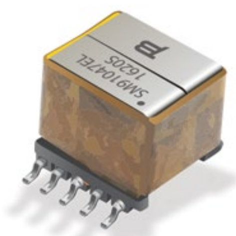
Transformers for Offline Flyback Converters

WHITE PAPER



SM91047EL

ABSTRACT

This paper examines the design of a Bourns® Model SM91047EL flyback transformer for a low power offline converter which could be used in applications such as smart meters, LCD displays, small appliances or smoke detectors. The controller on this converter is designed for non-isolated buck topologies. Using a flyback design allows higher output than the buck configuration. This article shows the calculations involved in selecting the primary inductance as well as the number of primary turns for a transformer.

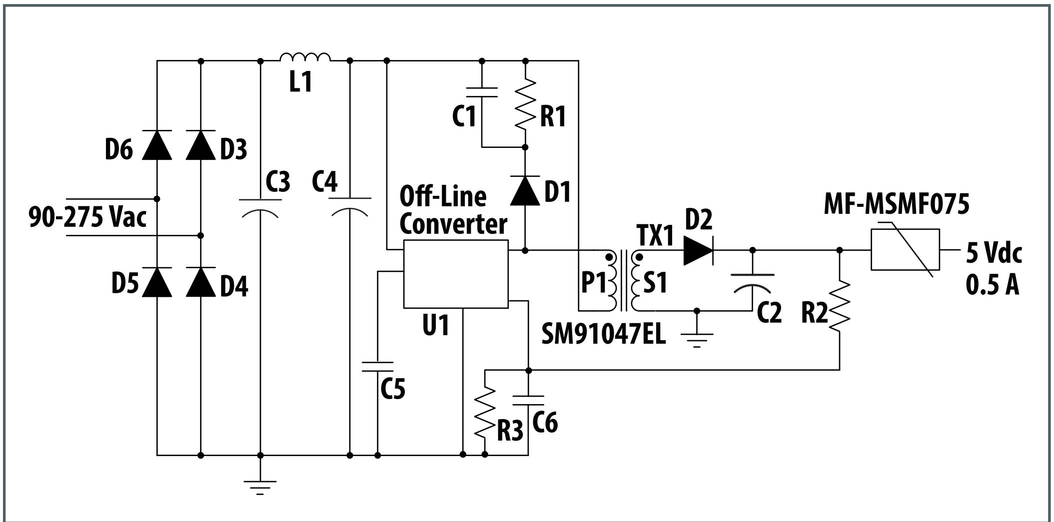


Figure 1. | *Schematic of offline converter with Bourns® Model SM91047EL flyback transformer*

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DESIGN CONSIDERATIONS FOR THE FLYBACK CONVERTER

Using a controller with a small MOSFET gives cost savings, albeit with very low peak currents. To get the maximum possible output from the flyback converter, the transformer should be created with Continuous Conduction Mode (CCM) in mind, rather than Discontinuous Conduction Mode (DCM.) DCM is a very popular mode for offline power supplies as this mode allows for smaller transformers and better rectification, albeit with very high peak currents in the primary side. CCM allows for a DC element in the primary current and an AC ripple which never exceeds the DC current.

This converter was designed to operate in CCM with 5 V +/-5 % output and a maximum load of 0.5 A from an input voltage range of (90-275 Vac). The controller has a peak current limit between 0.2 A and 0.3 A. The primary inductance was selected based on the fact that the controller has a maximum current at worst case (-40 °C) of 0.3 A. The minimum inductance required to keep the power supply in CCM is as follows:

$$L_p = \frac{VDCmin*Dmax}{I_{peak}*FSW} \qquad (1)$$

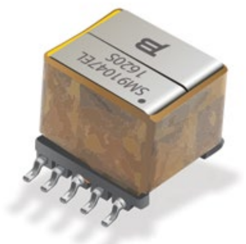
The minimum inductance L_p required, therefore, using (1) is 3.7 mH based on a minimum input of 90 V and a switching frequency of 62 kHz as well as a worst case peak current of 0.3 A.
The turns ratio N is calculated as:

$$N = \frac{Dmax*VDCmin}{V_{out}*(1-Dmax)} \qquad (2)$$

Increasing L_p does ensure CCM, enabling smaller and hence, more economical designs. There is the down side of the peak surge of current which comes through the MOSFET's drain during the leading edge blanking period. The energy of the inrush of current is proportional to the inductance value. It could destroy the MOSFET if the inductance used is too high.

$$Energy = \frac{1}{2} L_p (1)^2 \qquad (3)$$

Increasing L_p places stress on the MOSFET during the rising edge of every ON cycle. However, permeability can vary in ferrites, and inductance typically will drop under load. Therefore, a primary inductance set at the minimum value may well drop under load and over time. It is best to add another 20 % to take these factors into account.



