Closed Loop Current Sensors with Magnetic Probe

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Sensors in Power Electronics

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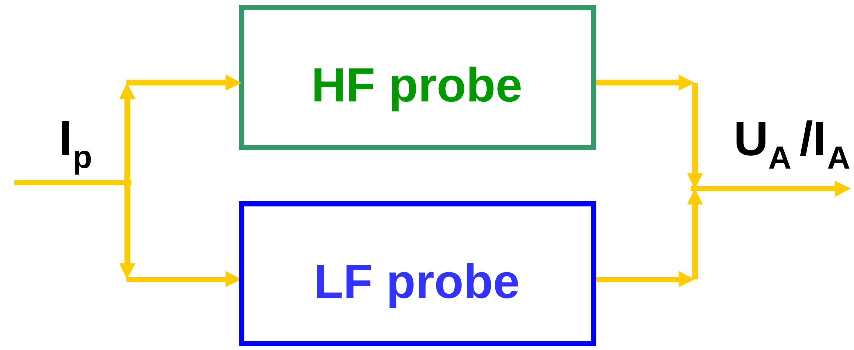
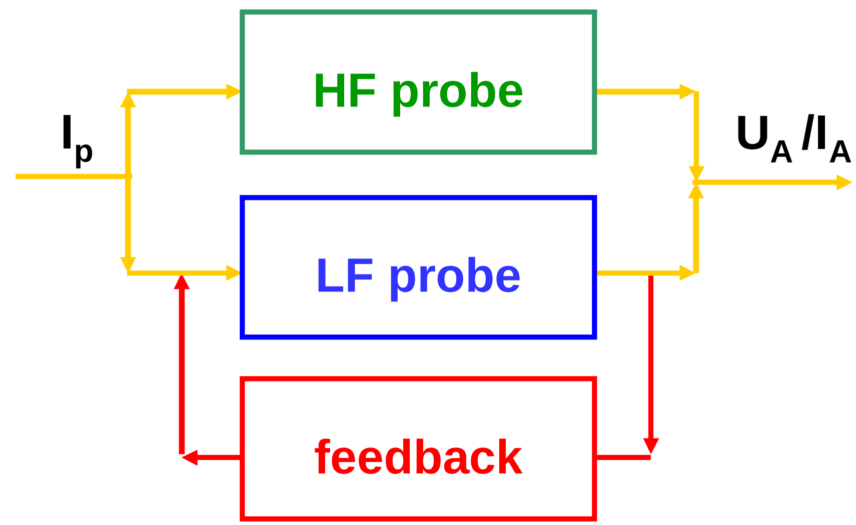
Fundamentals: What is a Open (OL)/ Closed Loop (CL) Current Sensor (CS) ?

OL CS sense primary current by measuring magnetic flux in air gap of magnetic core. Flux converted to output voltage/current



Improved HF properties with „current transformer“ added

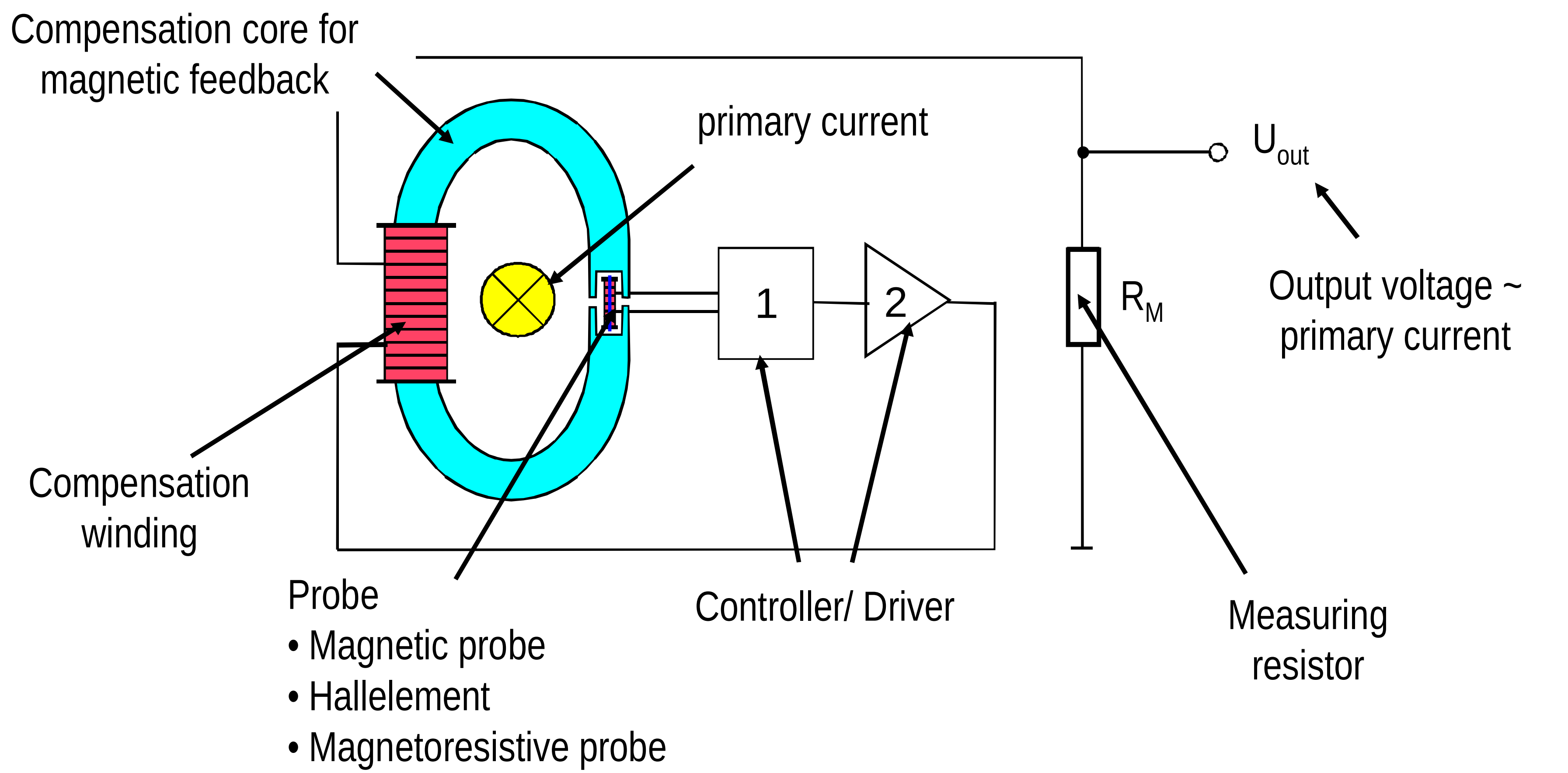


CL CS add feedback for LF probe to improve accuracy of measurement + immunity to perturbations

CL CS use „current transformer“ for measuring HF currents

Fundamentals: What is the setup of a Closed Loop Current Sensor ?

