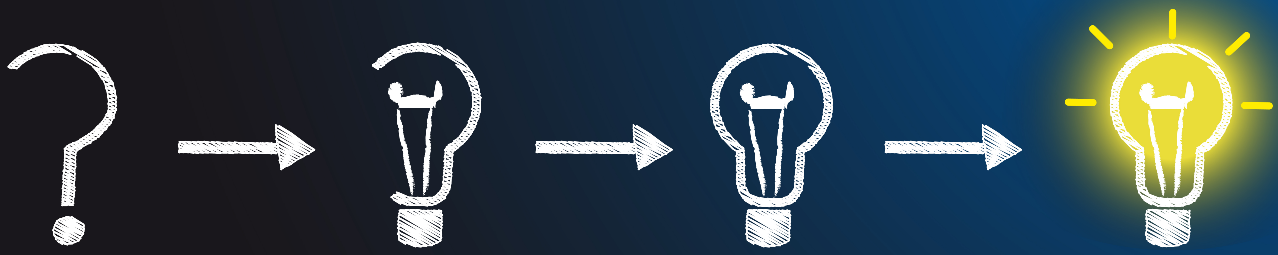

10th Power Analysis & Design Symposium

March 10th, 2021 - Worldwide (Virtual)

Measurement-based Characterization of Passive Electronic Components

by Martin Saliternig & Peter Maisel - MSPM Power

MSPM

HOT IDEAS FOR COOL PRODUCTS

power mechatronics

10th Power Analysis & Design Symposium 2021

Wednesday, March 10, 2021

Permeability terms I

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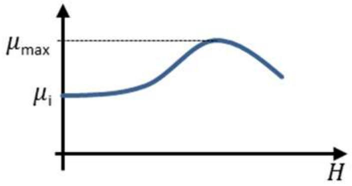
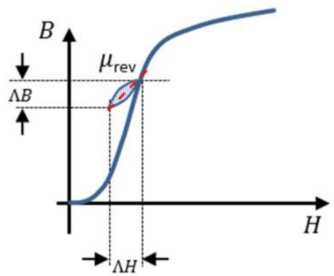
- Absolute permeability μ_0:
  permeability in free space, magnetic constant
  $$\mu_0 = 4\pi\, 10^{-7}\, \frac{N}{A^2}$$
- Relative permeability μ_r :
  is the characterisation of magnetic materials for all purposes
  $$\mu_r = \frac{\mu}{\mu_0} = \frac{1}{\mu_0} * \frac{B}{H}$$
- Initial permeability μ_i :
  is the slope of the initial magnetization curve at the origin when the magnetic field strength H and the magnetic flux density B is very small.



- Maximum permeability μ_{max} :
  is the maximum permeability along the initial magnetisation curve
- Incremental permeability μ_Λ :
  is the relative permeability for AC magnetisation with superimposed DC magnetisation
  $$\mu_\Delta = \frac{1}{\mu_0} * \left(\frac{\Delta B}{\Delta H}\right)_{H_{DC}}$$



- Reversible permeability μ_{rev} :
  is the limiting value of the incremental permeability for very low AC fields
  $$\mu_{rev} = \lim_{\Delta H \to 0} \mu_\Delta$$

- Amplitude permeability μ_a :

  is the relative permeability under alternating external fields H

$$\mu_a = \frac{1}{\mu_0} * \frac{B_{max}}{H_{max}}$$

- Effective permeability μ_e :

  is the total permeability of an air gapped magnetic circuit .

$$\mu_e = \frac{\mu_i}{1+\frac{l_g*\mu_i}{l_e}}$$

- Pulse permeability μ_p :

  for pulse (or arbitrary) waveforms the pulse permeability is the ratio of flux density ΔB swing to the corresponding field strength ΔH.

$$\mu_p = \frac{1}{\mu_0} * \frac{\Delta B}{\Delta H}$$

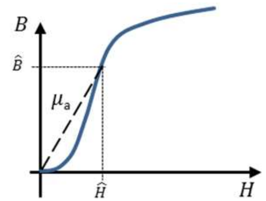
- Complex permeability $\underline{\mu}$:

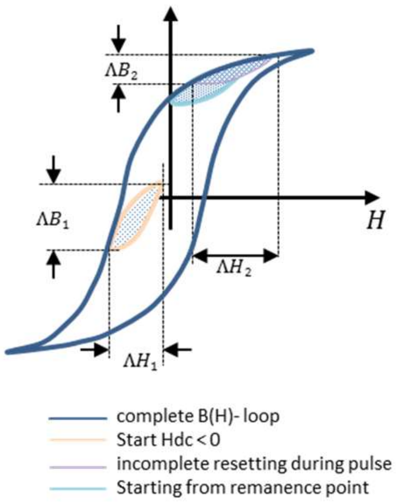
  the ratio of the flux density and the magnetic field strength is a complex number due to the phase shift between B and H in an alternating field.

$$\underline{\mu} = \mu' - j\mu''$$

Frequently used: loss angle $tan\delta$

$$tan\delta = \frac{\mu'}{\mu''} = \frac{R}{\omega L}$$





l_g : lenght of air gap
l_e : lenght of magnetic path
R : real resistance
L : inductive part
ω : circular frequency

Waveforms

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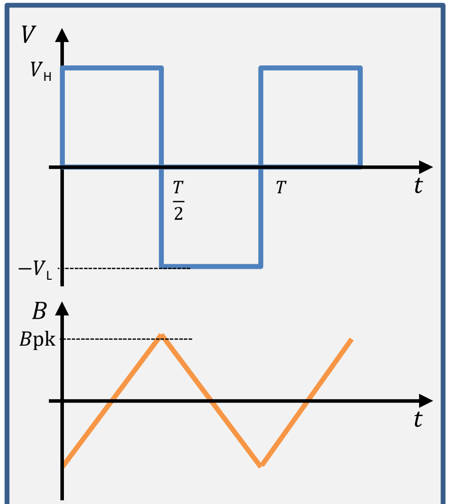
Square wave



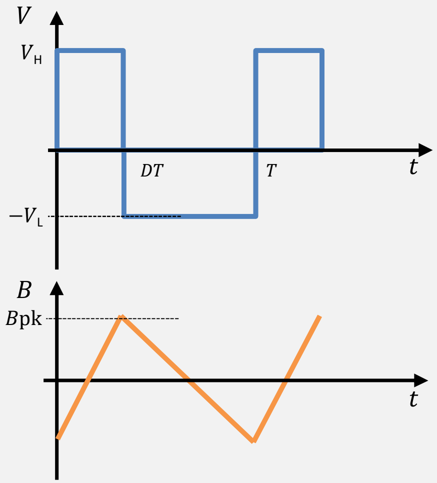
$$v_L = V_H \qquad 0 \le t \le \frac{T}{2}$$

$$v_L = -V_L \qquad \frac{T}{2} \le t \le T$$

$$\mathrm{K_f} = 4$$

$$B_{pk} = \frac{1}{4}\frac{V_{rms}}{fnA_e} = \frac{1}{4}\frac{V_H}{fnA_e}$$

Rectangular



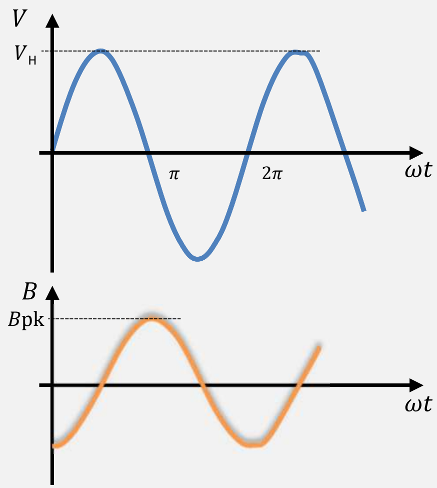
$$v_L = V_H \qquad 0 \le t \le DT$$

$$v_L = -V_L \qquad DT \le t \le T$$

$$\mathrm{K_f} = \frac{2}{\sqrt{D(1-D)}}$$

$$B_{pk} = \frac{\sqrt{D(1-D)}}{2}\frac{V_{rms}}{fnA_e} = \frac{DV_H}{2nA_ef}$$

Sinusoidal



$$v_L = V_L \sin \omega t$$

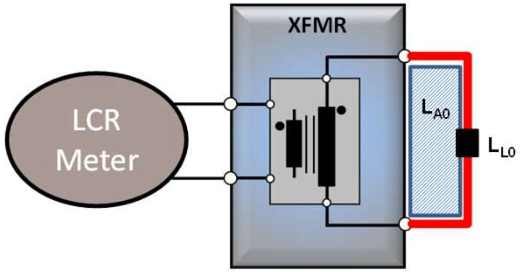
$$\mathrm{K_f} = \frac{2\pi}{\sqrt{2}} = 4{,}44$$

