AN10831

SSL2102 30 W flyback triac dimmable LED driver

Rev. 01 — 10 October 2009 | Application note

Document information

Info	Content
Keywords	SSL2102, LED driver, mains dimmable, triac dimmer, flyback
Abstract	This application note gives an overview of the design considerations when designing a 30 W flyback application with the SSL2102.

founded by Philips

Revision history

Rev	Date	Description
01	20091010	First issue

Contact information

For more information, please visit: **http://www.nxp.com**

For sales office addresses, please send an email to: **salesaddresses@nxp.com**

1. Introduction

The SSL2102 IC is designed as a mains LED driver for dimmable lighting. The SSL2102 can be used in either Buck or flyback convertor topology. A flyback topology is used if electric isolation of the output is required. This application note describes a high power flyback converter application design.

1.1 The application requirement

When designing an application that can support a wide output voltage range and a constant current, it is important to dimension all components for the maximum output power. This application is optimized for a 30 W output and it can be scaled down relatively easily. The application described in this note is a retro-fit application using a lamp within a existing infrastructure. The application targets the lower end of the market, which has the following requirements:

- The lamp should be inexpensive.
- The lamp should be compact.
- Output close to 30 W.
- Power factor of at least 0.76.
- 150 mA peak-to-peak output current ripple.
- The driver should have a high efficiency. The target is 72 %.
- The lamp should be compatible with a triac dimmer, without noticeable flicker or jumps on the output. Transistor dimmer compatibility is optional.
- The input voltage is 230 V (AC) 50 Hz.

1.2 The design choices

The SSL2102 is specified for a maximum output power of 25 W. The higher output power might cause life time issues due to improper cooling. This has to be taken into account when the PCB is designed. An extra heatsink might be required.The output power is important for the selection of the transformer. For outputs above 26 W, an E30 or an EFD30 core must be used. The transformer will take up a large part of the required space. The design is optimized for 230 V (AC) input.

Almost all component values will change when the design is modified for 120 V (AC). Because the input voltage is halved, the input current will have to be doubled to have the same output power. The buffer capacitance will have to be doubled, the turns ratio has to change, the damper resistor can be halved, etc. The brightness control circuit is also optimized for 230 V (AC), which determines the dimmer duty factor by averaging the rectified input voltage.

2. Designing the application

2.1 Basic triac dimmer circuit

A basic design for a 30 W triac only dimmable flyback circuit using the SSL2102 is shown in Figure 1.

