PSR Flyback DC/DC Converter Transformer Design for mHEV Applications

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TEXAS INSTRUMENTS

Magnetic component design is an important aspect when implementing isolated DC/DC converters. For the primary-side regulated (PSR) flyback converter in particular, the transformer plays a critical role as it sets the flyback operating mode boundaries and has an outsized impact on the performance of the converter.

This tech note describes a condensed transformer design procedure for a low-power PSR flyback DC/DC converter in an automotive application. The steps are useful whether the transformer design is carried out in-house or outsourced to a magnetic component vendor.

mHEV Power Solution

As an example, consider a mild-hybrid electric vehicle (mHEV) system with 12 V and 48 V batteries as shown in Figure 1. The isolated DC/DC power supply highlighted in red provides a tightly-regulated 12-V bias rail on the 48-V side.

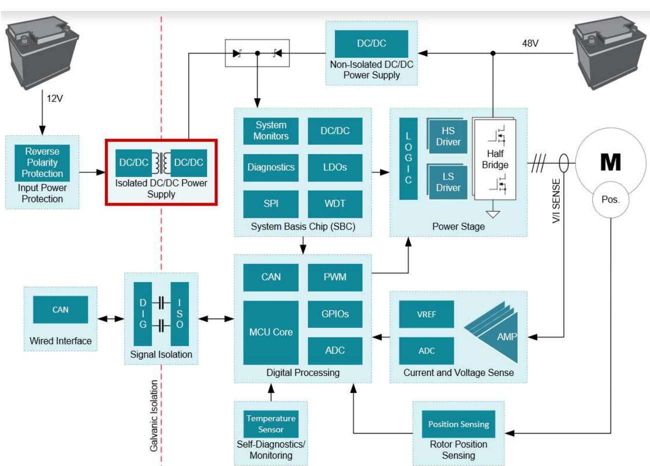

Figure 1. mHEV System Block Diagram

Figure 2 shows the LM25180-Q1 PSR flyback DC/DC converter schematic with a 12-V output up to 200 mA. Additional outputs are easily configured depending on the application requirements. The schematic above includes an optional negative output if bipolar output rails (±12 V) are required.

Note that the LM25180-Q1 does not need an optocoupler, voltage reference or transformer auxiliary winding for output voltage regulation.

Instead, the device senses the reflected isolated output voltage from the primary-side flyback voltage waveform, resulting in accurate load and line regulation performance. This simplifies the design, enables a smaller solution size and requires only one component crossing the isolation barrier.

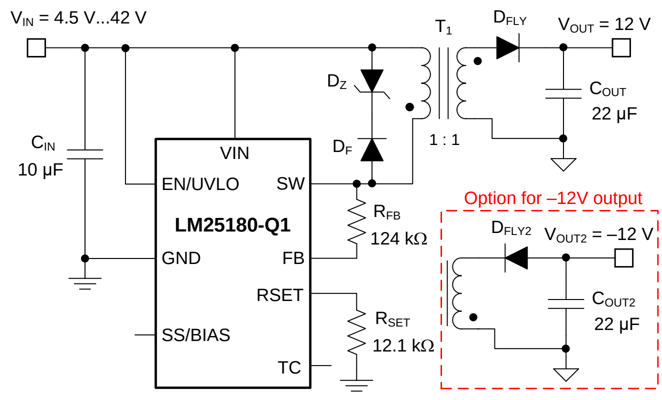

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Figure 2. PSR Flyback DC/DC Converter Schematic

Designing a Flyback Magnetic Component

The following outlines a 6-step transformer design procedure tailored for a PSR flyback DC/DC converter.

1. Define Specification

Table 1 gives the relevant design parameters for this mHEV application example.

Table 1. PSR Flyback Specifications

SYMBOL	PARAMETER	VALUE
V_{IN}	Min, nom, max input voltage	5.5 V, 13.5 V, 42 V
V_{OUT}, I_{OUT}	Output voltage and current	12 V, 0.2 A
F_{SW}	Full-load switching frequency at min/nom/max V_{IN}	100 kHz (BCM), 220 kHz (BCM), 350 kHz (DCM)
I_{PRI-PK}	Peak primary current	1.2 A
V_D	Flyback diode voltage drop	0.4 V

Equation 1 gives the duty cycle of a flyback converter when operating in boundary conduction mode (BCM).

$$D = \frac{\left(V_{OUT} + V_D\right) \cdot N_{PS}}{V_{IN} + \left(V_{OUT} + V_D\right) \cdot N_{PS}} \tag{1}$$

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Assuming a maximum duty cycle of 70% at minimum input voltage, find an initial estimate for the transformer turns ratio using Equation 2.

$$N_{PS} = \frac{D_{MAX}}{1-D_{MAX}} \cdot \frac{V_{IN(min)}}{V_{OUT}+V_D} = \frac{0.7}{1-0.7} \cdot \frac{5.5\,V}{12\,V+0.4\,V} \approx 1 \tag{2}$$

2. Core Selection

Select a core based on the required output power. Refer to section 4 of the *Magnetics Design Handbook* for more detail. Choose an EP7 ferrite core for this application with relevant parameters given in Table 2.

