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Application Note

AN-EVAL-SEPIC-1

CoolSET™
A CoolSET™ based non-isolated low-cost power supply

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Power Management & Supply

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Contents:

A CoolSET^{TM} based non-isolated low-cost power supply

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General

Switched-mode power supplies are increasingly gaining ground also in the market for very low output power supplies (< 5W), where the traditional solution comprising line transformer, rectifier and linear regulator has long been dominant.

Power supplies in this power range are primarily used as chargers and plug-in power supplies for small electronic devices such as mobile phones, personal stereos, radios, answering machines etc.; but we find them also "on-board" in numerous equipments in the field of consumer, home and industrial electronics.

The use of switched-mode power supplies offers significant benefits also in the area of very low-power applications, because:

- it is easy to implement a wide input voltage range (80 - $240V_{AC}$) without manual switching
- low weight and system size
- higher efficiency compared to a linear regulator
- lower stand-by power consumption

The standard circuit topology for low-power switched-mode power supplies is the flyback converter, since it requires the fewest components and thus allows the cheapest solutions.

The engineering of a switched-mode power supply has become much more easier during the last years as a result of advanced integrated circuits such as those of the CoolSET family, which contain both the high-voltage transistor (CoolMOS) and all the control electronics.

Electrical isolation

Considering device costs, the transformer is shurely one of the most expensive components in a power supply. Its primary task is to isolate the output voltage from the line potential.

However, there are numerous applications where this isolation is not necessary. Examples are completely isolation-protected systems or supply units to circuit parts that are themselves on line potential. One such example is that of power converters in bridge topology (e.g. for drives or welding applications), where the highside driver is supplied via the bootstrap principle as shown in Figure 1. In this case, the driver circuits for the power transistors - often together with the circuit for pulse pattern generation (via a PWM-IC or microcontroller) - is directly connected to (-) of the d.c. rail. The driver circuits can therefore be supplied directly from the d.c. rail by a non-isolated power supply.

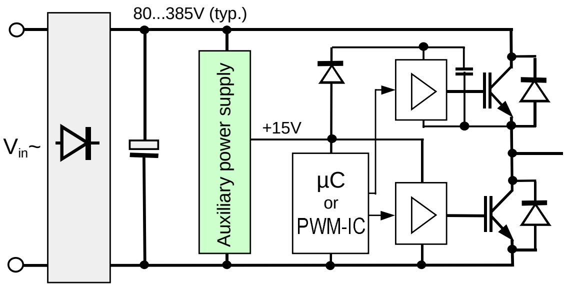

Figure 1: Auxiliary power supplies in bridge converters are an application example for low-power supplies with non-isolated output voltage.

SEPIC converter

If there is no requirement for electrical isolation, the expensive transformer can generally be omitted. The traditional solution in this case would be the use of a buck converter, but its power transistor in highside configuration represents a significant disadvantage. Namely in the higher voltage range, it is quite difficult and costly to realize a driver for the floating power transistor together with a control circuit for the output voltage.

Figure 2 shows a far more elegant solution to this problem, with a CoolSET device in SEPIC topology (Single Ended Primary Inductor Converter).

The advantages of this topology are:

1. the expensive transformer is replaced by two inexpensive chokes "off-the-shelf"
2. common ground connection for power switch, control circuit, input and output voltage
3. ideal for the use of integrated power circuits like CoolSET
4. no optocoupler required to return the output voltage information
5. small number of components
6. no polarity inversion of the output voltage
7. very wide input and output voltage range
8. low voltage stress for the power switch

The SEPIC topology can be derived from the flyback, when we replace the transformer by two chokes linked via a coupling capacitor. The RCD clamping circuit can be omitted altogether, while the reverse voltage at the output diode D1 increases to roughly the value of the input d.c. rail voltage V_{in}.

The operation of the circuit is quite easy to understand, when we remember that a d.c. voltage equal to the input voltage V_{in} appears across C_S.

If the power transistor in the CoolSET turns on, then a voltage equal to V_{in} is applied to both chokes. This causes a linear increase in the respective choke current (in a positive direction with respect to the current arrows in the diagram). When the power transistor turns off, both chokes drive the currents forward, where they flow via diode D1 to the output capacitor and the load. At the same time, a voltage occurs at point A, which is higher than the output voltage by one diode forward voltage drop. The voltage at the drain of the power transistor reaches a value that is approximately the sum of the input and output voltages. The drain voltage is very effectively clamped via the array C_S, D1 and C5.