$$B_{pk} = \frac{\sqrt{2}}{2\pi}\frac{V_{rms}}{fnA_e} = \frac{V_H}{2\pi fnA_e}$$

K_f : waveform coefficient
f : frequency
n : number of windings
A_e: cross section area
D : duty cycle
B : flux density
T : period

What is the effective leakage inductance?

Effective leakage inductance of the transformer



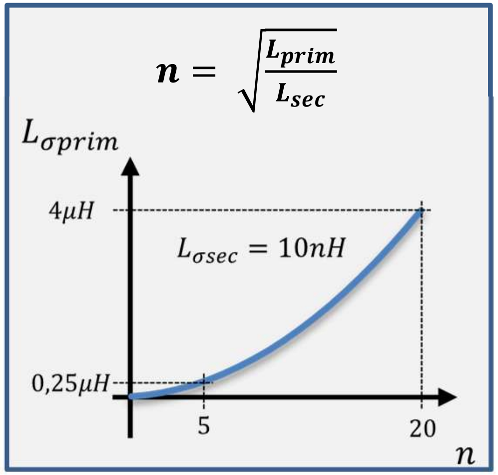
$$L_{tot}^{\sigma} = L_{XFMR}^{\varrho}$$

L_{A0} ⋘
L_{L0} ⋘

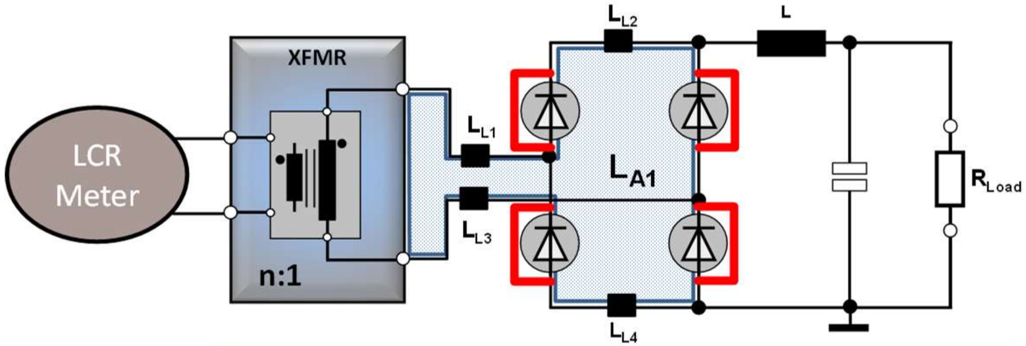
Rule of thumb

$$L_{LX} = 5..10nH/cm^{(1)}$$

$$L_{Ax} \propto \sqrt{A}$$



Effective leakage inductance in application circuit



$$L_{appl}^{\varrho} = L_{XFMR}^{\varrho} + n^2 L_{sec}^{\varrho}$$

$$L_{sec}^{\varrho} = L_{L1} + L_{L2} + L_{L3} + L_{L4} + L_{A1}$$

(1) Typical values used on PCBs

Parasitic Intra-Winding Capacitance

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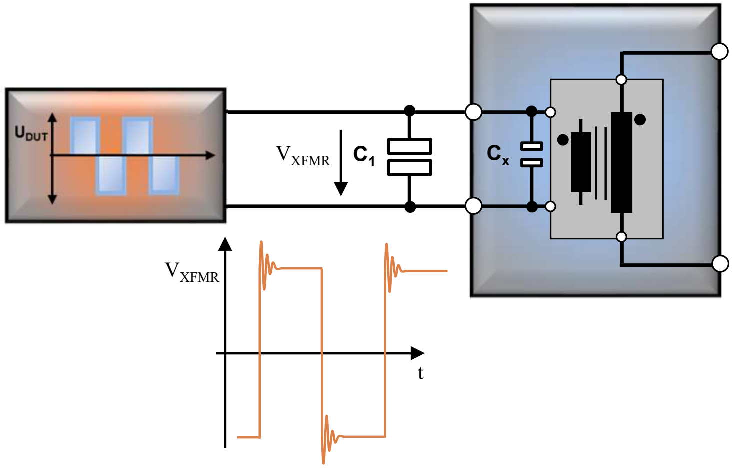


