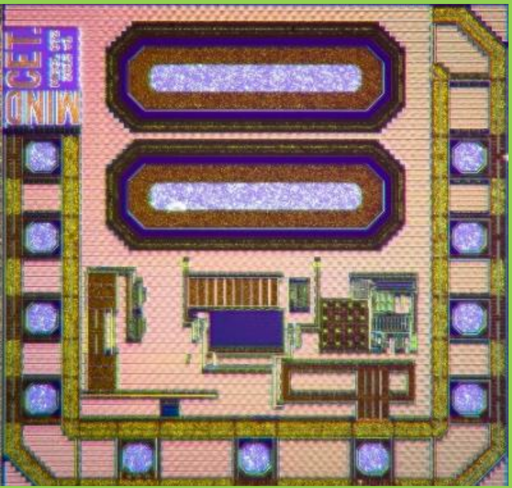
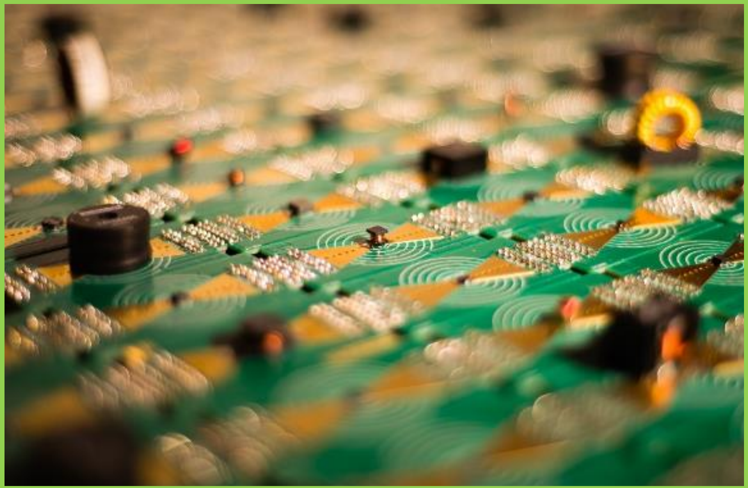
Custom Integrated Power Management Solutions

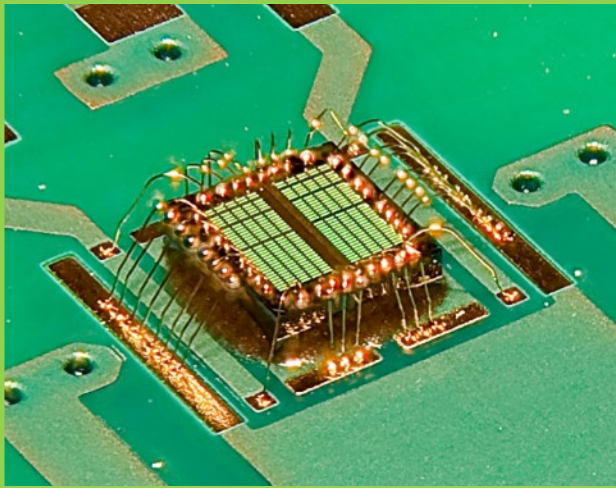
Custom
Integrated Power
Management
Solutions

MADCAP

21/04/2020, Mike Wens, PSMA Capacitor Workshop







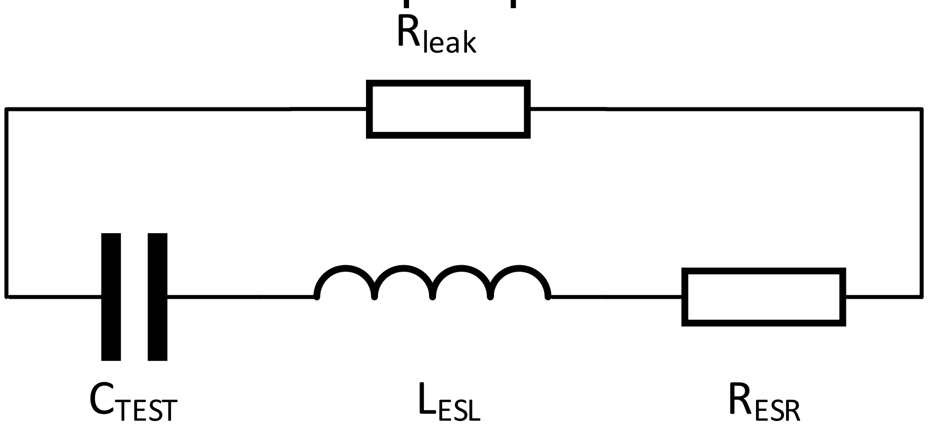
Content

1. Real-World SMPS Capacitors
2. Measuring Capacitors
3. The MADCAP Approach
4. What Can We Learn?
5. Outlook
6. Conclusions

1. Real-World SMPS Capacitors

Capacitor types and model

- Many types exist, all with their own properties:
  - Electrolytic
  - Ceramic
  - Film
  - Tantalum
  - ...