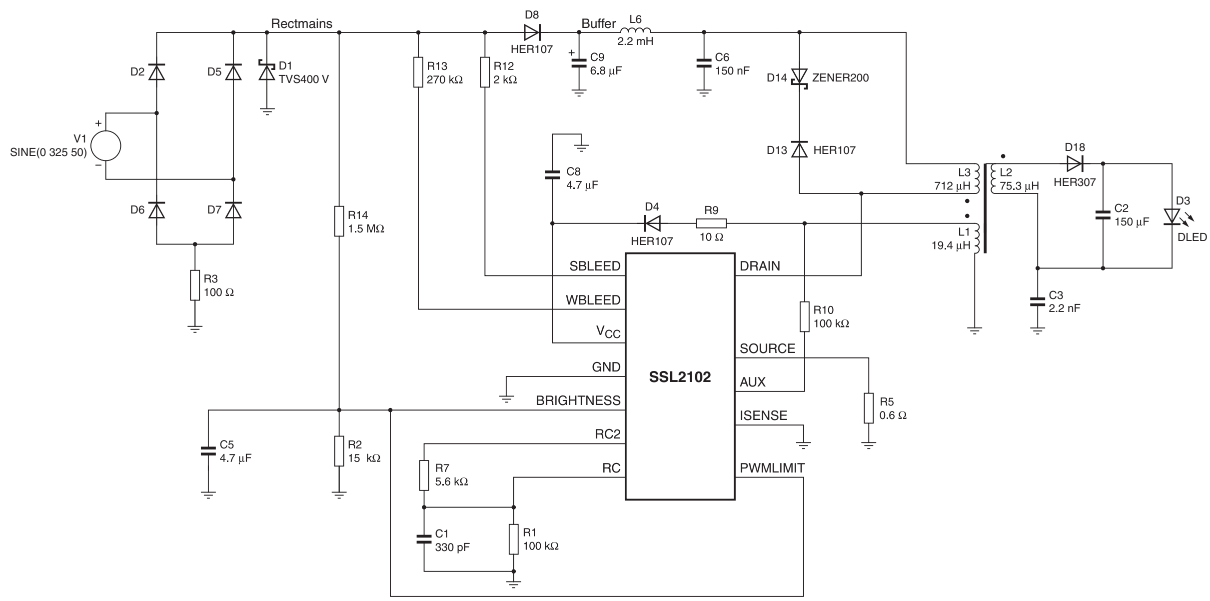


Fig 1. Simple 30 W flyback design

2.2 Transformer specification

The transformer specification is as follows:

- E30/EFD30 core.
- Primary (L3): 90 turns, 0.315 mm wire.
- Secondary (L2): 30 turns, mesh 30*0.071 mm.
- Auxiliary (L1): 15 turns, 0.1 mm wire.
- Primary inductance of 700 µH, determined by the air gap.

The transformer should be sandwiched to improve coupling.

The recommended layer build-up is as follows:

- Center layer: 45 primary turns.
- Second layer: 30 secondary turns.
- Third layer: 45 primary turns.
- Forth layer: 15 auxiliary turns.

If dissipation is an important factor, this efficiency of 72 % may not be sufficient. The input power is 40 W and the output power is 29 W, which means more than 11 W is dissipated in the circuit. The major contributor to this power loss is the damper resistor R3 with

5.25 W. A damper resistor is required to limit the inrush current. To improve efficiency the damper resistor can be bypassed when the inrush current peak has passed. See Section 2.3.

At 700 mA output current, approximately 1 W is lost using a conventional flyback diode. This loss can be reduced by implementing synchronous rectification. This is discussed in Section 2.4.

Adding output current regulation or open output protection is discussed in Section 2.5.

Transistor dimmer compatibility is discussed in Section 2.6.

ElectroMagnetic Interference (EMI) considerations are discussed in Section 2.7.

A circuit incorporating all suggested modifications is discussed in Section 5.

2.3 Active damping

The damper resistor plays a major factor in the power losses in the system. A single resistor is the cheapest solution, but could lead to thermal issues and low efficiency.

The damper resistor is required to limit the inrush current. This current peak occurs when the capacitors encounter a large change in V as in the following examples.

- When the system is first connected to mains.
- Every phase when the system is connected to a leading edge phase cut dimmer.

Even with a 100 Ω damper resistor, this initial current peak can be as high as 1.8 A.

As the damper resistor is not required after the inrush peak bypassing it after the peak increases efficiency. This can only be achieved with an active circuit. The input current can be limited to a maximum value with a current source circuit. Such a circuit can be seen in Figure 2.

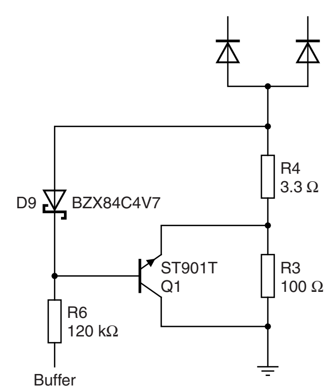


Fig 2. Active damper circuit example

The transistor will be in saturation as long as the its base voltage is higher than the voltage at the emitter plus the V_{BE}. The voltage across R4 increases with the current. When the voltage at the emitter rises over the threshold, the transistor goes out of saturation, turns off and R3 limits the current. The values of D9 and R6 have to be tuned. A Darlington transistor provides the necessary high current gain.

This modification changes the following specifications:

- Efficiency 81 % (36.9 W in, 29.8 W out).
- Power factor 0.65.

