Application Note
AN-SMPS-ICE2xXXX-1

CoolSET™
ICE2xXXX for OFF – Line Switch Mode Power Supply (SMPS)

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Operating Principles

The ICE2AXXX is designed for a current-mode flyback configuration in **discontinuous (DCM)** or **continuous conduction (CCM)** mode.

The control circuit has a fixed frequency. The duty cycle (D) of the integrated CoolMOS Transistor is controlled to maintain a constant output voltage (VOUT).

Fig. 1 shows the input voltage (VDC_IN), the primary current (ILPK), and the secondary (ISEC) transformer current of the flyback converter depicted on p. 3.

When the CoolMOS Transistor is switched on, the initial state of all windings on the transformer is at positive potential.

The rectifier diode (D1) on the secondary side is reverse biased and therefore does not conduct. Consequently no current flows in the secondary winding. During this phase, energy is stored in the inductance of the primary winding and the transformer can be treated as a simple series inductor.

Fig. 1 shows that there is a linear increase of the primary current (IPRI) while the CoolMOS Transistor is on.

When the CoolMOS Transistor is switched off, the voltage reverses on all transformer windings (flyback action) until it is clamped by rectifier diode on the secondary side. Now the secondary rectifier diode (D1) is conducting, and the magnetizing energy stored in the transformer core is transferred to the secondary side during the reset interval.

In the **discontinuous conduction mode DCM** the secondary current (ISEC) decreases from its peak value to zero (Fig. 1). During this period the whole energy stored in the primary inductance is transferred to the secondary side (neglecting losses and energy stored in the primary leakage inductance), then the next storage cycle starts. Taking into account the transformer turns ratio, the secondary voltage (VSEC) is “reflected” back (V_R) to the primary winding and adds to the input voltage (VDC_IN + V_R). An additional transient voltage may appear on the primary winding due to energy stored in the uncoupled “leakage” inductance in the primary winding. This voltage is not clamped by the secondary side winding. If the flyback current (ILPK and ISEC) does not reach zero before the next “on” – cycle the converter is operating in **continuous conduction mode** (Fig. 2).

Note:

When the system shifts to continuous conduction operation, its transfer function is changed to a two pole system with low output impedance. In this case additional design rules have to be taken into account including different loop compensation and slope compensation on the primary side.
Voltage and current waveforms in **discontinuous conduction mode** (DCM) operation:

**Duty Cycle: D = 0.5**

\[ V_{DC\ IN} = V_{DC\ IN\ min} \]

**Duty Cycle: D < 0.5**

\[ V_{DC\ IN} > V_{DC\ IN\ min} \]

**Fig. 1**

\[ D = \frac{t_{ON}}{T} \]
Comparison of continuous conduction (CCM) and discontinuous conduction (DCM) mode.

Fig. 2
Input stage
As shown in Fig. 3 the AC input power is rectified and filtered by the bridge rectifier (BR1) and the bulk capacitor C3. This creates a DC high voltage bus which is connected to the primary winding of the transformer (TR1). The transformer is driven by the CoolSET integrated high voltage, avalanche rugged CoolMOS transistor, with an external sense resistor (R17) for precision current measurement.

Output stage
The secondary winding power is rectified and filtered by a diode (D1), capacitors (C5, C9 and C20). The output LC-filter (L3, C23) reduces the output voltage ripple.

Other output voltages
Other output voltages can be realized by adjusting the transformer turn ratio and the output stage.

Chip supply
The current in the bias winding is rectified and filtered by a diode (D2) and a resistor (R8) in order to charge the supply capacitor (C4). This creates a bias voltage that powers the CoolSET ICE 2AXXX. The resistors R6 and R7 charge the VCC Cap and supply the chip during startup. The Zener diode (D4) clamps the chip supply voltage (Vcc) in order to protect the chip in case of an over-voltage condition. Capacitor C13 filters high frequency ripples on the chip supply voltage (Vcc).

Soft-Start
A soft-start function is activated during start-up, and can be adjusted by capacitor C14. In addition to start-up, soft-start is activated at each restart attempt during auto-restart and when restarting after one of the several protection functions are activated. This effectively minimizes current and voltage stresses on the CoolMOS MOSFET, the snubber network, and the output rectifier during start-up. The soft-start feature further helps to minimize output overshoot and prevents saturation of the transformer during start-up.

Clamping network
The clamping network which consists of a diode (D3), a resistor (R10) and a capacitor (C12) clamps the voltage spike caused by the transformer leakage inductance to a safe value this limits the avalanche losses of the CoolMOS transistor.
Control Loop
The resistors R1 and R2 represent the voltage divider for the reference diode TL431CLP (IC2). R4 supplies the TL431CLP reference diode with a minimum current and R3 the LED of the optocoupler. The network which consists of capacitors C1 and C2 determines the corner frequencies \( f_g1 \) and \( f_g2 \). R5 sets the gain of the control loop.

Slope Compensation
The current mode controller becomes unstable whenever the steady – state duty cycle \( D \) is larger than 0.5. In order to realize a design with a duty cycle greater 0.5, the slope of the current needs to be compensated. The slope compensation is realized by the network consisting of capacitor C17, C18 and the resistor R19.

Ripple Reduction
Inductor L5 and capacitor C23 attenuate the differential – mode emission currents caused by the fundamental and harmonic frequencies of the primary current waveform.

SMPS Calculation Software FLYCAL
FLYCAL is an EXCEL spread sheet with all Equations needed for the easy calculation of your SMPS. FLYCAL corresponds with the calculation example in this application note. You only have to enter the main parameters of your application in FLYCAL and to follow step by step the principle outlined in the calculation example. FLYCAL contains all equations used in the example with the same consecutive numbering.
Circuit Diagram:

Fig. 3
**Protection Functions**

The block diagram displayed in Fig. 4 shows the internal functions of the protection unit. The comparators C1, C2, C3 and C4 compare the soft-start and feedback-pin voltages. Logic gates connected to the comparator outputs ensure the combination of the signals and enables the setting of the “Error-Latch”.

![fig. 4](image_url)

*Fig. 4*
Fig. 5 shows the relation between the voltages at the soft start (Vss) and the feedback pins (V_{FB}) of ICE2AXXX, as a function of the supply voltage (Vcc) during an overvoltage condition at CoolSET soft start.