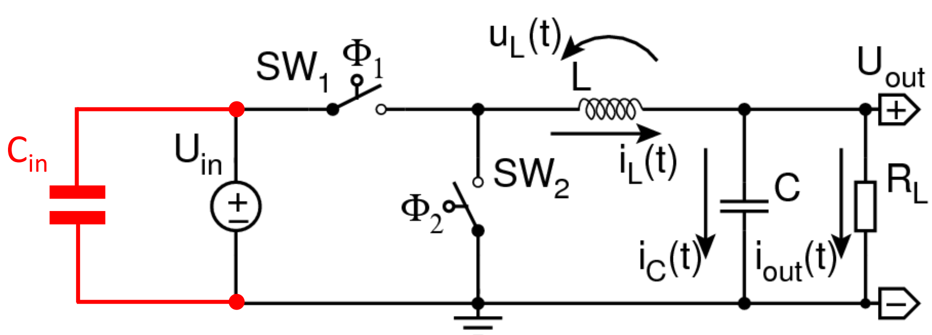


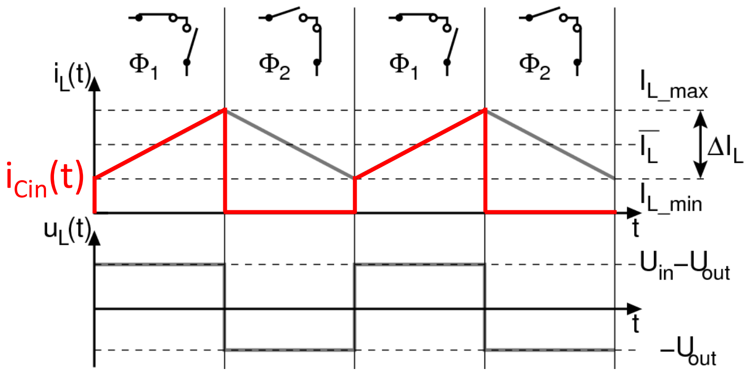
- Basic models incorporate ESR, ESL and Leakage.
- These are measured using (small signal) sine wave excitation -> This is not representative for SPMS use!
- What about self-heating (losses), non-linear behavior, handling large discontinuous currents...?

1. Real-World SMPS Capacitors

Buck Converter

- Cout sees the AC continuous part of the inductor current
- Cin sees the discontinuous AC + DC current through SW1
- In reality there will also be ringing through parasitic L & C in the circuit
- Non-ideal capacitor behavior may cause voltage overshoot, higher ripple, additional dissipation, efficiency degradation, EMI issues and control loop problems.

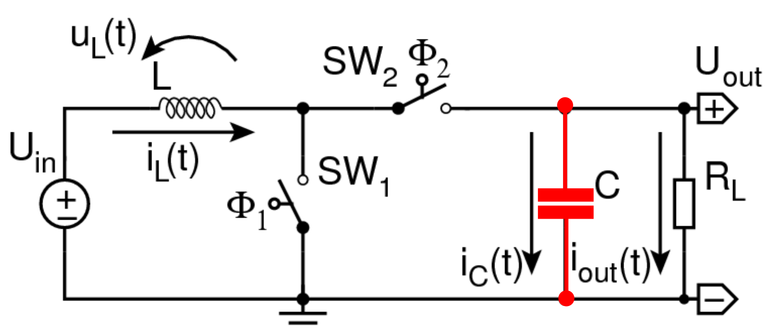


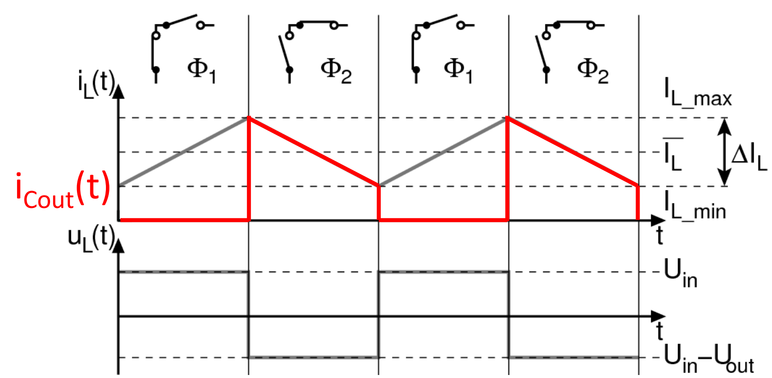


1. Real-World SMPS Capacitors

Boost Converter

- Cin sees the AC continuous part of the inductor current
- Cout sees the discontinuous AC + DC current through SW1
- In reality there will also be ringing through parasitic L & C in the circuit
- Non-ideal capacitor behavior may cause voltage overshoot, higher ripple, additional dissipation, efficiency degradation, EMI issues and control loop problems.