2.4 Synchronous rectification

The maximum current through the flyback diode (D18 in Figure 1) is over 2 A, because the LEDs are driven with up to 700 mA continuously. However, the reverse voltage is in the order of 150 V, due to the small turns ratio. This means a conventional high voltage diode is required. High voltage Schottky diodes are available, but they also have a relatively high forward voltage bias. Over 1 W is dissipated in the diode as a result of the forward bias voltage. Synchronous rectification can reduce the power lost in the diode. When synchronous rectification is used, a MOSFET with low $R_{DS(on)}$ replaces the diode.

The MOSFET requires an active control circuit, which has operational amplifiers and a number of passive components. ICs like the TEA1791 offer an integrated solution to reduce the number of components. The modifications required to implement the TEA1791 can be seen in Figure 3. The TEA1761 is an alternative to the TEA1791 and offers more functionality, including output voltage protection and current feedback.

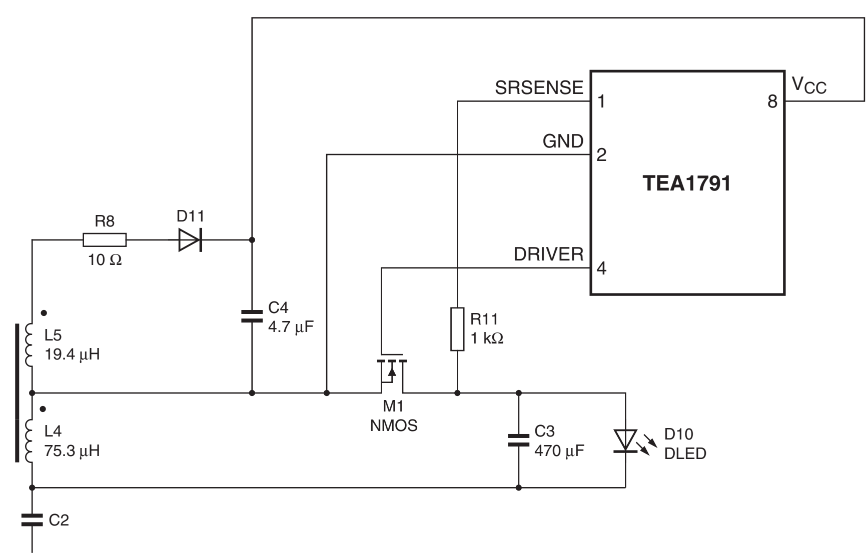


Fig 3. Synchronous rectification using the TEA1791

The synchronous rectification control circuit requires a supply voltage. Figure 3 shows an additional winding on the transformer, which has 15 turns of 0.1 mm wire. This can also be achieved by increasing the number of secondary turns and adding a tap. The supply voltage can be generated on the primary side in the same way as the supply voltage for the SSL2102. Alternatively, the output voltage across C3 can be used to generate a supply voltage. In that case, it is required to change the topology. The switch needs to be placed between the transformer and the secondary ground, however, this can result in EMI issues.

The properties of the MOSFET selected for this circuit will determine the efficiency. As the reverse voltage is 150 V to 200 V, a 200 V MOSFET will be the minimum requirement. Additionally, the $R_{DS(on)}$ will have to be much lower than 1 Ω to have advantage over a diode. The circuit will have to be tuned. This modification can boost the efficiency by another 2 %.

2.5 Output voltage and current feedback

The basic design shown in Figure 1 is not protected against an open output. If that occurs, the output voltage will rise to the point where the electrolytic capacitor is destroyed. Some ways to resolve this issue, if required, are as follows:

- The level on the output can be detected on the primary side by determining the level of the auxiliary winding. Due to the turns ratio, the supply voltage generation circuit generates a voltages that is half that of the output. When the supply voltage increases over a maximum voltage threshold derived from the output voltage, the PWM limit is pulled to ground to stop the converter. An example of a circuit which achieves this is shown in Figure 4.
- A more accurate measurement can be performed by adding a circuit to the secondary side. This circuit can also be improved to provide accurate output current control. An example of such a circuit can be seen in Figure 5. A current mirror is used to determine the current. An opto-coupler is used to keep the secondary side isolated from the primary side.

