Application Note

Selection guide for a coupled inductor used in Sepic DC/DC Converter.

The most popular DC/DC Converter topology used on the led drivers in automotive industry is SEPIC topology (single ended primary inductance converter), in this topology the output voltage can be higher or lower than the input voltage. This topology combines charateristics of buck and boost converter and in most cases operates in CCM (Continuous conduction mode). As far as the led drivers in automotive application are concerned they don't need the insulation between the input side and output side for the DC-DC converter, the SEPIC topology is ideal for this kind of application.

In this application note we will discuss step by step the design for the coupled inductor used in the SEPIC topology.

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Working principle for the SEPIC DC/DC Converter.

The schematic diagram for a basic SEPIC topology is shown in Figure 1, As with other switched DC-DC converter, the SEPIC topology also exchange energy between the capacitors and inductors in order to convert from one voltage to another the amount of energy exchanged is controlled by switch Q1.

The output of the SEPIC is controlled by the duty cycle of the switch Q1.

Assuming 100 % efficiency, the duty cycle, D is given by:

D=(Vout+Vfwt)/(Vin+Vout+Vfwt) **Equation NB1.**

D is the duty cycle.

Vout : is the output voltage

Vin : is the input voltage.

Vfwt : is the forward voltage drop of the schottky diode.

The SEPIC topology uses two inductors L1 and L2, the two inductors can be wound on separately core or can use the same core.

Two inductor wound on the same core it has a lot of advantages the most important ones are listed below:

1- Space saving (less space on the PCB).
2- Cost saving (cheaper than to use two inductances).
3- Lower current ripple.
4- The leakage inductance can be an advantage for this application.

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Basic Operation for the SEPIC converter:

Figure 1 shows a simple circuit diagram of a SEPIC converter consisting of an input capacitor, Cin an output capacitor, Cout coupled inductors L1 and L2 an AC coupling capacitor, CS a power MOs FET Q1 and a shotcky diode D1.

When Q1 is OFF, the voltage across L1 must be Vout, since Cin is charged to Vin, the voltage across L1 is Vout. When Q1 is ON capacitor CS, charged to Vin, is connected in parallel with L2, so the voltage across L2 is Vin.

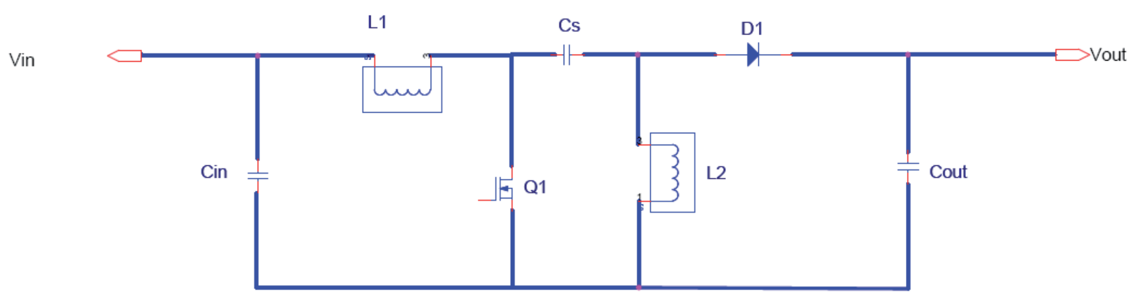

Figure 1 : SEPIC TOPOLOGY.

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Basic Operation for the SEPIC converter:

The current flowing through various circuit components are shown in figure 2. When Q1 is ON energy is being stored in L1 from the input and in L2 from CS. When Q1 turns OFF, L1 current continues to flow through CS and D1, and into Cout and the Load. Both Cout and CS get recharched so that they can provide the load current and charge L2 respectively, when Q1 turns back ON.