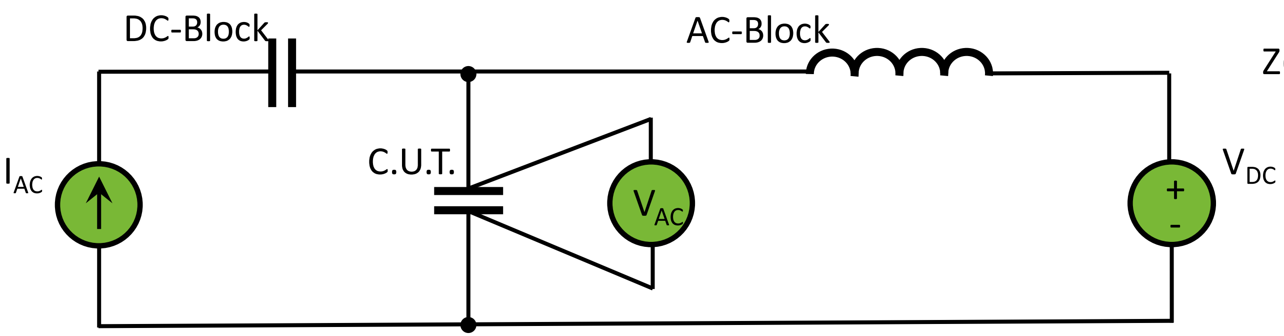


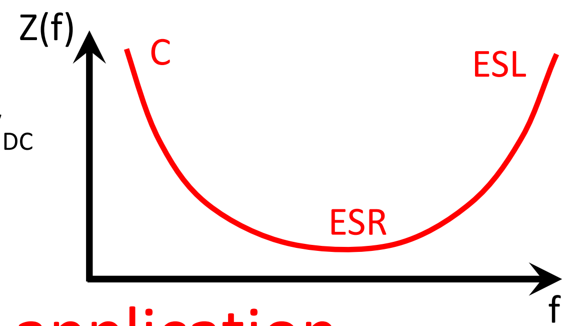
2. Measuring Capacitors

Standard measuring methods

- Discharge and charge with constant current to determine capacitance -> DMM approach
- Apply a (small signal) continuous sine wave voltage and analyse amplitude and phase shift of the current. Optionally a DC-bias voltage can be added.
- Through frequency domain calculations ESR, C and ESL can be determined

$$Z = \sqrt{ESR^2 + \left(2\pi f ESL - \frac{1}{2\pi f C}\right)^2}$$





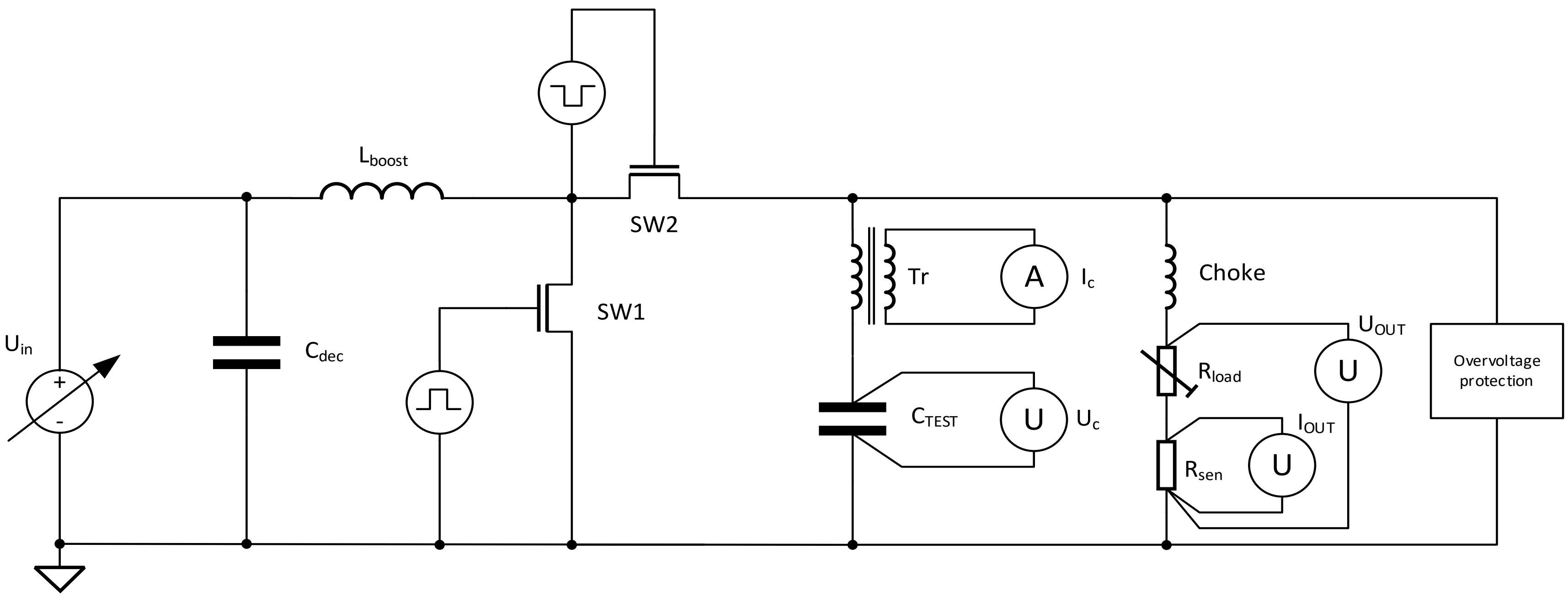
⇒Sine wave is not representative for the application

⇒Need a square-wave current with varying DC bias voltage, frequency and duty-cycle to include losses