With an output voltage of V_O = 15V and a rated breakdown voltage of the CoolSET power transistor of 600V, the circuit can be used without any problems at d.c. link voltages of 450V and above. The considerably reduced voltage stress is an important advantage compared to a flyback converter, especially when the circuit is used in conjunction with a PFC or in a drive converter with brake chopper.

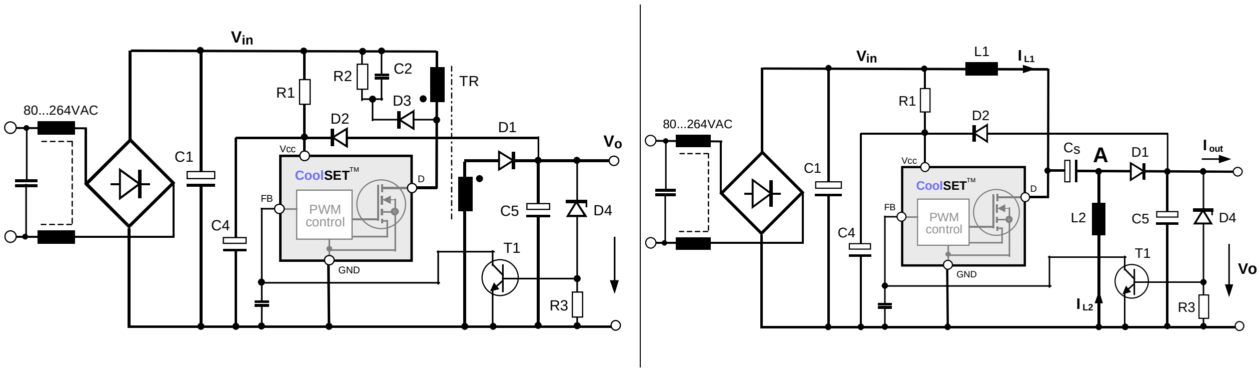

Figure 2: Circuits for a flyback converter (left) and a SEPIC converter (right) based on the CoolSET device.

However, the reduced voltage stress at the power transistor is achieved at the cost of a higher current load. This is a result of loosing the "winding ratio" as a degree of freedom compared to a transformer solution. The form and amplitude of the currents through L2 and through the power transistor are shown in Figure 3 as functions of the load current. The current in the power transistor is a combination of the currents through L1 and L2.

Since the average current through L2 corresponds approximately to the load current, the peak current load of the power transistor is generally higher than the value of the load current, depending on the choke current ripple. However, in the intended low-power application range with typical output powers up to about 5W, the output currents are still manageable (e.g. 0.3A @ 15V/5W).

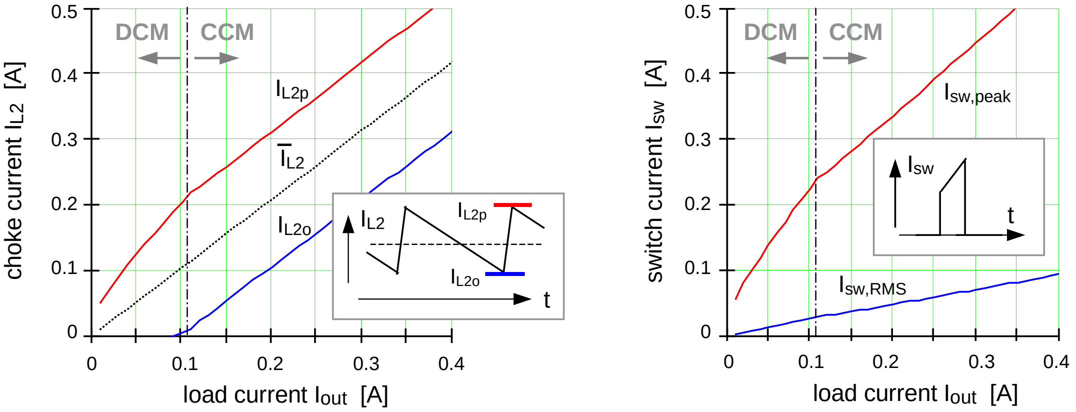

Figure 3: Current flow in the output choke L2 and in the switching transistor as functions of the load current (V_{in} =310V, L1=4.7mH, L2=0.68mH, V_0 =14.5V)