Closed loop CS regulate difference between magnetic fluxes, generated by primary current and compensation current, to zero ⇒ compensation current ~ primary current.
Control loop improves accuracy, reduces internal (electronics) + external perturbations (temperature,…).

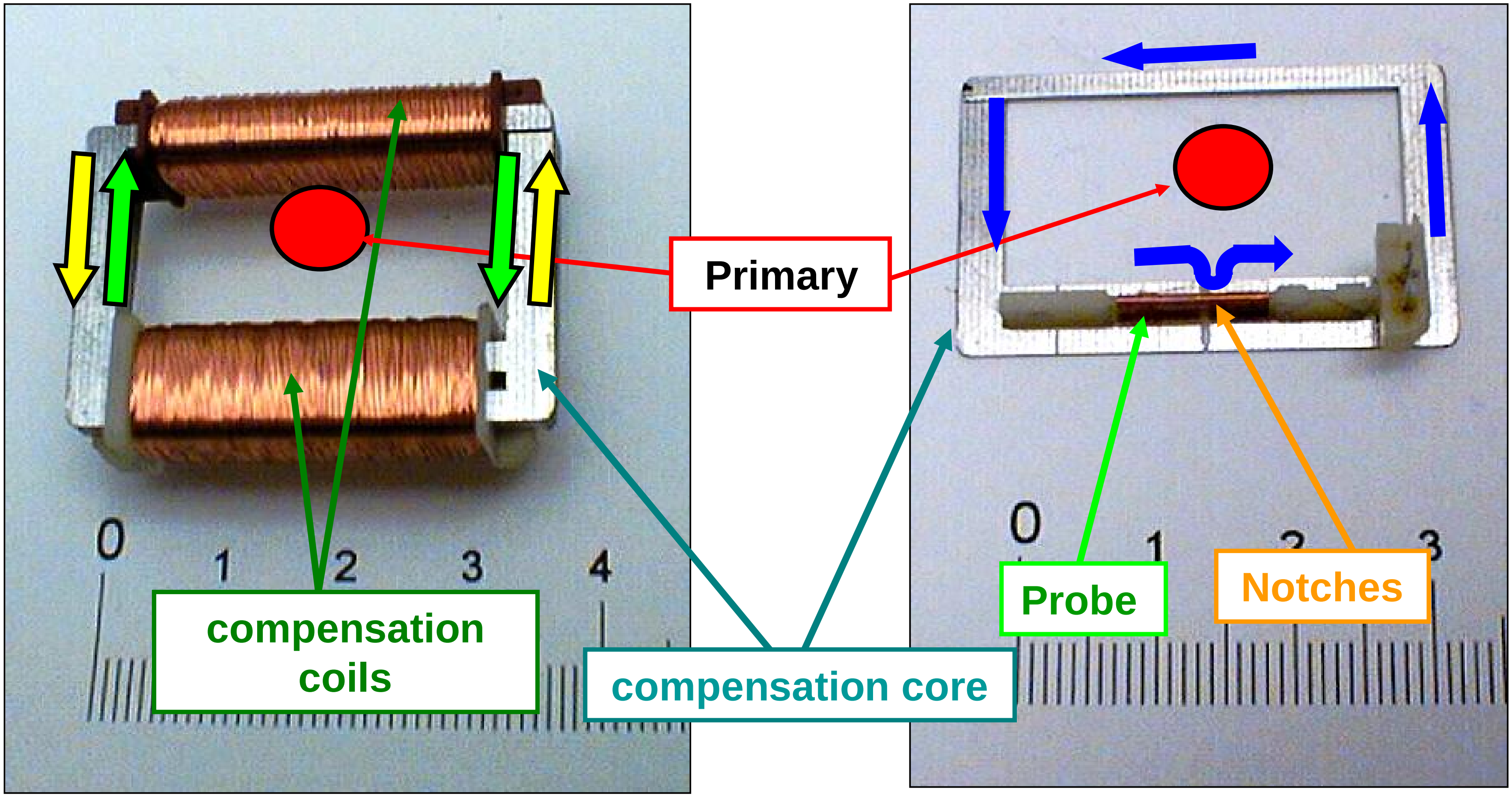


Fundamentals: How is Closed Loop Current Sensor built ?

