Princeton MagNet
Princeton Power Electronics Research Lab

PRINCETON UNIVERSITY

Validating quality and verification of core loss measurements for databases

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Presented at Event Name and Date.

Structure

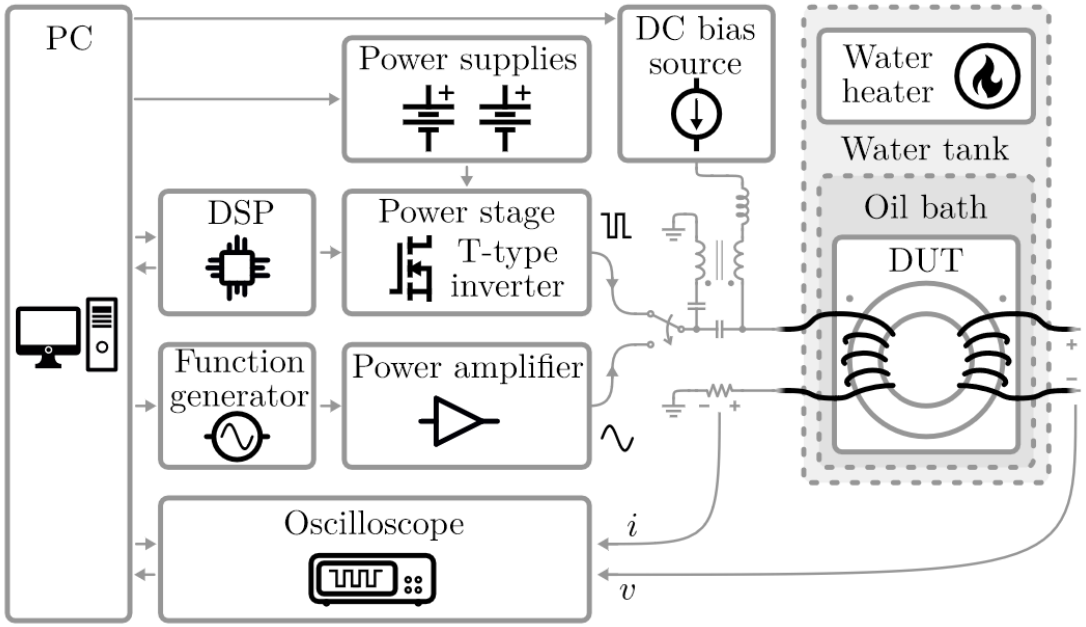
MagNet database
V-I method
Effect of phase delay
Effect of probes and oscilloscope error
Effect of parasitic elements in the circuit
Non-ideal excitations
Effect of the variation of temperature during testing
Assessing reproducibility
Effect of the variation of the core parameters