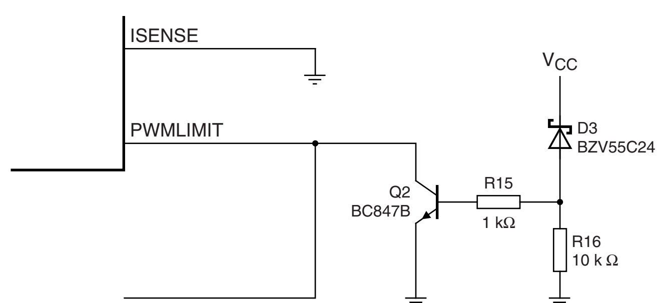


Fig 4. Primary side sensed output voltage limiting

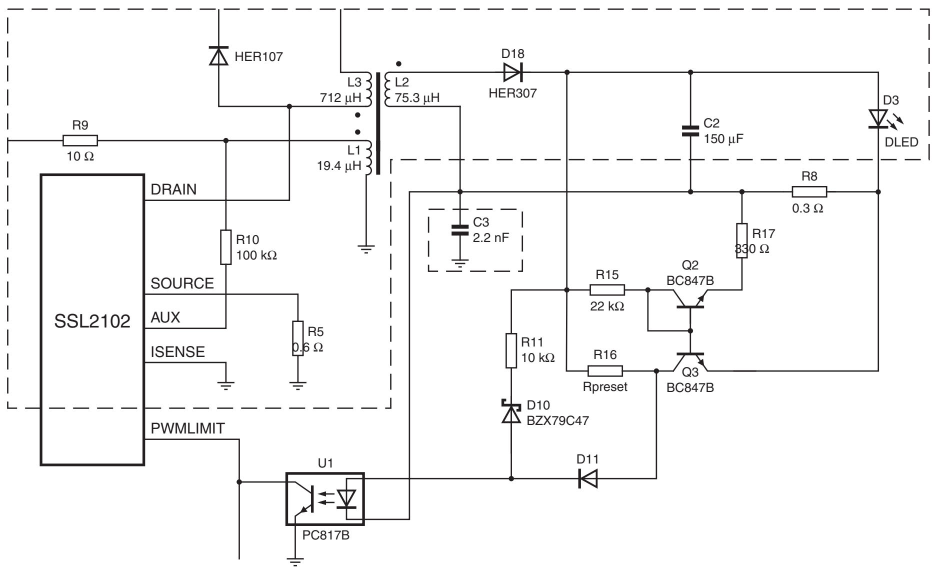


Fig 5. Output voltage and current feedback

2.6 Transistor dimmer compatibility

The circuit described in Section 2.1 to Section 2.5 is not transistor dimmer compatible. Transistor dimmers require a constant current to internally generate a supply voltage. The proposed circuit has a time-frame between the charging current for the buffer capacitor and the strong bleeder resistor switching on. In this time-frame, current is only flowing through the weak bleeder resistor, which is not sufficient for transistor dimmers. They will switch off and on again, resulting in flicker. To compensate for this, it is possible to decrease the weak bleeder resistor value to 27 kΩ. This is the maximum that the internal switch can handle. This is not an ideal solution:

- A permanently on 27 kΩ weak bleeder resistor will dissipate over 2 W and reduce efficiency by approximately 5 %.
- Decreasing the weak bleeder resistor can cause issues for some triac dimmers as they start oscillating in certain phase-cut duty factors due to insufficient hold current.

The SSL2101/2102 15 W flyback demo board utilizes an external transistor to be able to draw a larger current. An additional circuit is added to the ISENSE pin that only enables the weak bleeder when the input current drops below a certain threshold. The modifications required can be seen in Figure 6. Note that the component values in the figure are optimal for the 230 V demo board. They should be tuned for a specific application.

