionally increases or decreases respectively (see Figure 10). Many dimmers available in the market have limited maximum conduction angle (e.g. < 130°) that when an incandescent or a LED bulb is connected to such dimmer, loses light output significantly. To maintain light output brightness, LYTSwitch-3 devices maintain full output current regulation up to approximately 115° conduction angle before it starts reducing output current to dim the light. The VFB is maintained at 300 mV up to 115° and reduced proportionally with 5% (~15 mV) until load shutdown if enabled, is activated or the TRIAC stops conducting due to lack of holding current (see Figures 6 and 7).

Depending on the designer’s dimming preference, there are three (3) dimming curves to choose from, which can be programmed through a selection of RBS resistor value shown in Table 5. The 24 kΩ RBS selection has Load Shut Down (LSD) feature, in which the IC terminates the switching once conduction angle falls below 40° and remains off unless the conduction angle increases above 50° (see Figure 7). During the LSD condition the bleeder is active to keep the TRIAC dimmer conducting to minimize pop-on and dead travel. Should the TRIAC unable to maintain conducting, the bleeder would still be active to keep the input voltage from rising due to a leakage current from the dimmer, this prevents possible ghosting or fluttering of the light output while the dimmer is off. Usually the voltage leaks via the pilot lamp and / or a large internal shunt capacitor of a dimmer.

The 6 kΩ and 12 kΩ RBS selections offer no-Load Shut-Down (LSD) feature, while both have extended dimming range, the 12 kΩ RBS selection has the widest dimming range among the dim curves. See Figure 6.

![Schematic](https://via.placeholder.com/150)

**Table 5:** BLEEDER SENSE (BS) Pin Resistor Programming Table.

<table>
<thead>
<tr>
<th>RBS (Ω)</th>
<th>Dim Curve</th>
<th>Dimming-Start Conduction Angle</th>
<th>Load Shut Down (LDS)</th>
<th>Cut-In Conduction Angle</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 k</td>
<td>Max. Dim Curve</td>
<td>115°</td>
<td>No</td>
<td>Dependent on Dimmer</td>
<td>Lowest Bleeder Dissipation</td>
</tr>
<tr>
<td>12 k</td>
<td>Min. Dim Curve</td>
<td>125°</td>
<td>No</td>
<td>Dependent on Dimmer</td>
<td>Highest Dim Range</td>
</tr>
<tr>
<td>24 k</td>
<td>Min. Dim Curve</td>
<td>125°</td>
<td>Yes</td>
<td>50°</td>
<td>Reduced Dim Range</td>
</tr>
</tbody>
</table>
These are topology dependent and programmed through $R_{DS}$ resistor value. With topologies where the output ground reference is not common with the input ground reference of the IC controller such as buck or isolated flyback, indirect current sensing (IPSR) is used, this will eliminate the need for a use of a complex optocoupler or a level shifter circuitry to detect the output current. The sensing is done via the $R_{DC}$ sensing resistor where the signal is fed into the DRIVER CURRENT SENSE (DS) pin of the IC through the $R_{DS}$ resistor. The signal is processed internally and the interpolated value is outputted to the FEEDBACK pin which is filtered by $C_{FB}$ and $R_{FB}$ (see Figure 11). The latter is used if the ground references are common between the input and output circuity. With direct sensing (DSSR), the $R_{DS}$ resistor is just simply connected to the SOURCE (S) pin and the FEEDBACK pin is used to sense directly the output current via $R_{FB2}$ sense resistor connected in series with the load and a small low pass filter ($R_{FB}$ and $C_{FB}$) is needed for the feedback signal (Figure 12).

Table 6. RDS Resistor Selection for Topology Current Sensing.

<table>
<thead>
<tr>
<th>$R_{DS}$ (Ω)</th>
<th>Current Sensing</th>
<th>Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 k</td>
<td>Indirect or Primary Sense Regulation (IPSR)</td>
<td>Buck, Buck-Boost, Isolated Flyback</td>
</tr>
<tr>
<td>12 k</td>
<td>Direct or Secondary Sense Regulation (DSSR)</td>
<td>Non-Isolated Flyback, Boost</td>
</tr>
</tbody>
</table>

Figure 10. Dimming Curve Showing Feedback Voltage in Relation to Output Current versus Conduction Angle.