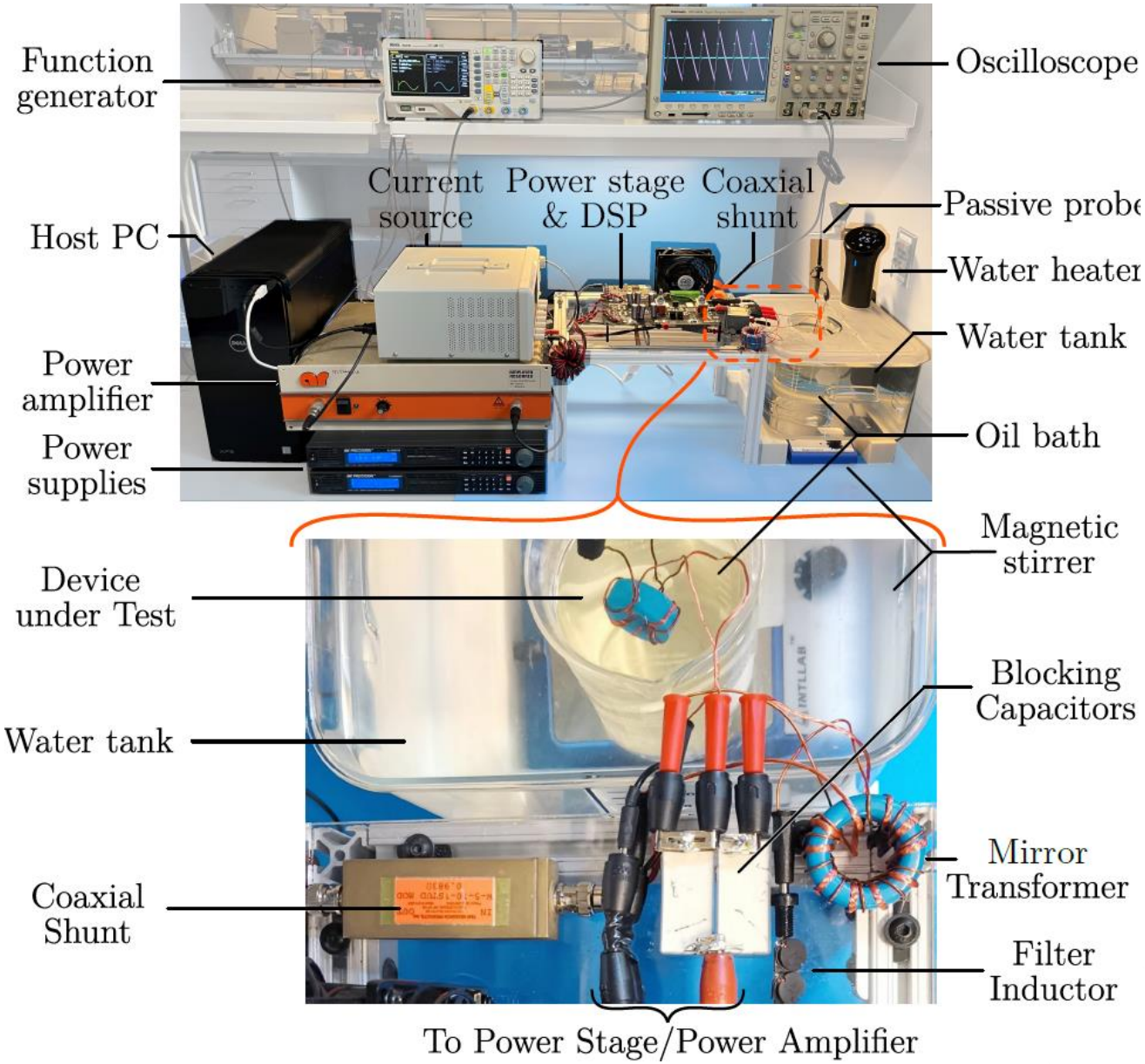
MagNet database

Automated

V-I method

B_{ac}, f, waveshape, T, H_{dc}

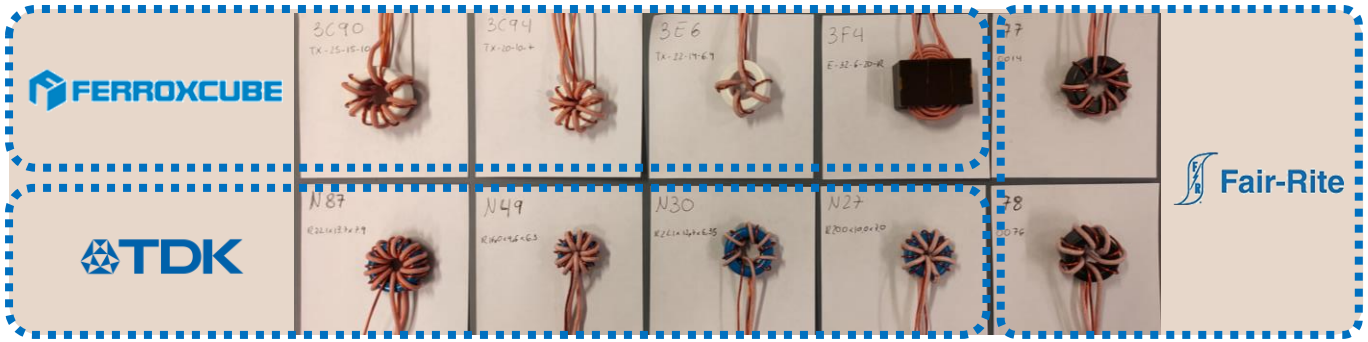




MagNet database

Measurements formatted as database

- Different formats:
  - MAT
  - JSON
  - HDF5
  - CSV



	Field	Value
DUT Information	Date_processing	'2022-08-10'
	Material	'N87'
	Core_Shape	'R34.0X20.5X12.5'
	Effective_Area	8.2600e-05
	Effective_Volume	6.7780e-06
	Effective_Length	0.0821
	Primary_Turns	5
	Secondary_Turns	5
Raw Time Series Data	Voltage	*24773x10000 double*
	Current	*24773x10000 double*
	Time	*24773x10000 double*
	Sampling_Time	1.0000e-08
Post-processed Data	Frequency	*24773x1 double*
	Flux_Density	*24773x1 double*
	Hdc	*24773x1 double*
	Duty_P	*24773x1 double*
	Duty_N	*24773x1 double*
	Temperature	*24773x1 double*
	Volumetric_Loss	*24773x1 double*
	B_Field	*24773x100 double*
	H_Field	*24773x100 double*

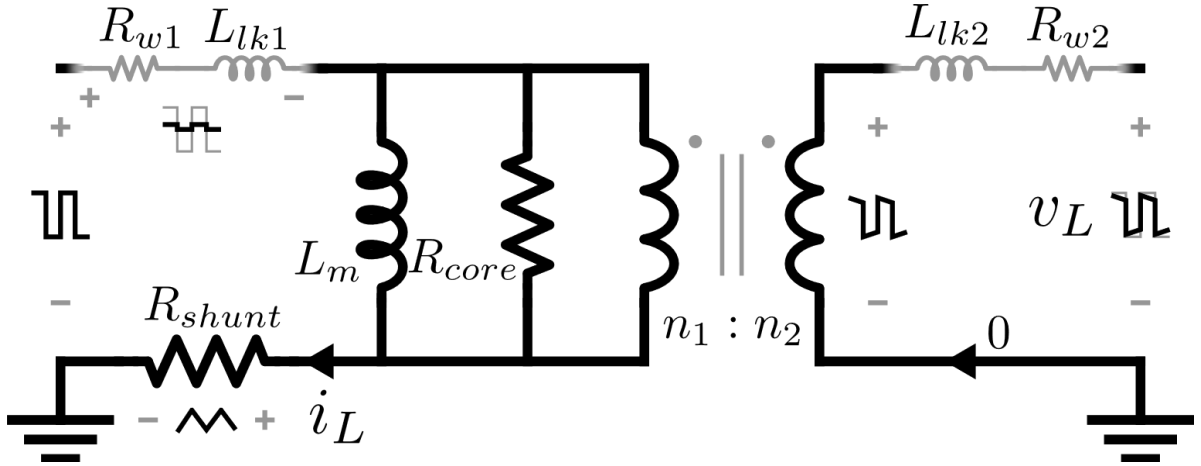
V-I method (voltamperometric or two-winding method)

