AN10831

SSL2102 30 W flyback triac dimmable LED driver

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Document information

Info	Content
Keywords	SSL2102, LED driver, mains dimmable, triac dimmer, flyback
Abstract	This application note provides an overview of the considerations when designing a 30 W flyback application using the SSL2102 integrated circuit.

Revision history

Rev	Date	Description
v.2	20110323	Modifications: • Text updated • Template upgraded to latest version • All illustrations upgraded to new AQL standard • Section 6 “Legal information” amended to include new items
v.1	20091010	first issue

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 converter topology. A flyback topology can be used if electrical isolation of the output is required. It can also provide greater freedom when selecting output voltage ratings when considering efficiency and switch size. This application note describes how to improve the basic triac dimmable circuit to produce a high performance design.

SSL2102 is part of the SSL210x product family of dimmable led drivers consisting of:

- SSL2101: SO16 package, with integrated mosfet and bleeder switches
- SSL2102: SO20 package, with integrated mosfet and bleeder switches
- SSL2103: SO14 package, for external mosfet and bleeder switches

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. The basic application is optimized for a 30 W output and it can be scaled down relatively easily. The application described here, is a retro-fit application using a lamp within an existing infrastructure. The application targets the lower end of the market (commercial, domestic) and has the following specifications:

- Output power of 30 W
- Power factor of 0.7 or larger
- 150 mA peak-to-peak output current ripple (± 10 %)
- Efficiency of 72 %
- The lamp is compatible with a triac dimmers, without noticeable flicker or jumps on the output
- The input voltage is 230 V, 50 Hz
- The output voltage is 42 V, 700mA

1.2 The design choices

The SSL2102 is rated for a maximum output power of 25 W. A higher output power might cause life time issues due to improper cooling. This must be taken into account when the PCB is designed and 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 a 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 must be doubled to have the same output power. The buffer capacitance must be doubled, the turns ratio must be changed, 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.

1.3 Improvement steps overview

Table 1 provides a concise list of some possible improvements that can be applied to the board and the effects that these improvements have on efficiency and PF.

Table 1. Improvement overview

No.	Figure	Description	Efficiency %	PF	Improvement applied
1	1	Initial design	72	>0.7	1
2	2	Active damping	81	0.65	1+2
3	3	Synchronous rectification	83	0.65	1+2+3
4	4	Primary side OVP	not affected	not affected	-
5	5	Output current feedback	not affected	not affected	-
6	7	Separate rectified paths	83.30	not affected	1+2+3+4
7	8	Power factor improvement	88	0.94	1+2+3+4+7

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.

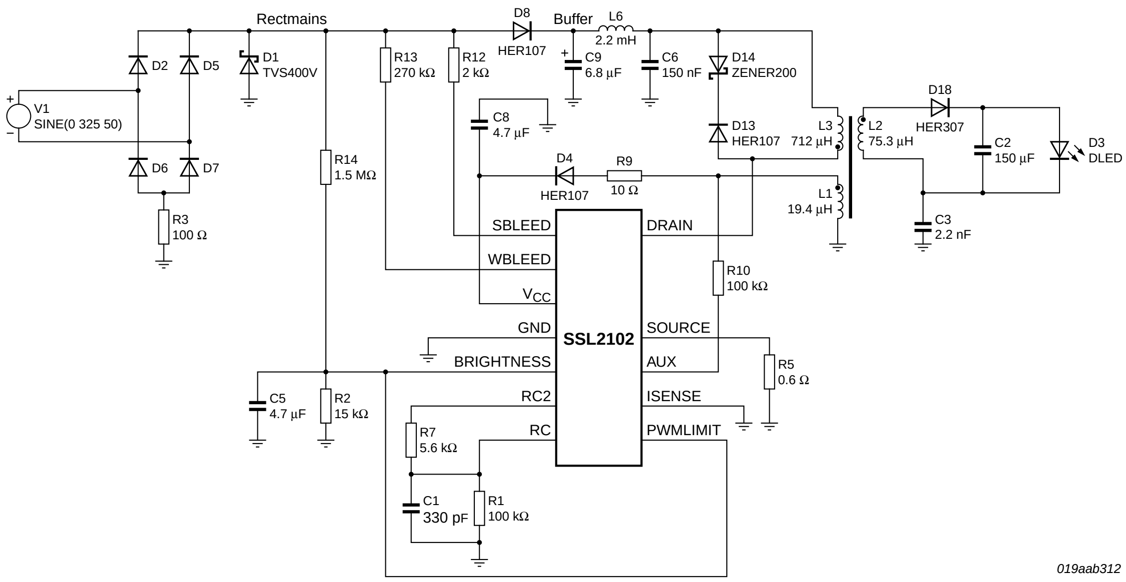


Fig 1. Simple 30 W flyback design

The transformer specifications are as follows:

- E30/EFD30 core
- Primary winding (L3) - 90 turns, 0.315 mm wire
- Secondary winding (L2) - 30 turns, mesh 30*0.071 mm
- Auxiliary winding (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 and the recommended layer build-up should be as follows:

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

When dissipation is an important factor, an efficiency of 72 % may not be sufficient. With an input power of 40 W and an output power of 29 W, more than 11 W is dissipated in the circuit. The major contributor to this power loss is the damping resistor R3 with 5.25 W. A damping resistor is required to limit the inrush current. To improve efficiency the damping 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 which 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 4.