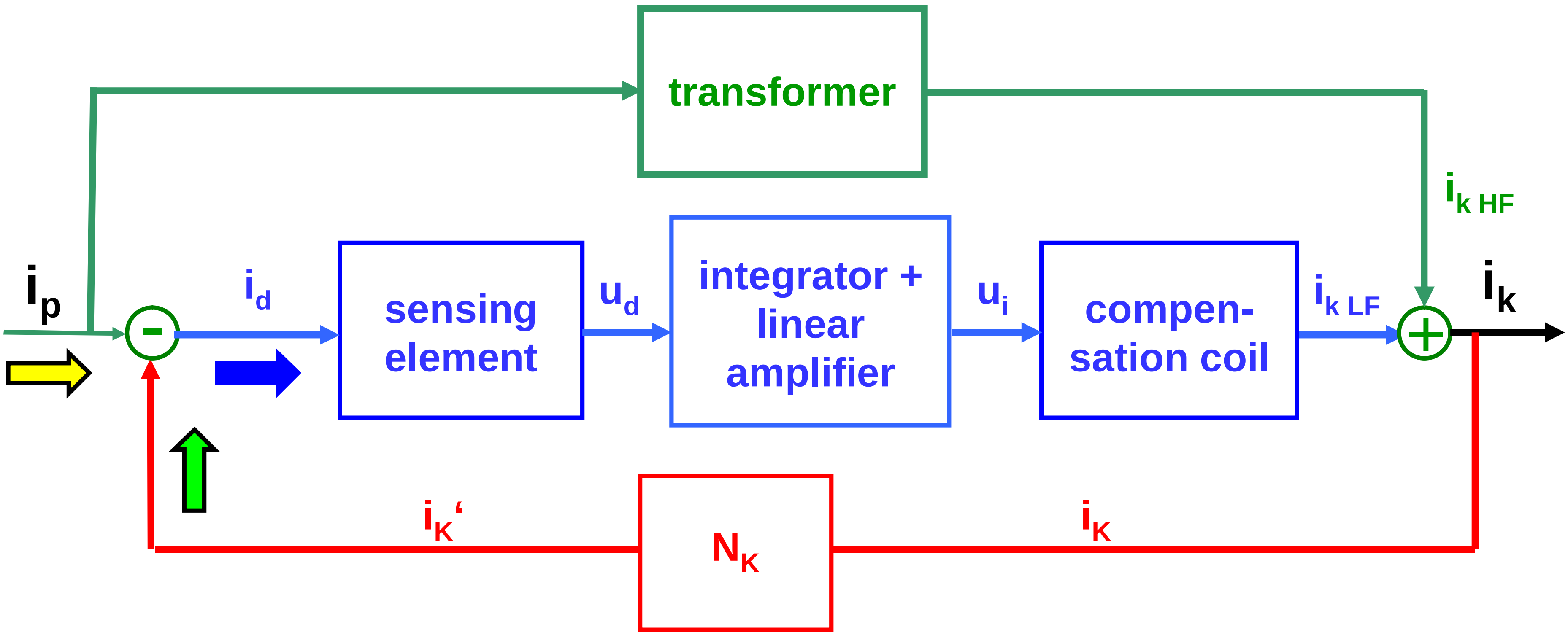
Flux Φ_p generated by primary current

Flux Φ_K generated by compensation coil

Flux difference Φ_p - Φ_K sensed by probe

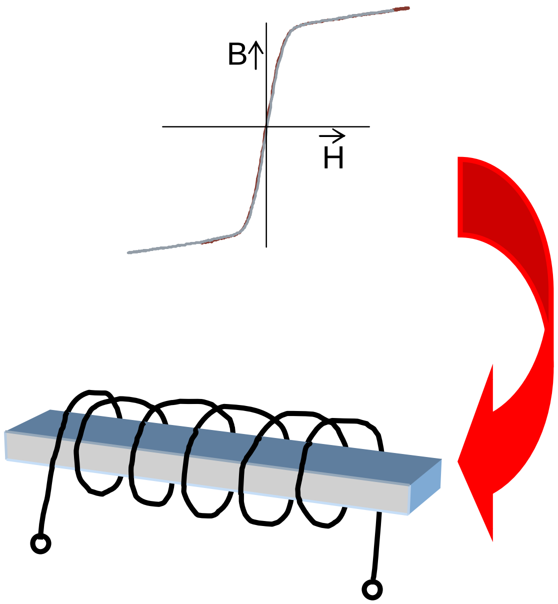


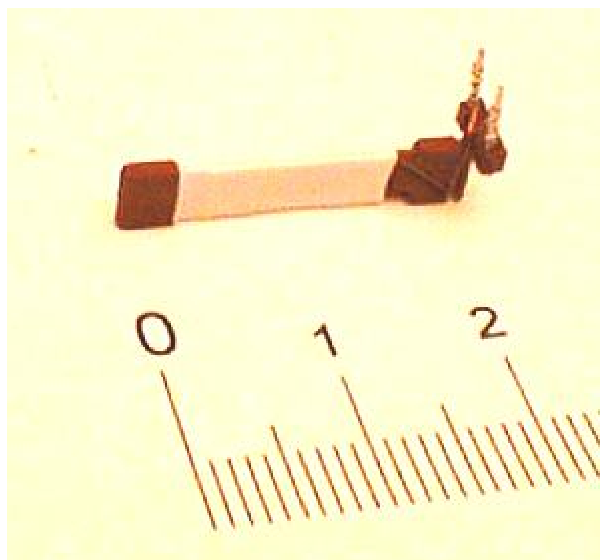
Fundamentals: What is the Closed Loop (Control Loop) ?

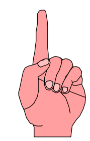


Probe = one strip of amorphous alloy VITROVAC (thickness ~20µm, 10mm*3mm) with 150 turns

Z-shaped hysteresis loop ⇔ high L, if not close to saturation, low L, if saturated ~ magnetic switch

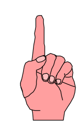




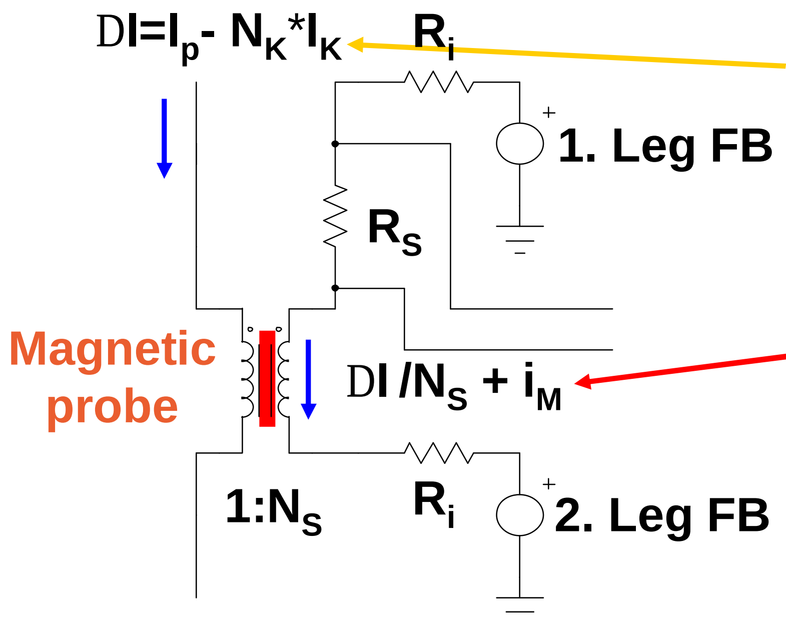


low costs compared to Hall elements or magnetoresistive probe

Magnetic Probe does not require uniform field distribution of compensation core in contrast to Hall element probe:

$\Rightarrow$ smaller, **low-cost compensation core** can be used 

Fundamentals: How does a Magnetic Probe work?



