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Impact of Winding Configuration on Leakage Inductance and Circuit Performance

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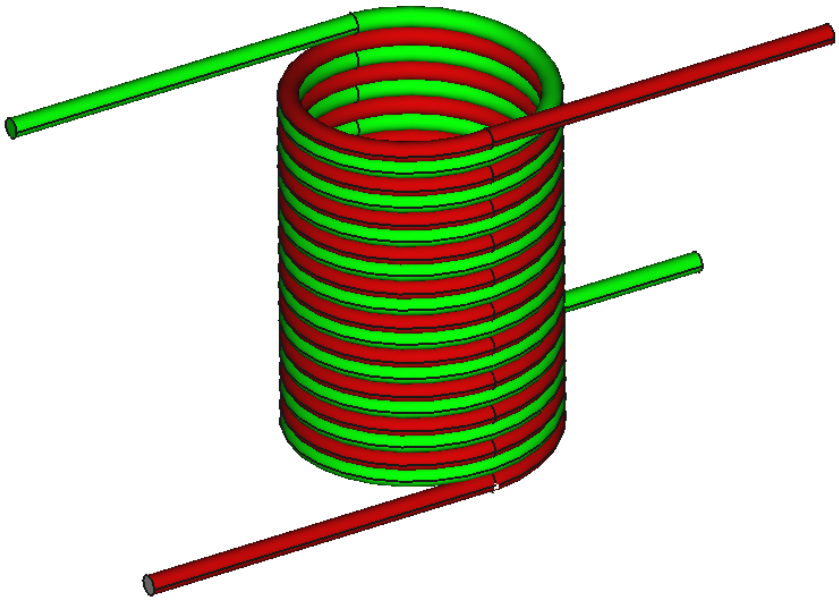
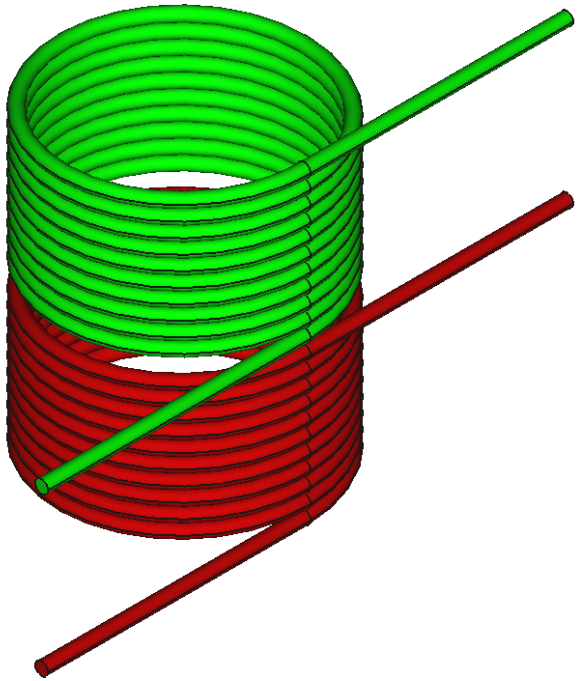
Standard Winding Styles in relation with Coupling Coefficient/Leakage Inductance





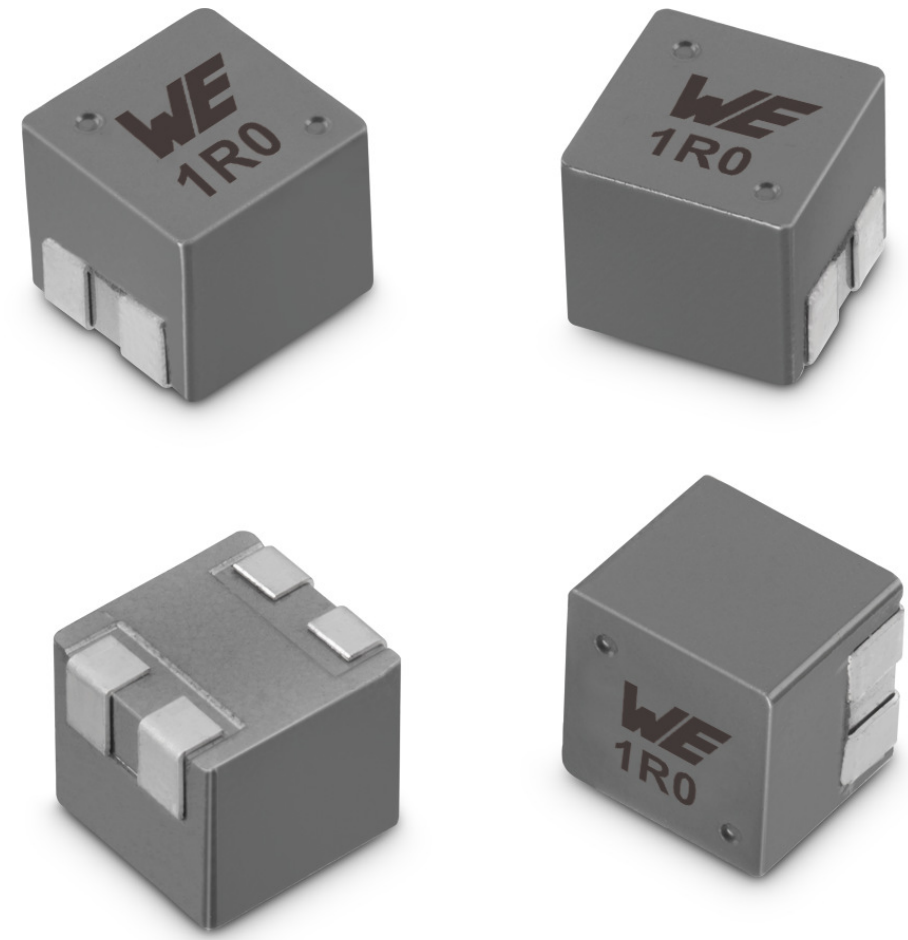
Bifilar Winding

- 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

CASE Study: SEPIC Converter Application

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<u>THE QUESTION IS</u>:

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

Case Study: SEPIC Converter

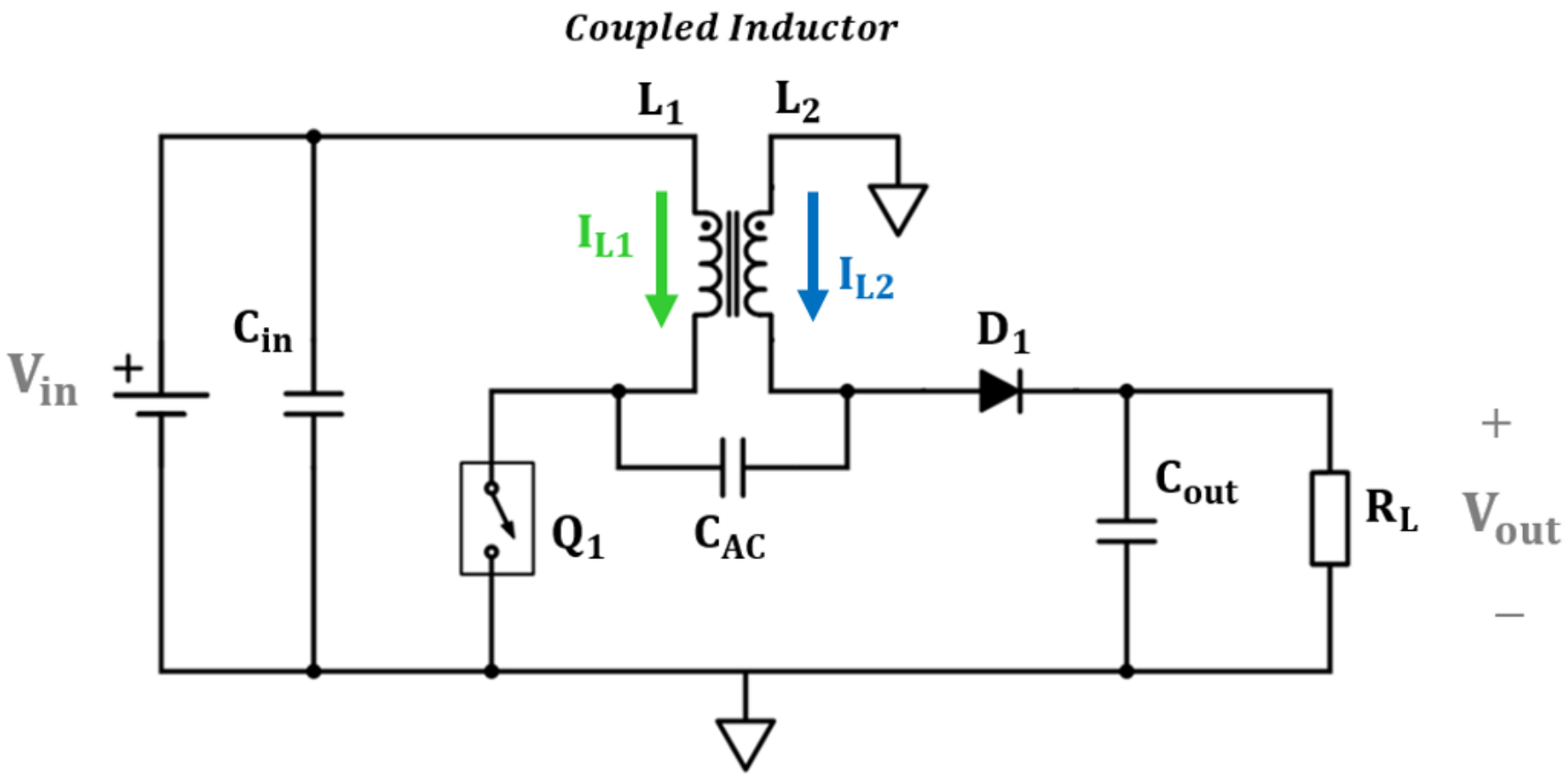
Comparison of two Molded Coupled Inductors (MCRI):

- 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

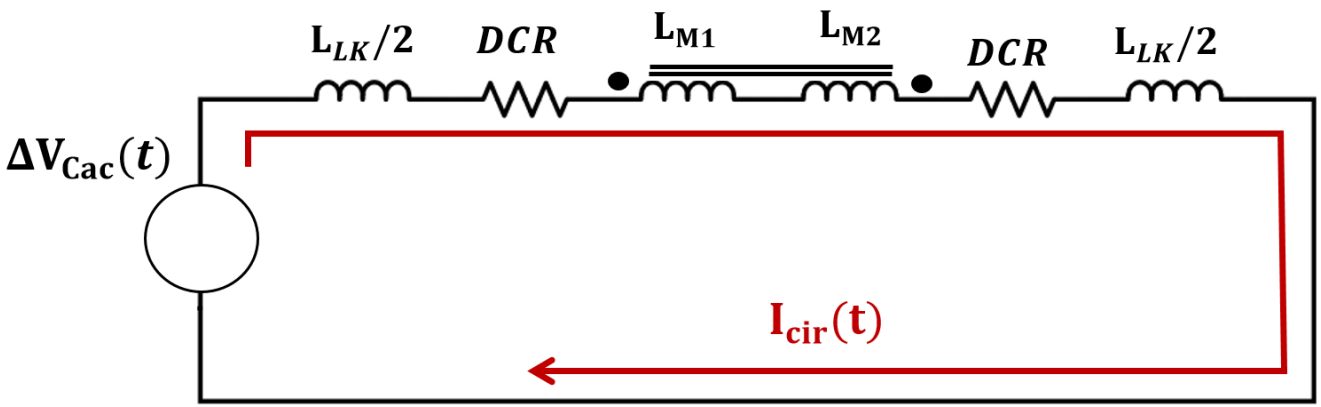
SEPIC Converter with Coupled Inductor Power Stage



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)



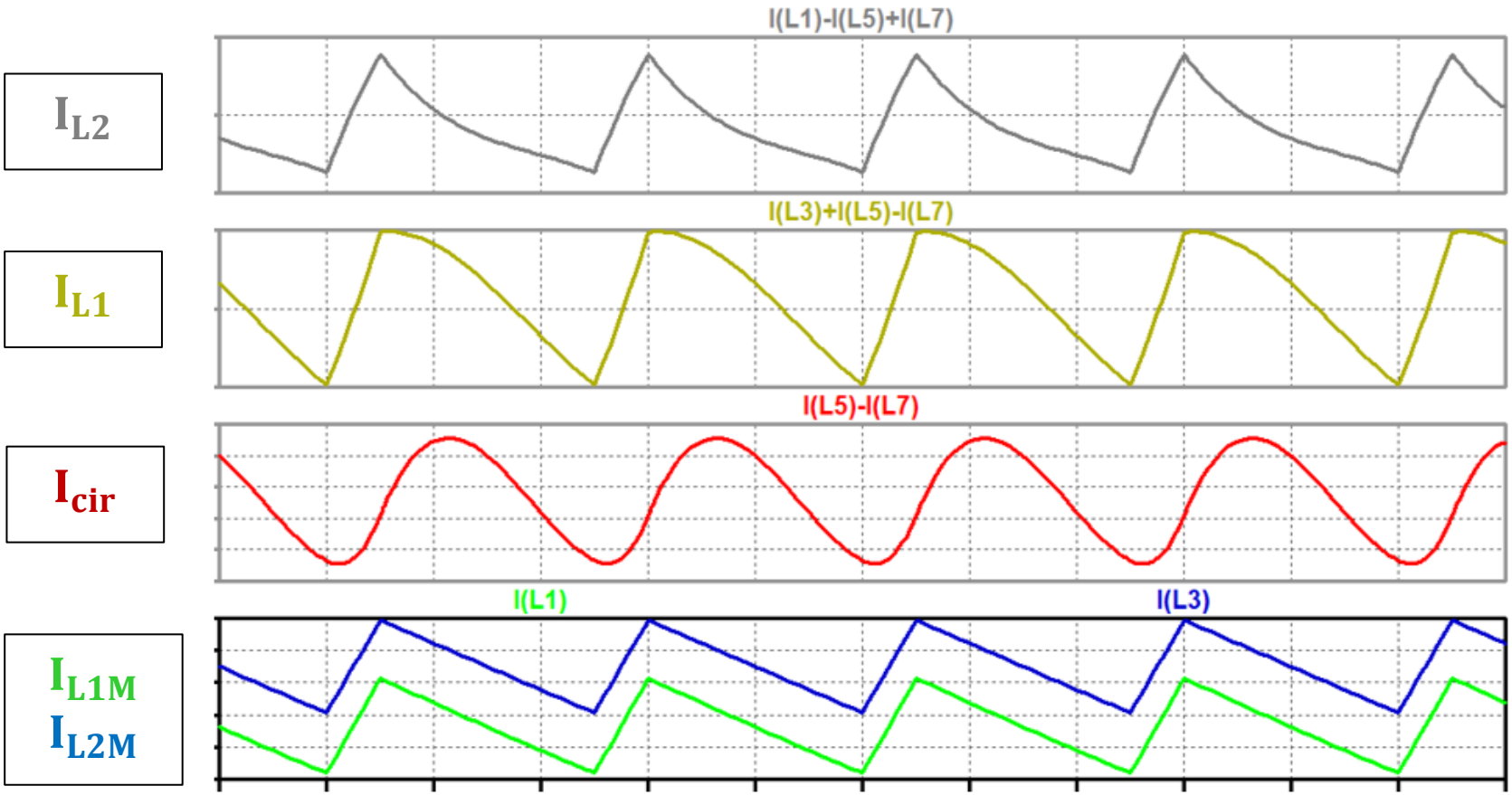
There is Magnetic Flux Cancellation on Lm1 and Lm2, thus the AC ripple appears only across DCR and leakage inductance.
If DCR << Z(Llk), then (approximation):