3. The MADCAP Approach

Principle

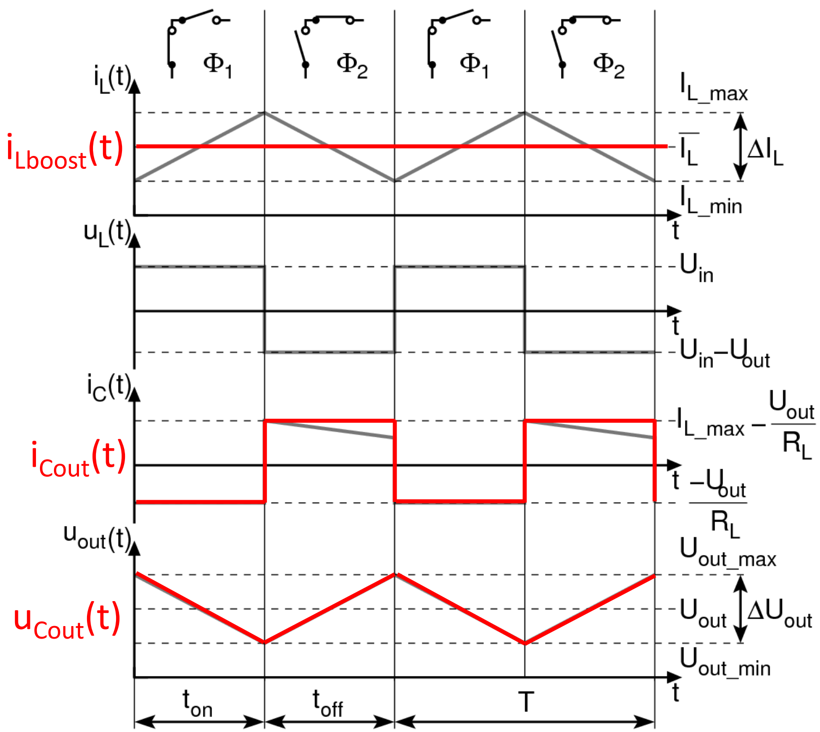
- Boost converter where the output capacitor is C.U.T.
- Large boost inductance creates low ripple current, acting like a DC current source



3. The MADCAP Approach

Wave forms

- C.U.T. sees a square-wave current waveform (large L)
- An ideal C.U.T. would yield a triangular-wave voltage



3. The MADCAP Approach

Input Parameters

- F_{sw}: can be chosen, 10kHz – 2MHz
- Duty-cycle: can be chosen, 5% – 95%
- Uin: can be chosen, 1V – 70V
- U_{out}: = C.U.T. DC-bias = U_{in} / (1-duty), 1.5V – 80V
- I_{load} = 10mA to 20A
- $I_{charge} = I_L = I_{load} / (1\text{-duty}) - I_{load}$
- $I_{disch} = I_{load}$
- $U_{cripple}$ (no ESR & ESL) = $(I_{charge} \times duty) / (F_{sw} \times C)$
- Example: C = 1µF, U_{in} = 30V, duty = 30%, I_{load} = 5A, F_{sw} = 1MHz
  - ➢ I_{charge} = 7,14A
  - ➢ I_{disch} = 5A
  - ➢ I_{C_ptp} = 12,14A
  - ➢ $U_{cripple}$ = 2,14V

3. The MADCAP Approach

Key Measurements

- C = Average capacitance over one period
- ESR = Equivalent series resistance
- ESL = Equivalent series inductance
- PAC = Total power loss
- PESR = Power loss due to ESR
- PDIE = Power loss in dielectricum
- T1 = Temperature of the C.U.T.