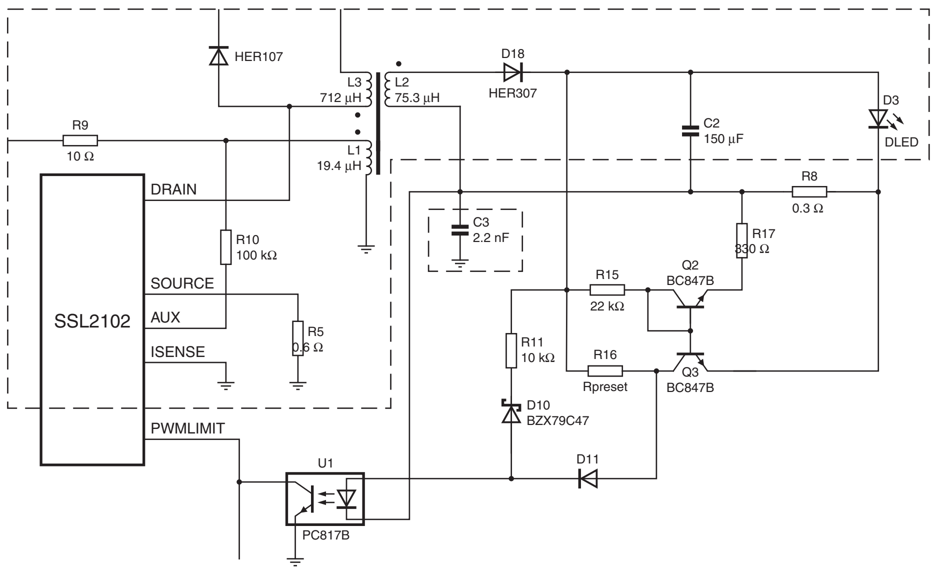


Fig 6. Current sensing and weak bleeder modifications

It might be required to slightly tune the brightness/PWM limit circuit for transistor dimmer support. While triac dimmers usually give and average voltage of 0 % to 80 % of the mains, transistor dimmers often give an average voltage of 40 % to 100 %.

Note that the efficiency will drop when the weak bleeder is on for longer periods.

2.7 EMI considerations

The converter is the main source of EMI. The example circuit shown in Section 2 already uses a LC filter to filter the convertor frequency. It has to be tuned to the specific convertor frequency.

The switching of the bleeders can also be a cause of EMI. If required, a filter should be placed before the rectifier.

3. Other design considerations

3.1 Separate rectified paths

A small modification, which can slightly improve efficiency, is to have separate rectified paths for the bleeders and for the buffer. This modification requires one extra high voltage diode. It saves dissipation due to the voltage drop over one diode. An example schematic is shown in Figure 7.

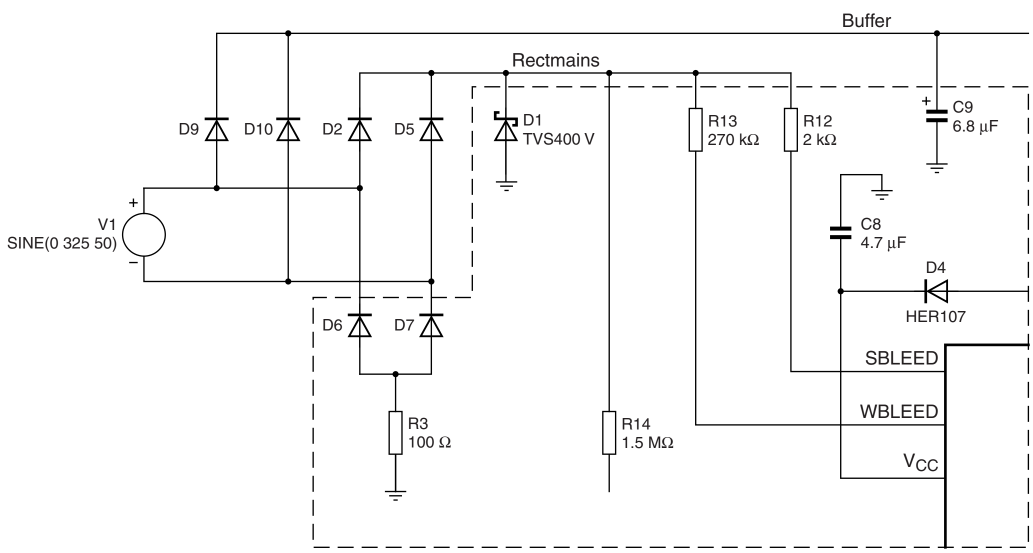


Fig 7. Separate rectified paths for improved efficiency

3.2 Power factor improvement

The power factor can be increased by reducing the primary capacitance to an absolute minimum to filter the converter. The current will then follow the input voltage. This modification has several consequences:

- It will be required to greatly increase the output capacitance to minimize the output current ripple.
- Because the voltage ripple on the primary buffer is larger, the peak current through the inductor must increase to have the same output power. This results in higher switching losses that can cause thermal issues. A transformer that can handle the higher current is also required.
- Dimmer support is improved, because the current follows the input voltage. However, for some dimmer duty factors additional current bleeding will still be necessary.

The SSL2101/2102 15 W flyback demo board gives an example of such a high power factor implementation.

3.3 PCB design considerations

Some important points that should be taken into account when designing a PCB are:

- The components connected to the rectified input should be able to withstand the high voltages.
- The components is series with the rectified input voltage should be able to handle the peak current without generating audible noise.
- The ISENSE pin, the RC pins and the BRIGHTNESS and PWMLIMIT pins are low voltage pins. They are susceptible to crosstalk on the PCB. The distance between low voltage and high voltage tracks should be sufficient. Ground plains and tracks should be utilized as shielding. The low voltage components should be as close as possible to the IC and the tracks should be short.
- All the GND and TC pins of the IC should be connected to a large ground plain to ensure proper IC cooling.

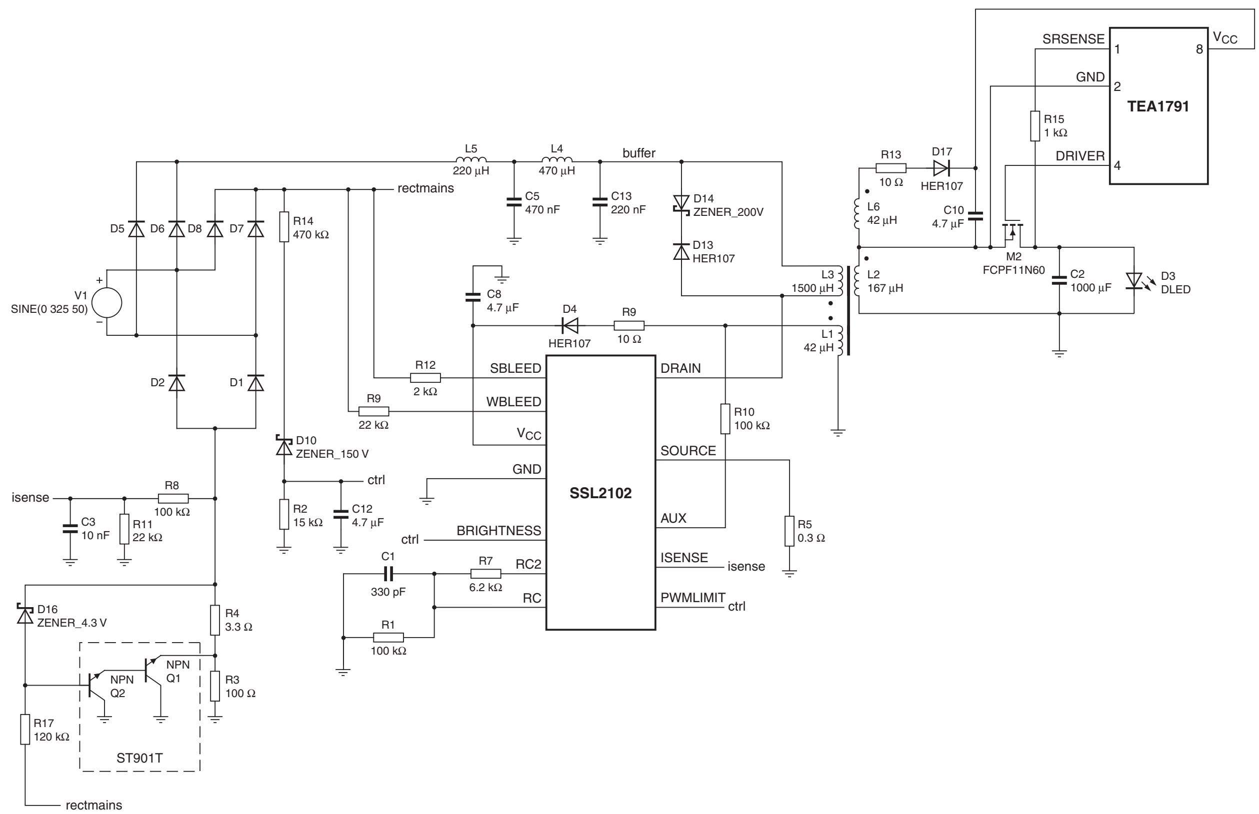
4. SSL2102 pinning list

Table 1. Pin description

Symbol	Pin	Description
SBLEED	1	drain of internal strong bleeder switch
GND	2	ground
GND	3	ground
WBLEED	4	drain of internal weak bleeder switch
V_{CC}	5	supply voltage
GND	6	ground
GND	7	ground
BRIGHTNESS	8	brightness input
RC2	9	setting for frequency reduction
RC	10	frequency setting
PWMLIMIT	11	PWM limit input
ISENSE	12	current sense input for WBLEED
AUX	13	Input for voltage from auxiliary winding for timing (demagnetization)
GND	14	ground
SOURCE	15	source of internal power switch
GND	16	ground
GND	17	ground
GND	18	ground
GND	19	ground
DRAIN	20	drain of internal power switch; input for start-up current and valley sensing

5. High Performance SSL2102 flyback design

When all the modifications mentioned in this document are combined into one design, this results in the circuit that can be seen in Figure 8.



Note the TEA1791 has a separate supply to the SSL2102 derived from an additional transformer winding.

Fig 8. SSL2102 flyback design with high power factor and high efficiency

This circuit improves on several points over the basic design as follows:

- High power factor: the input capacitance is small and the output capacitance is large, which result in a power factor of 0.94.
- High efficiency: active damping, synchronous rectification and the improved power factor together give an efficiency of 88 % (approximately 32 W input, approximately 28.3 W output).