$$\Delta V_{Cac}(t) \approx L_{LK} \cdot \frac{di_{cir}(t)}{dt}$$

The higher the leakage inductance, the lower Cac required for the same circulating current ripple!!

CASE Study: SEPIC Converter Application
LTSpice Simulation Example

Measured Winding Current = Circulating current + Eq. Magnetizing Current



CASE Study: SEPIC Converter Application
Experimental Results Example

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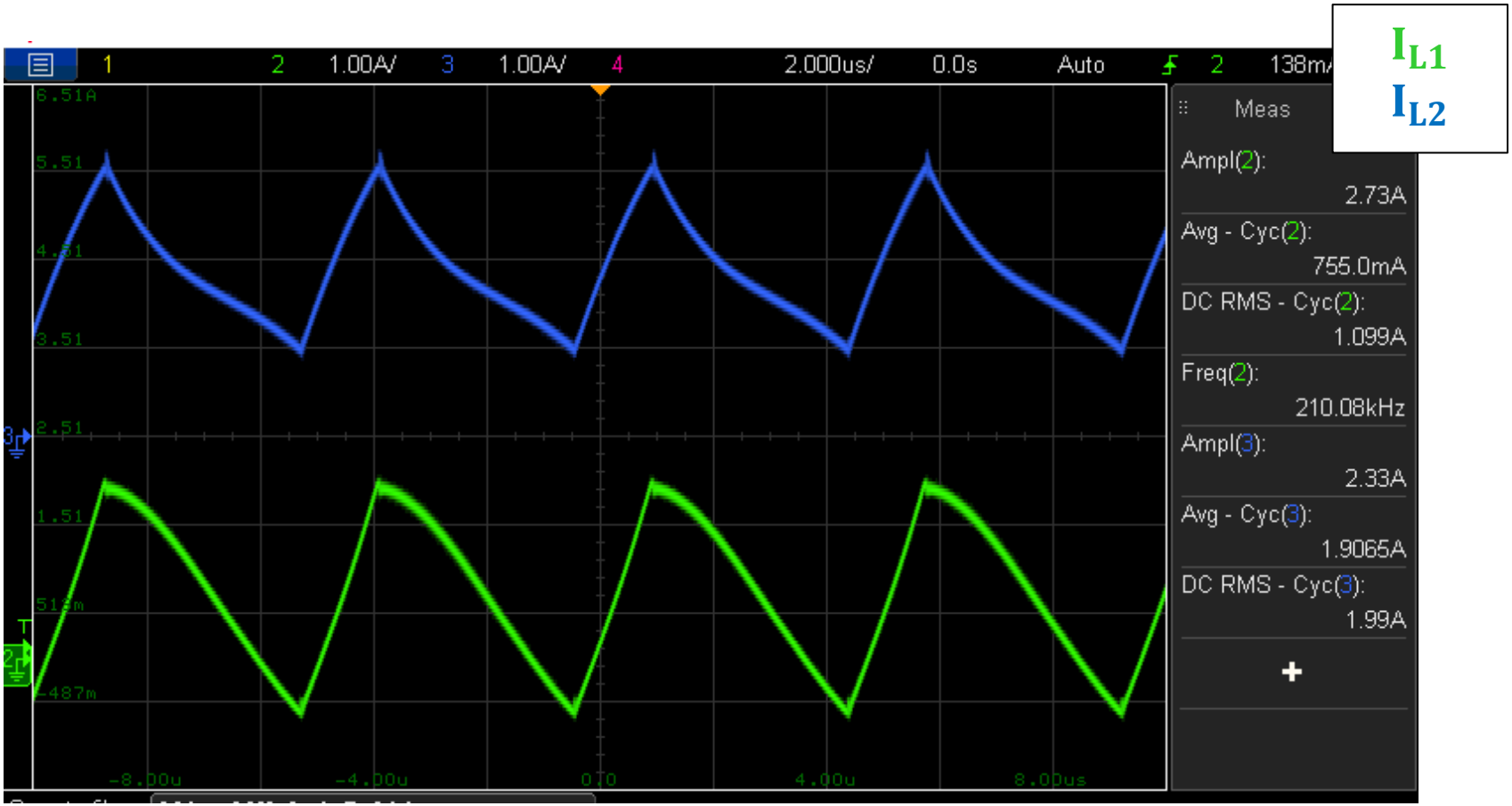
EXAMPLE OF EXPERIMENTAL RESULTS
WINDING CURRENT WAVESHAPE AS EXPECTED IN SIMULATION



