



GMI noise performance optimisation

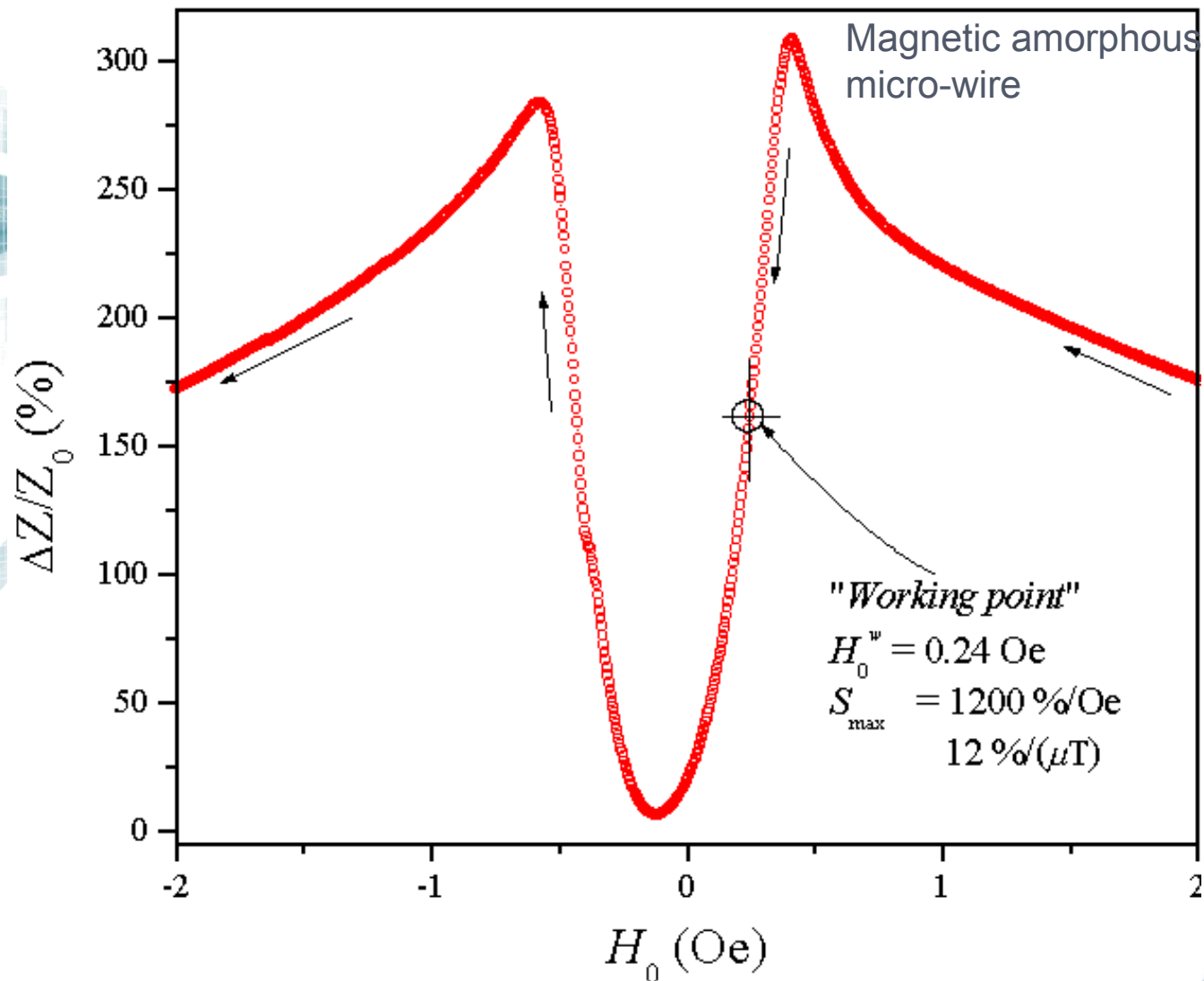
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A. Yelon², and D. Ménard².