2.2 Improvements to the basic design

The followings list comprises several improvements that can be made to improve the basic application:

1. An 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 which has a loss of 5.25 W. A damper resistor is required to limit the inrush current and to damp input current oscillations. To improve efficiency the damper resistor can be bypassed when the inrush current peak has passed. See Section 2.3.
2. Using a conventional flyback diode, approximately 1 W is lost at 700 mA output current. This loss can be reduced by implementing synchronous rectification. This is discussed in Section 2.4.
3. Adding output current regulation or open output protection as discussed in Section 2.5.
4. Achieving transistor dimmer compatibility as discussed in Section 2.6.
5. ElectroMagnetic Interference (EMI) considerations that are discussed in Section 2.7.

A modified circuit incorporating all the above improvements is shown in Section 4.

2.3 Active damping

The damping 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 damping resistor is required to limit the inrush current. This current peak occurs when the capacitors encounter a large change in voltage as described 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 damping resistor, the 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 using a current source circuit, an example of which is provided by Figure 2.

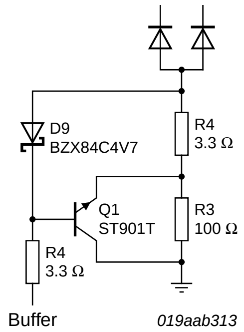


Fig 2. Active damper circuit example

The transistor will be in saturation as long as its base voltage is higher than the voltage at the emitter plus the V_{BE}. The voltage across R4 increases with current. When the voltage at the emitter rises above the threshold, the transistor goes out of saturation, turns off and resistor R3 limits the current. The values of D9 and R6 must 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 (see Figure 1) is above 2 A, because the LEDs are continuously driven with up to 700 mA. 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 such as 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.

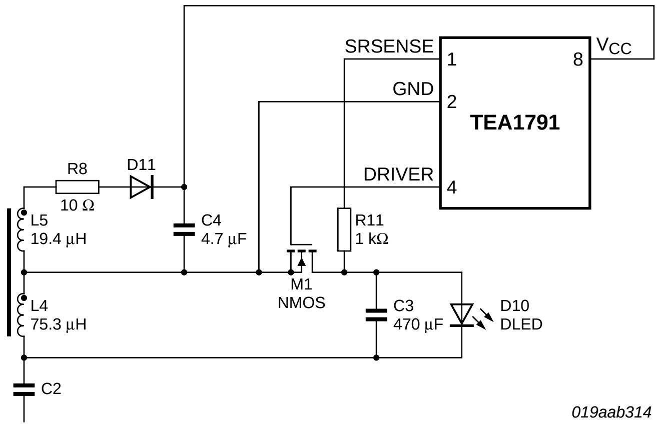


Fig 3. Synchronous rectification using the TEA1791

The synchronous rectification control circuit requires a supply voltage. An additional winding on the transformer is shown in Figure 3, and the winding 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 but this can result in EMI issues.

The properties of the MOSFET selected for this circuit will determine the efficiency. The reverse voltage is between 150 V and 200 V, requiring a 200 V MOSFET as the minimum requirement. In addition to this, the $R_{DS(on)}$ must be much lower than 1 Ω to have an 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 an open circuit occurs, the output voltage rises to the point where the electrolytic capacitor is destroyed. This issue can be resolved as follows:

- The output level can be detected on the primary side by determining the level of the auxiliary winding. Due to the turns ratio, the voltage generated by the supply voltage generation circuit 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 and an optocoupler is used to keep the secondary side isolated from the primary side.