Magnetic flux in probe ~ $\Delta I = I_p - N_K {*} I_K$ (as in Hall element CS)

FB generates magnetising current i_M, $\Delta I/N_S + i_M > i_{M\ threshold}$ ~ 30mA (at R_s) $\Rightarrow$ probe saturates, FB reverses polarity

➡ **Probe self-oscillates** (at typ. 400 kHz)

Voltages at probe ~ ΔI, $R = 2{*}R_i + R_s$ $\Rightarrow$ saturation in one direction faster than in other

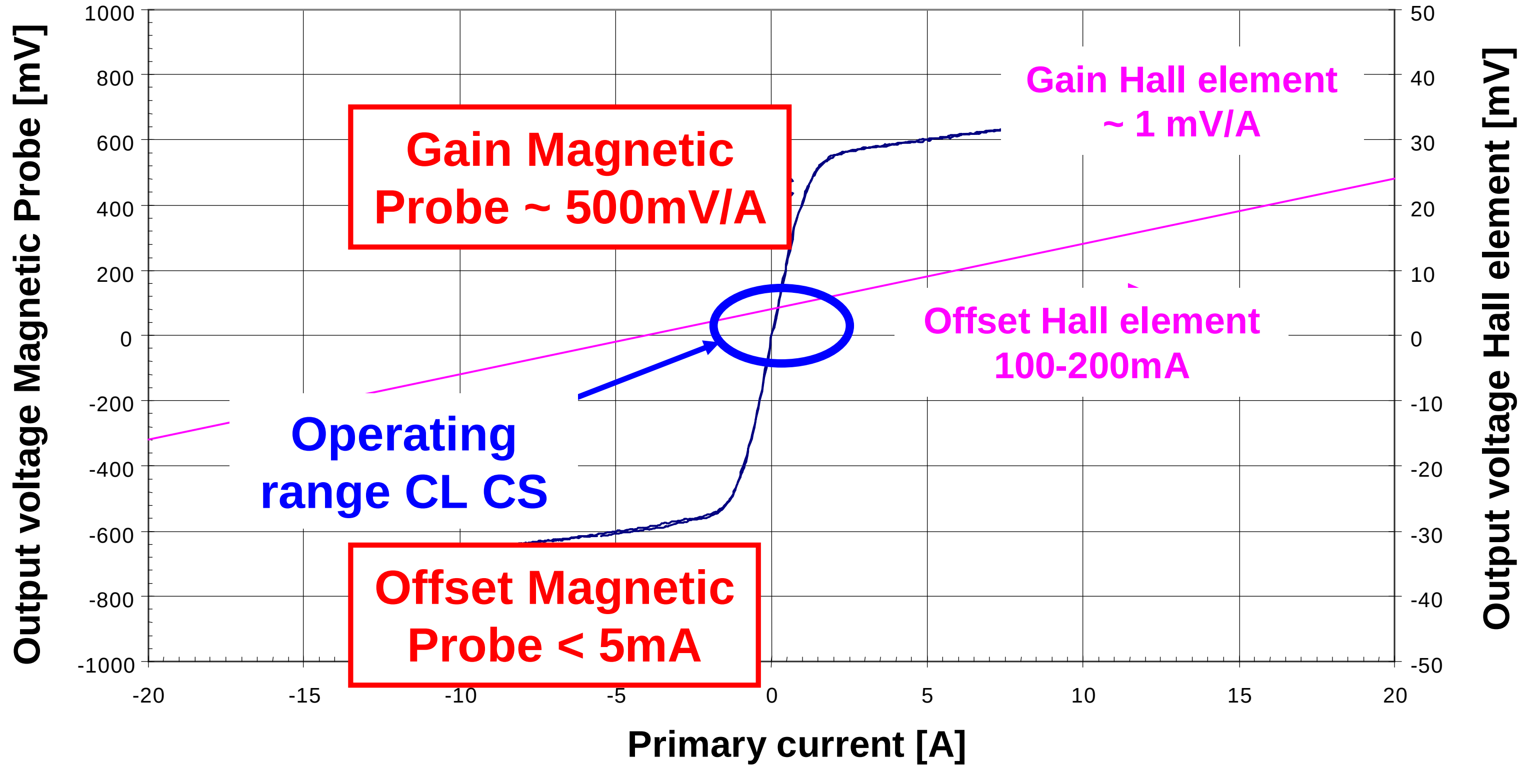
➡ **Oscillation pulse-width-modulated**

$\Delta I = 0A \Rightarrow D = 50\%$, D increases by ~20% for $\Delta I = 1A \Rightarrow D = 30\%$ for $\Delta I = +1A$, $D = 70\%$ for $\Delta I = -1A$

Conversion into voltage by averaging $U_a \sim (D - 50\%){*}U_S$

➡ **Output voltage probe ~ DI**

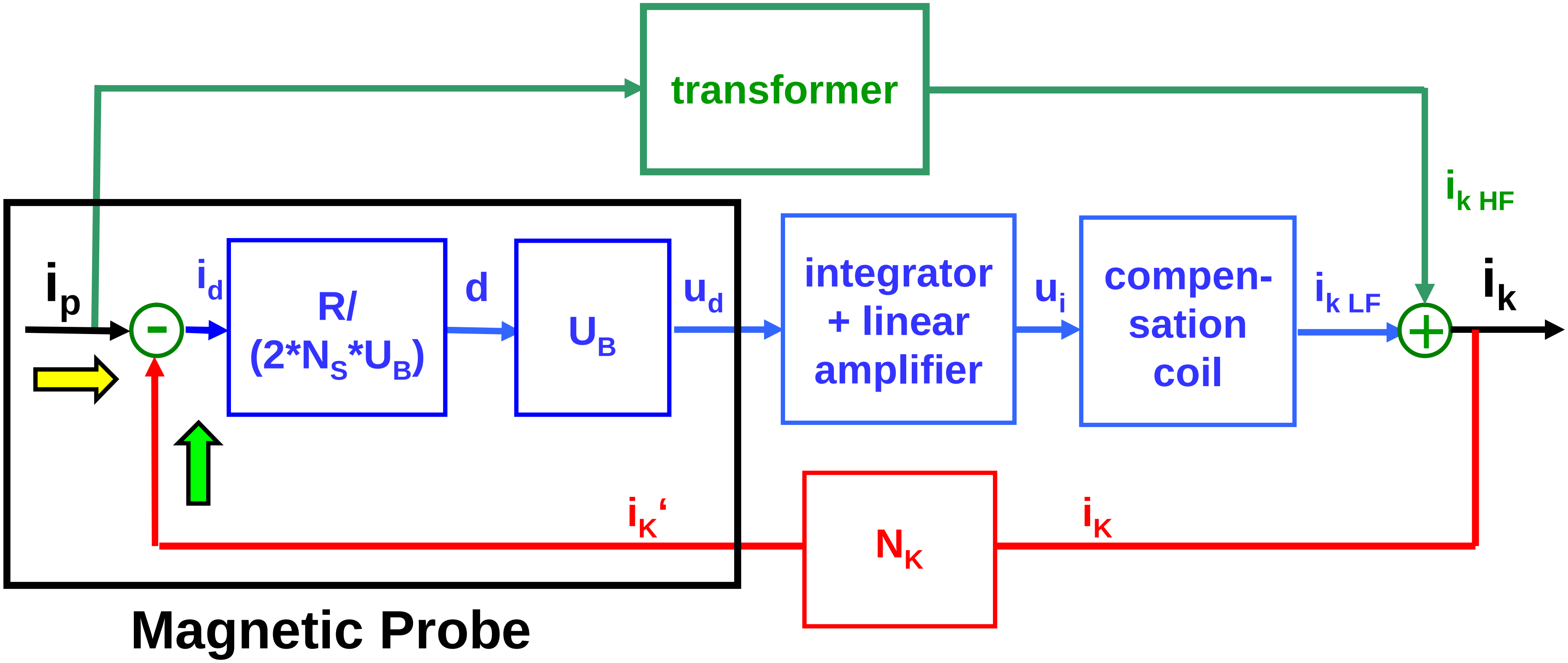
Fundamentals: What are the properties of a Magnetic Probe ?