Depending on the voltage levels at the inputs, the overvoltage and (Vcc – PIN 7) and overload (V_{FB} – PIN 2) protection functions are activated.
**Overload and Open-Loop Protection**

- Feedback voltage (VFB) exceeds 4.8V and soft start voltage (VSS) is above 5.3V (soft start is completed) \( t_1 \)
- After a 5µs delay the CoolMOS is switched off \( t_2 \)
- Voltage at Vcc – Pin (VCC) decreases to 8.5V \( t_2 \)
- Control logic is switched off \( t_3 \)
- Start-up resistor charges Vcc capacitor \( t_3 \)
- Operation starts again with soft start after Vcc voltage has exceeded 13.5V \( t_4 \)

![Fig. 6](image)

![Fig. 7](image)

![Fig. 8](image)
**Overvoltage Protection During Soft Start**

- Feedback voltage (VFB) exceeds 4.8V and soft-start voltage (VSS) is below 4.0V (soft start phase) \(t_1\)
- Voltage at Vcc pin (VCC) exceeds 16.5V \(t_2\)
- CoolMOS transistor is immediately switched off \(t_2\)
- Voltage at VCC pin decreases to 8.5V \(t_3\)
- Control logic is switched off \(t_3\)
- Start-up resistor charges VCC capacitor \(t_4\)
- Operation starts again with soft start after VCC voltage has exceeded 13.5V \(t_5\)

![Fig. 9](image)

![Fig. 10](image)

![Fig. 11](image)
**Frequency Reduction**

The frequency of the oscillator depends on the voltage at pin FB. Below a voltage of typ. 1.75V the frequency decreases down to 21.5 kHz. Due to this frequency reduction the power losses in low load condition can be reduced very effectively. This dependency is shown in Fig. 12.

![Graph showing the relationship between V_FB and f_OSC]
### Design Procedure

for fixed frequency Flyback Converter with **ICE2AXXX** operating in *discontinuous* current mode.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define input Parameters:</td>
<td></td>
</tr>
<tr>
<td>Minimal AC input voltage:</td>
<td>$V_{AC \text{ min}}$</td>
</tr>
<tr>
<td>Maximal AC input voltage:</td>
<td>$V_{AC \text{ max}}$</td>
</tr>
<tr>
<td>Line frequency:</td>
<td>$f_{AC}$</td>
</tr>
<tr>
<td>Max. output power:</td>
<td>$P_{OUT \text{ max}}$</td>
</tr>
<tr>
<td>Nom. output power:</td>
<td>$P_{OUT \text{ nom}}$</td>
</tr>
<tr>
<td>Min. output power:</td>
<td>$P_{OUT \text{ min}}$</td>
</tr>
<tr>
<td>Output voltage:</td>
<td>$V_{OUT}$</td>
</tr>
<tr>
<td>Output ripple voltage:</td>
<td>$V_{OUT \text{ Ripple}}$</td>
</tr>
<tr>
<td>Reflection voltage:</td>
<td>$V_{R\text{max}}$</td>
</tr>
<tr>
<td>Estimated efficiency:</td>
<td>$\eta$</td>
</tr>
<tr>
<td>DC ripple voltage:</td>
<td>$V_{DC \text{ IN Ripple}}$</td>
</tr>
<tr>
<td>Auxiliary voltage:</td>
<td>$V_{Aux}$</td>
</tr>
<tr>
<td>Optocoupler gain:</td>
<td>$G_C$</td>
</tr>
<tr>
<td><em>Used CoolSET</em></td>
<td><strong>ICE2A365</strong></td>
</tr>
</tbody>
</table>

There are no special requirements imposed on the input rectifier and storage capacitor in the flyback converter. The components will be selected to meet the power rating and hold-up requirements.

Maximum input power:

$$P_{IN \text{ max}} = \frac{P_{OUT \text{ max}}}{\eta} \quad \text{(Eq 1)}$$

$$P_{IN \text{ max}} = \frac{50W}{0.85} = 59W$$
Input Diode Bridge (BR1):

\[ I_{ACRMS} = \frac{P_{IN\,MAX}}{V_{AC\,min} \cdot \cos \phi} \]  
(Eq 2)

\[ I_{ACRMS} = \frac{59W}{90\,V \cdot 0,6} = 1,09\,A \]

Maximum DC IN voltage

\[ V_{DC\,max\,PK} = V_{AC\,max} \cdot \sqrt{2} \]  
(Eq 3)

\[ V_{DC\,max\,PK} = 264\,V \cdot \sqrt{2} = 373\,V \]

Determine Input Capacitor (C3):

Minimum peak input voltage at "no load" condition

\[ V_{DC\,min\,PK} = V_{AC\,min} \cdot \sqrt{2} \]  
(Eq 4)

\[ V_{DC\,min\,PK} = 90\,V \cdot \sqrt{2} = 127\,V \]

we choose a ripple voltage of 30V

\[ V_{DC\,min} = 127\,V - 30\,V = 97\,V \]

Calculation of discharging time at each half-line cycle:

\[ T_D = 5ms \cdot \left( \arcsin \frac{V_{DC\,min}}{V_{DC\,min\,PK}} \right) \]  
(Eq 6)

\[ T_D = 5ms \left( \arcsin \frac{97V}{127V} \right) = 7,7ms \]

Required energy at discharging time of C3:

\[ W_{IN} = P_{IN\,max} \cdot T_D \]  
(Eq 7)

\[ W_{IN} = 59W \cdot 7,7ms = 0,46Ws \]

Calculation of input capacitor value C_{IN}:

\[ C_{IN} = \frac{2 \cdot W_{IN}}{V_{DC\,min\,PK}^2 - V_{DC\,min}^2} \]  
(Eq 8)

\[ C_{IN} = \frac{2 \cdot 0,46Ws}{16129V^2 - 9409V^2} = 136,9\,\mu F \]
Alternatively a rule of thumb for choosing $C_{IN}$ can be applied:

| Input voltage | $C_{IN}$  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>115V</td>
<td>2µF/W</td>
</tr>
<tr>
<td>230V</td>
<td>1µF/W</td>
</tr>
<tr>
<td>85V ...270V</td>
<td>2 ...3µF/W</td>
</tr>
</tbody>
</table>

Recalculation of input Capacitor:

Select a capacitor from the Epcos Databook of Aluminium Electrolytic Capacitors.

The following types are preferred:

For 85°C Applications:
- Series B43303-........ 2000h life time
- B43501-........ 10000h life time

For 105°C Applications:
- Series B43504-........ 3000h life time
- B43505-........ 5000h life time

We choose 150µF 400V (based on Eq 8)

Note that special requirements for hold up time, including cycle skip/dropout, or other factors which affect the resulting minimum DC input voltage and capacitor time should be considered at this point also.
Transformer Design (TR1):

Calculation of peak current of primary inductance:

\[
D_{\text{max}} = \frac{V_{\text{R max}}}{V_{\text{R max}} + V_{\text{DC min}}} \quad \text{(Eq 10a)}
\]

\[
I_{\text{LPK}} = \frac{2 \cdot P_{\text{IN MAX}}}{V_{\text{DC min}} \cdot D_{\text{max}}} \quad \text{(Eq 10b)}
\]

\[
I_{\text{LRMS}} = I_{\text{LPK}} \cdot \sqrt[3]{D_{\text{max}}} \quad \text{(Eq 11)}
\]

Calculation of primary inductance within the limit of maximum Duty-Cycle:

\[
L_p = \frac{D_{\text{max}} \cdot V_{\text{DC min}}}{I_{\text{LPK}} \cdot f} \quad \text{(Eq 12)}
\]