Figure 11. Schematic Shows $R_{DS}$, $R_{DC}$, $R_{FB}$ and $C_{FB}$ used for Indirect Sensing of Output Current with Buck Topology.
Step 4 – Enter Inductor Core and Construction

Variables CORE TYPE, AE, LE, AL, VE, AW, BW

Core type selection as a default is set in Auto. The spreadsheet will automatically choose the smallest, but commonly used core suitable for the output power specified. Should the designer prefers a different type of core to use, a list of common cores can be selected from the drop down menu in cell Core Type [C41] of the PIXls spreadsheet or enter manually the parameters for the desired core to use.

Override cells can be used to enter the core and bobbin parameters onto cells AE [C42], LE [C43], AL [C44], VE [C45], AW [C46] and BW [C47]. This is useful if a preferred core is not on the list, or the specified core or bobbin information differs from that referenced by the spreadsheet.

<table>
<thead>
<tr>
<th>ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES</th>
<th>CELL</th>
<th>VALUE 1</th>
<th>VALUE 2</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORE TYPE</td>
<td>40</td>
<td>EE10</td>
<td>EE10</td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>42</td>
<td>12.10</td>
<td>12.10</td>
<td>mm²</td>
</tr>
<tr>
<td>LE</td>
<td>43</td>
<td>26.10</td>
<td>26.10</td>
<td>mm</td>
</tr>
<tr>
<td>AL</td>
<td>44</td>
<td>850</td>
<td>850</td>
<td>nH/T²</td>
</tr>
<tr>
<td>VE</td>
<td>45</td>
<td>300</td>
<td>300</td>
<td>mm³</td>
</tr>
<tr>
<td>AW</td>
<td>46</td>
<td>12.21</td>
<td>12.21</td>
<td>mm²</td>
</tr>
<tr>
<td>BW</td>
<td>47</td>
<td>6.60</td>
<td>6.60</td>
<td>mm</td>
</tr>
</tbody>
</table>

Figure 12. Schematic shows $R_{DS}$, $R_{FB2}$, $R_{FB}$ and $C_{FB}$ used for Direct Sensing of Output Current with Non-Isolated Flyback.

Figure 13. Inductor Core and Construction Variables Input of the Design Spreadsheet.
Step 5 – Enter Transformer Design Parameters

<table>
<thead>
<tr>
<th>51 TRANSFORMER DESIGN PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 INDUCTANCE 420 420 μ-Henrys Typical value of inductance.</td>
</tr>
<tr>
<td>54 INDUCTOR_TOL 5 5 % Tolerance of inductance.</td>
</tr>
<tr>
<td>55 INDUCTANCE_MIN 399 μ-Henrys Minimum value of inductance.</td>
</tr>
<tr>
<td>56 INDUCTANCE_MAX 441 μ-Henrys Maximum value of inductance.</td>
</tr>
<tr>
<td>57 N 124 124 Turns Number of inductor turns.</td>
</tr>
<tr>
<td>58 ALG 27.32 nH/T² Gapped core effective inductance.</td>
</tr>
<tr>
<td>60 BM 3506 Gauss</td>
</tr>
<tr>
<td>61 BAC 4168 Gauss Peak flux density.</td>
</tr>
<tr>
<td>62 LG 1753 Gauss Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak).</td>
</tr>
<tr>
<td>63 LAYERS_DESIRED 5 5 Dimensionless Desired number of inductor's winding layers.</td>
</tr>
<tr>
<td>64 LAYERS_ACTUAL 5.11 Dimensionless Actual number of inductor's winding layers.</td>
</tr>
<tr>
<td>65 AWG 31 31 AWG Inductor's wire gauge.</td>
</tr>
<tr>
<td>66 OD_INDUCTOR_INSULATED 0.272 mm Outer diameter of the inductor winding wire with insulation.</td>
</tr>
<tr>
<td>67 OD_INDUCTOR_BARE 0.227 mm Outer diameter of the inductor winding wire without insulation.</td>
</tr>
<tr>
<td>68 IRMS_INDUCTOR 0.309 Amperes Maximum RMS current flowing through the inductor's winding.</td>
</tr>
<tr>
<td>69 CMA_INDUCTOR 258 Cmils/A Inductor winding effective circular Mils area.</td>
</tr>
<tr>
<td>70 J_INDUCTOR 7.65 A/mm² Inductor Winding Current density.</td>
</tr>
<tr>
<td>71 PRIMARY_WINDING_FILL_FACTOR 75% Dimensionless Percentage of bobbin window filled up by the inductor winding.</td>
</tr>
</tbody>
</table>

Figure 14. Transformer Design Parameters Section: Inductance Parameters and Bias Winding Parameters of the Design Spreadsheet.