Table 2. EP7 Ferrite Core Parameters

SYMBOL	PARAMETER	VALUE
A_e	Effective area (mm^2)	10.7
A_{min}	Minimum area (mm^2)	8.65
V_e	Effective volume (mm^3)	165
l_e	Effective length (mm)	15.5

3. Calculate Inductance

To ensure adequate time to reset the magnetizing current to zero, Equation 3 determines the minimum magnetizing inductance using current and off-time parameters specific to the LM25180-Q1.

$$L_{MAG} \geq \frac{V_{OUT} \cdot N_{PS} \cdot t_{OFF(min)}}{I_{PRI\text{-}PK(FFM)}} = \frac{12\,V \cdot 1 \cdot 0.45\,\mu s}{0.3\,A} = 18\,\mu H \tag{3}$$

A magnetizing inductance of 30 µH provides an acceptable design margin and enables the converter to operate in BCM at a lower switching frequency for a greater portion of the load and line range.

Using a core with 880-µm airgap that sets an inductance factor A_L of 25 nH per turn squared, calculate the number of primary turns using Equation 4. Given the unity turns ratio, the number of secondary turns is also 36.

$$N_P = \sqrt{\frac{L_{MAG}}{A_L}} = \sqrt{\frac{30\,\mu H}{25\,nH/Turns^2}} \approx 36 \tag{4}$$

4. Calculate Copper Loss

Determine the appropriate wire gauge and number of paralleled strands using the bobbin fit factor and buildup calculations found in the *Practical Magnetic Design: Inductor and Coupled Inductors Seminar*.

As described there, derive the AC/DC wire resistance ratio due to skin effect at the applicable frequency. Selecting 34 AWG wire size for both primary and secondary, calculate the primary and secondary winding resistances as 180 mΩ based on the mean length of the bobbin per turn (MLT) of 17.9 mm.

Find the total copper loss using Equation 5 as 0.2 W.

$$P_{CU} = P_{CU\text{-}PRI} + P_{CU\text{-}SEC} = R_{PRI} \cdot I_{PRI\text{-}RMS}^{\;2} + R_{SEC} \cdot I_{SEC\text{-}RMS}^{\;2}$$
$$= \frac{1}{3} \cdot \left[D \cdot R_{PRI} \cdot I_{PRI\text{-}PK}^{\;2} + (1-D) \cdot R_{SEC} \cdot (N_{PS} \cdot I_{PRI\text{-}PK})^2 \right] \tag{5}$$

5. Calculate Flux Density and Core Loss

Given the minimum cross-sectional area of the selected core, calculate the peak flux density in an overcurrent (OC) condition using Equation 6 and ensure that it is less than the saturation level of the core material, typically 250 mT or higher for a ferrite. The flux cycles from zero to peak in the first quadrant of the B-H curve of the core.

$$B_{PK} = \frac{L_{MAG} \cdot I_{PRI\text{-}PK(OC)}}{N_P \cdot A_{min}} = \frac{30\,\mu H \cdot 2\,A}{36 \cdot 8.5\,mm^2} = 196\,mT \tag{6}$$

Find the flux density swing for core loss calculations using Equation 7.

$$B_{AC} = \frac{L_{MAG} \cdot I_{PRI\text{-}PK}}{2 \cdot N_P \cdot A_e} = \frac{30\,\mu H \cdot 1.2\,A}{2 \cdot 36 \cdot 10.7\,mm^2} = 47\,mT \tag{7}$$

Identify a specific power loss of 40 kW/m^3 using flux density and frequency as parameters in the applicable characterization plot of the core vendor. Multiply by the effective volume to obtain a core loss of 7 mW.

5. Calculate Temperature Rise

Given a total power loss of 207 mW, use the core and bobbin effective thermal impedance of 40°C/W to estimate a temperature rise of 8°C.

Iterate these calculations as needed to obtain a transformer design optimized for the desired input voltage and ambient temperature ranges.

6. Construct Transformer

Figure 3 shows a transformer winding construction with single-filar primary and secondary windings. The split-primary winding sandwiches two secondary layers to obtain a low leakage inductance of 300 nH.

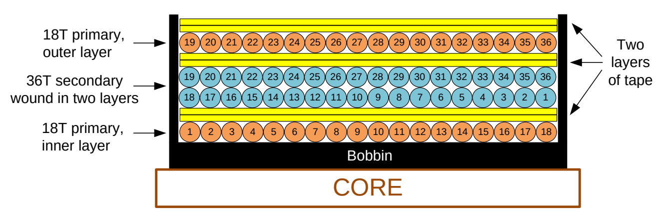

Figure 3. Interleaved Transformer Construction with Split-primary Winding

As functional grade isolation is typically sufficient for mHEV applications, two layers of tape are placed between adjacent primary and secondary layers.

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