Further properties of Magnetic Probe:

• basically no temperature drift (duty-cycle not dependent on absolute saturation induction values, only on symmetry $B_{pos.\ sat} = -B_{neg.\ sat}$) $\Rightarrow$ superior to Hall elements

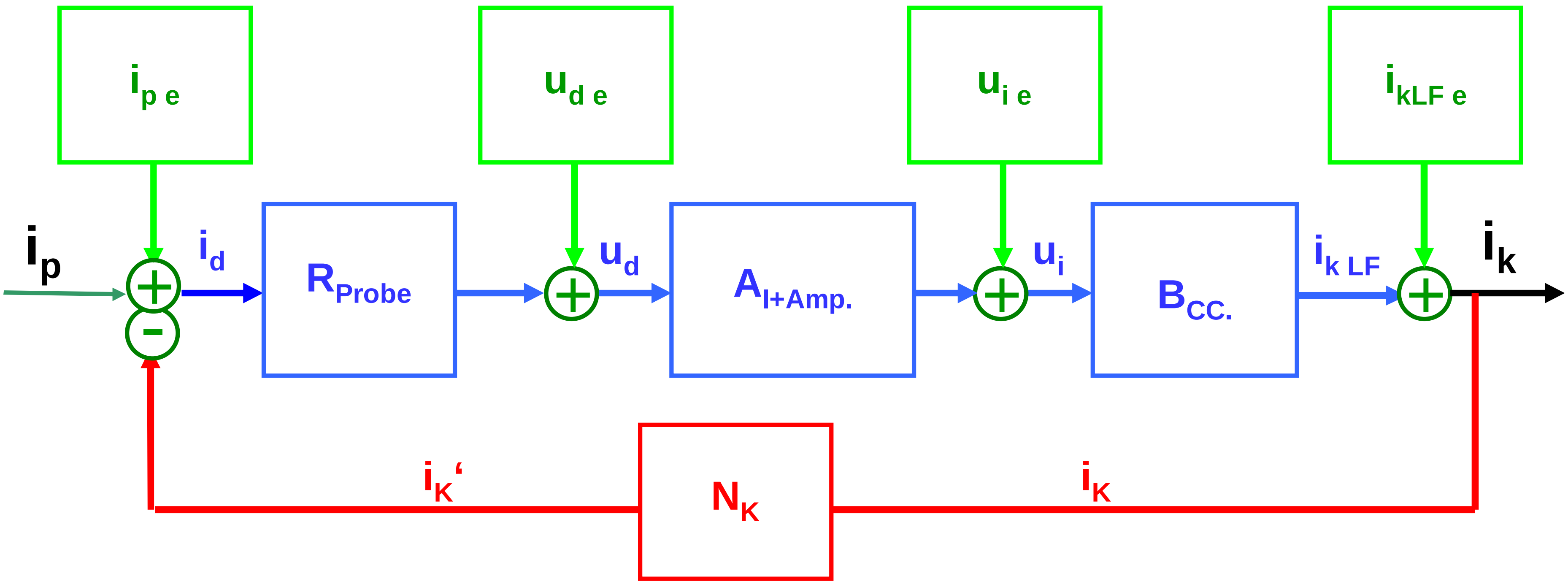
• probe noise with lower magnitude, higher frequency (400kHz) than semiconductor noise of Hall element $\Rightarrow$ easier to filter out



Verification of gain of Magnetic Probe:

Typical values: R ~ 150 Ω, N_S~150 $\Rightarrow$ u_d/i_d ~ 150 Ω /(2*150) = 500mV/A

Fundamentals: What are the benefits of the high gain of a Magnetic Probe?



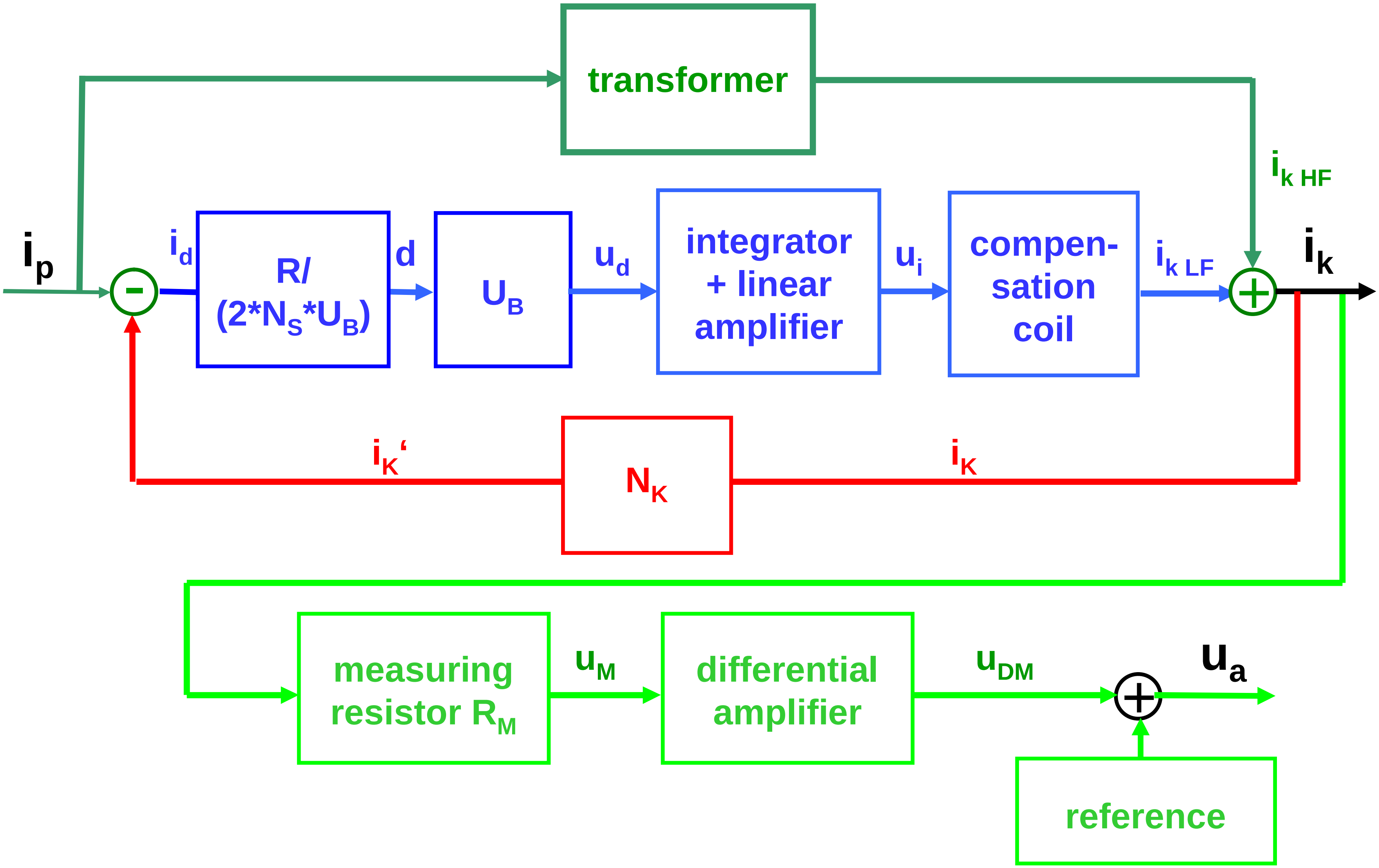
Open loop gain ~ probe gain: $V_{OL} = N_K * R_{Probe} * A_{I+Amp.} * B_{CC.}$