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- Introduction
- Electrical model of the sensing element :
 - Description
 - Characterization
- Electronic conditionning
 - Description
 - Noise sources
- Sensitivity evaluation
- Equivalent magnetic noise level
- Conclusion

Giant MagnetImpedance (GMI)

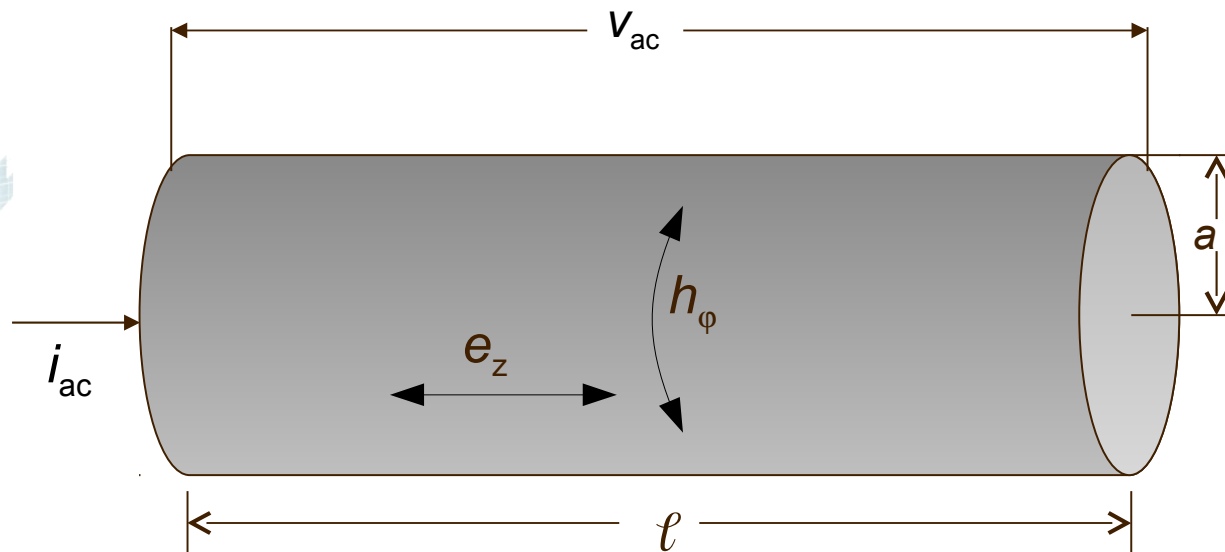


- Large effect
- Low field
- Room temperature
- ...

Introduction

Impedance of cylindrical conductive wire

$$Z = R + jX = \frac{v_{ac}}{i_{ac}} \quad \left[\begin{array}{l} v_{ac} = e_z I \\ i_{ac} = 2\pi a h_\phi \end{array} \right. \quad Z = \frac{I}{2\pi a} \left(\frac{e_z}{h_\phi} \right)_{\text{surface}} \text{ surface impedance}$$