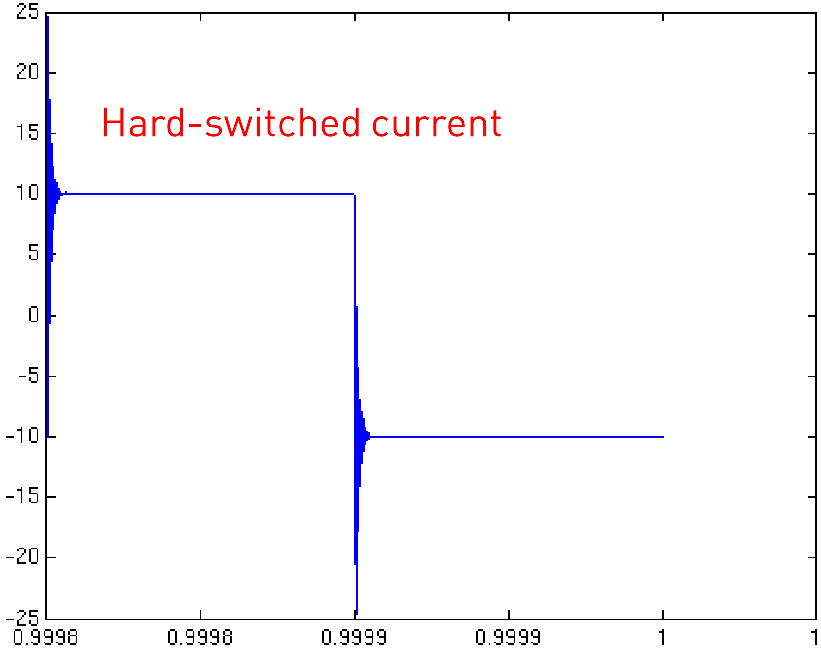
3. The MADCAP Approach

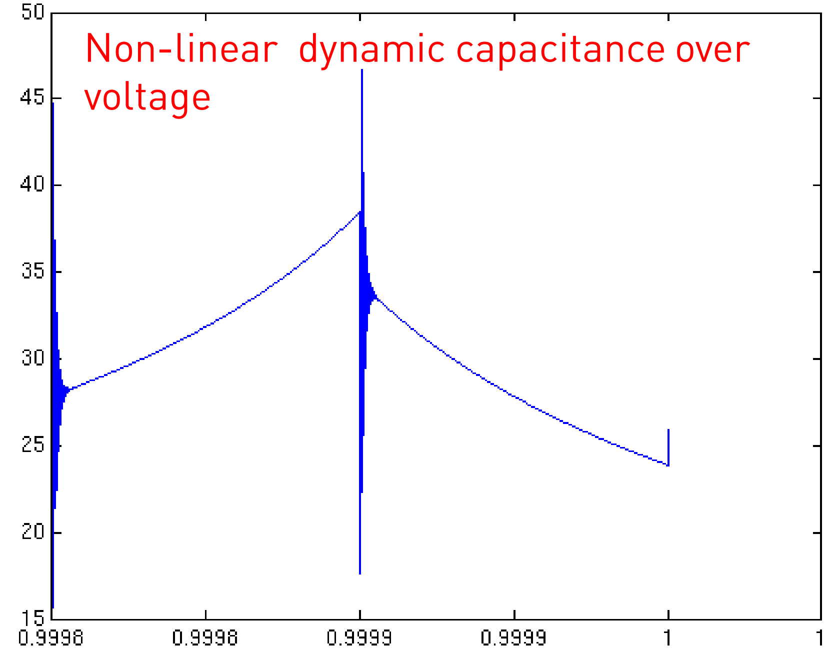
The Hardware

- Fully Automated through software
- Thermostreamer to heat or cool the C.U.T. -45 to +225°C
- Calibrated using Calorimetric techniques by compareing AC self heating with a known heating power

4. What Can We Learn?

- Real-life waveforms contain additional ringing due to the non-ideal measurement circuit -> calibrated