Dimensioning

Like the flyback converter, the SEPIC converter offers two operating modes, which are distinguished in accordance with the current flow through D1: discontinuous conduction mode (DCM) and continuous conduction mode (CCM). The transition between these two modes occurs at the critical load current:

$$I_{out,cr} = \frac{V_0}{2L_p\, f_{sw}} \left(\frac{V_{in}}{V_{in}+V_0} \right)^2 \tag{1}$$

where f_{sw} is the switching frequency and Lp is the effective overall inductance as follows:

$$L_p = \frac{L_1\, L_2}{L_1 + L_2} \tag{2}$$

Above the critical load current, the converter works in CCM mode. The advantage of this operating mode is in the low current ripple and the consequent reduction in peak currents. The disadvantage is that each switching cycle involves a hard current commutation at diode D1, which leads to increased turn-on losses in the transistor. For this reason, a very fast diode is required for D1 in CCM mode.

The DCM mode is generally preferred due to the lower switching losses. Owing to its very low R_{dson} CoolMOS transistor, the low conduction losses of the CoolSET make this device especially well suited to the increased peak currents encountered in this operating mode.

The basic parameter for determining the currents and voltages in the circuit is the duty cycle, which is derived as a function of the operating conditions as follows:

$$D = \begin{cases} \dfrac{V_0}{V_{in}} \sqrt{\dfrac{2L_p\, f_{sw}\, I_{out}}{V_0}} & for \quad I_{out} < I_{out,cr} \\[2ex] \dfrac{V_0}{V_{in}+V_0} & for \quad I_{out} \geq I_{out,cr} \end{cases} \tag{3}$$

Note that the duty cycle in CCM mode is independent of the load.

Based on the efficiency η, the average current through choke L1 is:

$$\bar{I}_{L1} = \frac{V_0\, I_{out}}{V_{in}\, \eta} \tag{4}$$

and the average current through L2 is:

$$\bar{I}_{L2} = \frac{V_{in}+V_0}{V_{in}} I_{out} \tag{5}$$

A ripple is superimposed on each of these average currents as follows:

$$\Delta I_{L1} = \frac{V_{in}\, D}{L_1\, f_{sw}} \tag{6}$$

$$\Delta I_{L2} = \frac{V_{in}\, D}{L_2\, f_{sw}} \tag{7}$$

Figure 4 gives a feeling for the parameter dependencies. It shows the ripple of the current through L2 as a function of the inductance value. The figure also shows the minimum I^2L value required for the choke to avoid saturation. The higher this value, the larger and therefore more expensive the choke.

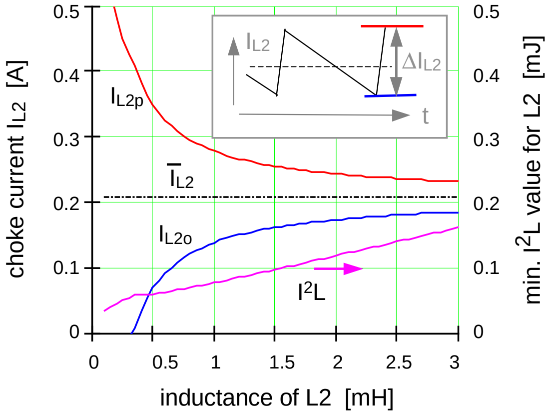

Figure 4: Current ripple in the output choke and required I^2L value as a function of the value of L2 for a specified load current I_{out}.
(V_{in} =310V, L1=4.7mH, V_0 =14.5V, I_{out} =0.2A)

It is clear that there has to be a trade-off between current ripple and choke costs. In practice, inductance values in the range of 0.2-1mH have worked well for L2.

Suitable chokes can be found e.g. in the EPCOS LBC series (large-bobbin core, B82144-A, etc.), providing inductance values between 220 and 1000 uH for nominal currents of 200-400mA. These can be used for output currents up to approximately 125mA. For output currents up to about 300mA, corresponding chokes are available in the HLBC series (B82 145-A, etc.) and in SMT format (e.g. B82475-A, etc.).

Since only a relatively small current flows through choke L1 (see equ.(4)), a smaller-size device is generally acceptable here. Furthermore, it is advantageous to use higher inductance values for L1 in order to reduce the current ripple. The EPCOS BC series (B78108-S, etc.) is highly suitable for L1, with inductance values of 2200-4700uH and nominal currents of 80-55mA. For output powers significantly higher than 2W and a wide input voltage range, the LBC series (large BC, B82144-A, etc.) offering nominal currents up to 120mA for the same inductance range is recommended.