$$\Rightarrow \quad i_K \sim \frac{1}{N_K} * i_p + \frac{1}{N_K} * i_{p\,e} + \frac{1}{N_K * R_{Probe}} * u_{d\,e} + \ldots$$

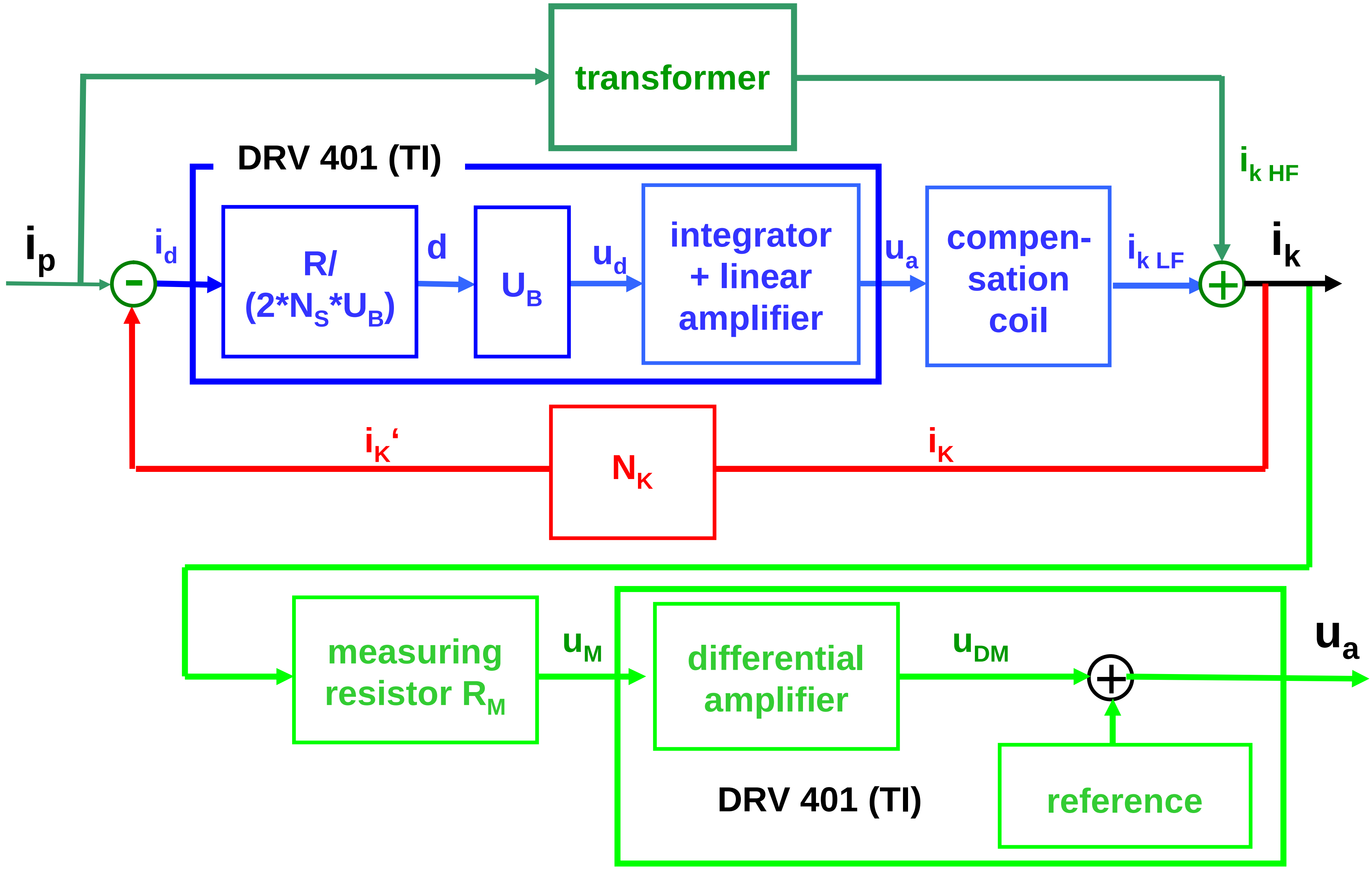
High probe gain
$\Rightarrow$ error contribution of control loop electronics highly attentuated
$\Rightarrow$ simplifies electronics
$\Rightarrow$ allows separation electronics from magnetic module