- Transistor dimmer support: the dimmer curve is modified and the weak bleeder resistor is only switched on when the total current drops below a threshold level.
- Increased EMI filtering: this is required because of the low input buffer capacitance.

The transformer used in the circuit is the exact same transformer described in Section 2.1, except for the air-gap which has been reduced to increase primary inductance to 1500 µH.

To improve the power factor, the circuit is no longer running in Boundary conduction mode. The output power can be tuned by modifying the RC resistor R7. For instance 6.2 kΩ results in an output power of approximately 28 W, while a resistor of 6.8 kΩ results in an output power of approximately 31 W.

Remark: This circuit will still require tuning and testing before it can be used in commercial applications.

6. Conclusion

Remark: This document shows some design possibilities when designing a dimmable 30 W flyback converter with the SSL2102. A basic circuit can be build using a minimum of components. This circuit will have an efficiency of 72 %. Because of the large input power, this means 11 W is dissipated in the circuit. The efficiency can be greatly improved by implementing an active damper circuit. The efficiency can be further improved by adding synchronous rectification. Both modifications add to the size and the BOM cost.

The basic circuit does not have open output protection. This application note discusses two methods of adding feedback from the secondary side to the primary side. Transistor dimmer compatibility can be obtained by adding two circuits. This will reduce the efficiency. The basic circuit contains a LC filter to filter the converter frequency but does not have open output protection. Additional filtering may be required on the input. Some extra modifications are possible; the power factor can be improved, for instance. Combining all suggested modifications creates a circuit that has both high efficiency and high power factor. Each modification will require several components to be tuned.

7. Legal information

7.1 Definitions

Draft — The document is a draft version only. The content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included herein and shall have no liability for the consequences of use of such information.

7.2 Disclaimers

General — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in medical, military, aircraft, space or life support equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors accepts no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from national authorities.

7.3 Trademarks

Notice: All referenced brands, product names, service names and trademarks are the property of their respective owners.

8. Contents

Date of release: 10 October 2009
Document identifier: AN10831_1