Introduction

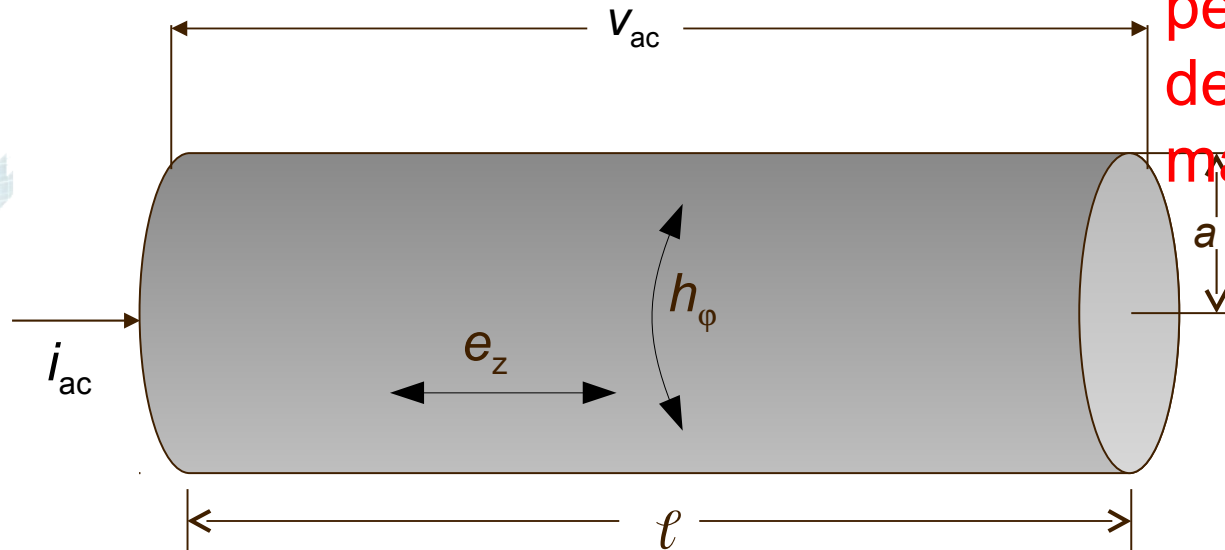
Impedance of cylindrical conductive wire

$$Z = R + jX = \frac{v_{ac}}{i_{ac}} \quad \left[\begin{array}{l} v_{ac} = e_z I \\ i_{ac} = 2\pi a h_\phi \end{array} \right. \quad Z = \frac{I}{2\pi a} \left(\frac{e_z}{h_\phi} \right)_{\text{surface}} \text{ surface impedance}$$

$$\frac{Z}{R_{dc}} = \frac{ka J_0(ka)}{2 J_1(ka)}$$

$$k = \frac{1-i}{\delta} \quad \delta = \sqrt{\frac{2}{\sigma\omega\mu}}$$

In magnetic materials, permeability depends on applied magnetic field!