CONSEQUENCES OF HIGH CIRCULATING CURRENT

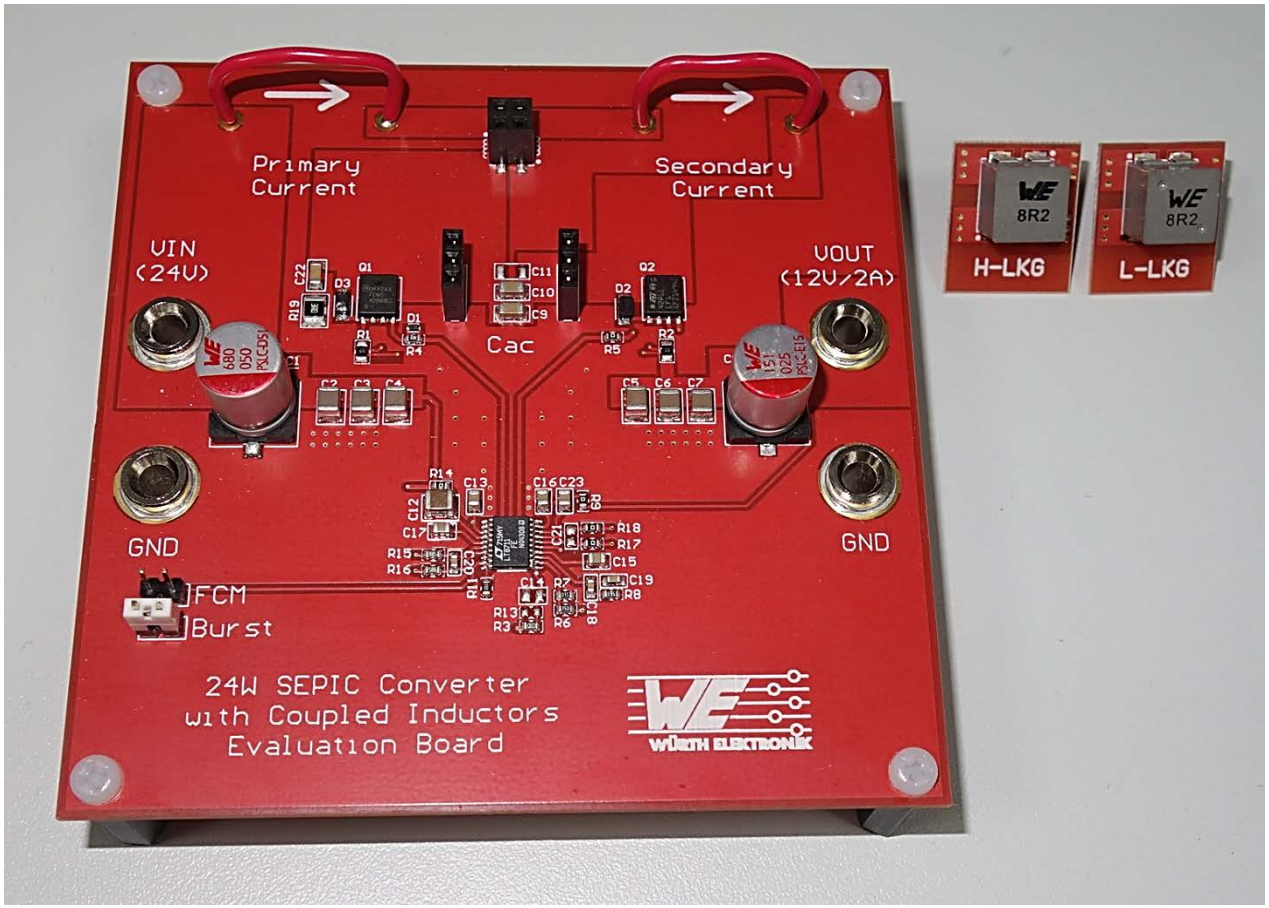
- Lower Power Efficiency
- Higher Operating Temperature and Thermal Stress of Power Components
- Input EMI Filter Requirements

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

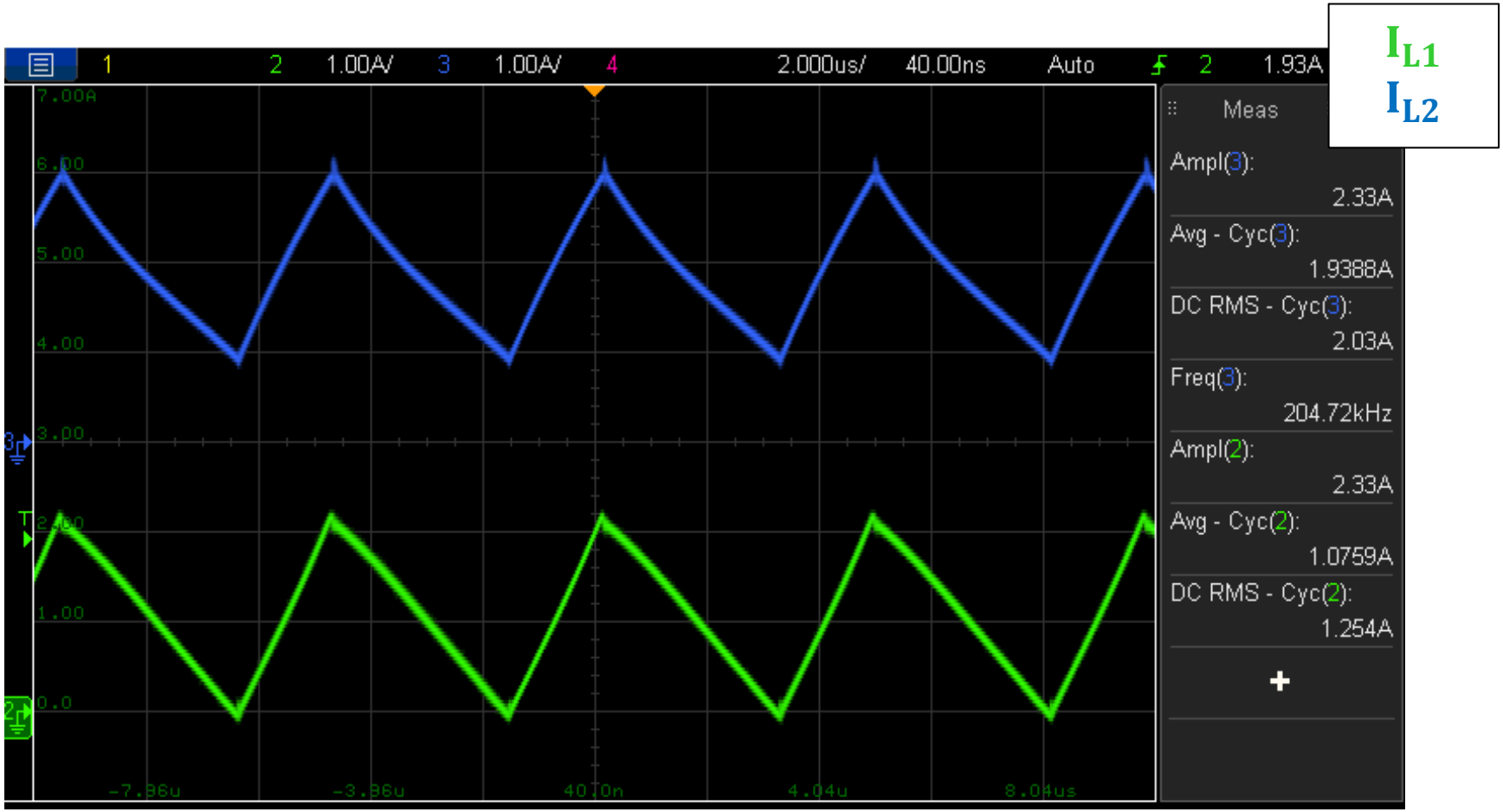
RMS Current
Efficiency
Thermal Performance