The number of primary turns can be calculated as:

\[
N_p = \sqrt{\frac{L_p}{A_L}} \quad \text{(Eq 13)}
\]

The number of secondary turns can be calculated as:

\[
N_s = \frac{N_p \cdot (V_{\text{OUT}} + V_{\text{FDIODE}})}{V_{\text{R max}}} \quad \text{(Eq 14)}
\]

The number of auxiliary turns can be calculated as:

\[
N_{\text{Aux}} = \frac{N_s \cdot (V_{\text{Aux}} + V_{\text{FDIODE}})}{V_{\text{R max}}} \quad \text{(Eq 15)}
\]

---

Selected core: E 25/13/7
Material = N27
\(A_L = 111 \, \text{nH}\)
\(s = 0.75 \, \text{mm}\)
\(A_e = 52 \, \text{mm}^2\)
\(A_{\text{Aux}} = 61 \, \text{mm}^2\)
\(l_{\text{Aux}} = 57.5 \, \text{mm}\)

Selected maximum flux density:

\(B_{\text{max}} \approx 0.2 \, \text{T} \ldots 0.3 \, \text{T}\) for ferrite cores depending on core material.
We choose \(0.2 \, \text{T}\) for material N27

\[
L_p = \frac{0.55 \cdot 100 \, \text{V}}{2.16 \cdot 100 \cdot 10^3 \, \text{Hz}} = 253 \, \mu \text{H}
\]

\[
N_p = \sqrt{\frac{253 \, \mu \text{H}}{111 \, \text{nH}}} = 47.7 \, \text{turns}
\]

we choose \(N_p = 46 \, \text{turns}\)

\[
N_s = \frac{46 \cdot (16 \, \text{V} + 0.8 \, \text{V})}{120 \, \text{V}} = 6.46
\]

we choose \(N_s = 7 \, \text{turns}\)

\[
N_{\text{Aux}} = \frac{46 \cdot (12 \, \text{V} + 0.7 \, \text{V})}{120 \, \text{V}} = 5.6
\]

we choose \(N_{\text{Aux}} = 5 \, \text{turns}\)
Verification of primary inductance, primary peak current, max. duty cycle, flux density and gap:

\[ L_p = N_p^2 \cdot A_t \]  \hspace{1cm} (Eq 16)  \hspace{1cm} L_p = 46^2 \cdot 11nH = 235\mu H

\[ I_{LPK} = \sqrt{ \frac{P_{IN\,max}}{0.5 \cdot L_p \cdot f} } \]  \hspace{1cm} (Eq 17)  \hspace{1cm} I_{LPK} = \sqrt{ \frac{59W}{0.5 \cdot 235\mu H \cdot 100 \cdot 10^3 \, Hz} } = 2.24A

\[ V_R = \frac{(V_{OUT} + V_{FDIODE}) \cdot N_p}{N_S} \]  \hspace{1cm} (Eq 18)  \hspace{1cm} V_R = \frac{(16V + 0.8V) \cdot 46}{7} = 110V

\[ D_{\max} = \frac{L_p \cdot I_{LPK} \cdot f}{V_{DC_{min}}} \]  \hspace{1cm} (Eq 19)  \hspace{1cm} D_{\max} = \frac{235\mu H \cdot 2.24A \cdot 100kHz}{100V} = 0.53

\[ D'_{\max} = \frac{L_p \cdot I_{LPK} \cdot f}{V_{R}} \]  \hspace{1cm} (Eq 20)  \hspace{1cm} D'_{\max} = \frac{235\mu H \cdot 2.24A \cdot 100kHz}{110V} = 0.47

\[ B_{\max} = \frac{L_p \cdot I_{LPK}}{N_p \cdot A_c} \]  \hspace{1cm} (Eq 21)  \hspace{1cm} B_{\max} = \frac{235\mu H \cdot 2.24A}{46 \cdot 52mm^2} = 210mT

\[ s = \frac{4 \cdot \pi \cdot 10^{-7} \cdot N_p^2 \cdot A_c}{L_p} \]  \hspace{1cm} (Eq 22)  \hspace{1cm} s = \frac{4 \cdot \pi \cdot 10^{-7} \cdot 46^2 \cdot 52mm^2}{235\mu H} = 0.588mm

**Sense resistor**

The sense resistance \( R_{\text{Sense}} \) can be used to individually define the maximum peak current and thus the maximum power transmitted.

**Caution:**

When calculating the maximum peak current, short term peaks in output-power must also be taken into consideration.

\[ V_{csth} = 1.0V \text{ typ. (taken from data sheet)} \]

\[ R_{\text{Sense}} = \frac{V_{csth}}{I_{LPK}} \]  \hspace{1cm} (Eq 23)  \hspace{1cm} R_{\text{Sense}} = \frac{1.0V}{2.24A} = 0.45\Omega

we select 0.43\Omega  \hspace{1cm} I_{LPK} = 2.33A

\[ P_{OUT_{\max}} = 54W \]
Winding Design:

see also page 38

Transformer Construction

The primary winding of 46 turns has to be divided into 23+23 turns in order to get the best coupling between primary and secondary winding.

The effective bobbin width and winding cross section can be calculated as:

\[ BW_e = BW - 2 \cdot M \]  (Eq 24)

\[ A_{Ne} = \frac{A_N \cdot BW_e}{BW} \]  (Eq 25)

Calculate copper section for primary and secondary winding:

From bobbin datasheet E25/13/7: BW = 15,6mm
Margin determined: M = 0mm

we use triple insulated wire for secondary winding

\[ BW_e = 15,6mm \]

\[ A_{Ne} = 61mm^2 \]

The winding cross section \( A_N \) has to be subdivided according to the number of windings.

Primary winding \( 0,5 \)
Secondary winding \( 0,45 \)
Auxiliary winding \( 0,05 \)

Copper space factor \( f_{Cu} : 0,2 \ldots 0,4 \)

We calculate the available area for each winding:
Used for calculation: \( f_{Cu} = 0,3 \)

\[ A_p = \frac{0,5 \cdot A_N \cdot f_{Cu} \cdot BW_e}{N_p \cdot BW} \]  (Eq 26)

\[ A_p = \frac{0,5 \cdot 61mm^2 \cdot 0,3}{46} = 0,2mm^2 \]

\[ AWG = 9,97 \cdot (1,8277 - (2 \cdot \log(d))) \]  (Eq 27)

\[ diameter \; dp = 0,5mm \]

25 AWG
\[
A_e = \frac{0.45 \cdot A_N \cdot f_{Cu} \cdot BW_e}{N_s \cdot BW} \quad \text{(Eq 28)}
\]

\[
A_s = \frac{0.45 \cdot 61 \text{mm}^2 \cdot 0.3}{7} = 1.18 \text{mm}^2
\]

\[
A_{aux} = \frac{0.05 \cdot A_N \cdot f_{Cu} \cdot BW_e}{N_{aux} \cdot BW} \quad \text{(Eq 29)}
\]

\[
A_{aux} = \frac{0.05 \cdot 61 \text{mm}^2 \cdot 0.3}{5} = 0.18 \text{mm}^2
\]

With the effective bobbin width we check the number of turns per layer:

\[
N_P = \frac{BW_e}{d_P} \quad \text{(Eq 30)}
\]

\[
N_P = \frac{15.6 \text{mm}}{0.46 \text{mm}} = 31 \text{ turns per layer}
\]

2 layer needed

Primary:

Secondary:

\[
N_s = \frac{15.6 \text{mm}}{2 \cdot 1.2 \text{mm}} = 6 \text{ turns per layer}
\]

2 layer needed

Auxiliary: 1 layer!
Output Rectifier (D1):

The output rectifier diodes in flyback converters are subjected to a large PEAK and RMS current stress. The values depend on the load and operating mode. The voltage requirements depend on the output voltage and the transformer winding ratio.