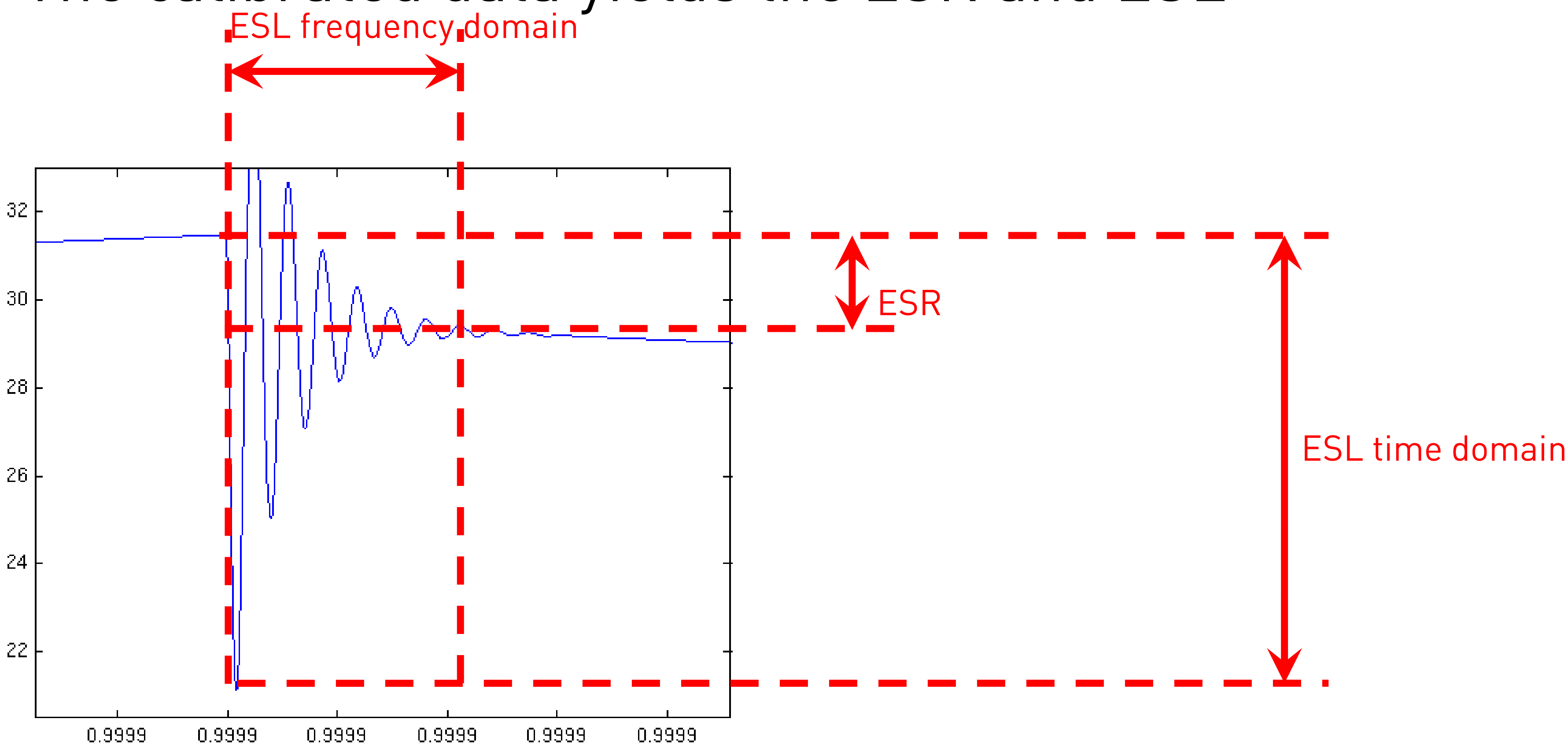




4. What Can We Learn?

The raw data

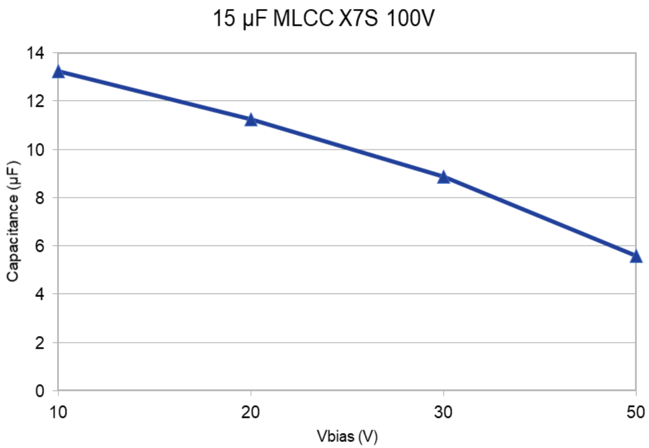
- The calibrated data yields the ESR and ESL

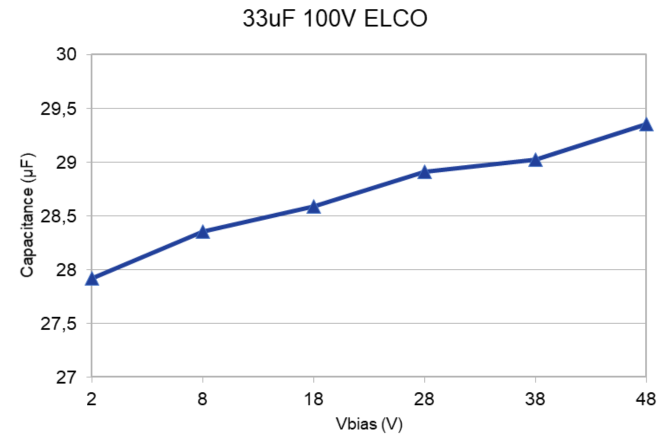


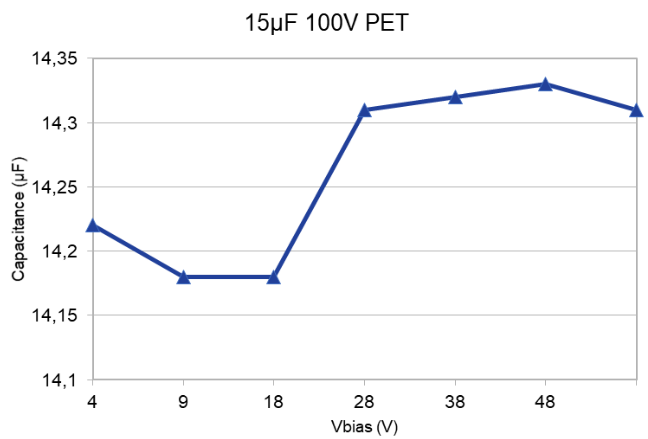
4. What Can We Learn?