lower cost electronics

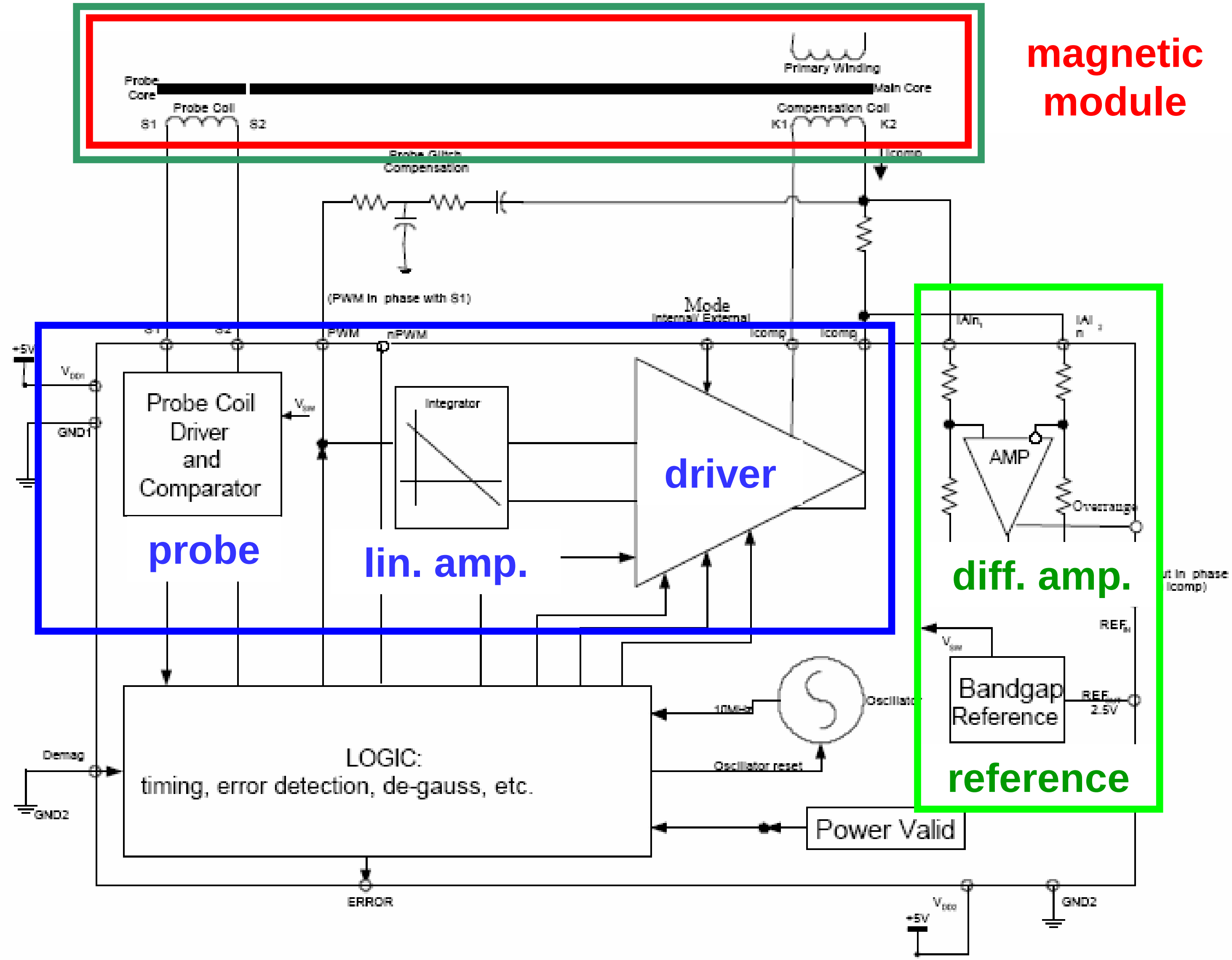
Fundamentals: How to generate a voltage output from the current output?