Calculation of the maximum reverse voltage:

$$V_{RDiole} = V_{OUT} + \left( V_{DC\,max\,PK} \cdot \frac{N_S}{N_P} \right) \quad \text{(Eq 31)}$$

Calculation of the maximum current on secondary side:

$$I_{SPK} = I_{LPK} \cdot \frac{N_P}{N_S} \quad \text{(Eq 32)}$$

$$I_{SRMS} = I_{SPK} \cdot \sqrt{V_D \cdot D_{max}} \quad \text{(Eq 33)}$$
Output Capacitors (C5, C9):

Output capacitors are highly stressed in flyback converters. Normally the capacitor will be selected for 3 major parameters: capacitance value, low ESR and ripple current rating.

Max. voltage overshoot: $\Delta V_{OUT}$

Number of clock periods: $n_{CP}$

$$C_{OUT} = \frac{I_{OUT_{max}} \cdot n_{CP}}{\Delta V_{OUT} \cdot f} \quad (Eq \ 34)$$

$$I_{OUT} = \frac{P_{OUT_{max}}}{V_{OUT}} \quad (Eq \ 34a)$$

$$I_{Ripple} = \sqrt{I_{SRMS}^2 - I_{OUT}^2} \quad (Eq \ 34b)$$

Select a capacitor out of Epcos Databook for Aluminium Electrolytic Capacitors.

The following types are preferred:

For 105°C Applications low impedance:
Series B41856-......... 4000h life time

For 105°C Applications lowest impedance:
Series B41859-......... 4000h life time

To calculate the output capacitor, it is necessary to set the maximum voltage overshoot in case of switching off @ maximum load condition.

After switching off the load, the control loop needs about 10...20 internal clock periods to reduce the duty cycle.

$$\Delta V_{OUT} = 0.5V$$

$$n_{CP} = 20$$

$$C_{OUT} = \frac{3.1A \cdot 20}{0.5V \cdot 100 \cdot 10^3 \text{ Hz}} = 1250\mu F$$

$$I_{OUT} = \frac{50W}{16V} = 3.1A$$

$$I_{Ripple} = \sqrt{5.9A^2 - 3.1A^2} = 5.0A$$

We select 1000$\mu$F 35V (based on Eq 34):

B41859-F7108-M

ESR $\approx Z_{max} = 0.034\Omega$ @ 100kHz

$1ac_{R} = 1.94A$

we need 2 capacitors in parallel
Output Filter (L3, C23):

The output filter consists of one capacitor (C23) and one inductor (L3) in a L-C filter topology.

Zero frequency of output capacitor (C5,C9, C20) and associated ESR:

\[
f_{ZCOUT} = \frac{1}{2 \cdot \pi \cdot R_{ESR} \cdot C_{OUT}} \quad \text{(Eq 35)}
\]

\[
\frac{OUTESR}{ZCOUT} = \frac{\pi}{2}
\]

\[
\text{We use } C_{LC} \text{ (C23) } 470 \mu F
\]

Calculation of the inductance (L3) needed for the substitution of the zero caused by the output capacitors:

\[
L_{OUT} = \frac{\left(C_{OUT} \cdot R_{ESR}\right)^2}{C_{LC}} \quad \text{(Eq 36)}
\]

\[
L_{OUT} = \frac{(1000\mu F \cdot 0,034\Omega)^2}{470\mu F} = 2,5\mu H
\]

RC-Filter at Feedback Pin
(C6, R9)

The RC Filter at the Feedback pin is designed to supress any noise which may be coupled in on this track.

Typical values:
C6 : 1...4,7nF
R9 : 22 Ohm

Note that the value of C6 interacts with the internal pullup (3,7k typical) to create a filter.
Soft-start capacitor
(C14)

The voltage at the soft-start pin together with feedback voltage controls the overvoltage, open loop and overcurrent protection functions.

The soft-start capacitor must be calculated in such a way that the output voltage and thus the feedback voltage is within the working range \( V_{FB} < 4.8V \) before the over-current threshold (typ. 5.3V) is reached.

\[
I_{Start} = \frac{V_o^2 \cdot C_{out}}{P_{OUT_{max}} - P_{OUT_{nom}}} \quad \text{(Eq37)}
\]

\[
C_{SS} = I_{Start} \cdot \frac{1}{R_{Soft-Start} \cdot \ln(1 - \frac{V_{Soft-Start1}}{V_{REF}})} \quad \text{(Eq38)}
\]

\[
R_{soft\_start} = 50\,\Omega \text{ typ (from datasheet).}
\]

\[
I_{Start} = 16V^2 \cdot \frac{2470\,\mu F}{54W - 40W} = 45\,ms
\]

\[
C_{SS} = 45\,ms \cdot \frac{1}{50\,\Omega \cdot \ln(1 - \frac{5.1V}{6.5V})} = 586nF
\]

choose 560nF
VCC Capacitor:

(C4, C13)

The VCC capacitor needs to ensure the power supply of the IC until the power can be provided by the auxiliary winding. In parallel with the VCC Capacitor it is recommended to use a 100nF ceramic capacitor very close between pin 7 & 8. Alternatively, an HF type electrolytic with low ESR and ESL may be used.

\[
C_{VCC} = \frac{I_{VCC}}{V_{CHV}} \cdot V_{softstart} \cdot \frac{2}{3} \quad \text{(Eq 39)}
\]

we choose 47uF

\[
C_{VCC} = \frac{8.2mA \cdot 45ms}{5V} \cdot \frac{2}{3} = 49uF
\]

Start-up Resistor (R6, R7):

- \(I_{VCC1}\) = max. quiescent current (Control IC)
- \(I_{LoadC}\) = VCC-Capacitor load-current (C4)
- \(C_{VCC}\) = Value of VCC-capacitor (C4)

\[
R_{Start} = \frac{V_{DC\ min}}{I_{VCC1} + I_{LoadC}} \quad \text{(Eq 40)}
\]

\[
R_{Start} = \frac{100V}{(55 + 70)\mu A} = 80k\Omega
\]