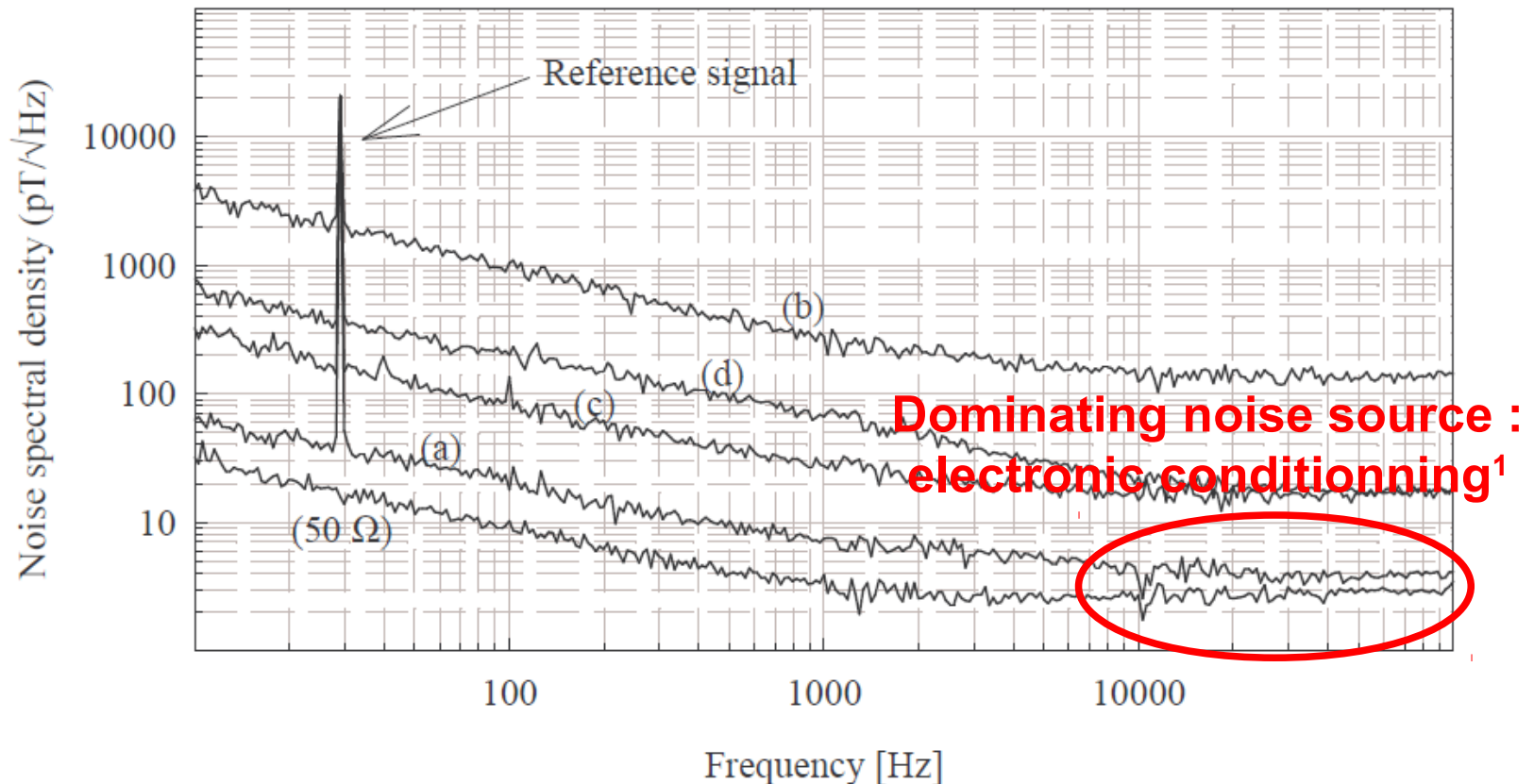


Magnetic noise considerations:

- Thermal fluctuation of the magnetization yields fluctuations of impedance (impedance noise or magnetic noise)
- Johnson noise

For $T = 300\text{K}$ and using typical values for amorphous wire properties :

$$b_n \approx 8.5 / \sqrt{l(\text{cm})} \quad \text{fT} / \sqrt{\text{Hz}}$$

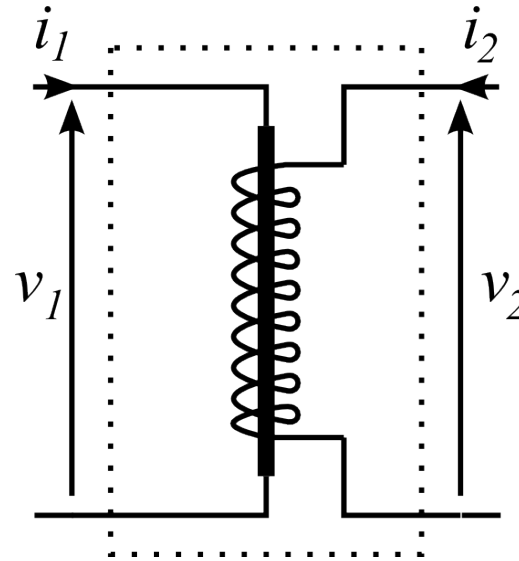
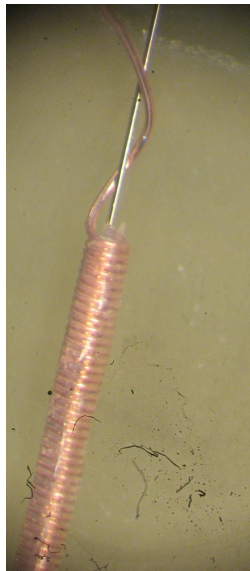


- Reduce the electronic noise.
- Increase the *intrinsic sensitivity* of the sensing element.

Introduction

- Increase the *intrinsic sensitivity* of the sensing element.