$$f_x = \frac{1}{2\pi\sqrt{LC_x}}$$

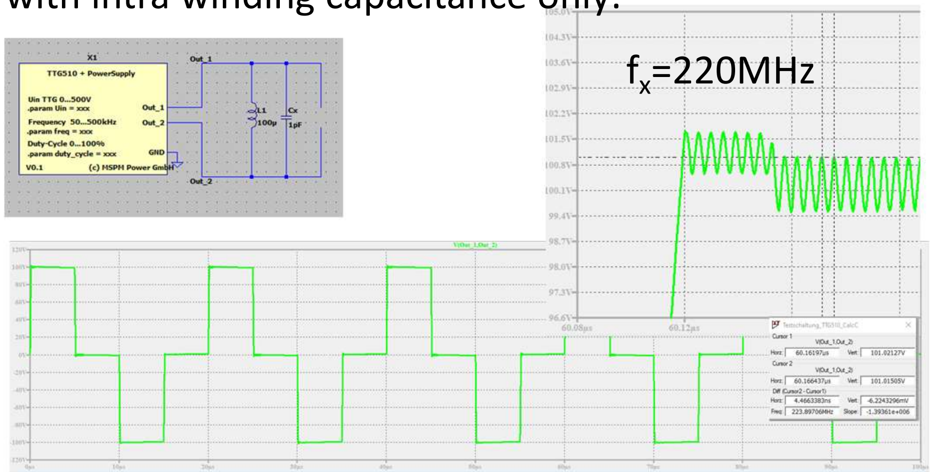
$$f_1 = \frac{1}{2\pi\sqrt{L(C_x + C_1)}}$$

$$C_x = \frac{C_1}{\left(\frac{f_x}{f_1}\right)^2 - 1}$$

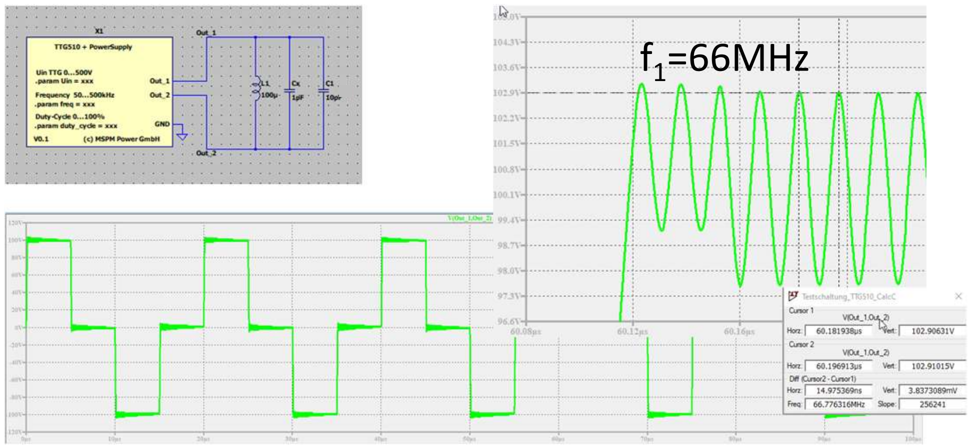
$$f_x \geq f_1$$

C_x ... Intra winding capacitance
f_x...frequency with winding capacitance
C_1 ... reference capacitance
f_1...frequency with winding capacitance and added reverence capacitance

Frequency measurement
with intra winding capacitance only:

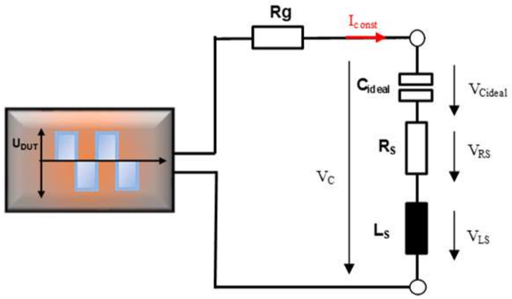


Frequency measurement
with reverence capacitance C_1 added:

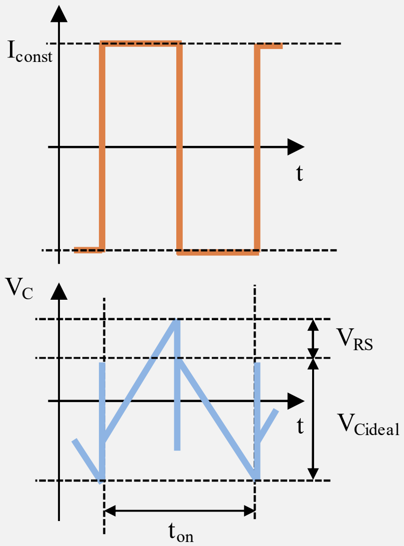


Capacitor DC-Impedance

Serial Equivalent Circuit Model



DC-Impedance



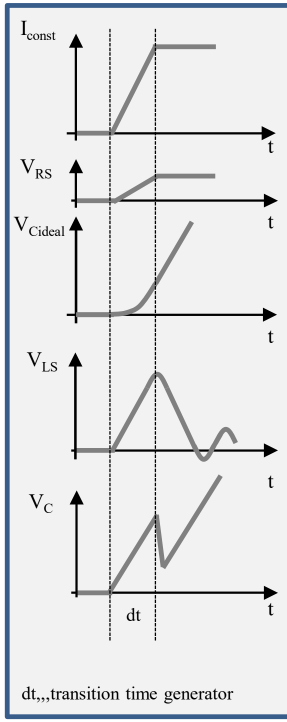
$$I_{const} = \frac{V_{out}}{R_g}$$

$$i = C\frac{du}{dt}$$

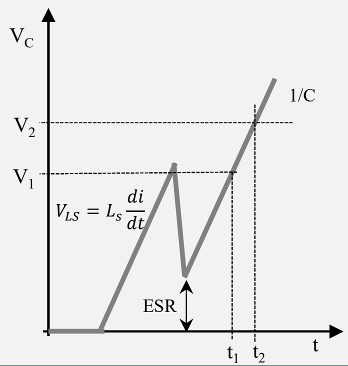
$$C = \frac{I_{const}\,(t_2 - t_1)}{(V_2 - V_1)}$$

$$R_S = \frac{V_{RS}}{2 * I_{const}}$$

Current step respose



Comon wave V_C indicates sum of all three components



DC-Impedance is more directly related to device behavior in many pulse power applications

Scope measurement I: Offset and Phase error

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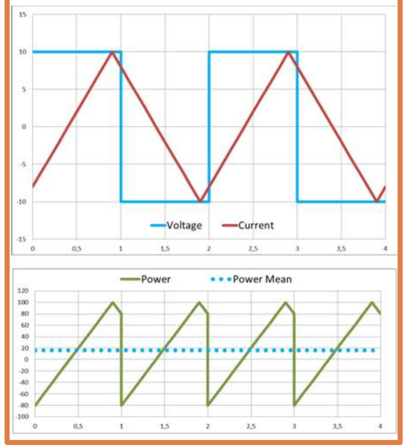
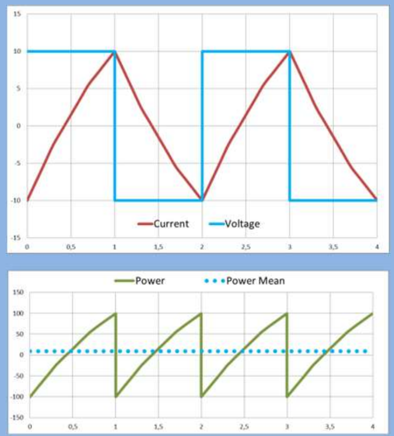
Negative phase error ≈ 10%