Inductance [E53]
This is the target nominal primary inductance for the main inductor. If left blank, the spreadsheet will calculate the inductance based on the VAC_MIN [E53] to guarantee discontinuous conduction mode over the entire dimming operation. User has the flexibility to override the calculation on cell [C53] and optimize the inductance according to desired operation.

Inductor Tolerance [E54], Inductance_Min [E55] and Inductance_Max [E56]
Expected inductance production tolerance can be assigned in cell [B54]. This tolerance is used in the calculation of the worst case condition of electrical parameters for primary current and operating duty cycle.

Inductor Turns, N [E57]
This is the number of turns for the main primary winding. The spreadsheet will automatically optimize the number of turns based on estimated maximum flux density, BM [E59] and worst case AC flux density BAC [E61]. User can assign number of turns on cell [C57] for any necessary adjustment to optimize design.

Gapped Core Effective Inductance, ALG [E58]
ALG (nH/T²) is used in the production of core to set the inductance of the transformer. It is used by the transformer vendor to specify the core center leg air gap. This is the value of inductance obtained for the squared number of turns around the core.

Maximum Operating Flux Density, BM [E59]
To avoid core saturation during normal operation at maximum operating temperature, a maximum value of 3300 gauss is recommended.

Peak Flux Density, BP [E60]
A maximum 4200 gauss is recommended to avoid core saturation. Peak flux density usually occurs during start-up and/or output short-circuits conditions. The peak flux density is estimated at the maximum device current limit. It is important to verify that core saturation does not occur at maximum ambient temperature under start-up with maximum load.

AC Flux Density, BAC [E61]
This is the flux density used in estimating the core loss for a given core material and volume in steady state condition. BAC = 0.5 x BM

Core Gap Length, LG [E62]
Gap used in the transformer production to set the correct inductance based on core material permeability (AL).

Layers_Desired [D63] and Layers_Actual [D64]
Number of winding layers used to estimate the size of magnetic wire to fit in the transformer bobbin. Cell [C63] is open which can be used to override cells [C53], [C54], [C57], [C63] and [C65] can be used to enter desired parameters.

Transformer Wire Details, OD_Diameter_Insulated [E66]
Outside wire diameter with insulation is calculated with the maximum diameter that allows the wire to fit given number of primary turns (N), bobbin width (BW) and assigned number of winding layers (L).

Inductor RMS Current, IRMS_Inductor [E68]
The RMS current can be used to estimate winding copper loss of the inductor.

The other useful magnetic parameters given in the spreadsheet are:

OD_Inductor_Bare [E66], diameter of wire without insulation.
CMA_Inductor [E67], inductor winding effective circular Mil area.
Current_Density [E68], inductor winding effective current density.
Primary Winding Fill Factor [E71], percentage of bobbin window filled up by the primary winding to estimate if there is sufficient space.
Step – 6 Transformer Bias Winding and Bias Components

Bias supply is necessary to supply current into the BYPASS pin to operate normally even at low conduction angle during dimming and it also provides feedback information into the OUTPUT COMPENSATION pin for regulation. The rectifier diode $D_B$ can be any fast or ultrafast recovery type with a voltage rating above the peak inverse voltage value given in the design spreadsheet (PIVBS [E77]), typically >200 V, and current rating >200 mA. The 1N4936 and UF4004 are good examples to use. See Figure 15.

**Bias Diode Voltage Drop, $V_{D\_BIAS}$ [E74]**
Typical voltage drop of 0.7 V for the bias rectifier diode. Also used in the calculation of the feedback resistor $R_{OC}$.

**Bias Winding Turns, $N_{BIAS\_TURNS}$ [E75]**
This is the number of turns of the bias winding calculated based on bias voltage chosen and output voltage.

$$N_{BIAS} = \frac{V_{BIAS}}{V_{OUT}} \times N_{PRI}$$

**Bias Voltage, $V_{BIAS}$ [E76]**
Default value is 20 V to ensure voltage supply for the bias to support the IC and the bleeder circuit during dimming operation, especially at start-up in low conduction angle. Excessive ripple is not recommended, at least 10 µF electrolytic filter capacitor ($C_B$) must be used and if ceramic type capacitor is used, a 22 µF value is recommended to account for huge tolerance for the said type of capacitor. Cell CBIAS [E78] displays the recommended value for capacitor $C_{BP}$ as shown in Figure 15.