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DESIGN CONSIDERATIONS FOR THE FLYBACK CONVERTER *(Continued)*

Operating the circuit in DCM removes the magnetizing current completely from the primary side during the ON time of the MOSFET. Being able to operate the controller at the maximum duty cycle of at least 45 % requires a higher turns ratio but this also increases the stress on the output diode. Therefore, a schottky diode capable of handling transient overloads of up to N times the current limit is required. The controller protects itself from short circuit currents or overloads by entering a “run-away” protection mode, whereby the switching frequency is reduced allowing the secondary side more time to discharge. However, as there is a transformer in this design, the controller offers no protection on the secondary side. Under worst-case conditions the current limit could be 0.3 A. The rms current in the secondary side is given by the following equation, where I represents the DC value of the current:

$$I_{msout} = I * \sqrt{(1-D)} * \sqrt{1+\frac{1}{3}\left(\frac{\Delta I}{I}\right)^2} \qquad (4)$$

The duty cycle during overload will be very low, so (4) can be simplified to:

$$I_{msout} = I * \sqrt{1+\frac{1}{3}\left(\frac{\Delta I}{I}\right)^2} \qquad (5)$$

ΔI is calculated as 0.2 A on the secondary side. This gives I_{rmsout}=3.25 A. If we ignore the ripple we can use the following formula:

$$I_{out} = I_{limit} * N * (1-D) \qquad (6)$$

Using (6), I_{out} is 3.4 A during overload. A 3 Amp surface mount schottky barrier rectifier diode can survive transient conditions like those described. The turns ratio can be lowered to reduce the current. However, this also will reduce the input voltage range of the converter. If a wide input range is necessary, overcurrent protection will be needed.

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TRANSFORMER DESIGN

We can use a small form factor core and bobbin as the power generated by this circuit is quite small (output 2.5 watts). However, due to the fact that the step down factor is quite high and the voltages on the input side are high, there must be a high number of turns on the primary side which imposes physical limitations on how small the transformer can be. Bourns keeps a stock of both very small standard cores for low power as well as larger cores for more complicated higher power circuits. Our sample laboratory is typically able to produce a CAD drawing and one sample with test report within 24 hours of receiving a specification, provided it is based around a standard core in stock. The following list shows the cores typically available.

Core Type	Typical Power Handling Capability
EP5, ER7.5, EP7	Up to 20 watts
EPC10, EFD10, EPC16, EE10, EE13, EP13	Up to 50 watts
EE16, EPC20, EE20, EE25, EPC24	Up to 150 watts
EPC30, EPC25, PQ26	Up to 500 watts
EC35, EC29A, EC28B, EC40B, RM14	Up to 700 watts

The Bourns® Model SM91047EL is based around an industry standard EP13 core and SMD bobbin. The turns ratio has already been determined by the power supply design criteria as shown in the previous section. The turns on the primary side are determined by the dimensions of the core, as well as the current and the primary inductance itself. However, the final number of turns also must take into account the magnetic properties of the core as we shall discuss now. We know this core is running in CCM which means we need to be able to conduct a continuous DC current without demagnetizing the core. The minimum number of turns N with the given DC current and ripple current needed to avoid saturation is given by the following equation:

$$N > \frac{LIpeak}{AeB_{sat}} \qquad (7)$$

A common mistake is to take B_{sat} directly from the core manufacturer's datasheet. As a rule of thumb it is best to be prudent when using B_{sat} and to use 0.3 T maximum. This automatically increases the number of turns needed, but it does avoid saturation. Using this rule of thumb, the primary number of turns had to be at least 170.

The inductance of an inductor is given by the following equation:

$$L = \frac{\mu i \mu A N^2}{lm} \qquad (8)$$

The permeability is, however, not constant and the manufacturer's data sheet should be checked for changes versus magnetic field as well as temperature.