Any excitation waveform

- Excitation applied to primary
- Current measured in primary
- Voltage measured in secondary

Not affected by:

- L_{lk}
- R_w
- R_{shunt}



$$B(t) = \frac{1}{n_2 \cdot \mathrm{A}_e} \int v_L(t)\mathrm{d}t$$

B_0 unknown

$$H(t) = \frac{n_1}{l_e} i_L(t)$$

$$P_V = \frac{1}{V_e} \frac{1}{T} \int_0^T v_L(t)\, i_L(t)\mathrm{d}t$$

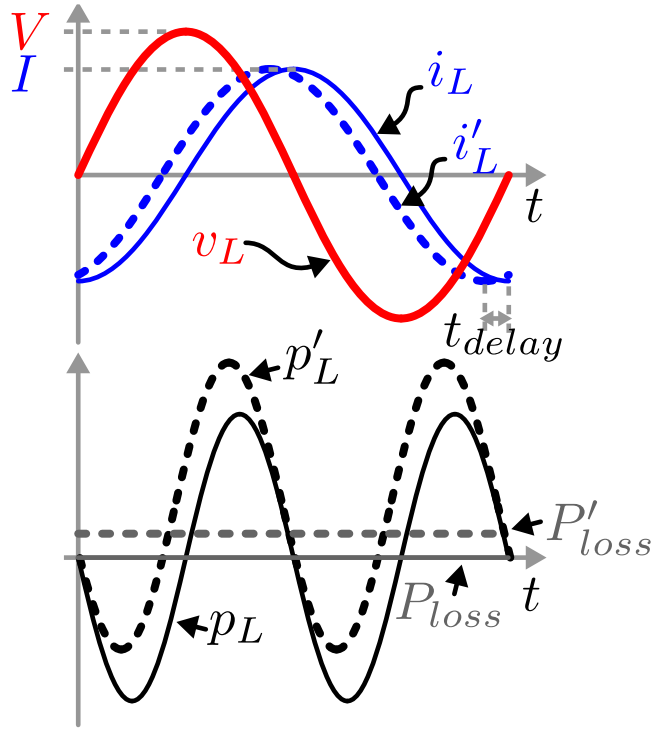
- Only core variables measured … in theory

Effect of phase delay

Well studied issue and known limitation of this method:

- High frequencies
- High quality factor materials

Main reason to use other methods instead



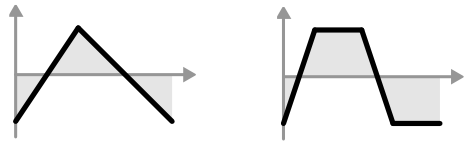
- Small delay between the voltage and current lead to large errors in the measurement:
  - A delay in the current cannot be distinguished from losses

$$\Delta P_{loss} \approx V \cdot I \cdot \left|t_{delay}\right| \cdot \pi \cdot f$$

Neglecting losses; small angle approximation

Effect of phase delay

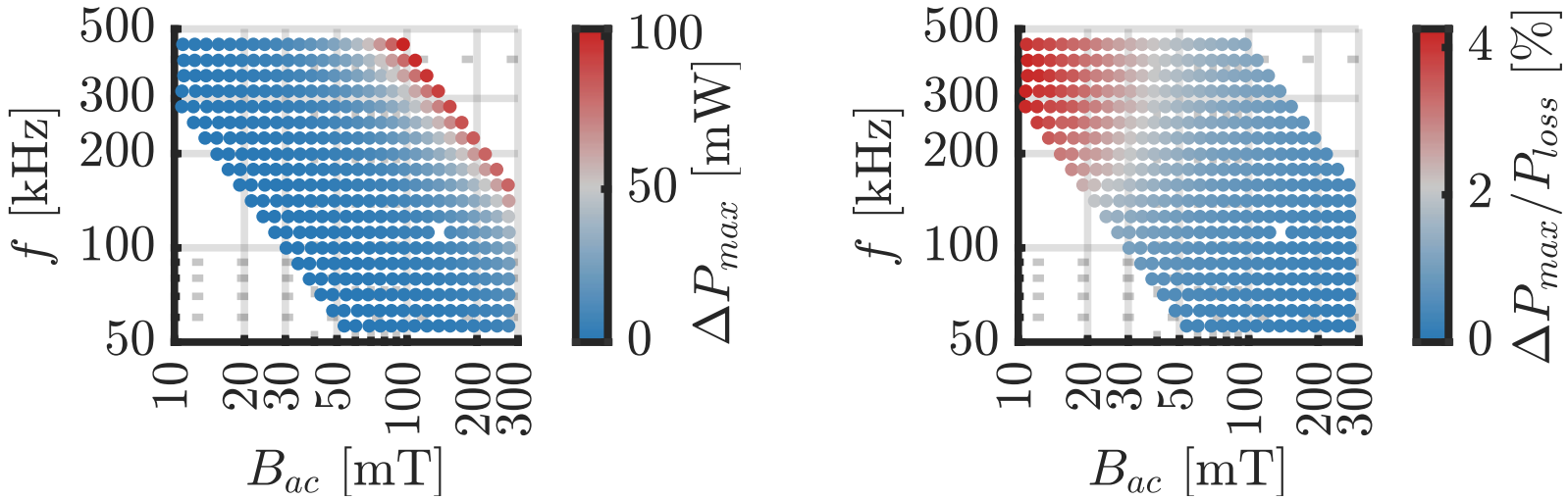
For triangular and trapezoidal symmetric