The capacity value of C_S should be chosen so that the voltage ripple at C_S does not become too large (typically ≤10..20V_{pp}). Suitable products include both aluminum electrolytic capacitors in the value range 0.5-2.2uF/400V and film capacitors from approximately 0.15uF upward - depending on the output power.

Circuit variants

Figure 5 shows a circuit proposal for a low-cost power supply with an output voltage in the range between 12.5V and 16V. Within this voltage range, the CoolSET can be supplied directly from the power supply output. Diode D2 enables the CoolSET to be supplied via resistor R1 during the start-up phase. For output voltages higher than 16V, a resistor (R5) should be connected in series with D2, so that the CoolSET internal zener diode between Vcc and GND is not overloaded. A good choice here is:

$$R_5 = \frac{V_0 - 16\,\text{V}}{10\,\text{mA}} \tag{8}$$

Simple voltage regulation via the zener diode D3 and the transistor T1 is entirely adequate where the demands in terms of output voltage accuracy and control dynamics are not too stringent. Proposed circuit configurations to improve these parameters are given in [1].

If a digital transistor is used for T1 (e.g. the BCR 148), then it is possible to dispense with the series resistor (typically 47kΩ) that is otherwise necessary at the base of T1.

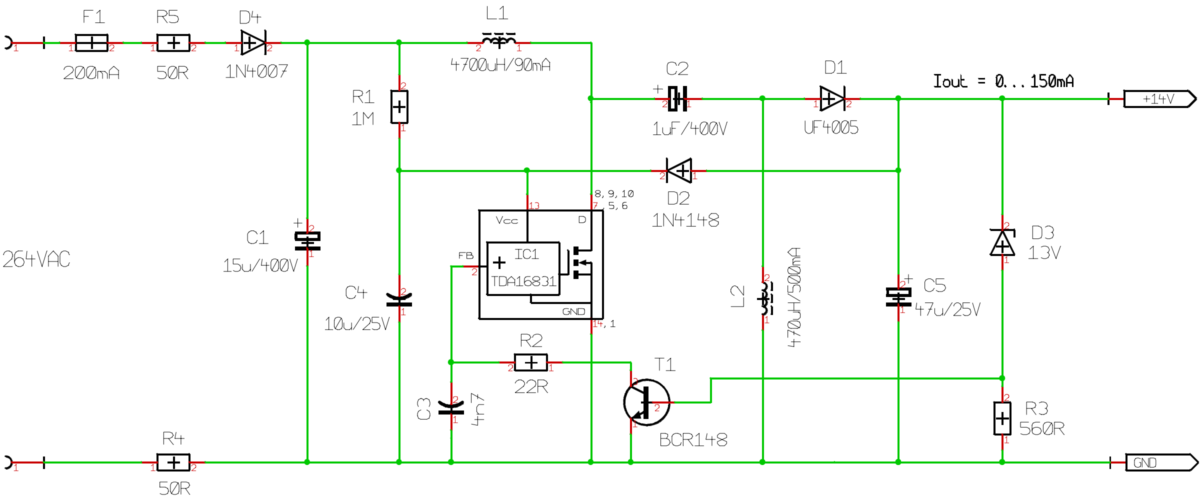

Figure 5: Circuit for a 14V/2W power supply

More difficult than the generation of output voltages above 12.5V is the generation of lower voltages, since the control circuit can no longer be supplied directly from the output in this case. If, as it is the case in many on-board power supplies, the output load is reasonably constant, then the CoolSET can be supplied via an inexpensive choke L3 in series with L2, as shown in Figure 6. The inductance value for L3 should be chosen so that the power that can be obtained covers the power consumption of the CoolSET. It therefore follows for L3:

$$L_3 \ge \frac{2\,I_{cc}}{I_{L2p}^2\, f_{sw}}(V_{cc} - V_0 + R_5\, I_{L2p}) \qquad (9)$$

where I_{CC} and V_{CC} are the supply current and operating voltage of the CoolSET, respectively, V_O is the output voltage, and I_{L2p} is the peak current through L2/L3 at nominal output current (s. Fig. 3).