For designs which require a wider LED voltage operation, increasing the bias voltage is recommended to maintain tight regulation with lower LED voltage.

**Output Rectifier Maximum Peak Inverse Voltage, $PIVBS$ [E77]**
This is maximum stress voltage across the bias diode at the maximum input voltage.

Override cells [C74] and [C76] can be used to enter desired parameters for $V_{D\_BIAS}$ and $V_{BIAS}$ respectively.

---

**Figure 15. Schematic Shows Bias Supply Circuit of Typical LYTSwitch-3.**

**Figure 16. Transformer Bias and Parts Variables of the Design Spreadsheet.**
Step – 7 Secondary Output Diode Parameters

Use ultrafast diode for output rectification and the recommended diode rating should be 2 times of the output current, i.e. $2 \times I_o < I_{AVG\_DIODE}$, for higher efficiency.

**Output Diode Voltage Drop, $V_F\_DIODE$ [E85]**
Enter the average forward voltage drop for the output diode. Use 0.7 V for a PN diode. Estimated forward power loss to this diode estimated by taking the product of $I_o \times V_F$.

**Output Diode RMS Current, $I_{RMS\_DIODE}$ [E86]**
The RMS current through the diode is calculated that can be used to calculate the copper loss of the inductor.

**Output Diode Peak Current, $I_{P\_DIODE}$ [E87]**
Peak current in the output diode is calculated in a worst case condition to guide the user to select the diode current rating and package size.

**Peak Inverse Diode Voltage, $PIV\_DIODE$ [E88]**
Use this parameter in selecting the voltage rating of the output diode. The worst case reverse peak voltage is calculated in open load condition which is the worst-case condition.

Step – 8 Feedback and Protection Parameters with Fine Tuning

This section will guide the user in selecting the external parts to be used in the design for achieving the specified output current. Leaving the section blank PIXls will recommend the initial value to be used. Once a prototype has been built, the output current can be fine tuned to the center by entering an actual measurement of the using the override cells [C93], [C95], [C98], [C99] and [C101].

**Line-Sense Resistor, $RL$ [E93]**
Line sense resistor is used for line compensation for regulation, phase angle measurement in dimming, line input overvoltage detection. To achieve tight output current regulation and dimming angle measurement resistor with 1% tolerance is recommended and also it should be connected to the positive of the bridge rectifier for better sensing of the line as shown in Figures 1 and 2. It is also recommended to use 2-1206 or 2-1/4W package resistor for high line application and 1-1206 or 1-1/4W for low line application.

$$RL = 1.2 \times \frac{V_{AC\_MAX}}{\sqrt{2}}$$

**Maximum RMS Input Voltage for Line Overvoltage, $OVP\_LINE$ [E94]**
The spreadsheet will calculate the equivalent RMS input voltage for OVP. The unit will enter to auto restart when the threshold is reached.

Instantaneous peak voltage during OVP is

$$V_{FR\_TH} = \sqrt{2} \times OVP\_LINE$$

**Theoretical Drain Current Sense Resistor, $RDC\_THEORETICAL$ [E95]**
The ideal resistor value to be used in the drain current sensing is calculated. The voltage drop across the resistor is sensed through DRIVER SENSE pin and the recommended average voltage drop across this sense resistor is 200 mV.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$RL$</td>
<td>4.00</td>
<td>4.00</td>
<td>M-Ohms</td>
</tr>
<tr>
<td>$OVP_LINE$</td>
<td>339.4</td>
<td>Volts RMS</td>
<td>Line overvoltage based on the actual L pin resistor used.</td>
</tr>
<tr>
<td>$RDC_THEORETICAL$</td>
<td>4.30</td>
<td>4.30 Ohms</td>
<td>Theoretical DS pin sense resistor.</td>
</tr>
<tr>
<td>$CDC$</td>
<td>10.0</td>
<td>u-Farads</td>
<td>Standard capacitor connected in parallel with the DS pin sense resistor.</td>
</tr>
<tr>
<td>$VBIAS_MEASURED$</td>
<td>19.7</td>
<td>19.7 Volts DC</td>
<td>Actual bias voltage (across the bias capacitor) measured on the bench.</td>
</tr>
<tr>
<td>$VO_MEASURED$</td>
<td>71.3</td>
<td>71.3 Volts DC</td>
<td>Actual load voltage measured on the bench.</td>
</tr>
<tr>
<td>$ROC$</td>
<td>178.0</td>
<td>k-Ohms</td>
<td>Standard (E96 / 1%) OC pin resistor.</td>
</tr>
<tr>
<td>$IO_ACTUAL$</td>
<td>115.0</td>
<td>115.0 m-Ampere</td>
<td>Actual output current seen on the bench.</td>
</tr>
<tr>
<td>$RFB_THEORETICAL$</td>
<td>39.3</td>
<td>k-Ohms</td>
<td>Calculated value of RFB, using standard values for RDS, ROVP, and RL</td>
</tr>
<tr>
<td>$RFB$</td>
<td>39.2</td>
<td>k-Ohms</td>
<td>Standard (E96 / 1%) F pin resistor.</td>
</tr>
<tr>
<td>$CFB$</td>
<td>150.0</td>
<td>n-Farads</td>
<td>Standard capacitor connected to the F pin.</td>
</tr>
</tbody>
</table>