R6 = R7 = 1/2 \(R_{Start}\) = 400k\Omega

Choose 2 with value: 390k\Omega

\[
I_{Start} = \frac{C_{VCC} \cdot V_{CCon}}{I_{LoadC}} \quad \text{(Eq 41)}
\]

\[
I_{Start} = \frac{47\mu F \cdot 13.5V}{73\mu A} = 8.7s
\]

Note:
Before the IC can be plugged into the application board, the VCC capacitor must be always discharged!
**Clamping Network:**

(R10/C12/D3)

\[ V_{\text{Clamp}} = V_{(BR)DSS} - V_{\text{DC max}} - V_R \]  
(Eq 42)

For calculating the clamping network it is necessary to know the leakage inductance. The most common way is to have the value of the leakage inductance \((L_{LK})\) given in percentage of the primary inductance \((L_p)\). If it is known that the transformer construction is very consistent, measuring the primary leakage inductance by shorting the secondary windings will give an exact number (assuming the availability of a good LCR analyser).

\[ L_{LK} = L_p \cdot x\% \]

\[ C_{\text{Clamp}} = \frac{I_{\text{LPK}}^2 \cdot L_{LK}}{(V_R + V_{\text{Clamp}}) \cdot V_{\text{Clamp}}} \]  
(Eq 43)

\[ R_{\text{Clamp}} = \frac{(V_{\text{Clamp}} + V_R)^2 - V_R^2}{0.5 \cdot L_{LK} \cdot I_{\text{LPK}}^2 \cdot f} \]  
(Eq 44)

\[ V_{\text{Clamp}} = 650V - 373V - 110V = 166V \]

In our example we choose 5% of the primary inductance for leakage inductance.

\[ L_{LK} = 235\mu H \cdot 5\% = 11.8\mu H \]

\[ C_{\text{Clamp}} = \frac{(2.24A)^2 \cdot 11.8\mu H}{(110V + 166V) \cdot 166V} = 1.2nF \approx \]

we choose 1.5nF

\[ R_{\text{Clamp}} = \frac{(166V + 110V)^2 - 110V^2}{0.5 \cdot 11.8\mu H \cdot (2.24A)^2 \cdot 100 \cdot 10^3 \text{Hz}} = 23.9k\Omega \]

we choose 22kΩ
Calculation of Losses:

Input diode bridge (BR1):

\[ P_{\text{DIN}} = I_{\text{ACRMS}} \cdot V_F \cdot 2 \quad \text{(Eq 45)} \]

\[ P_{\text{DIN}} = 1.1A \cdot 4V \cdot 2 = 2.2W \]

Calculation of copper resistance \( R_{Cu} \):

\[ R_{PCu} = \frac{I_n \cdot N_p \cdot p_{100}}{A_p} \quad \text{(Eq 46)} \]

Copper resistivity \( p_{100} @ 100^\circ\text{C} = 0.0172 \Omega \text{mm}^2/\text{m} \)

\[ R_{PCu} = \frac{0.0644 m \cdot 46 \cdot 17.2 m \Omega \text{mm}^2/\text{m}}{0.46 \text{mm}^2} = 277.1m\Omega \]

\[ R_{SCu} = \frac{0.0644 m \cdot 7 \cdot 17.2 m \Omega \text{mm}^2/\text{m}}{2.10 \text{mm}^2} = 6.6m\Omega \]

Calculation of copper losses (TR1):

\[ P_{PCu} = I_{\text{LPK}}^2 \cdot D_{\text{MAX}} \cdot \frac{1}{3} \cdot R_{PCu} \quad \text{(Eq 47)} \]

\[ P_{PCu} = (2.33A)^2 \cdot 0.53 \cdot \frac{1}{3} \cdot 277.1m\Omega = 225.7mW \]

\[ P_{SCu} = I_{\text{SPK}}^2 \cdot D_{\text{MAX}}' \cdot \frac{1}{3} \cdot R_{SCu} \]

\[ P_{SCu} = (15.3A)^2 \cdot 0.47 \cdot \frac{1}{3} \cdot 2.01m\Omega = 227.4mW \]

\[ P_{Cu} = 225.7mW + 227.4mW = 453.1mW \]

Output rectifier diode (D1):

\[ P_{\text{DDIODE}} = I_{\text{SPK}} \sqrt{D_{\text{MAX}}'} \cdot V_{FDIODE} \quad \text{(Eq 48)} \]

\[ P_{\text{DDIODE}} = 15.3A \cdot \sqrt{0.47} \cdot 0.8V = 5W \]
COOLMOS TRANSISTOR:
ICE2A365  \( C_{o(er)} = 30 \text{pF} \)
Calculated @ \( V_{\text{DC min}} = 100\text{V} \)
\( C_O = 80\text{pF} \ (C_O = C_{o(er)} + C_{\text{extern}}) \)
\( R_{\text{DSON}} = 1.1\Omega \) (@ 125°C)

Switching losses:
\[
P_{\text{SON}} = \frac{1}{2} C_O \cdot V_{\text{DC min}}^2 \cdot f \quad \text{(Eq 49)}
\]
\[
P_{\text{SON}} = \frac{1}{2} \cdot 80\text{pF} \cdot 100\text{V}^2 \cdot 100 \cdot 10^3 \text{Hz} = 40\text{mW}
\]

Conduction losses:
\[
P_D = \frac{1}{3} R_{\text{DSON}} \cdot I_{\text{PK}}^2 \cdot D_{\text{max}} \quad \text{(Eq 50)}
\]
\[
P_D = \frac{1}{3} \cdot 1\Omega \cdot (2.33\text{A})^2 \cdot 0.53 = 0.95\text{W}
\]

Summary of Losses:
\[
P_{\text{Losses}} = P_{\text{SON}} + P_D \quad \text{(Eq 51)}
\]
\[
P_{\text{Losses}} = 40\text{mW} + 950\text{mW} = 0.99\text{W}
\]

Thermal Calculation:
Table of typical thermal resistance \( \frac{K}{W} \):

<table>
<thead>
<tr>
<th>Heatsink</th>
<th>DIP8</th>
<th>DIP7</th>
<th>TO220</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>90</td>
<td>96</td>
<td>74</td>
</tr>
<tr>
<td>3 cm²</td>
<td>64</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>6 cm²</td>
<td>56</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

\[
dT = P_{\text{Losses}} \cdot R_{jh} \quad \text{(Eq 52)}
\]
\[
dT = 0.99\text{W} \cdot 56 \frac{K}{W} = 55.4\text{K}
\]
\[
T_j = dT + T_a \quad \text{(Eq 53)}
\]
\[
T_j = 55.4\text{K} + 50^\circ\text{C} = 115.4^\circ\text{C}
\]
**Regulation Loop:**

Reference: TL431 (IC2)

- $V_{\text{REF}} = 2.5V$
- $I_{\text{KAmin}} = 1mA$

Optocoupler: SFH617-3 (IC1)

- $Gc = 1 ... 2 = \text{CTR } 100\% ... 200\%$
- $V_{FD} = 1.2V$
- $I_{F\text{max}} = 20mA$ (maximum current limit)