DRV401: Integration of Control Loop + voltage output into TI-IC DRV401

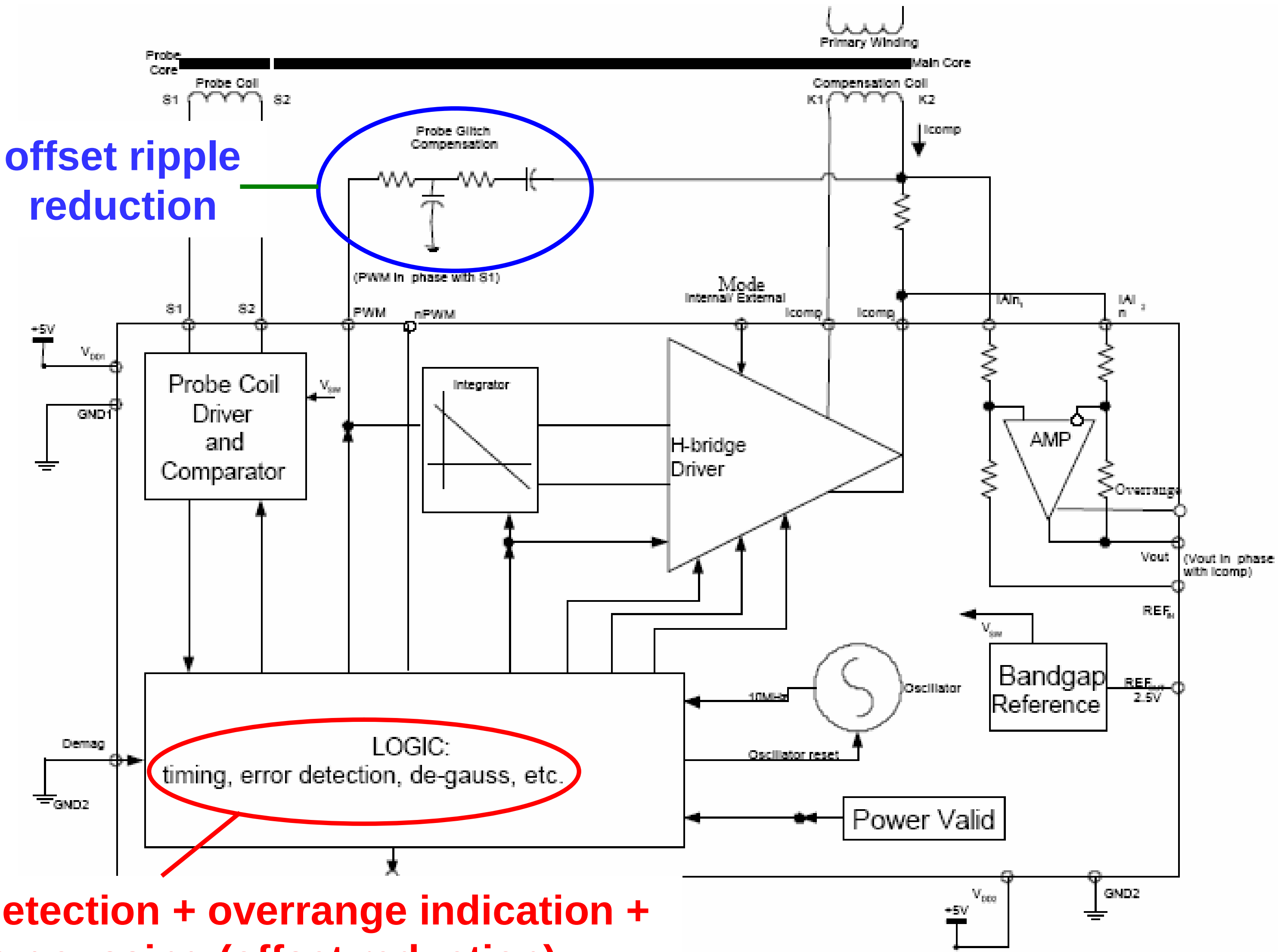


DRV401: Functional blocks
Basic functionality



http://focus.ti.com/docs/prod/folders/print/drv401.html

DRV401: Functional blocks
Added functionality

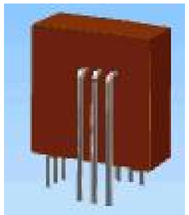


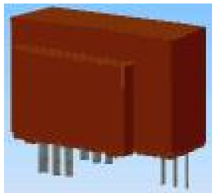
offset ripple reduction

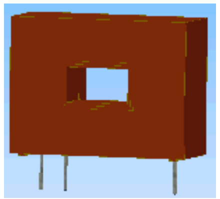
error detection + overrange indication + de-gaussing (offset reduction)

Magnetic modules: Magnetic Probe CS with 5V single supply + voltage output

5V single supply voltage current sensors up to I_{PN} = 150A:







50A 100A 150A

4646-X651…4 (int. Ref.)
4646-X661…4 (ext. Ref.)
4646-X671…-X684 (PTP)

4646-X460…461

4646-X160…161

Also available as passive CS with external DRV401.

Magnetic modules: Magnetic Probe CS with ±15V dual supply + current output

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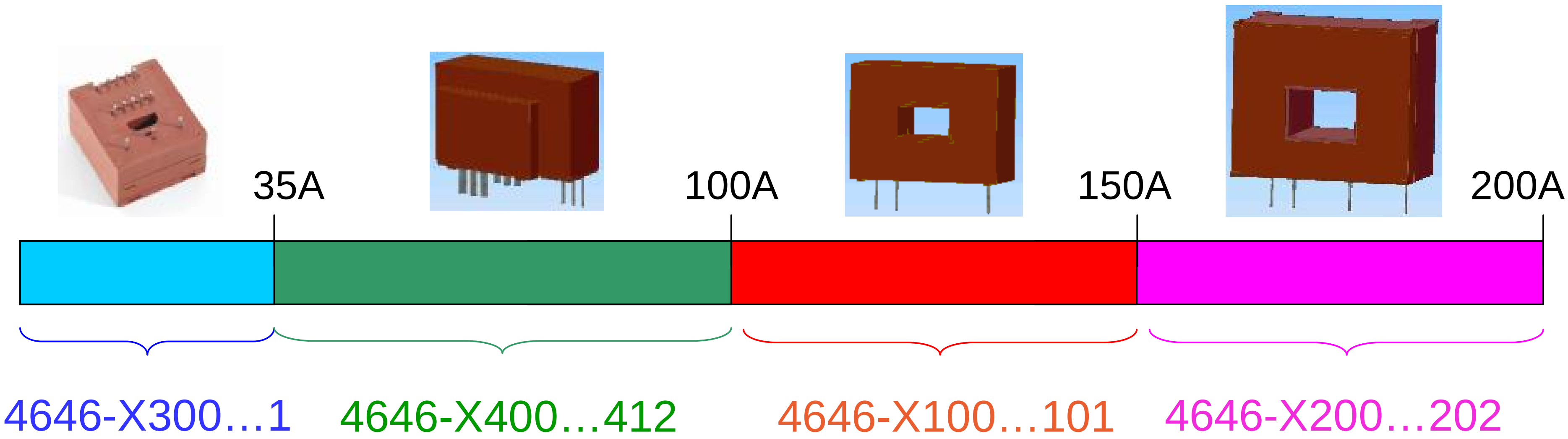
±15V dual supply voltage current sensors (until now) up to I_{PN} = 200A:



±15V dual supply voltage current sensors have external half-bridge, driven by H-bridge driver of DRV401.

Current range will be extended up to I_{PN} = 700A with external PWM-half-bridge.

Also available as passive CS with external DRV401.

Comparison between CL Magnetic Probe, CL Hall element and OL Hall element CS

Typical 100A CS	CL magnetic probe	CL Hallelement	OL Hall element
Offset current I_0 (ref. to prim. current)/ Hysteresis offset current I_{0H} ($I_P > 3*I_{PN}$)	< 100 mA	< 150 mA	< 500…1000 mA
Temperature drift offset current I_{0T} (25…85°C)	< 50mA	< 250…500 mA	< 500…800 mA
Gain error F_i	< 0.1…0.5 %		< 1 %
Temperature drift gain F_{iT} (25…85°C)	< 0.1…0.2%		< 2%
Linearity F_{Li}	< 0.1...0.2 %		< 0.7 %
3dB-corner frequency	200 kHz		50kHz
Response time (short circuit)	< 0.5…1µsec		< 3 µsec

Offset current/hysteresis offset current at CL Magnetic Probe CS related to compensation core, can be reduced by factor of 10 possible by de-gaussing (in-built feature of DRV401).

Comparison of OL and CL current sensors

Advantages of CL CS derive from compensating influences from amplifier electronics, compensation core (modulation),... :

• lower offset, gain error and linearity errors

• lower temperature + long-term drift of gain and linearity errors

• wider frequency range + shorter response time

Advantage of OL CS :

• no compensation current Þ lower power consumption

Summary:

• **CL CS with Magnetic/Hall element Probe technically superior to OL CS**

• **CL CS with Magnetic Probe at same cost level as advanced OL CS**

Comparison of CL current sensors: Magnetic Probe to Hall element CS

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Compensation core + compensation winding-related properties similar:

- gain error + linearity error
- hysteresis offset current
- 3-dB corner frequency + response time

Advantages of CS with Magnetic Probe derive from probe:

- basically zero offset
- lower temperature drift of offset
- lower long-term drift of offset
- no low frequency output noise as from Hall element probe

Summary:

- **CL Magnetic Probe CS technically superior to CL Hall element CS**
- **CL CS with Magnetic Probe at lower cost than CS with Hall element**