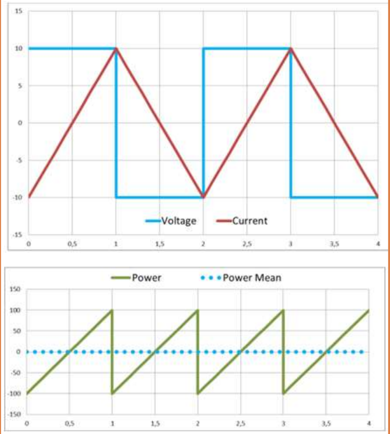
20W „losses“

Real Inductor



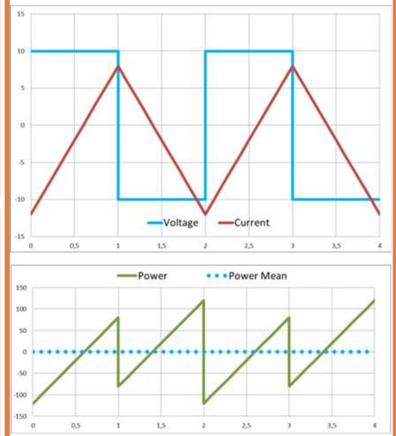
10W losses

Ideal inductor

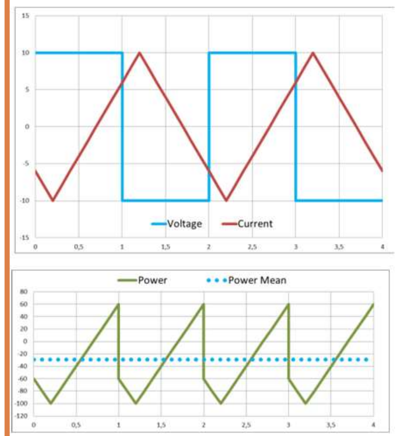


Zero losses

DC-offset error



Zero losses

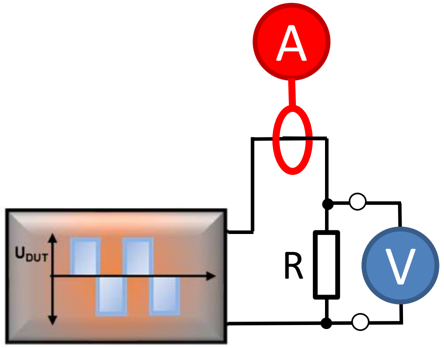


Positive phase error ≈ 20%

-30W „losses“

Current
Voltage
Power
Power Mean

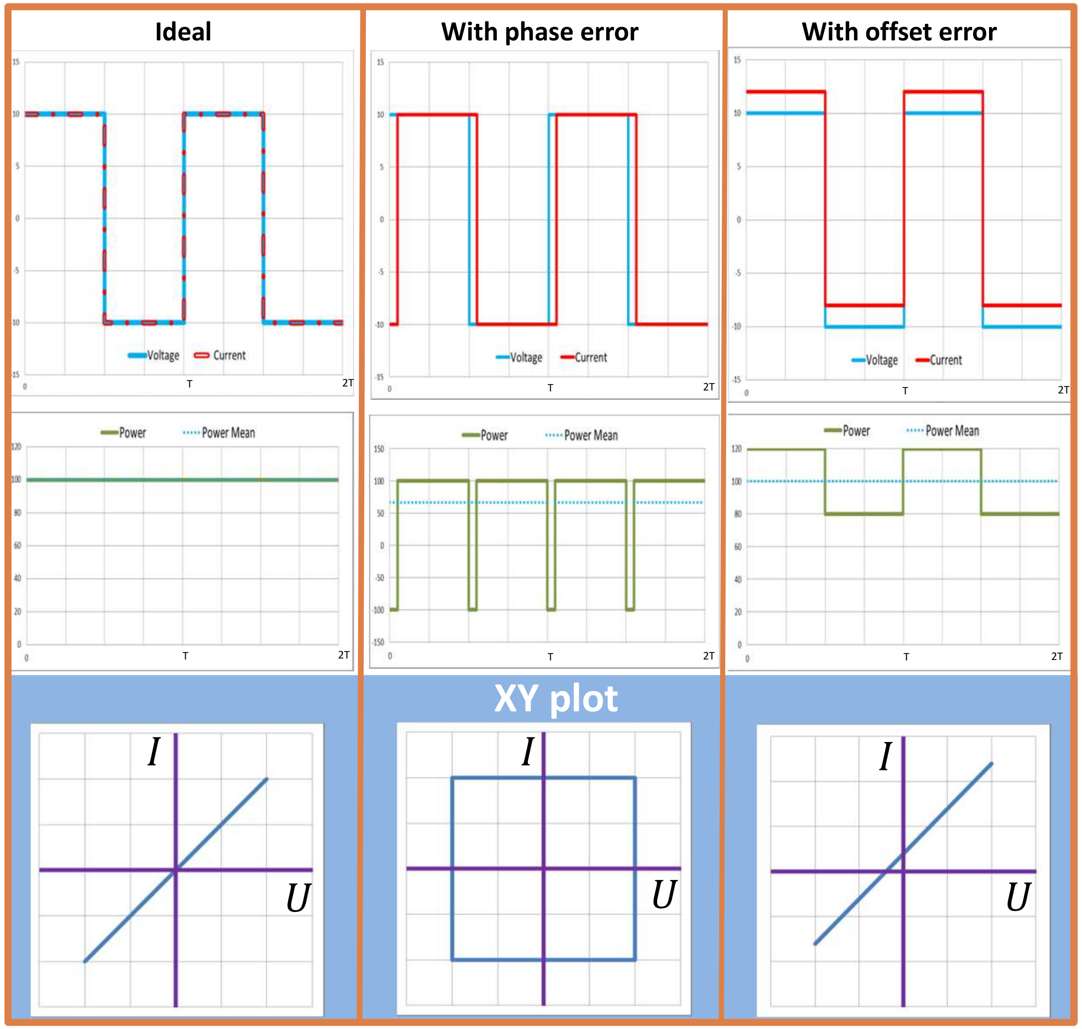
Scope measurement II: Voltage, Current and Time