**Primary side:**

Feedback voltage:

Values from ICE2AXXX datasheet

- $V_{\text{Ref int}} = 6.5V$ typ.
- $V_{FB\text{max}} = 4.5V$
- $A_v = 3.65$
- $R_{FB} = 3.7k$ typ.

\[
I_{FB\text{max}} = \frac{V_{\text{Ref int}}}{R_{FB}} \quad \text{(Eq 54)}
\]

\[
I_{FB\text{min}} = \frac{V_{\text{Ref int}} - V_{FB\text{max}}}{R_{FB}} \quad \text{(Eq 55)}
\]

**Secondary side:**

\[
R_1 = R_2 \left( \frac{V_{OUT}}{V_{REF}} - 1 \right) \quad \text{(Eq 56)}
\]

the value of $R_2$ can be fixed at 4.3k

\[
R_3 \geq \frac{(V_{OUT} - (V_{FD} + V_{REF}))}{I_{F\text{max}}} \quad \text{(Eq 57)}
\]

\[
R_4 \leq \frac{V_{FD} + \left( R_3 \cdot \frac{I_{FB\text{min}}}{Gc} \right)}{I_{KA\text{min}}} \quad \text{(Eq 58)}
\]
Regulation Loop Elements:

\[
\begin{align*}
K_{FB} &= \frac{G_C \cdot 3k7}{R3} \\
K_{VD} &= \frac{R2}{R1 + R2} = \frac{V_{REF}}{V_{OUT}} \\
F_{PWR}(p) &= \frac{1}{Z_{PWM}} \sqrt{\frac{R_L \cdot L_p \cdot f \cdot \eta}{2}} \left\{ \frac{(1 + p \cdot R_{ESR} \cdot C_5)}{1 + p \cdot \left(\frac{R_L}{2} + R_{ESR}\right) \cdot C_5} \right\} \\
F_{LC}(p) &= \frac{1 + p \cdot R_{ESR} \cdot C_9}{1 + p \cdot R_{ESR} \cdot C_9 + p^2 \cdot L \cdot C_9} \\
F_{R}(p) &= \frac{1 + p \cdot R5 \cdot (C1 + C2)}{p \cdot \frac{R1 \cdot R2}{R1 + R2} \cdot \frac{C1 \cdot (1 + p \cdot R5 \cdot C2)}{C1}}
\end{align*}
\]
Zeros and Poles of transfer characteristics:

Poles of powerstage @ min. and max. load:

\[
R_{LH} = \frac{V_{OUT}^2}{P_{OUT_{max}}} = \frac{16V^2}{54W} = 4.9\Omega \quad \text{(Eq 64)}
\]

\[
R_{LL} = \frac{V_{OUT}^2}{P_{OUT_{min}}} = \frac{16V^2}{0.5W} = 512\Omega \quad \text{(Eq 65)}
\]

\[
f_{OH} = \frac{1}{\pi \cdot R_{LH} \cdot C5}
\]

\[
f_{OL} = \frac{1}{\pi \cdot R_{LL} \cdot C5}
\]

\[
f_{OH} = \frac{1}{\pi \cdot 4.9\Omega \cdot 2000\mu F} = 31.1Hz
\]

\[
f_{OL} = \frac{1}{\pi \cdot 512\Omega \cdot 2000\mu F} = 0.31Hz
\]

We use the gain (Gc) of the optocoupler stage \(K_{FB}\) and the voltage divider \(K_{VD}\) as a constant.

\[
K_{FB} = \frac{G_c \cdot 3k7}{R3} \quad K_{FB} = 4.9 \quad G_{FB} = 13.9db
\]

\[
K_{VD} = \frac{R2}{R1 + R2} = \frac{V_{REF}}{V_{OUT}} \quad K_{VD} = 0.15 \quad G_{VD} = -16.4db
\]

With adjustment of the transfer characteristics of the regulator we want to reach equal gain within the operating range and to compensate the pole \(f_0\) of the powerstage \(F_{PWR}(\omega)\).

Because of the compensation of the output capacitor's zero (see page 22 Eq35, Eq36) we neglect it as well as the LC-Filter pole.

Consequently the transfer characteristic of the power stage is reduced to a single-pole response.

In order to calculate the gain of the open loop we have to select the cross-over frequency.

We calculate the gain of the Power-Stage with max. output power at the selected cross-over frequency \(f_g = 3kHz\):
Calculation of transient impedance $Z_{PWM}$ of ICE2AXXX

The transient impedance defines the direct relationship between the level of the peak current and the feedback pin voltage. It is required for the calculation of the power stage amplification.

PWM-Op gain $-Av = 3.65$ (according to datasheet)

$$Z_{PWM} = \frac{\Delta V_{FB}}{\Delta I_{pk}} = A_v \cdot \frac{R_{sense}}{V_{coh}}$$  \hspace{1cm} \text{(Eq 68)}$$

$$Z_{PWM} = \frac{\Delta V_{FB}}{\Delta I_{pk}} = 3.65 \cdot \frac{0.43\Omega}{1.00V} = 1.57 \frac{V}{A}$$

Gain @ crossover frequency:

$$|F_{PWM}(fg)| = \frac{1}{Z_{PWM}} \cdot \frac{R_L \cdot R_p \cdot f \cdot \eta}{2} \left( \frac{1}{\sqrt{1+\left(\frac{fg}{fo}\right)^2}} \right)$$  \hspace{1cm} \text{(Eq 69)}$$

$$|F_{PWM}(3kHz)| = \frac{1}{1.7} \sqrt{\frac{5.1R \cdot 235\mu H \cdot 100kHz \cdot 0.8}{2}} \cdot \frac{1}{\sqrt{1+\left(\frac{3000}{31.1}\right)^2}} = 0.05$$

$G_{PWM}(3kHz) = -26.2db$
Transfer characteristics:

Fig. 16

At the crossover frequency (fg) we calculate the open loop gain:

\[ G_{o}(\omega) = G_{s}(\omega) + G_{r}(\omega) = 0. \]

With the equations for the transfer characteristics we calculate the gain of the regulation loop @ fg.