CASE 1: Cac = 20uF
CASE 2: Cac = 1uF

SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 1: Cac = 20uF

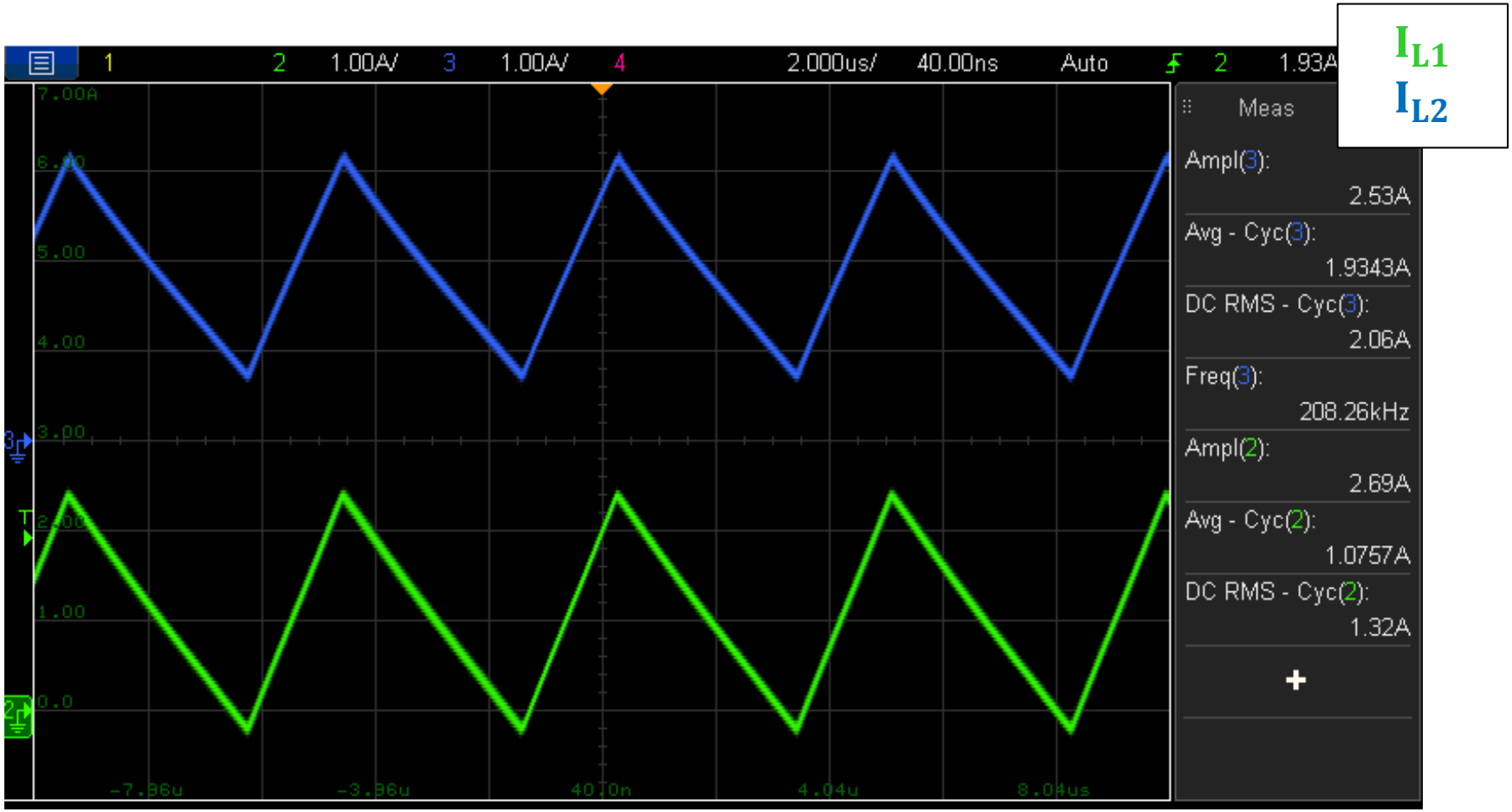
Coupled Inductor 1: **MCRI-8.2uH,** Low Llkg = **250 nH** (High **k = 0.98**)