Figure 17. Secondary Diode Parameters of the Design Spreadsheet.

Figure 18. Feedback and Protection Parameters with Fine Tuning of the Design Spreadsheet.
Standard Drain Current Sense Resistor, RDC [E96]
This identifies standard 1% resistor value nearest to the RDC_THEORETICAL to lessen the need of paralleling another resistor for centering the output, also saves cost and space (Figure 19).

Capacitance Across Drain Current Sense Resistor, CDC [E97]
This is the capacitor (CDC) across the Drain current sense resistor (RDC) that filters the switching Drain current to reduce the IRMS power dissipation across the sense resistor.

Low ESR ceramic type capacitor is recommended to use. Aluminum electrolytic capacitor due to its size, cost, relative high ESR and high capacitance tolerance is not recommended.

Actual Bias Voltage, VBIAS_MEASURED [E98]
Enter the actual bias voltage for fine tuning the output current. The actual may differ significantly from calculated due to leakage inductance of the transformer.

Actual Output Voltage, VO_MEASURED [E99]
Enter the actual output voltage with LED load for fine tuning the output current.

Output Current Compensation Resistor, ROC [E100]
Load variation, output overvoltage protection and output short-circuit is monitored through bias voltage via compensating resistor (ROC).

Spreadsheet will calculate this resistance based on the actual bias voltage (VBIAS_MEASURED). A 1% tolerance resistor is recommended in this location for tight output current tolerance.

Actual Output Current, IO_ACTUAL [E101]
Enter the actual current as measured from the bench for the fine tuning of external components to center the output to a desired level.

Theoretical Feedback Resistor, RFB_THEORETICAL [E102]
Spreadsheet calculates the exact feedback resistor resistance to set the output current based on the actual output current measured.

Feedback Resistor, RFB [E103]
The spreadsheet will determine the nearest single resistance value for use in RFB to avoid paralleling of components to get the desired current. But if the application requires tight output current tolerance then use the resistance calculated by RFB_THEORETICAL.

Feedback Filter Capacitance, CFB [E104]
Filter capacitance for the feedback current to average the signal to a desired voltage mean level of the FEEDBACK pin. The desired time constant can be in the range of 3 ms to 8 ms to maintain stable operation with tight current regulation.
Step - 9 Dimming Parameters

<table>
<thead>
<tr>
<th></th>
<th>DIMMING PARAMETERS</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>108</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>RDAMPER 197 Ohms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>P_RDAMPER 0.568 Watts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>I_BLEED 31 m-Ampere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>R_BLEED 5100 Ohms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>R_BLEED CASE TEMPERATURE 150 Degrees Celcius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>PLOSS_RBLEED 4.195 Watts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>PBJT 0.207 Watts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>116</td>
<td>RDEGENERATION 31.25 Ohms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>RBC 3.9 Ohms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>118</td>
<td>P_RBC 0.011 Watts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 20. PIXis Dimming Parameters of the Design Spreadsheet.

The schematics below in Figures 21 and 22, showing the LYTSwitch-3 active bleeder circuit for high line and low line applications respectively are recommended for high compatibility with most dimmers.

Dimming external components are calculated in this section to guide the designer the optimum holding current and component size.