For the gain of the regulation loop we calculate:

\[ G_{s} = G_{FB} + G_{PWR} + G_{VD} = 13.9\text{db} - 26.2\text{db} - 16.4\text{db} \]

\[ G_{s} = -28.7\text{db} \]

We calculate the separate components of the regulator:

\[ G_{s}(\omega) + G_{r}(\omega) = 0 \quad \text{Gr} = 0 - (-28.7\text{db}) = 28.7\text{db} \]
\[ Fr(p) = \frac{1 + p \cdot R5 \cdot (C1 + C2)}{p \cdot \frac{R1 \cdot R2}{R1 + R2} \cdot C1 \cdot (1 + p \cdot R5 \cdot C2)} \]

\[ Gr = 20 \cdot \log \frac{R5 \cdot (R1 + R2)}{R1 \cdot R2} \]

\[ R5 = 10^{\frac{Gr}{20}} \cdot \frac{R1 \cdot R2}{R1 + R2} \]

\[ R5 = 10^{\frac{32.2}{20}} \cdot 3.65k = 99.15k \approx 100k \]  \hspace{1cm} (Eq 70)

\[ fp = \frac{1}{2 \cdot \pi \cdot R5 \cdot C2} \]

\[ f_{com} = f_{oh} \cdot 10^{\frac{0.5 \log f_{oh}}{f_{oh}}} \]

\[ f_{com} = 31.1Hz \cdot 10^{\frac{0.5 \log 31.1}{31.1}} = 3.2Hz \]

\[ C1 = \frac{1}{2 \cdot \pi \cdot R5 \cdot (C1 + C2)} - \frac{1}{2 \cdot \pi \cdot R5 \cdot f_{com}} - C2 \]

\[ C1 = \frac{1}{2 \cdot \pi \cdot 100k \cdot 3.2Hz} - 560pF = 470nF \]  \hspace{1cm} (Eq 72)

In order to have enough phase margin @ low load condition we select the zero frequency of the compensation network to be at the middle between the min. and max. load poles of the power stage.

\[ f_z = \frac{1}{2 \cdot \pi \cdot R5 \cdot (C1 + C2)} \]

\[ f_z = \frac{1}{2 \cdot \pi \cdot 100k \cdot 3.2Hz} = 530pF \approx 560pF \]  \hspace{1cm} (Eq 71)
Open Loop Gain

![Open Loop Gain Graph](image)

**Fig. 17**

Open Loop Phase

![Open Loop Phase Graph](image)

**Fig. 18**
Continuous Conduction Mode (CCM)

**Transformer calculation:**

The transformer is calculated in such a way that DCM operation is just barely reached \((A=0)\) at minimum output power \(P_{0\text{min}}\).

\[ P_{0\text{min}} = 2W \]

\[ P_{0\text{max}} = 10W \]

\[ D_{\text{max}} = 0,6 \]

\[ p = \frac{P_{0\text{max}}}{P_{0\text{min}}} \]

\[ I_{pk} = \frac{P_{0\text{min}} + P_{0\text{max}}}{D_{\text{max}} \cdot V_{dc\text{min}} \cdot \eta} \]

\[ Lp = \frac{P_{0\text{max}} \cdot (p + 1)^2 \cdot D_{\text{max}}}{I_{pk}^2 \cdot f \cdot p} \]

\[ p = \frac{10W}{2W} = 5 \]

\[ I_{pk} = \frac{2W + 10W}{0,6 \cdot 100V \cdot 0,8} = 0,25A \]

\[ Lp = \frac{10W \cdot (5+1)^2 \cdot 0,6}{0,25^2 \cdot 100kHz \cdot 5} = 6,91mH \]
Slope Compensation

Slope compensation is necessary for stable regulator operation in Continuous Conduction Mode (CCM), up to and beyond a duty cycle of 0.5 (see also [4]).

An simple method of slope compensation using the components R19, C17 and C18 is illustrated in the circuit diagram on page 3.

Fig. 20

\[ V_R = n \cdot V_o \quad n = \frac{n_p}{n_s} \]

\[ m_2 = \frac{n \cdot V_o}{L_p} = \frac{V_R}{L_p} \quad m_{korr} = \frac{m_2}{2} = \frac{V_R}{2 \cdot L_p} \]

For duty cycle = 0.5 applies:

\[ m_{korr} = \frac{V_{FBkorr}}{5 \cdot m_2} \quad V_{FBkorr} = \left( \frac{V_R \cdot 5 \cdot m_2}{2 \cdot L_p} \right) \cdot Z_{PWM} \]

C_{Comp} (C17) is selected at 10nF.

C18 is selected at 100nF.

R_{Comp} (R19):

\[ R_{Comp} = \frac{t}{\ln \left( 1 - \frac{V_{FBkorr}}{VCC} \right) \cdot C_{Comp}} \]
**Transformer Construction**

The winding topology has a considerable influence on the performance and reliability of the transformer.

In order to reduce leakage inductance and proximity to acceptable limits, the use of a sandwich construction is recommended.

In order to meet international safety requirements a transformer for Off-Line power supply must have adequate insulation between primary and secondary windings.

This can be achieved by using a margin-wound construction or by using triple insulated wire for the secondary winding.

The creepage distance for the universal input voltage range is typically 8mm. This results in a minimum margin width (as a half of the creepage distance) of 4mm. Additionally the necessary insulation between primary and secondary winding is provided using three layers of basic insulation tape.

Example of winding topology for margin wound transformers:

![Fig. 21](image1)

Example of winding topology with triple insulated wire for secondary winding:

![Fig. 22](image2)

BW*: value from bobbin datasheet
**Layout Recommendation:**

In order to avoid crosstalk on the board between power and signal path we have to use care regarding the track layout when designing the PCB.

The power path (see Fig. 23) has to be as short as possible and needs to be separated from the VCC Path and the feedback path. All GND paths have to be connected together at pin 8 (star ground) of ICE2AXX.
## CoolSET Table

<table>
<thead>
<tr>
<th>Device</th>
<th>Package</th>
<th>Current A</th>
<th>Rdson Ω</th>
<th>Pout @ 190Vac in Ta=75°C / Tj = 125°C</th>
<th>Pout @ 85Vac in Ta=75°C / Tj = 125°C</th>
<th>Heatsink</th>
<th>Frequency KHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE2A0565</td>
<td>DIP8</td>
<td>0.5</td>
<td>6.0</td>
<td>23</td>
<td>13</td>
<td>6 cm²</td>
<td>100</td>
</tr>
<tr>
<td>ICE2A0565Z</td>
<td>DIP7</td>
<td>0.5</td>
<td>6.0</td>
<td>21</td>
<td>12</td>
<td>6 cm²</td>
<td>100</td>
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<tr>
<td>ICE2A165</td>
<td>DIP8</td>
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<td>3.0</td>
<td>31</td>
<td>18</td>
<td>6 cm²</td>
<td>100</td>
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<td>3.0</td>
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<td>18</td>
<td>6 cm²</td>
<td>67</td>
</tr>
<tr>
<td>ICE2A265</td>
<td>DIP8</td>
<td>2.0</td>
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<td>32</td>
<td>6 cm²</td>
<td>100</td>
</tr>
<tr>
<td>ICE2B265</td>
<td>DIP8</td>
<td>2.0</td>
<td>0.9</td>
<td>52</td>
<td>32</td>
<td>6 cm²</td>
<td>67</td>
</tr>
<tr>
<td>ICE2A365</td>
<td>DIP8</td>
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<td>0.45</td>
<td>67</td>
<td>45</td>
<td>6 cm²</td>
<td>100</td>
</tr>
<tr>
<td>ICE2B365</td>
<td>DIP8</td>
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<td>0.45</td>
<td>73</td>
<td>45</td>
<td>6 cm²</td>
<td>67</td>
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<tr>
<td>ICE2A765P</td>
<td>TO220</td>
<td>7.0</td>
<td>0.5</td>
<td>240</td>
<td>130</td>
<td>2.7 k/W</td>
<td>100</td>
</tr>
<tr>
<td>ICE2B765P</td>
<td>TO220</td>
<td>7.0</td>
<td>0.5</td>
<td>240</td>
<td>130</td>
<td>2.7 k/W</td>
<td>67</td>
</tr>
<tr>
<td>ICE2A180</td>
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<td>3.0</td>
<td>31</td>
<td>18</td>
<td>6 cm²</td>
<td>100</td>
</tr>
<tr>
<td>ICE2A180Z</td>
<td>DIP7</td>
<td>1.0</td>
<td>3.0</td>
<td>29</td>
<td>17</td>
<td>6 cm²</td>
<td>100</td>
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<tr>
<td>ICE2A280</td>
<td>DIP8</td>
<td>2.0</td>
<td>0.8</td>
<td>54</td>
<td>34</td>
<td>6 cm²</td>
<td>100</td>
</tr>
<tr>
<td>ICE2A280Z</td>
<td>DIP7</td>
<td>2.0</td>
<td>0.8</td>
<td>50</td>
<td>31</td>
<td>6 cm²</td>
<td>100</td>
</tr>
</tbody>
</table>