SEPIC Converter with WE Coupled Inductor: Winding Currents

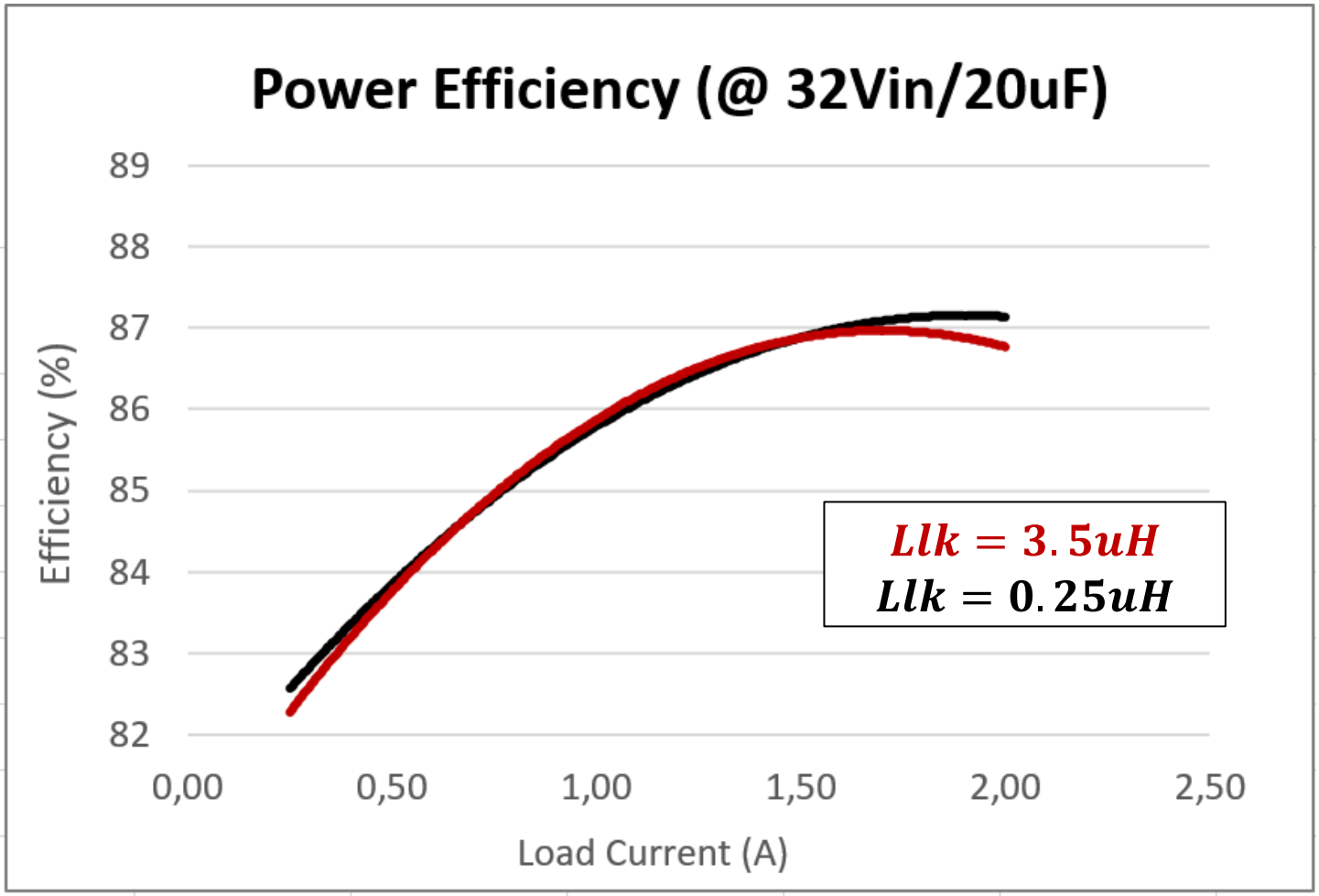
CASE 1: Cac = 20uF

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



NOW DECREASING COUPLING CAPACITANCE BY A FACTOR OF 10 ! …

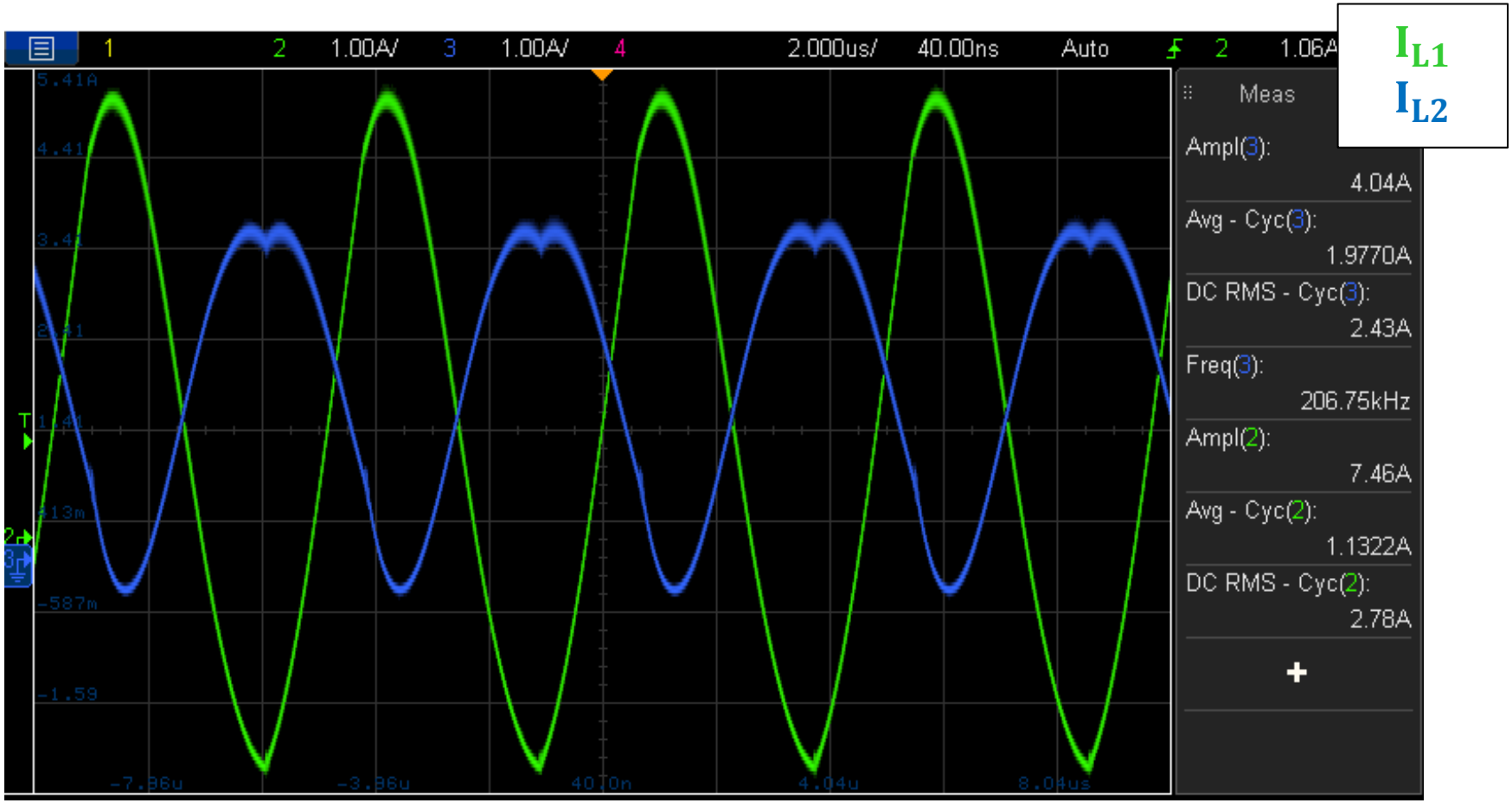
(Cac=2uF)

(lower cost and smaller solution size)