Capacitance vs DC-bias @ switching conditions

- Fsw = 100kHz, duty = 50%, Irip = $6A_{ptp}$, T_a = 25°C



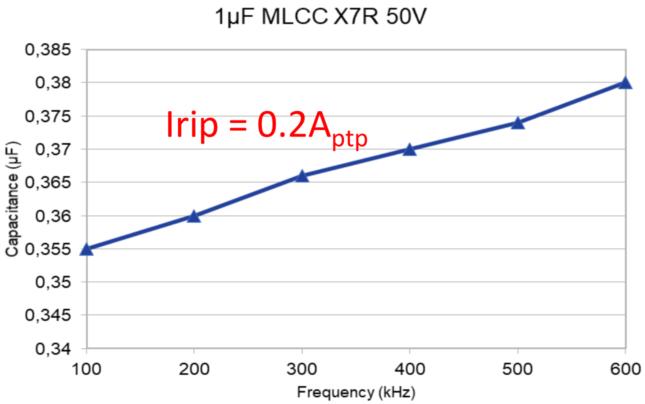


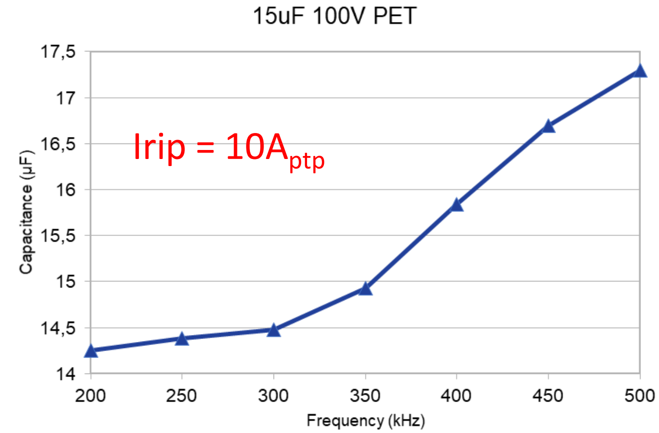


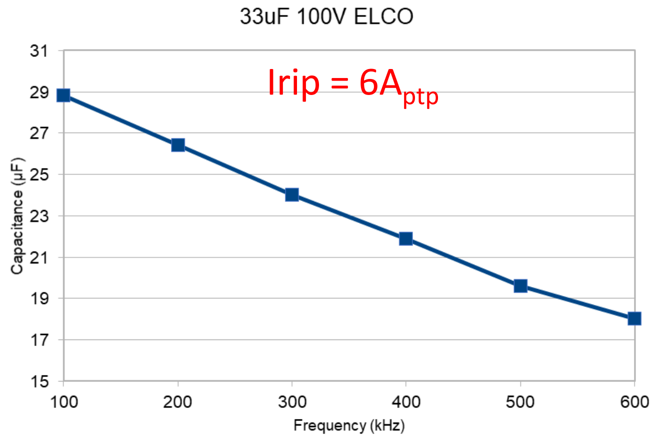
4. What Can We Learn?

Capacitance vs Frequency @ switching conditions

- V_{bias} = 20V, duty = 50%, T_a = 25°C



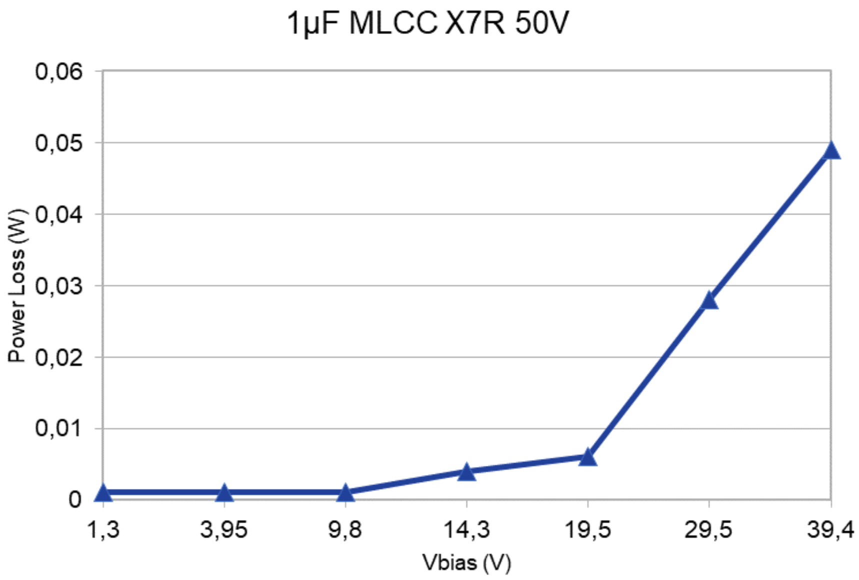




4. What Can We Learn?

Power loss vs DCbias @ switching conditions

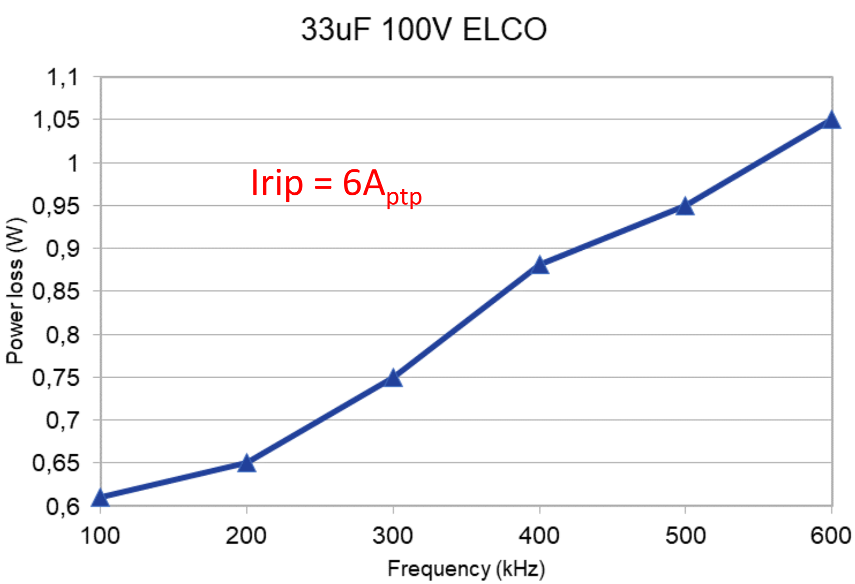
- Fsw = 100kHz, Irip = 0.2A_{ptp}, duty = 50%, T_a = 25°C