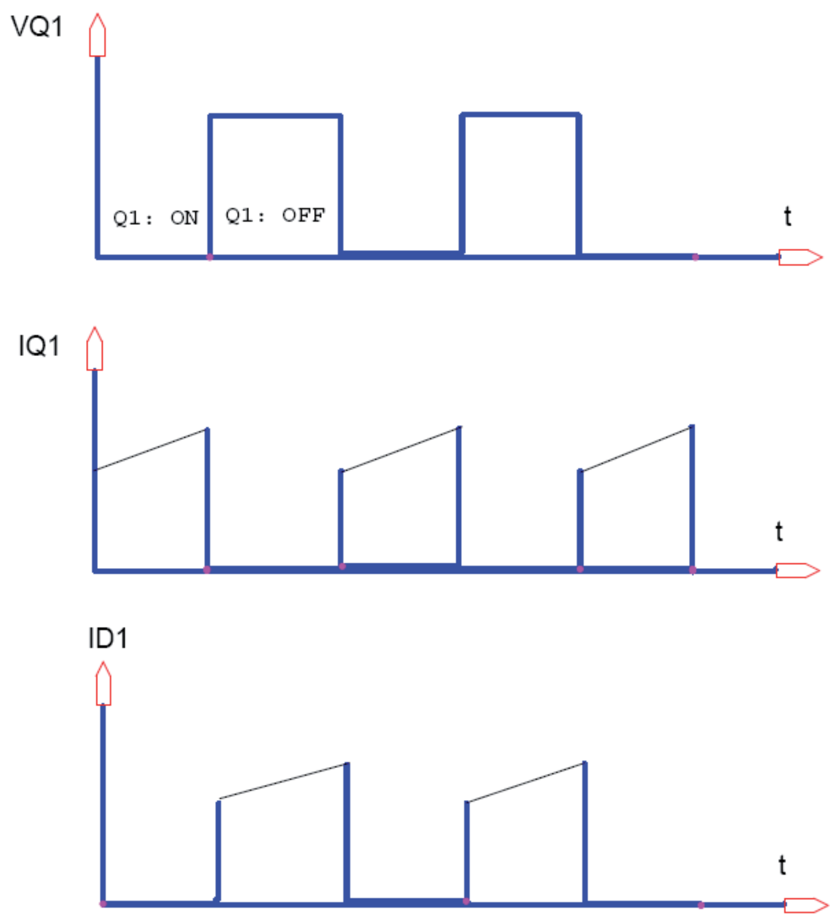

Figure 2.Current and Voltage accros D1 and Q1.

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Working principle for the SEPIC DC/DC Converter.

One of the first steps in designing any PWM switching regulators is to decide how much inductor ripple current DIl, to allow too much increases EMI while too little may result in unstable PWM operation. A rule of thumb is to use 20 to 40 % of the input current, as computed with the power balance equation:

DIl=30%Iin/efficiency.

Assuming 100 % efficiency the duty cycle D for a SEPIC converter operation in CCM is given by equation NB1.

Dmax occurs at Vinmin and Dmin occurs at Vinmax

In an ideal, tightly coupled inductor, with matched inductor having the same number of windings on a single core, the mutual inductance forces the ripple current to be split equally between the two coupled inductors. In a real coupled inductor the inductors do not have equal inductance and the ripple currents will not be exactly the same.

Regardless for a desired ripple current value the inductance required in a coupled inductor is estimated to be half of what would be needed if there were two separate inductors, as shown in the equation NB2 below:

L1amin=L2bmin=(Vinmin*Dmax)/(2*DIlµFswmin). **EQUATION NB2**

Value of the inductance requested.

Where, Fswmin is the minimum switching frequency.

To account for load transients, the coupled inductances saturation current rating needs to be at least 20 % higher than the steady state peak current in high side inductor as computed in equation NB3 below:

Il1peak=Iin+DI/2=Iin*(1+30 % /2)). **EQUATION NB3.**

Peak Current on the Inductance.

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Calculation of the RMS current.

The RMS current is given by a following formula:
I1Rms=(Vout*Iout)/(Vinmin*Efficiency)
I2rms=Iout.

Inductance losses calculation:

When we fix the electrical parameters for the inductance it is important to take in consideration the losses calculation for this inductance during the design stage.
They are two type for the losses in the inductance, a core losses and a copper losses

1 copper losses:

The Sink effect is given by the formula below:

$S=66/\sqrt{(Fsw)}$, the switching frequency is in Hz and the Sf will be in mm.
As the switching frequency is high for the DC-DC SEPIC topology it is important to use 2 or 3 wires in parallel to optimize the SF or better to use the litz wire.

The AC resistance for a round wire is given by A.LEVASSEUR formula:

$Rac=Rdc*(0.25+{}^{6}(\sqrt{(0.18+S//P.8))^{6}}$
S= is the wire section in mm^2
P= is the perimeter for the Section mm
S: is the sink effect

The copper losses for the L1 is given by :

$Pj1=RDC1*((SQR(Iavg)+(Rac1/Rdc1)*Irms^2)$; Rdc1 is the DC Resistance for winding1.

$Pj2=Rdc2*((SQR(Iavg)+(Rac2/Rdc2)*Irms^2)$; Rdc2 is the DC Resistance for winding2.

The total copper losses will be Pj= PJ1+PJ2.

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2. Core Losses

The core losses depend on the core material used flux density and the switching frequency, the core losses are given by a following formula

$$Pc=K\,F^{a}\,B^{b}$$

Where the parameters K, a and b are specific for material and can be determine in the data book for this material.

The power losses on the inductance are optimum when the Pj=Pc.

If Pj>1,4Pc the copper losses are important in this case we have to redo the wire gage design by decreasing the courrent density.