SEPIC Converter with WE Coupled Inductor: Winding Currents

CASE 2: Cac = 2uF

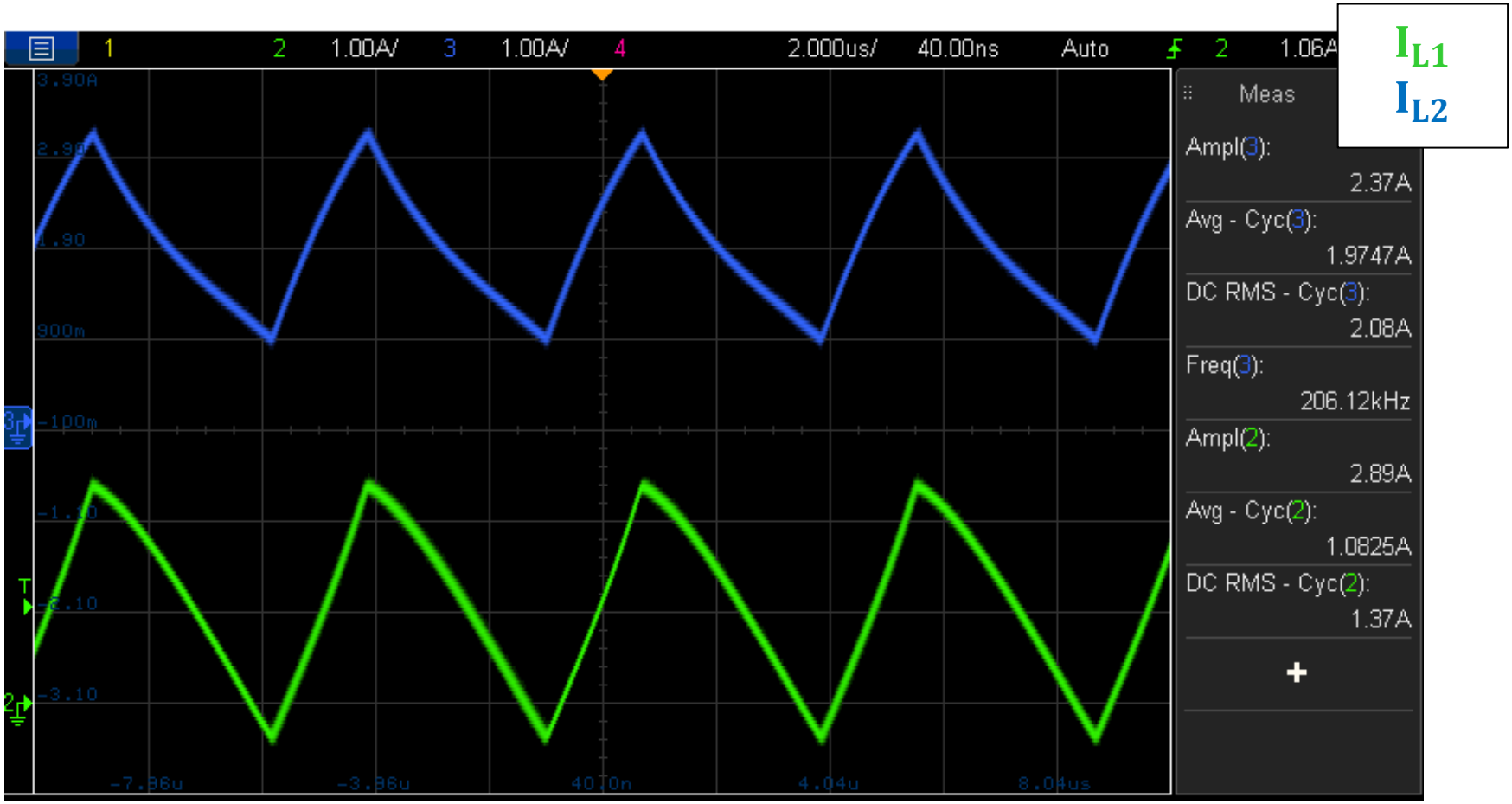
Coupled Inductor 1: **MCRI-8.2uH,** Low Llkg = **250 nH** (High **k = 0.98**)