- $\Delta P_{loss} \approx V_{in} \cdot I_{pk} \cdot |t_{delay}| \cdot 4 \cdot f$

Relative error: $\Delta P_{loss}/P_{loss}$

- ↑ when ΔP_{loss} ↑ ($\approx V \cdot I \cdot t_{delay} \cdot f$) → S ↑, f ↑, t_{delay} ↑
- ↑ when P_{loss} ↓ → quality factor ↑, f ↓, B_{ac} ↓

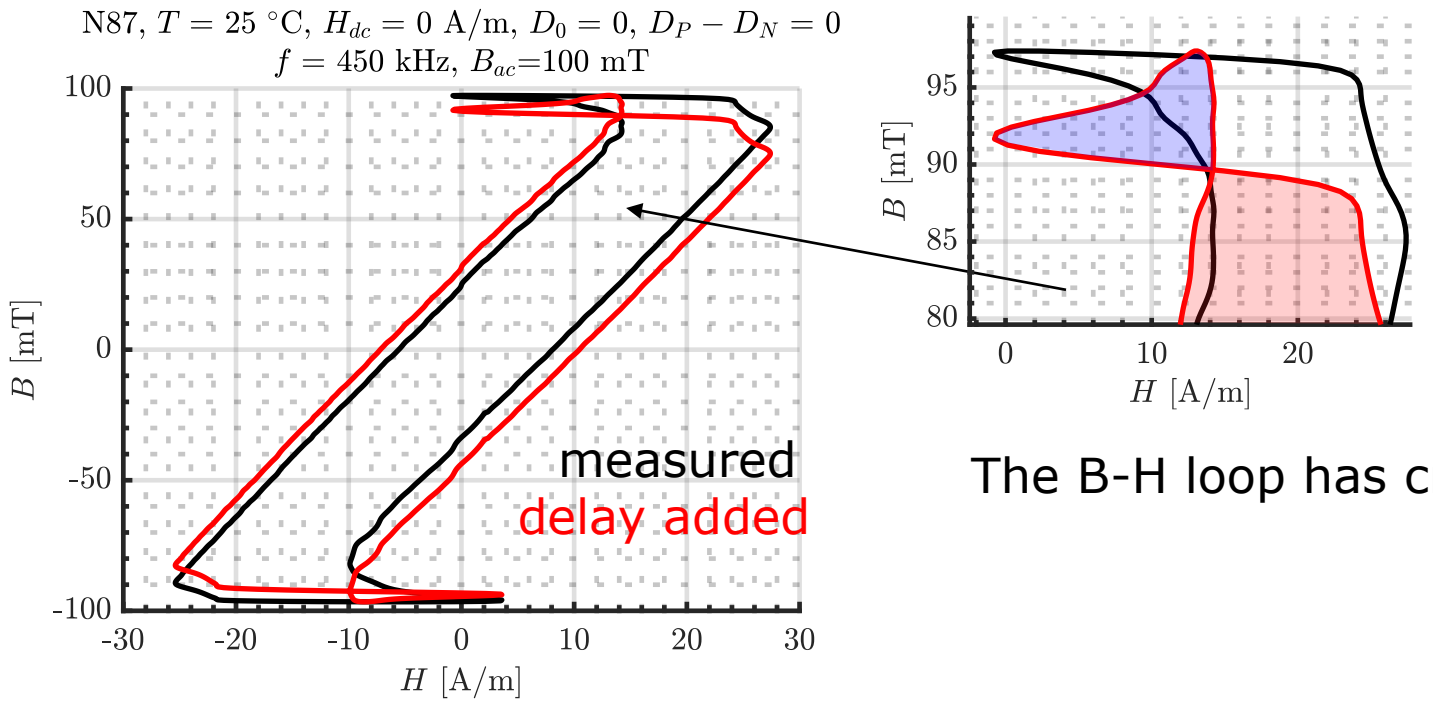


N87, R34.0X20.5X12.5

$T = 25$ °C, $H_{dc} = 0$ A/m, $D_0 = 0$, $D_P - D_N = 0$

Effect of phase delay

B-H loop enlarged (or shrank depending on the sign of the delay)
Critical for the shape when switching noise is present



The B-H loop has crossing points

Effect the oscilloscope

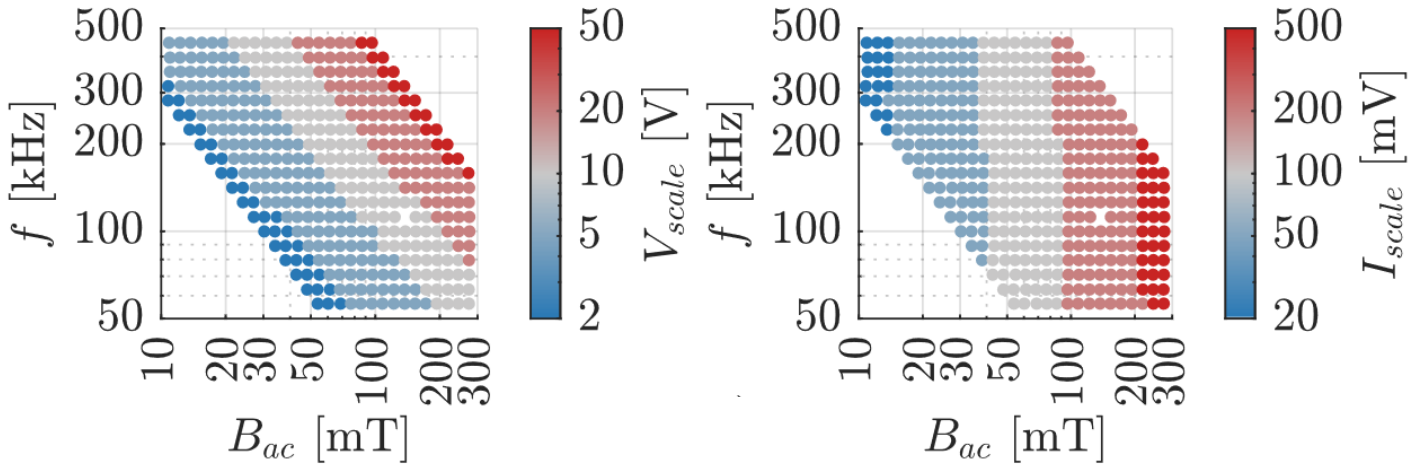
Besides the error in the probes, the oscilloscope introduces error:

- Vertical resolution
- Horizontal resolution
- Gain error
- Offset error

DPO4054

Gain error and offset error depend on the vertical scale

- Minimized while avoiding clipping of the waveform
- Depends on each specific operating point



N87, R34.0X20.5X12.5
$T = 25$ °C, $H_{dc} = 0$ A/m, $D_0 = 0$, $D_P - D_N = 0$

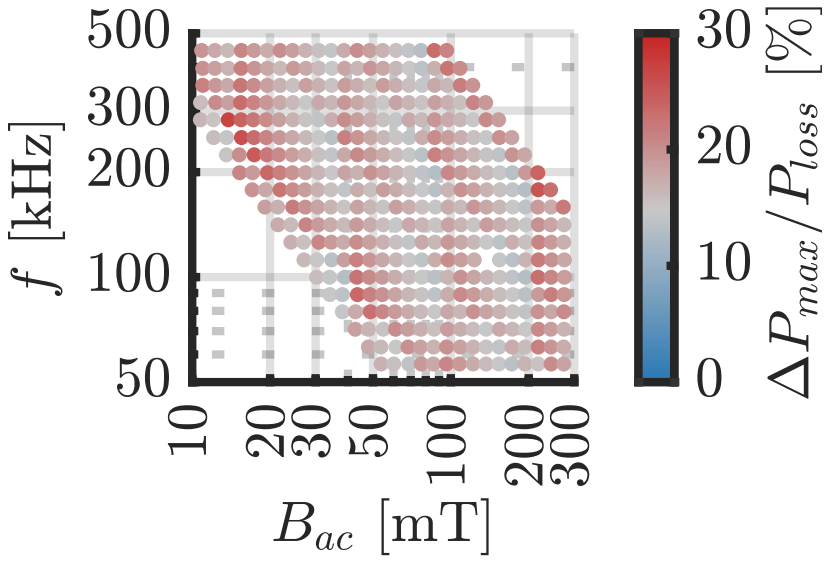
Effect the oscilloscope: gain error

For Tektronix DPO4054 → mostly from ±0.15 div (error between samples)

- For a signal of 10 V amplitude, measured at 5 V/div → ±0.75 V → 7.5% error!

The error depend heavily on the vertical scales

- Different error in each point



N87, R34.0X20.5X12.5

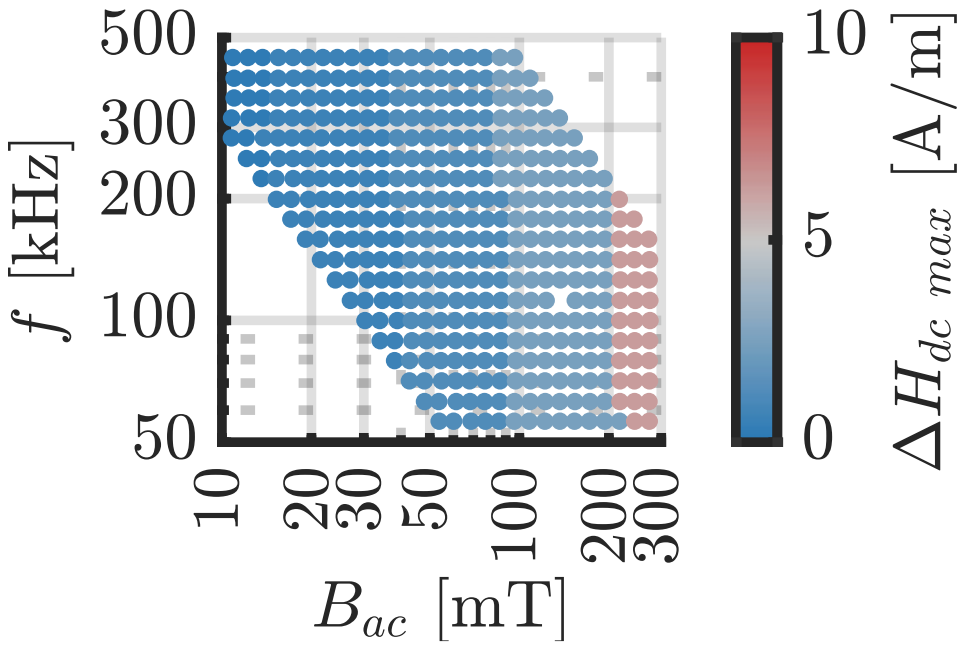
$T = 25\ ^{\circ}\mathrm{C},\ H_{dc} = 0\ \mathrm{A/m},\ D_0 = 0,\ D_P - D_N = 0$