IF THE Pc<1,4Pj the core losses are importante and we have to redo the design using a lower flux density Bmax.

The rule for the coupled power inductance is use the following criteria;

$$0,7<Pj/Pc<1,4$$

The last step for the design for the coupled inductance is to get an estimation for the leakage inductance value it can be established by using the following formula:

$$K=\sqrt{(1-Lcc/L1)}.$$

Where the K is coupled factor, Lcc leakage inductance and L1 is the primary inductance.

The coupled factor generally is fixed by design, to have a better coupled factor we have to use a bifilar winding for L1 and L2, and to have a worse coupled factor we have to use an insulation between the two winding.

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Design Example

A DC/DC converter is needed that can provide 10 volts at 3A ‘Maximum) with 90 % efficiency from an input voltage from 6volts to 12 volts, Fs (switching frequency) is 100khs and the typical voltage drop for the shotky diode is 0.5volts.

1- **Calculate the minimum and maximum duty cycle Dmin and Dmax/**

Dmax=(10volts+0.5volts)/(10volts+6volts+0.5volts)=0.64

Dmin=(10volts+0.5volts)/(10volts+12volts+0.5volts)=0.47

2- **Calculate peak to peak ripple current**

DI=I4pnx30%=(3Ax10volts)/(6voltsx90%)x30%=0.56x30%=1.7Amps

3- **Calculate Inductance**

Inductance is calculated by the fundamental equation

V=LxDI/DT

Because the two windings of a coupled inductor share the ripple current, the inductance value can be halved.

L1=L2=0.5x6voltsx0.64/(1.7Ampsx100Khz)=11,3μhenry.

We choose a standard value 12μhenry.

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4- **Calculate RMS current**
L1rms=(VoutxIout)/(Vinminxefficiency)

L1rms=10voltsx3Amps/(6voltsx0.9)=5.6Amps.
L2rms=Iout=3Amps.

5- **Calculate Ipeak**

L1peak=Irmsx+(0.5xIripple)=0.56+(0.5x1.7)=6.45Amps.

L2peak=0.3A+(0.5x1.7)=3.85Amps.

6- **Summarize inductor specifications**

L1=L2=12μhenry

Irms(L1)=5.6A

Irms(L2)=3.0A

Ipeak(L1)=6.45

Ipeak(L2)=3.85

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Select the coupled inductor

Choose TT Electronics HA78D-128120MLFTR has 12µhenry per winding, and a saturation rating of 9.60Amps, on this application the current on each winding or any combination doesn't exceed 6.45 Amps, the current will flow without saturation.

The HA78D-128120MLFTR has RMS rating of 6Amps for a single winding or 2.90 for both, this means that for 40°C temperature rise up to 2.90Amps can flow in each winding simultaneously or up 1.4Amps can flow in one winding.

For this application Irms of L1(5.6A) and Irms of L2(3.0Amps) as well below these limits, to calculate the temperature rise (DT):

Power loss (copper)=(Il12+IL22)Xdcr

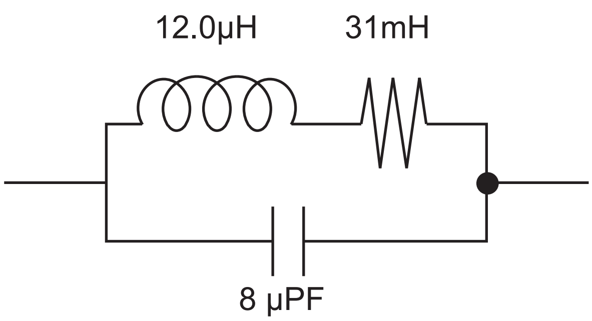
Temperature rise (DT)=Power loss (cooper)x30°C/W

Power loss (copper)=$(5.6^2 + 3.0^2)$x 0.031=1.25W

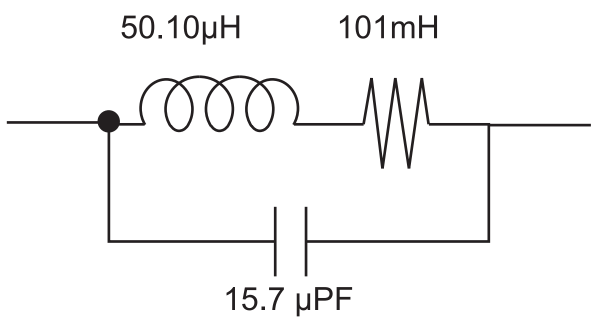
DT=1.25X30°C/W=37°C

This is only an estimation to be accurate we have to estimate the total losses including the effect of the frequency; however the calculation using only the RI^2 gives only an estimation.

SPICE MODEL For This part:



Coupled Inductance



Series Connection

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