SEPIC Converter with WE Coupled Inductor: Winding Currents

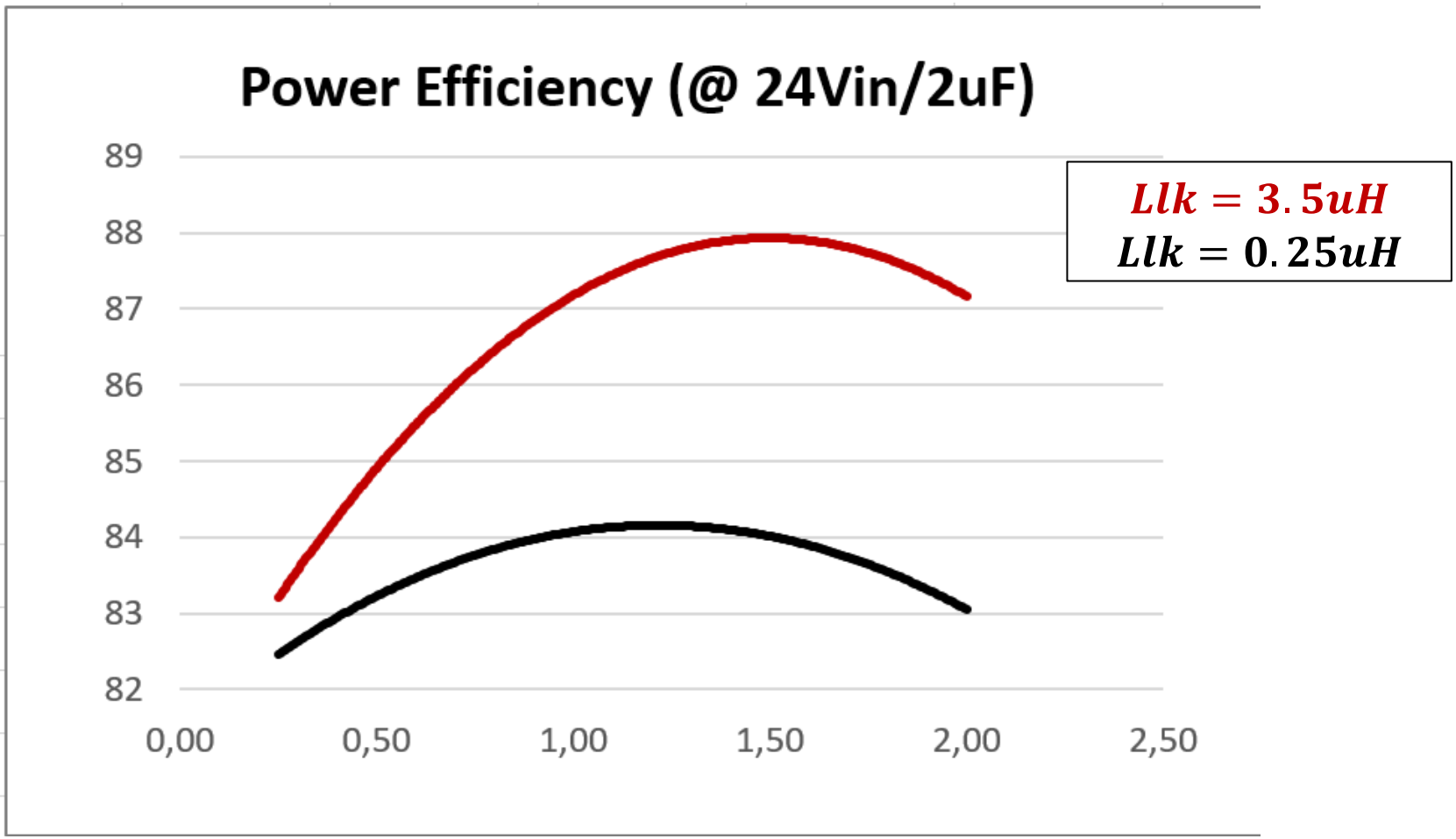
CASE 2: Cac = 2uF

Coupled Inductor 2: **MCRI-8.2uH,** High Llkg = **3.5 uH** (Low **k = 0.75)**



SEPIC Converter with WE Coupled Inductor: Efficiency Comparison

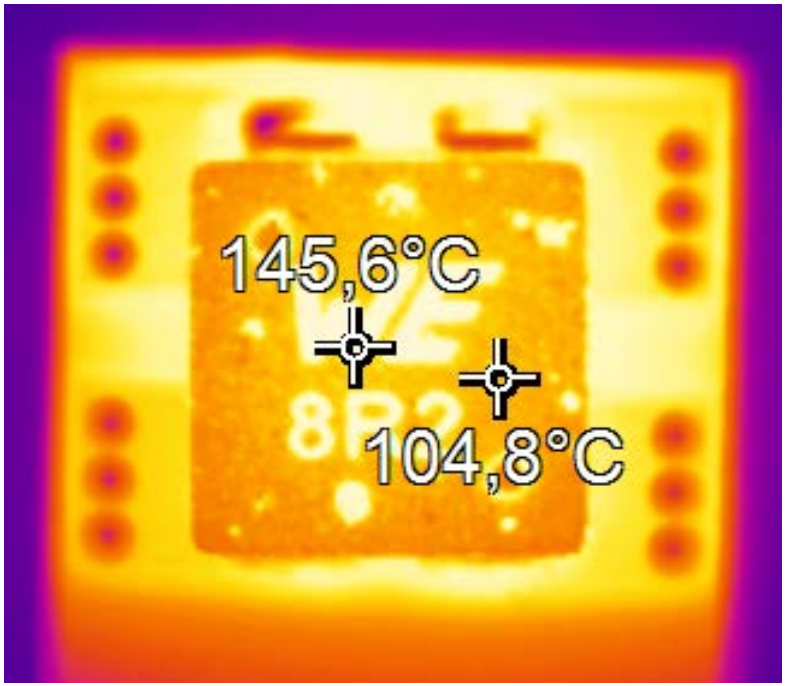
CASE 2: Cac = 2uF



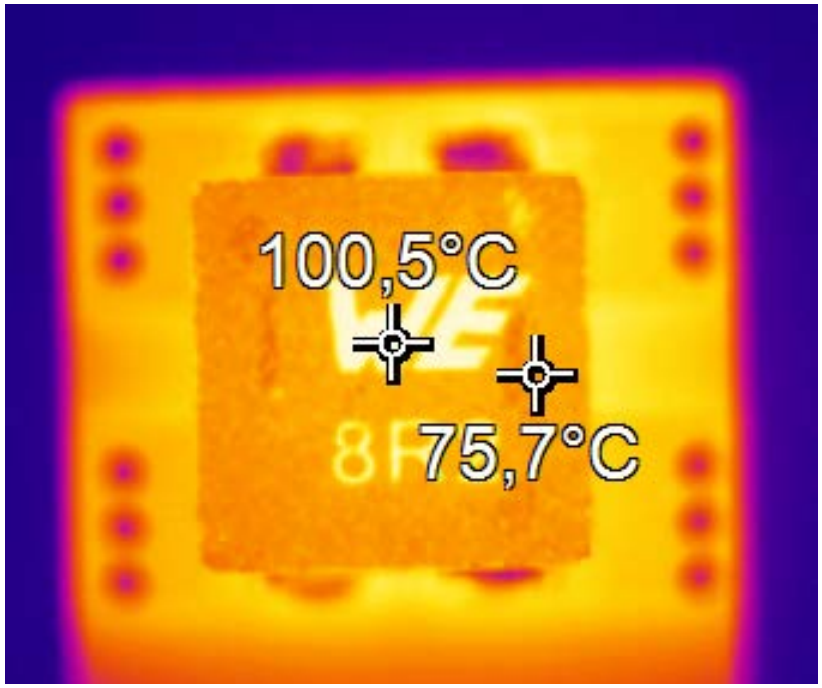
THERMAL PERFORMANCE COMPARISON

SEPIC Converter with WE Coupled Inductor
Thermal Performance Results: Coupled Inductors Comparison

Low Leakage Coupled Inductor



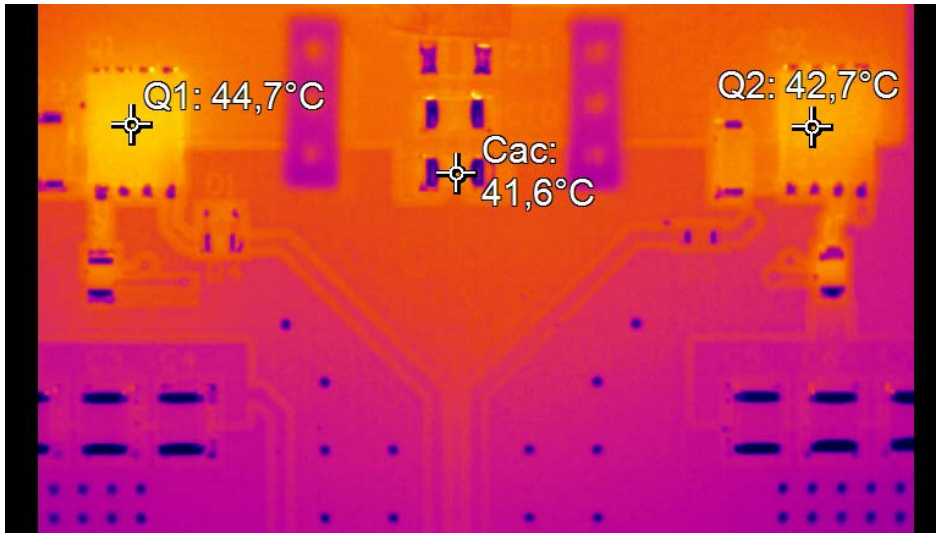
High Leakage Coupled Inductor



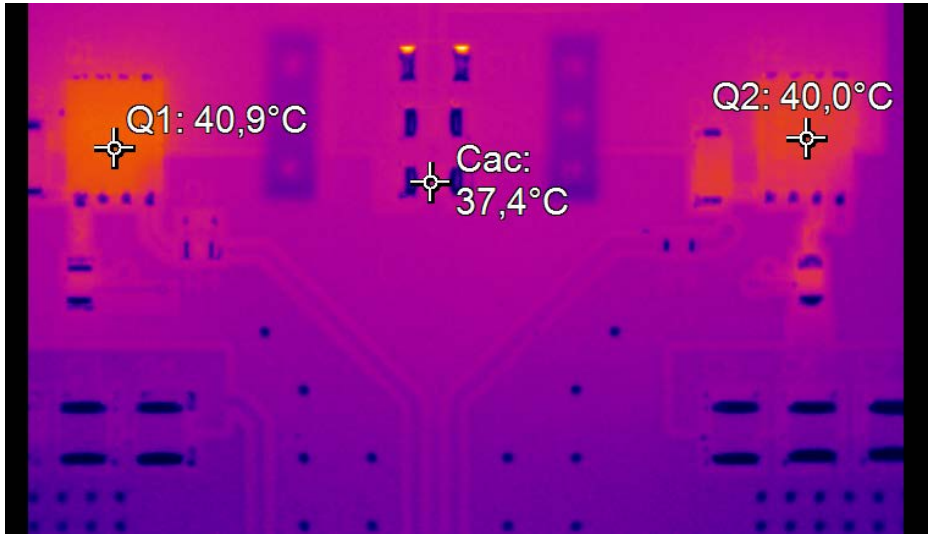
<u>Significantly higher</u> operating Temperature of the low-leakage coupled inductor versus the high-leakage equivalent

SEPIC Converter with WE Coupled Inductor
Thermal Performance Results: Power Stage Comparison

WITH
Low Leakage
Coupled Inductor



WITH
High Leakage
Coupled Inductor



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

Thanks