https://download.tek.com/manual/077024701Rev_A_web.pdf

Effect the oscilloscope: offset error

Voltage error, removed in the post-processing stage

Current error → problem when reporting Hdc



N87, R34.0X20.5X12.5

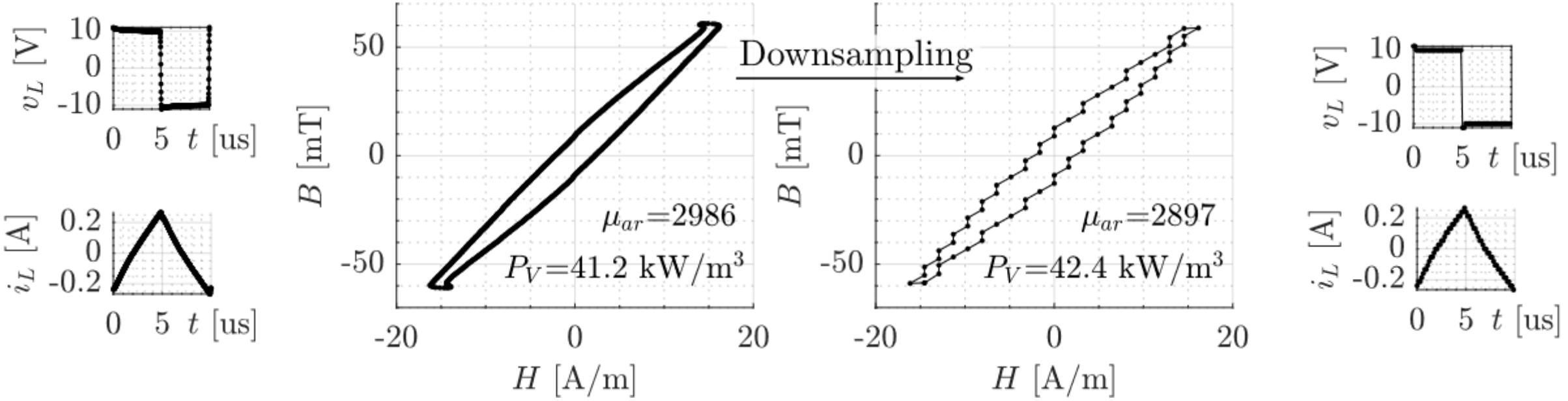
$T = 25$ °C, $H_{dc} = 0$ A/m, $D_0 = 0$, $D_P - D_N = 0$

Effect the oscilloscope: sampling

Vertical and horizontal sampling is enough in most cases

- 8 bits
- 8 ns

Example of heavy downsampling



N87, R34.0X20.5X12.5
$T = 25\ ^\circ\text{C}$, $H_{dc} = 0$ A/m, $D_0 = 0$, $D_P - D_N = 0$

Effect of parasitic elements in the circuit

- On the measurement side:
  - Change the current measured
  - C_{ps} is not so significant if a 1:1 transformer is used.

Fig Cp, Cs, Cio

- On the DUT
  - Affect the amount of current actually flowing through the core

Fig Cshunt, Rshunt

Non-ideal excitations

Voltage excitation + shunt → voltage drop

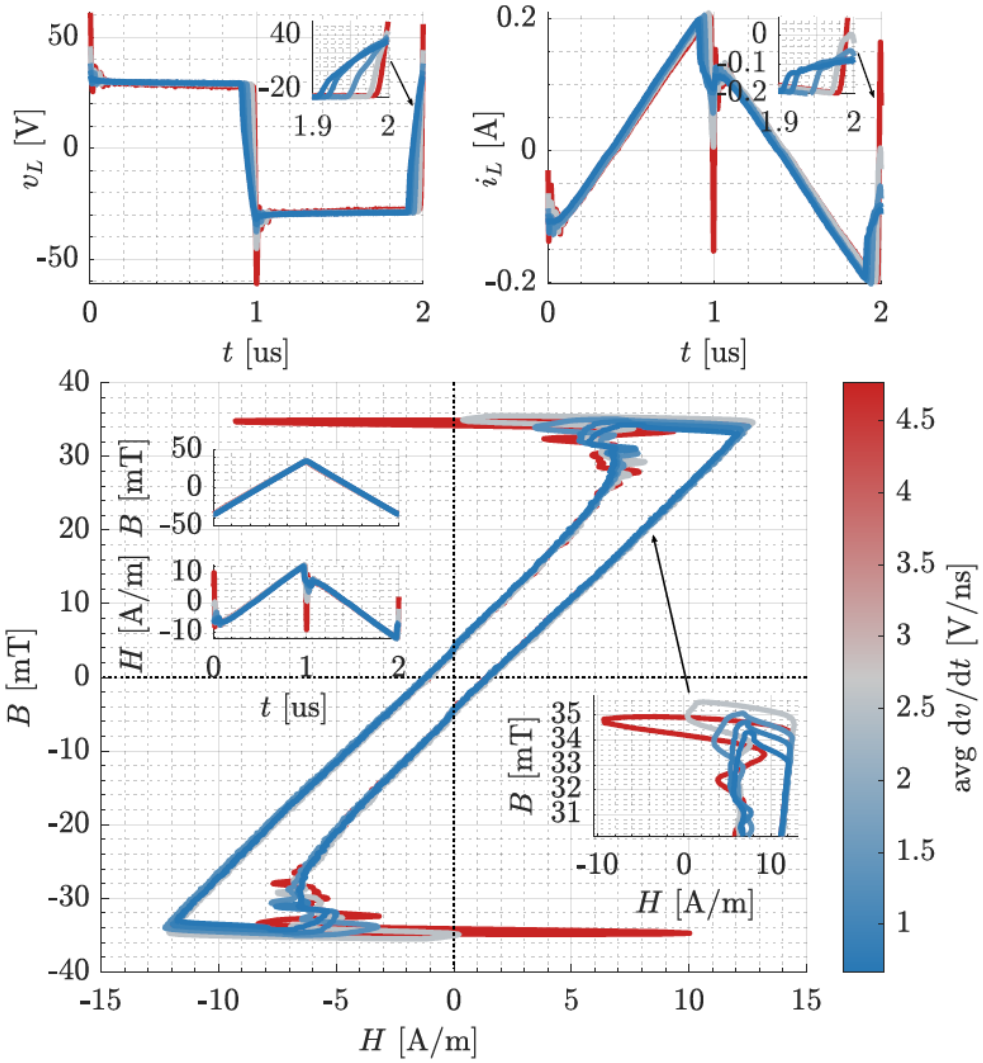
Power amplifier → Non ideal voltage gain