5V/100mA (1kHz)
versus
500V/1A (100kHz)

?

Future?



How to calculate L at work

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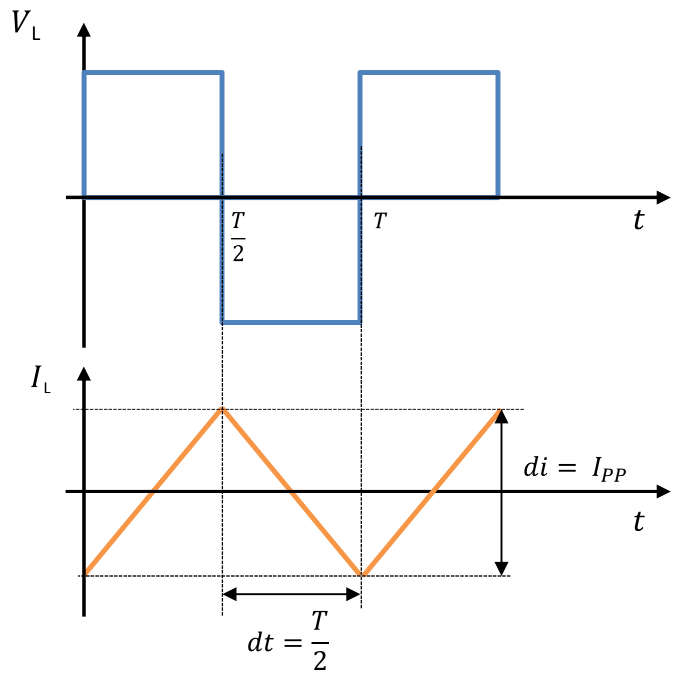
$$U = L\frac{di}{dt}$$