The magnetic field H in ampere turns per meter is calculated from the following equation:

$$H = \frac{IN}{lm} \qquad (9)$$

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TRANSFORMER DESIGN *(Continued)*

The Bourns® Model SM91047EL Flyback Transformer uses a EP13 core made with DMR44 ferrite material and whose permeability curve is shown in figure 2. The incremental permeability µi at 0.2 Amperes and 170 turns is 145. Putting this permeability into equation (8) gives us a primary inductance of 4.1 mH. This is a little too close to our minimum requirement of 3.7 mH. Adjusting the turns to 190 increases the inductance to 5.16 mH which is acceptable. Increasing the turns reduces the flux in the core to give the transformer a flatter and more stable magnetic field. This is valid when an air gap of 0.2 mm is used in the circuit. Adding a smaller air gap reduces the reluctance of the magnetic circuit and increases the inductance with the same number of turns.

One sample of the Bourns® Model SM91047EL was assembled with 190 turns and its inductance measured with a DC current of 0.2 A. The inductance dipped by 9.48 % from 4.992 mH to 4.519 mH which is acceptable.

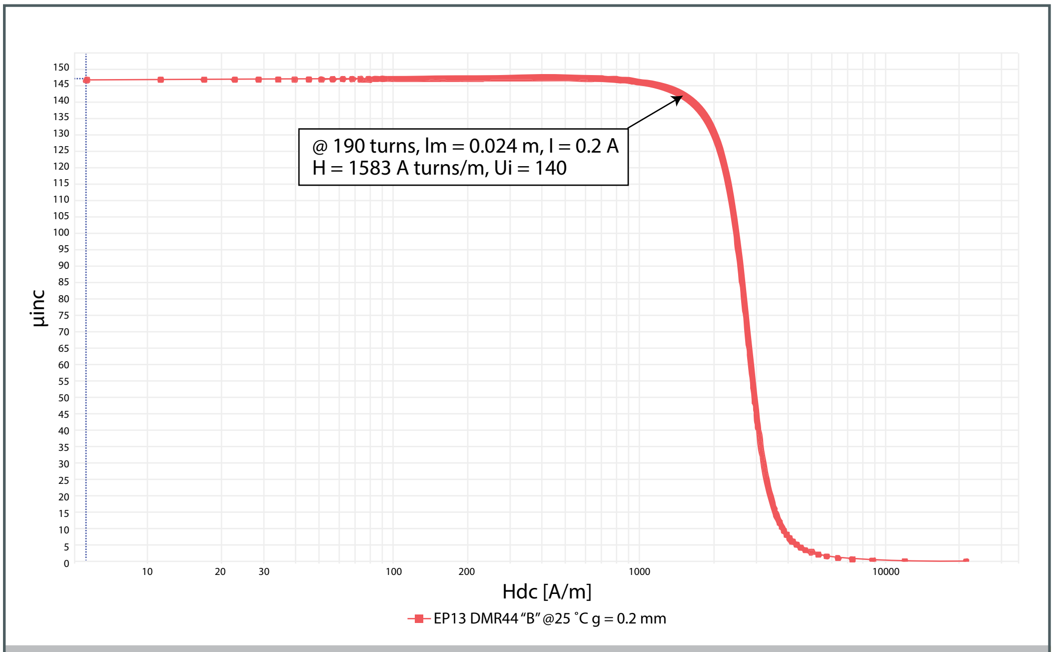

Figure 2. | *Graph of incremental permeability versus magnetic field strength with 170 turns on EP13 core*

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CONCLUSION

This article covered the design of the Bourns® Model SM91047EL for a low power offline converter, taking into account the input and output characteristics of the converter, as well as the primary inductance and the number of turns. The turns ratio in this converter is quite important as there is no secondary current detection during overload testing. If the turns ratio is not optimized during the design, a rather large diode would have to be used on the output side. Selecting the optimum number of turns in the transformer in practical terms must take the characteristics of the core material into account. The permeability of the core is not a constant value and is dependent on the magnetic field strength in ampere turns per meter. Using quality materials with information on the permeability is important in the design phase. Being able to check the transformer's inductance under load conditions is also a very important part of the design to ensure the inductance remains within specification. Bourns keeps a wide range of ferrite cores in stock for quick turnaround designs.

ADDITIONAL RESOURCES

For more information about Bourns' complete product line, please visit:

www.bourns.com

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Americas: *Tel* +1-951 781-5500
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