Fixed times for PWM waveforms (clock cycles) → limited time resolution

Dead time → affecting waveforms shape

- 500 kHz 10% duty cycle → 200 ns rise time, dead time = 70 ns

B-H loops are affected by switching speed



Effect of the variation of temperature

Sustained core loss heat up the core and

Core loss are temperature dependent →

Reporting the temperature of the test or testing at the desired temperature is necessary

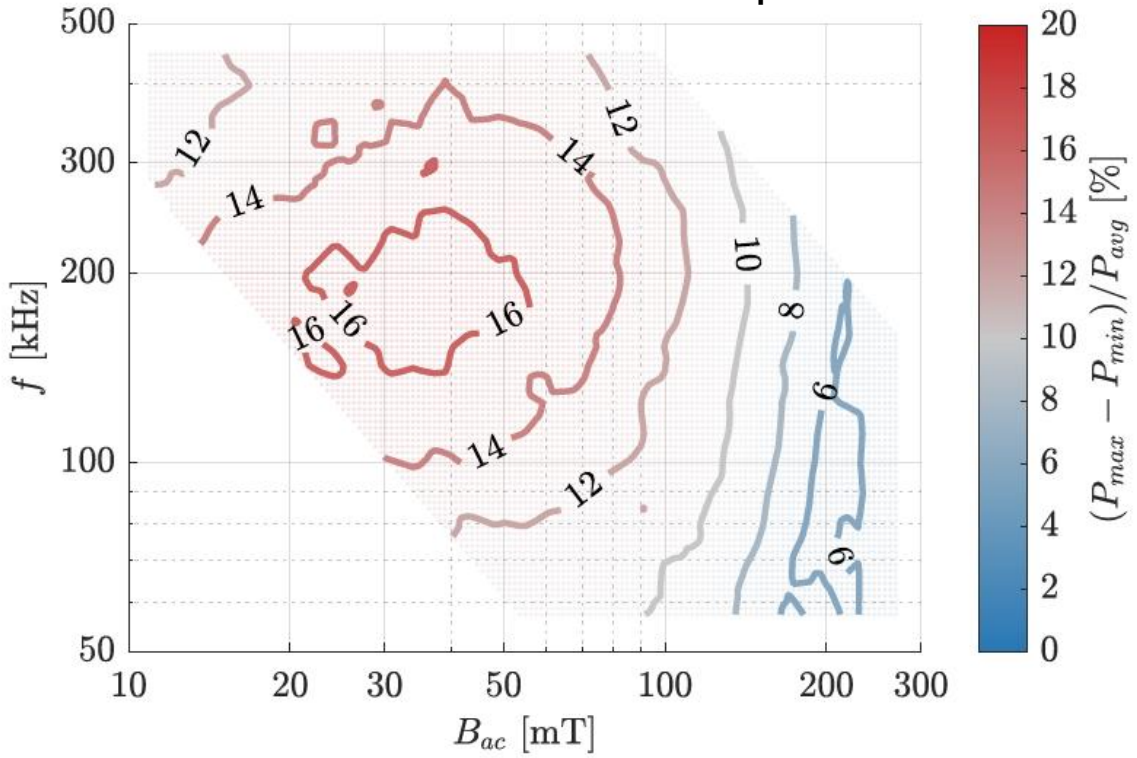
Oil bath + magnetic stirrer → Good solution but there is still some ΔT