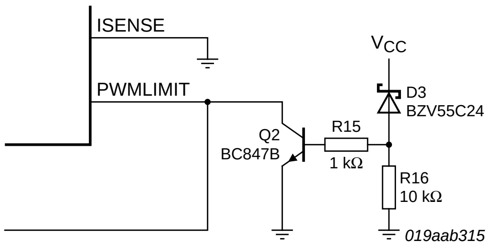


Fig 4. Primary side sensed output voltage limiting

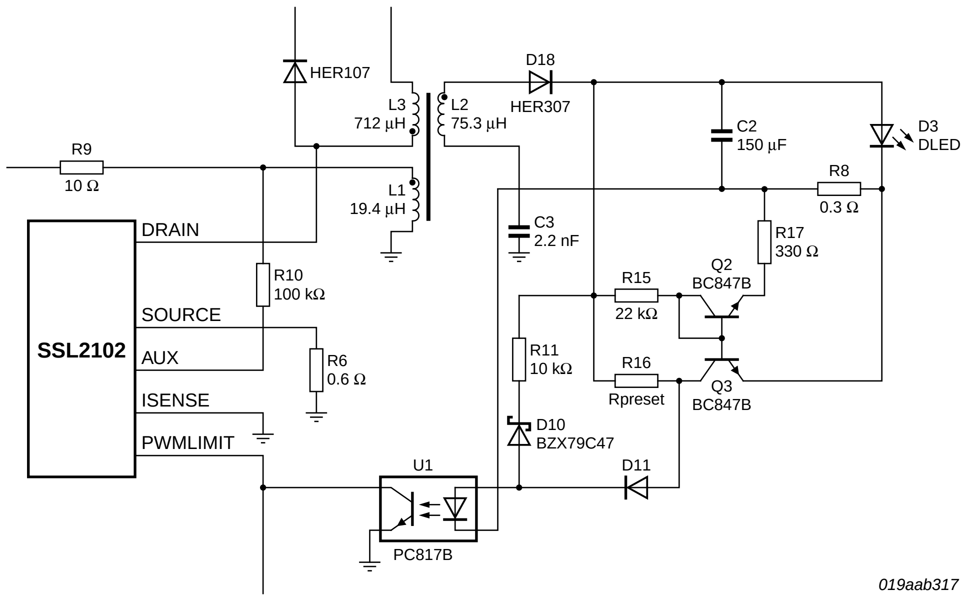


Fig 5. Output voltage and current feedback

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 generate an internal supply voltage. The proposed circuit has a time-frame between the charging current for the buffer capacitor and the strong bleeder resistor switching on. During this time-frame, current only flows through the weak bleeder resistor, which is insufficient 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 and it is not an ideal solution:

- When permanently on, the 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 Figure 6 are optimal for the 230 V demo board and must be tuned for specific applications.

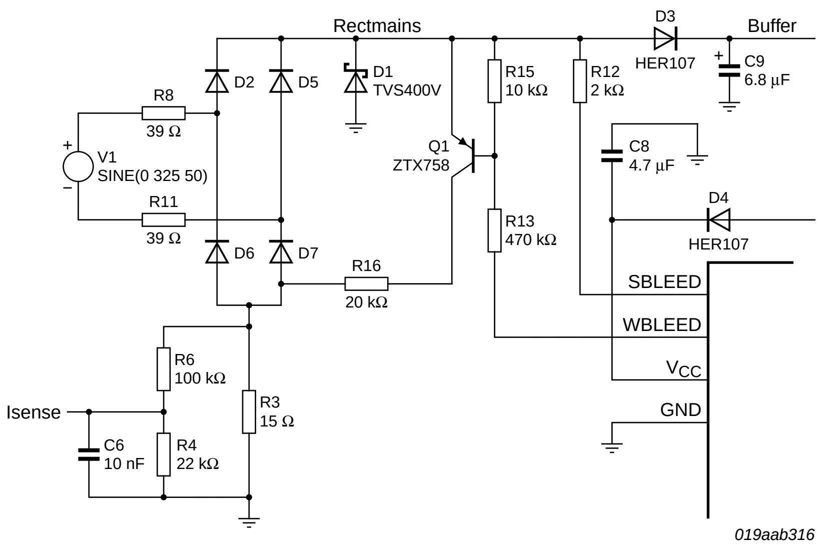


Fig 6. Current sensing and weak bleeder modifications

It might be required to slightly tune the brightness/PWM limit circuit for transistor dimmer support. While triac dimmers usually give an average voltage of 0 % to 80 % of the mains supply, 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 an LC filter to filter the converter frequency which has to be tuned to the specific 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 reduces dissipation due to the voltage drop over one diode. An example schematic is shown in Figure 7.

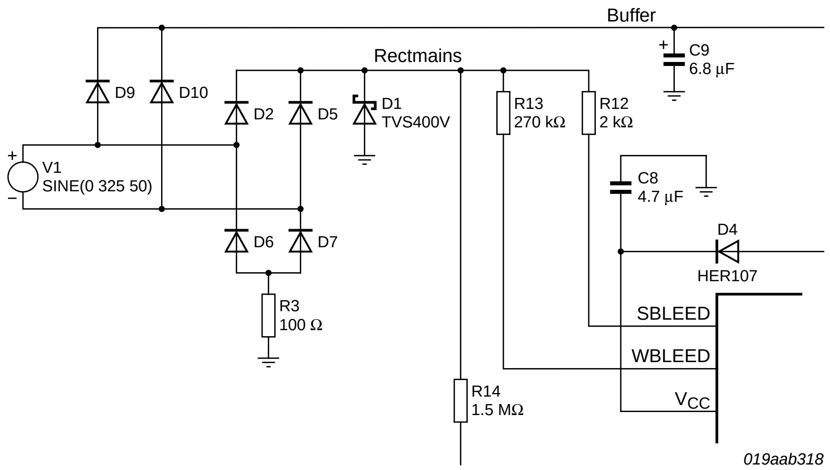


Fig 7. Separate rectified paths for improved efficiency

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:

- The output capacitance must be greatly increased 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 provides an example of implementing such a high power factor.