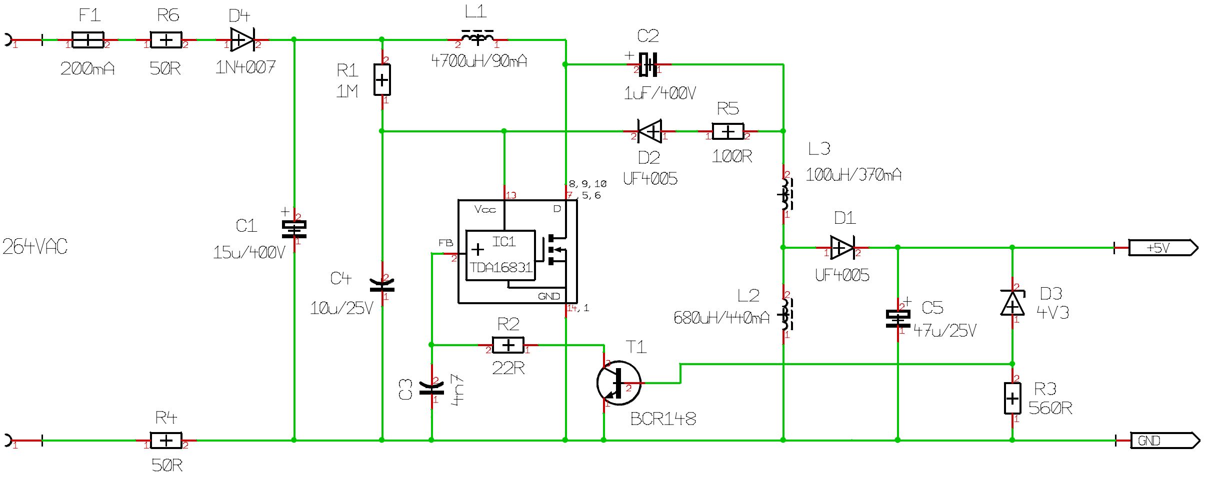

Figure 6: Proposed circuit for a 5V/1W power supply. With approximately constant output current, the CoolSET can be supplied via a magnetically non-coupled auxiliary choke L3.

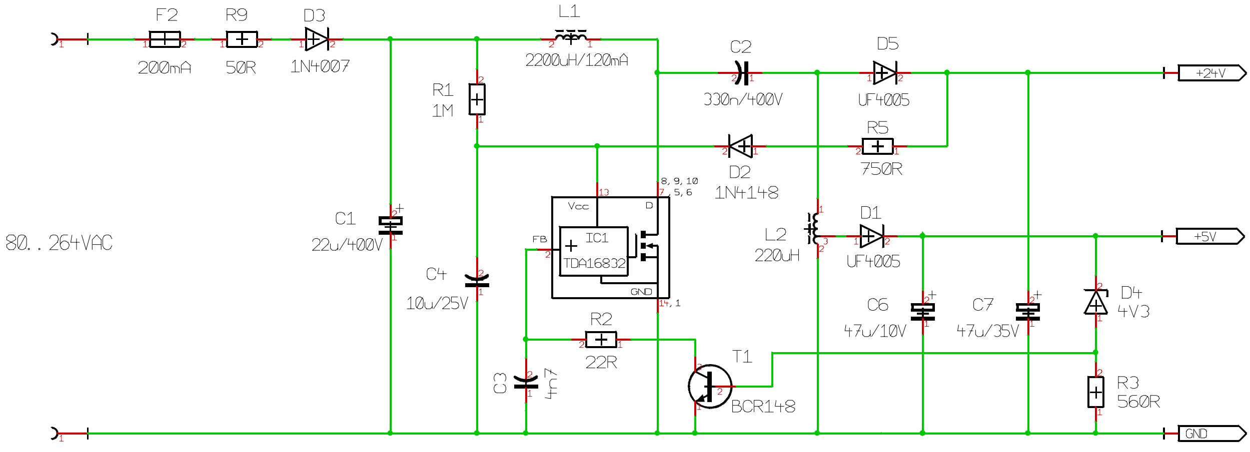

Figure 7: Circuit for a power supply with two output voltages

In many industrial electronic systems and home appliances, a +24V voltage is required to operate relays, magnetic valves etc. Normally this voltage is necessary in addition to a 5V supply for the control unit (microcontroller etc.). Since the load on the +24V rail is generally subject to wider fluctuations in this case, a tapped choke is required to generate both voltages. The magnetic coupling significantly reduces the load dependency of the output voltages. Figure 7 shows the corresponding circuit for a dual output power supply. The tap on choke L2 is in accordance with the ratio of the two output voltages.

References:

[1] TDA16831...-34 for OFF-Line Switch Mode Power Supplies
Application Note, Infineon Technologies

[2] TDA16831-4
Off-line SMPS Controller with 600V CoolMOS on Board
Datasheet, Infineon Technologies

Revision History		
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Page of actual Release	Page of prev. Release	Subjects changed since last release
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