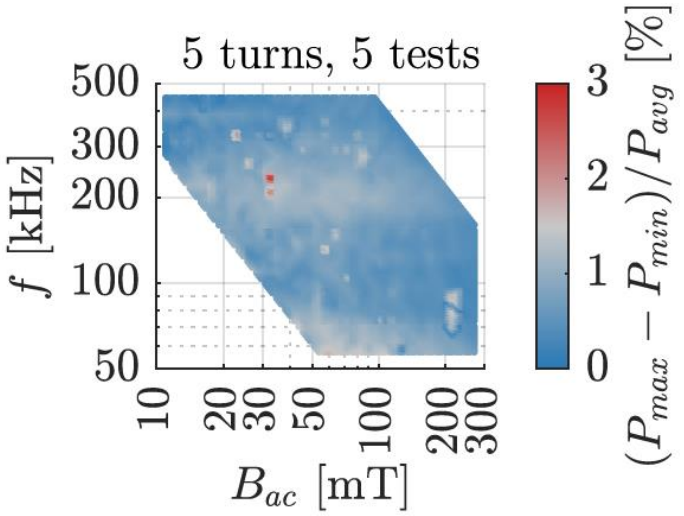
Fig DeltaT thermal camera

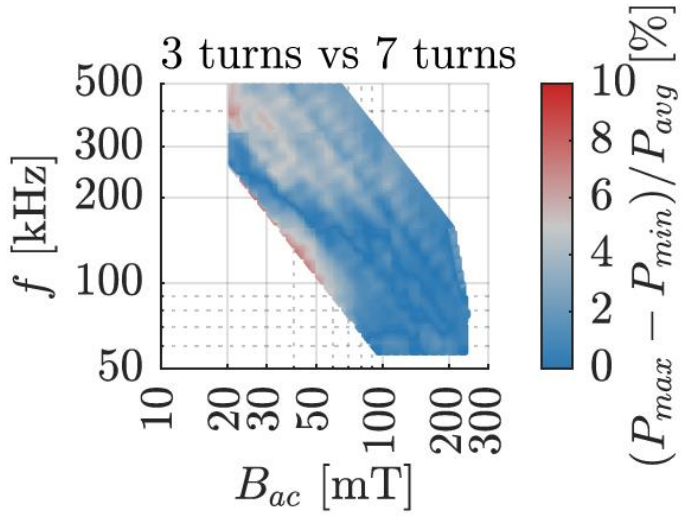
Assessing reproducibility

Data is reproducible, but core to core variation is significant

Variation between 5 “equal” cores





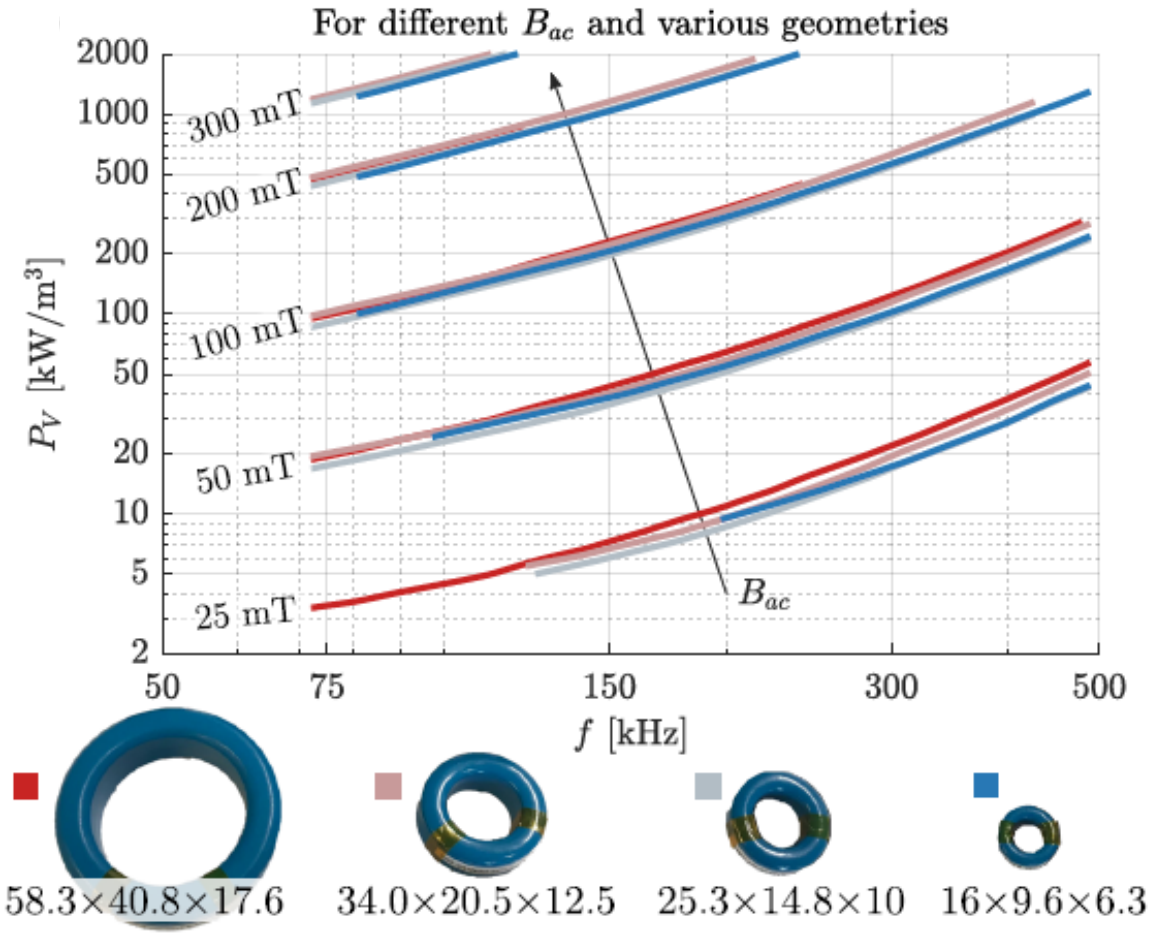


Variation of the core parameters

Different shapes can impact core loss too, which is usually overlooked

$$l_e = \frac{\pi \ln \frac{d_o}{d_i}}{\frac{1}{d_i} - \frac{1}{d_o}};\ A_e = \frac{h}{2}\frac{\ln^2 \frac{d_o}{d_i}}{\frac{1}{d_i} - \frac{1}{d_o}};\ V_e = \frac{h}{2}\frac{\pi \ln^3 \frac{d_o}{d_i}}{\left(\frac{1}{d_i} - \frac{1}{d_o}\right)^2}$$

- $l_e \pm 2.3\%$
- $A_e \pm 11\%$
- $V_e \pm 10.5\%$



Summary

Importance of error analysis

Reporting error for each datapoint

Complete, add fig

Thank you for your interest!

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