Output Power Notes:
The output power was created using the equations of this application note (see „Calculation of Losses“ on page 27). It shows the maximum practical continuous power @ Ta = 75 °C and Tj = 125 °C with the recommended heatsink as a copper area on PCB for DIP7 / 8 and PDSO14 packages.
Summary of used Nomenclature

- B\text{max}: Magnetic Inductance
- BW: Bobbin Width
- B\text{We}: Effective Bobbin Width
- C\text{IN}: Capacitance of Bulk Capacitor
- C\text{OUT}: Output Capacitance
- C\text{OSS}: Output Capacitance of CoolMOS
- C\text{tem}: Capacitance of external Components
- C\text{clamp}: Capacitance of Clamping – Capacitor
- C\text{VCC}: Capacitance of VCC – Capacitor
- D: Duty Cycle
- D\text{max}: Maximum Duty Cycle
- f: Operating Frequency of CoolSET (f = 100kHz)
- f\text{AC}: Line Frequency (Germany f\text{AC} = 50Hz)
- f\text{Cu}: Copper Space Factor (0,2 ... 0,4)
- f\text{OH}: Frequency Open Loop (High)
- f\text{Om}: Frequency Open Loop (middle)
- f\text{OL}: Frequency Open Loop (Low)
- f\text{ZCOUT}: Zero Frequency of output Capacitor
- G\text{C}: Optocoupler Gain
- I\text{FBmax}: Maximum Feedback Current
- I\text{FBmin}: Minimum Feedback Current
- I\text{max}: Maximum Current (Optocoupler)
- I\text{max}\text{CLAMP}: Maximum Current (Clamping)
- I\text{max}K: Maximum Current of TL431
- I\text{PCLAMP}: Peak Current through the primary Inductance
- I\text{RMS}: Root Mean Square Current through the primary Inductance
- I\text{RMS}\text{RECT}: Root Mean Square Current through the Bridge Rectifier
- I\text{TDO}: Primary Current @ time t
- I\text{SEC}: Secondary Current @ time t
- I\text{PK}: Peak Current through the secondary diode
- I\text{RMSSEC}: RMS Current through the secondary diode
- I\text{VCC}: Maximum quiescent Current of CoolSET (Control IC)
- I\text{OUT}: Inductive output Filter
- I\text{L}: Primary Inductance
- I\text{LX}: Leakage Inductance
- M: Margin (of Transformer)
- N\text{CP}: Number of Clock Periods
- N\text{OUT}: Number of parallel output Capacitors
- N\text{P}: Number of primary Turns
- N\text{S}: Number of secondary Turns
- N\text{Aux}: Number of auxiliary Turns
- P\text{Cu}: Power losses of Copper Resistor
- P\text{DC}: Conduction losses
- P\text{ON}: Power losses input Diode
- P\text{PDIOE}: Power losses rectifier Diode (secondary side)
- P\text{IN}: Maximum Input Power
- P\text{OUT}: Maximum Output Power
- P\text{OUTmin}: Minimum Output Power
- P\text{CuO}: Power losses of Copper Resistor (primary Inductance)
- P\text{CuI}: Power losses of Copper Resistor (secondary Inductance)
- P\text{OFF}: Switching losses of CoolMOS Transistor (Off – Operation)
- P\text{ON}: Switching losses of CoolMOS Transistor (On – Operation)
- R\text{Cu}: Copper Resistor (Transformer)
- R\text{DSON}: Resistance of switching CoolMOS Transistor (On – Operation)
- R\text{L}: Load – Resistance
- R\text{Lmax}: Maximum Load
- R\text{Lmin}: Minimum Load (defined by Designer)
- R\text{FB}: Internal Feedback Resistor (CoolSET)
- R\text{CuO}: Copper Resistor of primary Inductance
- R\text{CuI}: Copper Resistor of secondary Inductance
- R\text{Clamp}: Clamping Resistor
- R\text{Start}: Start up Resistor
- T\text{O}: Time of one Period
- T\text{D}: Discharging Time of Input Capacitor C3
- T\text{ON}: On Time (CoolSET)
- T\text{OFF}: Off Time (CoolSET)
- t\text{R}: Rising Time (Voltage)
- t\text{Start}: Start up Time
- V\text{ACmin}: Minimal AC Input Voltage
- V\text{ACmax}: Maximal AC Input Voltage
- V\text{Aux}: Auxiliary Voltage
- V\text{BR}: Drain Source Breakdown Voltage
- V\text{CC}: Turn On Threshold for CoolSET @ Vcc - Pin
- V\text{DC IN}: DC Input Voltage
- V\text{DC IN max}: Maximum DC Input Voltage
- V\text{DC IN min}: Minimum DC Input Voltage
- V\text{DC}: Max DC Input Voltage Peak
- V\text{DCmin}: Minimum DC Input Voltage
- V\text{DD}: Reverse Voltage rectifier Diode (secondary side)
- V\text{DD}: Maximum Feedback Voltage (CoolSET)
- V\text{D}: Forward Diode Voltage (Optocoupler)
- V\text{OUT}: Output Voltage (secondary Side)
- V\text{OUT Ripple}: Output Ripple Voltage (secondary Side)
- V\text{H}: Reflected Voltage (from secondary side to primary side)
- V\text{H}: Reverse Voltage Diode
- V\text{H}: Internal Reference Voltage (CoolSET)
- V\text{REF}: Reference Voltage TL431
- V\text{Ripple}: DC Ripple Voltage (on primary Side)
- V\text{SEC}: Voltage on Secondary Inductor
- V\text{Clamp}: Maximum Voltage overshoot @ clamping network
- W\text{IN}: Discharging Energie Input Capacitor
- Z\text{PWM}: Transimpedanz
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