**Damper Resistance, RDAMPER [E109]**
Damper resistor (R_{DAMPER}) is necessary to minimize inrush current and damps the spurious ringing of the input current in a leading edge dimmer. This ringing should be minimized to prevent the input current from ringing below the holding current of a TRIAC, which can make the TRIAC to turn-off prematurely and causes flickering of the light output.

**Damper Resistor Power Loss, P_RDAMPER [E110]**
Damper resistor loss is estimated in a worst case condition during dimming at 90º for leading edge dimmer. It is recommended to measure the actual temperature of the resistor and verify against the manufacturer specification power de-rating guideline.

**Bleeder Current, I_BLEED [E111]**
Setting for bleeder current (I_{BLED}) for optimum dimming compatibility. The higher the bleeder current the better the compatibility, but higher power dissipation. It is up to the designer to optimize the design depending on the target available dimmer. Typically for 120 V rated dimmers the bleeder current (I_{BLED}) should be set at 50 mA, while 240 V rated dimmers should be at 30 mA.

**Bleeder Resistor, R_BLEED [E112]**
The spreadsheet will calculate the maximum resistance of the bleeder resistors (R_{BLEED}, R_{BC}, or R_{PB}) for optimum dimming compatibility, then selects lower resistance based on the calculated value. This value is optimized to minimize the power dissipation in the bleeder Darlington transistor (Q1 and Q2). It is recommended to measure the actual temperature of the resistor and verify against the manufacturer specification for power de-rating guideline.

**Bleeder Case Temperature, R_BLEED CASE TEMPERATURE [E113]**
Enter the expected temperature of the bleeder resistor once operated in a given lighting enclosure. This value is used in recommending the right resistor rating at 25 ºC. It is recommended to measure the actual temperature of the resistor and verify against the manufacturer specification power de-rating guideline.

**Power Rating of Bleeder Resistor, PLOSS_RBLEED [E114]**
Since power rating is derated at higher temperature, the spreadsheet will calculate the equivalent rating at 25 ºC. Use this as minimum power rating value to guarantee safe operation of the unit at elevated temperature.

**Power Loss in Bleeder Transistor, PBJT [E115]**
The power dissipation of Darlington transistor (Q1 and Q2) is estimated by the spreadsheet. Select the transistor size base from the data sheet to determine the required package at elevated temperature.

**Degeneration Resistor, RDEGENERATION [E116]**
Degeneration resistor (R_{DEG}) is calculated to limit the gain of the transistor to keep the bleeder circuit stable even at high operating temperature.

**Bleeder Current Sense Resistor, RBC [E117]**
Compensating current or bleeder current (I_{BLEED}) through the bleeder is programmed through bleeder current sense resistor (R_{BC}). The holding current can be set using the equation;

\[
R_{BC} = 120 \, mV / I_{BLEED}
\]

**Power Loss in Bleeder Current Sense Resistor, P_RBC [E118]**
The spreadsheet will calculate the estimated power loss on the bleeder resistor in non-dimming operation.
Figure 21. Recommended High-Line Active Bleeder Circuit with RC Damper $C_p$ and $R_p$.

Figure 22. Recommended Low-Line Active Bleeder Circuit with Blocking Diode D1.

$\text{IBLEED (mA)} = \frac{120 \text{ mV}}{R_{BC}}$
Phase-Cut Dimming

The biggest challenge in designing dimmable LED bulb is high compatibility with a broad range of dimmer types of different power ratings. Since different types of dimmers have different minimum loading requirements, the dimmable LED bulb may manifest varying incompatibility behavior depending on the dimming conditions from light flickering or shimmering, ghosting, or huge pop-on to low dimming ratio.

There are two main types of phase-cut dimmers namely forward phase or leading edge (Figure 23) and reverse phase or trailing edge (Figure 24). Each type has its own characteristic and nuances that make it challenging for LED bulb drivers to achieve high compatibility. Many low-line dimmers especially high-power rated (i.e. >600 W) require high holding current up to 35 mA, this would make a LED bulb prone to flickering if not met. While high-line dimmers may require less than 20 mA of holding current, many have high leakage voltage (especially trailing-edge dimmers) enough to power a LED bulb momentarily which may result in fluttering, ghosting or flashing of light occasionally even when the dimmer is off. The challenge is the user may never know what type of dimmer and/or LED bulb to buy that will be compatible with each other. A LED driver using LYTSwitch-3 ICs can address this dilemma.

