Impact of Winding Configuration on Leakage Inductance and Circuit Performance

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Standard Winding Styles in relation with Coupling Coefficient/Leakage Inductance

- **Bifilar Winding**
  - Good Coupling coefficient (Low leakage inductance)

- **Stacked winding**
  - Poor Coupling coefficient (High Leakage Inductance)
CASE Study: SEPIC Converter Application
Under Test: Bifilar Winding vs Stacked Winding

Molded Coupled Inductor

Two winding structures for different leakage inductance

Case 01: Bifilar Winding
Case 02: Stacked Winding
THE QUESTION IS:

Is Leakage Inductance always detrimental? or can it actually become beneficial in some applications?

Case Study: SEPIC Converter

Comparison of two Molded Coupled Inductors (MCRI):

- Coupled Inductor 1: MCRI-8.2uH, Low Llkg = 250 nH (High k = 0.98)
- Coupled Inductor 2: MCRI-8.2uH, High Llkg = 3.5 uH (Low k = 0.75)

• All other specifications the same.
• Only change the winding structure and therefore the Leakage Inductance!
CASE Study: SEPIC Converter Application
SEPIC Power Stage with Coupled Inductor

SEPIC Converter with Coupled Inductor Power Stage

*Coupled Inductor*

![Diagram of SEPIC Converter with Coupled Inductor Power Stage](image-url)
CASE Study: SEPIC Converter Application
The circulating loop current in the SEPIC Converter

Circulating Current on SEPIC Converter
Equivalent Circuit for AC ripple of Coupling Capacitance
(considering Z(Cin) negligible)

There is Magnetic Flux Cancellation on \( L_{m1} \) and \( L_{m2} \), thus the AC ripple appears only across DCR and leakage inductance.
If DCR << Z(Llk), then (approximation):

The higher the leakage inductance, the lower \( C_{ac} \) required for the same circulating current ripple!!

\[
\Delta V_{Cac}(t) \approx L_{LK} \cdot \frac{di_{cir}(t)}{dt}
\]
CASE Study: SEPIC Converter Application
LTSpice Simulation Example

Measured Winding Current = Circulating current + Eq. Magnetizing Current

$I_{L2}$

$I_{L1}$

$I_{cir}$

$I_{L1M}$  
$I_{L2M}$
EXAMPLE OF EXPERIMENTAL RESULTS

WINDING CURRENT WAVESHAPE AS EXPECTED IN SIMULATION
CASE Study: SEPIC Converter Application

CONSEQUENCES OF HIGH CIRCULATING CURRENT

• Lower Power Efficiency
• Higher Operating Temperature and Thermal Stress of Power Components
• Input EMI Filter Requirements

FIRST-ORDER APPROXIMATION

\[ C_{AC} = \frac{I_{o(max)} \cdot L_M \cdot D_{max} \cdot T_s}{L_{LKG} \cdot V_{in(min)}} \]

AC Coupling Capacitance required to obtain a circulating current ripple amplitude approximately equal to the magnetizing current
CASE Study: SEPIC Converter Application
SEPIC Converter Experimentation Board

SEPIC Converter

Vin = 24 V (nom.)
Vout = 12 V
Iout = 2 A
Fsw = 200 kHz

Synchronous Control with N-MOSFET and P-MOSFET (replacing diode)
EXPERIMENTAL RESULTS

RMS Current
Efficiency
Thermal Performance

CASE 1: \( \text{Cac} = 20\mu\text{F} \)
CASE 2: \( \text{Cac} = 1\mu\text{F} \)
SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 1: Cac = 20uF

**Coupled Inductor 1:** MCRI-8.2uH, Low Llkg = 250 nH (High k = 0.98)

![Graph showing winding currents](image-url)
SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 1: Cac = 20uF

Coupled Inductor 2: MCRI-8.2uH, High Llkg = 3.5 uH (Low k = 0.75)
SEPIC Converter with WE Coupled Inductor: Efficiency Comparison
CASE 1: Cac = 20uF

Power Efficiency (@ 32Vin/20uF)

\[ L_{lk} = 3.5\mu H \]
\[ L_{lk} = 0.25\mu H \]
NOW DECREASING COUPLING CAPACITANCE
BY A FACTOR OF 10 ! …

(Cac=2uF)
(lower cost and smaller solution size)
SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 2: Cac = 2uF

**Coupled Inductor 1**: MCRI-8.2uH, Low L_lkg = 250 nH (High k = 0.98)
SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 2: Cac = 2uF

Coupled Inductor 2: MCRI-8.2uH, High Llkg = 3.5 uH (Low k = 0.75)
SEPIC Converter with WE Coupled Inductor: Efficiency Comparison

CASE 2: $C_{ac} = 2\mu F$

![Graph showing Power Efficiency at 24Vin/2uF]

- $L_{lk} = 3.5\mu H$
- $L_{lk} = 0.25\mu H$
THERMAL PERFORMANCE COMPARISON
SEPIC Converter with WE Coupled Inductor
Thermal Performance Results: Coupled Inductors Comparison

Low Leakage Coupled Inductor

High Leakage Coupled Inductor

Significantly higher operating Temperature of the low-leakage coupled inductor versus the high-leakage equivalent
SEPIC Converter with WE Coupled Inductor
Thermal Performance Results: Power Stage Comparison

WITH
Low Leakage
Coupled Inductor

WITH
High Leakage
Coupled Inductor

Slightly higher operating temperature of N-MOSFET, P-MOSFET and MLCC Coupling Capacitors with a low-leakage coupled inductor
Thanks