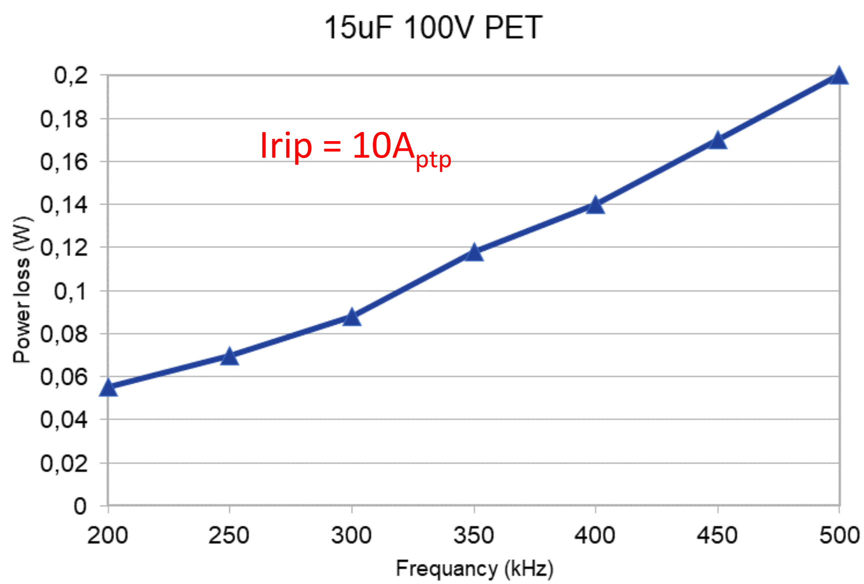


4. What Can We Learn?

Power loss vs Frequency @ switching conditions

- V_{bias} = 60V, duty = 50%, T_a = 25°C

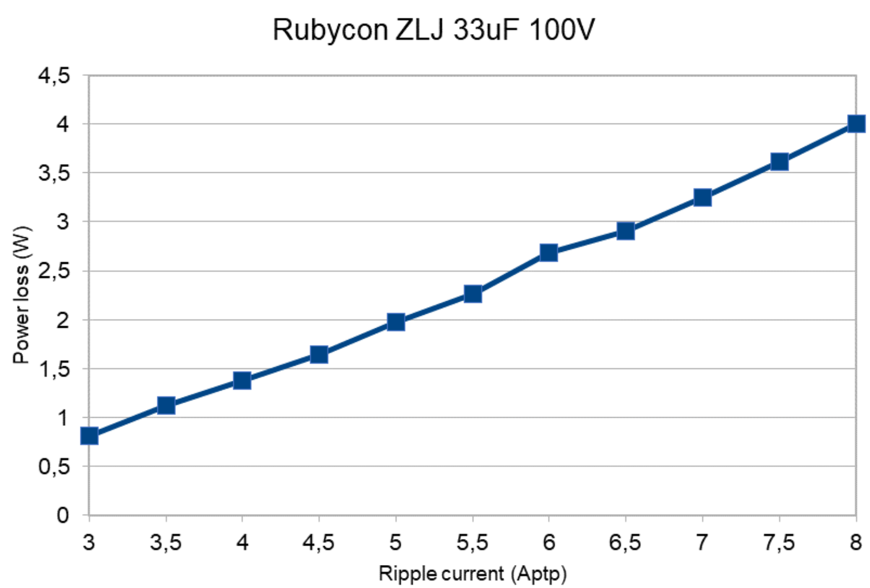




4. What Can We Learn?

Power loss vs Ripple current @ switching conditions

- Fsw = 100kHz, V_{bias} = 60V, duty = 50%, T_a = 25°C



4. What Can We Learn?

What Else?

- Implemenation of the following automated measurements in progress:
  - ESR vs Fsw
  - ESR vs Irip
  - ESR vs Vbias
  - ESL vs Fsw
  - ESL vs Irip
  - ESL vs Vbias
  - Real-time dynamic effects (non-linearities)
  - Self-heating under continuous load
  - Splitting AC losses into ESR and Dielectric
  - ...

5. Outlook

What the future will bring

- Become the standard for measuring SMPS capacitors -> MADMIX (equivalent for inductors) has preceeded this already
- Measuring Caps in real-life operating conditions will learn both their developers and users the safe limits and trade-offs to optimize future designs
- Comparing different types and brands in an objective way to make a fair comparison
- Stressing caps as in the application will allow improved reliability analysis, avoiding over- or under-design
- In the end bring new insights in one of the oldest components in electronics

6. Conclusions

- MADCAP is unique and additional way to measure SMPS capacitors in real-life conditions
- All crucial parameters can be measured, including Capacitance, ESL, ESR and AC Power loss.
- Bias voltage, hard-switched current amplitude, duty-cycle and switching frequency can be chosen

Dr. ir. Mike Wens received the Master of Engineering degree in electronic design techniques from the Karel de Grote Hogeschool, Antwerp, Belgium, in 2004. In 2006 he received the Master of Science degree in microelectronics from the Katholieke Universiteit Leuven, Leuven, Belgium. From 2006 on, he worked as a research assistant at the ESAT-MICAS (MICroelectronics And Sensors) laboratories (K.U.Leuven) towards his PhD degree entitled *"Monolithic Inductive CMOS DC-DC Converters"*, which he achieved in 2010. In 2011 he co-founded MinDCet NV, a mixed-signal Power Management design house, together with Dr. ing. Jef Thoné. His extensive knowledge in the field of switched mode power supplies, both discrete and (fully-)integrated dates back to 2002. Together with Dr. ing. Jef Thoné he is the co-inventor of the patented MADMIX and MADCAP equipment to measure the core loss of SMPS inductors under large-signal triangular flux excitation and the losses of SMPS capacitors under real-life operating conditions. His other interests are analog & high-voltage mixed-signal chip design, high-voltage applications, renewable energy, discrete design, LED-lighting, High-End tube amplifiers and analog & digital photography.

What can we do for you?

Headquarters

MinDCet NV

Researchpark Haasrode

Romeinse Straat 10

3001 Leuven

Belgium

www.mindcet.com

info@mindcet.com

t: +32 16 40 95 28

t: +32 16 40 14 88

f: +32 16 40 83 38