Figure 23. Typical Voltage and Current Waveform and Schematic of a Forward Phase-Cut Leading Edge Dimmer (TRIAC-Switched).

Figure 24. Typical Voltage and Current Waveforms and Schematic of a Reverse Phase-Cut Trailing Edge Dimmer (MOSFET-Switched).
Active Bleeder Circuit with LYTSwitch-3

To overcome the challenges of designing dimmable LED driver with high compatibility on any type of dimmer, all LYTSwitch-3 ICs have a built-in TRIAC detector that discriminates between leading-edge and trailing-edge type dimmers which is detected through the LINE-SENSE pin. This capability together with load monitoring circuitry via BLEEDER CURRENT SENSE pin regulates bleeder current every AC half-cycle from full to low conduction angle. In a non-dimming application where the LED driver is connected to the line directly, that is without a dimmer, the controller will detect a no TRIAC operation and disables the bleeder circuit via pulling BLEEDER CONTROL pin to ground. This will prevent additional power dissipation from the bleeder, consequently increasing system efficiency.

In Figure 25, a LYTSwitch-3 device is operating with a leading edge dimmer, the output of BLEEDER CONTROL pin drives Q1 with Q2 in emitter follower connection, a high gain active switch that pulls current from the input bus via R, to provide latching current and maintain holding current necessary to keep the TRIAC from turning off during the entire input AC cycle. Figure 26, during the initial turn-on of the TRIAC, the BLEEDER CONTROL pin will drive bleeder transistors on for ~250 µs and pulls the necessary latching current from the bus via RB, after which the bleeder current will be maintained if the total input current falls below the bleeder current threshold to which it was set to maintain the holding current of the TRIAC. The holding current is maintained even in low conduction angle as shown in Figure 27. The analog signal from the BLEEDER CONTROL pin of U1 drives Q1 and Q2 linearly when the input current falls below the holding current thus maintaining the current set by the resistor R.. The holding current can be set using the equation R.. = 120 mV/I..BLEED. Bleeder resistor R value is 5.1 kΩ with at least 2 W power rating for high-line application at 20 mA holding current and 1.2 kΩ, 2 W for low-line at 35 mA holding current. The designer is advised to take worst case operating temperature and follow the manufacturer’s power de-rating guideline to size the bleeder resistor. The condition at which the bleeder resistor tends to dissipate the most power is around 90° conduction angle.

Figure 25, Capacitor C.. and degenerative resistor R.. serve as stabilizing network for the bleeder transistors for stable dimming performance. R.. typical range of value is 20 - 47 Ω while C.. is between 4.7 nf to 22 nf.
Figure 26. At 150º Forward Phase-Cut Angle Waveforms of Active Bleeder Current, Converter Current and Total Input Current.

Figure 27. At 45º Forward Phase-Cut Angle Waveforms of Active Bleeder Current, Converter Current and Total Input Current.
Passive Damper
Passive RC damper is recommended for high-line application for optimum dimming compatibility. The $\frac{dv}{dt}$ at high-line is much higher than low-line, which make the internal LC filter of a dimmer (Figure 28) and EMI filter of a driver more susceptible to severe ringing when the TRIAC of the dimmer turns on.

In Figure 21, capacitor $C_p$ and resistor $R_p$ together with fusible resistor $R_f$ and damper $R_{dp}$ act as dampening network to reduce the ringing of current and prevent it from falling below the TRIAC holding.

The value of $C_p$ is in the range of 47 nF to 220 nF, while $R_p$ can be between 47 Ω to 1 kΩ with 1 W rating typical for low-line input or 2 W for high-line input.

PIXls design spreadsheet for other topologies is available in Power Integrations public website (https://piexpertonline.power.com/site/login).

![Diagram](PI-7608a-110316.png)

**Figure 28.** Typical TRIAC Dimmer Showing the LC Filter that Resonates with EMI Filter of Driver During TRIAC Turn-On.
Figure 29. Typical LYTSwitch-3 Low-Line Buck Configuration.
Figure 30. Typical LYTSwitch-3 High-Line Buck-Boost with RC Bleeder Configuration.

Figure 31. Typical LYTSwitch-3 Low-Line Isolated Flyback Configuration.
Figure 32. Typical LYTSwitch-3 Low-Line Non-Isolated Flyback with Direct Sense Regulation Configuration.

Figure 33. Typical LYTSwitch-3 Low-Line Boost with Direct Sense Regulation Configuration.
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