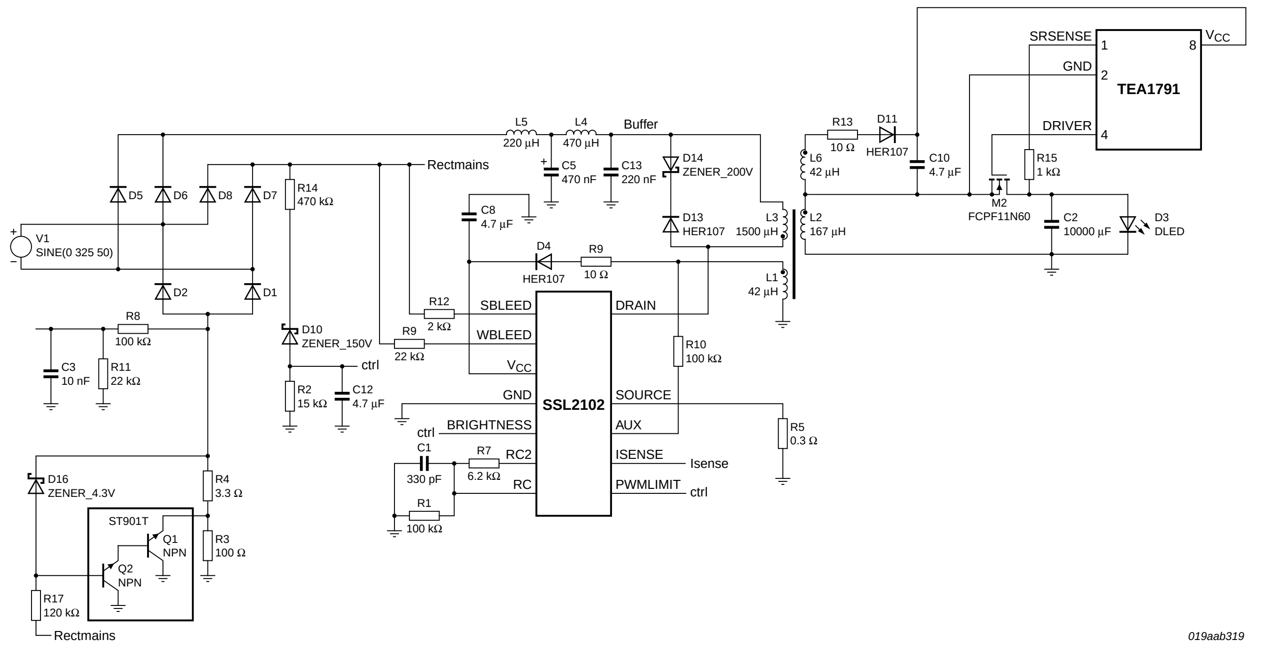
3.3 PCB design considerations

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

- Components connected to the rectified input must be able to withstand the high voltages.
- Components in series with the rectified input voltage must 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 and the distance between low voltage and high voltage tracks should be sufficient to avoid this. 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. High Performance SSL2102 flyback design

When all the modifications mentioned in this document are combined into one design, the result is the circuit depicted by Figure 8.



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

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

This circuit improves the basic design in a number of ways as follows:

- High power factor - the input capacitance is small and the output capacitance is large, which results in a power factor of 0.94.
- High efficiency - a combination of active damping, synchronous rectification and the improved power factor 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 identical to the transformer described in Section 2.1, except for the air-gap which has been reduced to increase the primary inductance to 1500 µH.

To improve the power factor, the circuit no longer runs in boundary conduction mode. The output power can be tuned by modifying the RC resistor R7. For example, 6.2 kΩ results in an output power of approximately 28 W, whereas 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.

5. Conclusion

This document offers some design possibilities when designing a dimmable 30 W flyback converter using the SSL2102 IC. A basic circuit with an efficiency of 72 %, can be built using a minimum of components. Because of the high input power, 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 and this will reduce the efficiency. The basic circuit contains an LC filter to filter the converter frequency but it does not have open output protection. Additional filtering may be required on the input. Some extra modifications are possible to improve the power factor. Combining all the suggested modifications, creates a circuit that has both high efficiency and a high power factor. Each modification will require several components to be tuned.

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