$$di = I_{PP}$$

$$dt = \frac{T}{2}$$

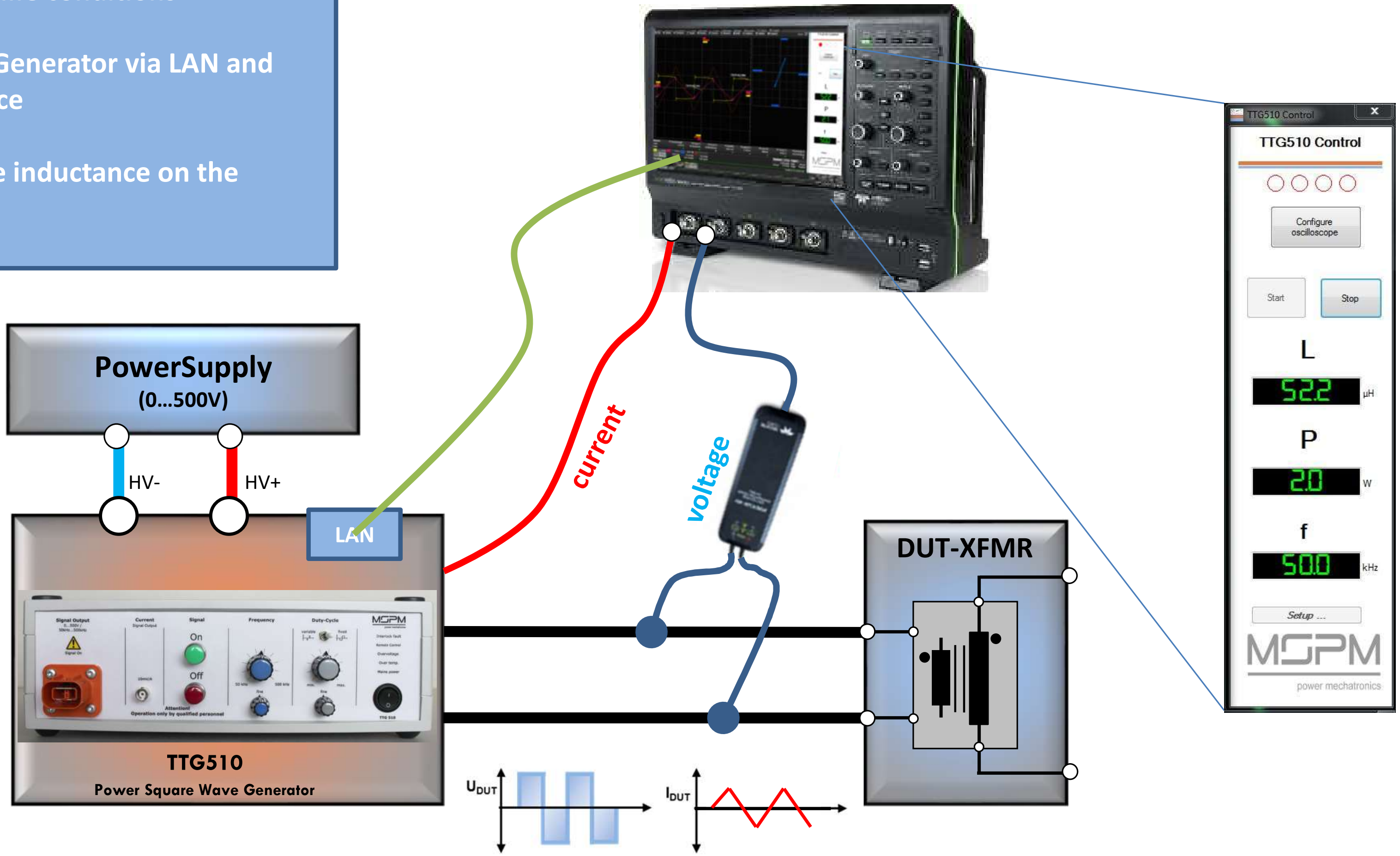
simple scope functions



to inductance

$$L[H] = \frac{\Phi[Vsec]}{I_{PP}[A]} = \frac{V_{rms}}{I_{PP}}\frac{T}{2} = \frac{V_{rms}}{I_{PP}}\frac{1}{2f} = \frac{U\,dt}{di}$$

- Inductance measurement under real life conditions
- Scope is used to control the TTG510 Generator via LAN and analyze the measurement data at once
- MSPM App calculates and display the inductance on the screen



MSPM HOT IDEAS FOR COOL PRODUCTS

power mechatronics

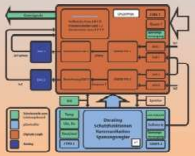
Hardware Development

Hardware Architecture
Hardware Design
Feasibility Study
Technology Assessment
Design Reviews
- Electrical
- Thermal
- Mechanical

Device Development
Circuit Diagram and Layout

Digital Power

Application Software
Embedded Systems
Lab Automation
Digital Control
VHDL Design



TTG Series

Universal Square Wave Generator

Determination of power losses in magnetic materials
Identification of saturation limits in magnetics
Identification of the parasitic capacitances
Source for inductive power transmission
Source to inject ripple current into components

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Addon: Saturation detection