Using of thin pick-up coil



Also labelled :

Off-diagonal GMI ; orthogonal flux-gate in the fundamental mode

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Electrical model of the sensing element

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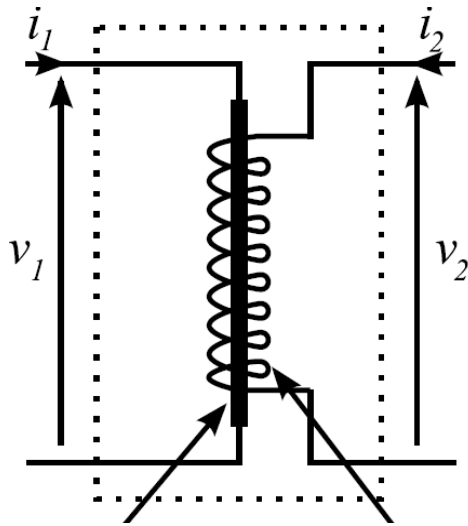
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GMI wire

Amorphous CoFeSiB
100 μ m diameter
2.5cm long

Pick-up coil

Bi-layer
500 turns per layer

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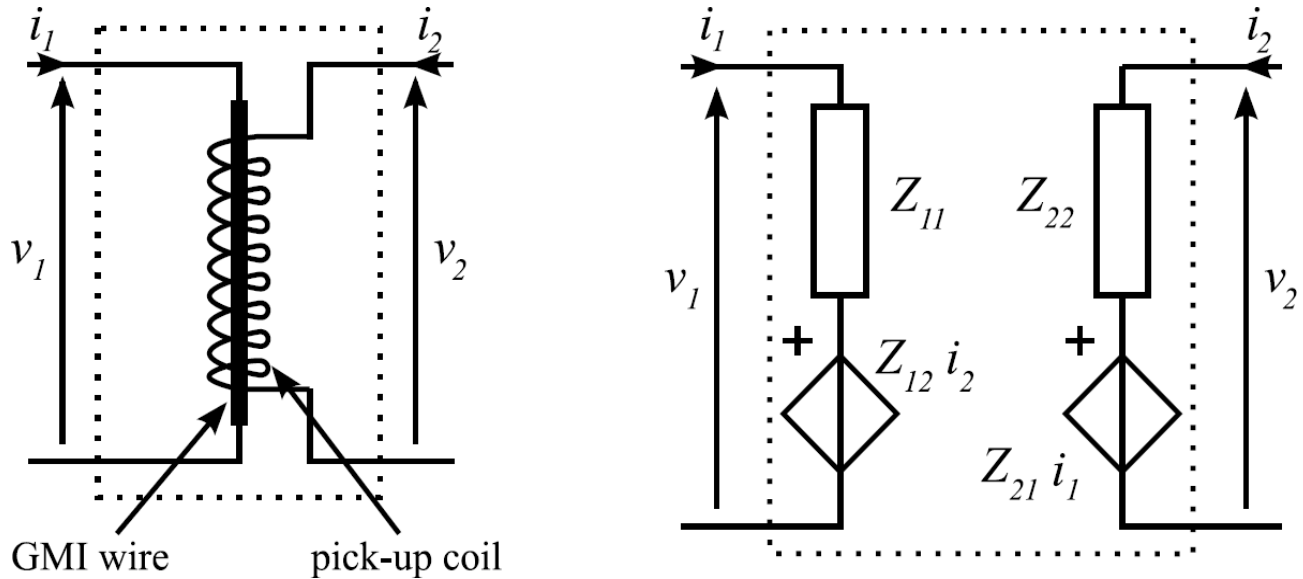
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Fully described by its equivalent two-port network model

$$\begin{pmatrix} v_1 \\ v_2 \end{pmatrix} = [Z(B)] \begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{bmatrix} Z_{11}(B) & Z_{12}(B) \\ Z_{21}(B) & Z_{22}(B) \end{bmatrix} \begin{pmatrix} i_1 \\ i_2 \end{pmatrix}$$

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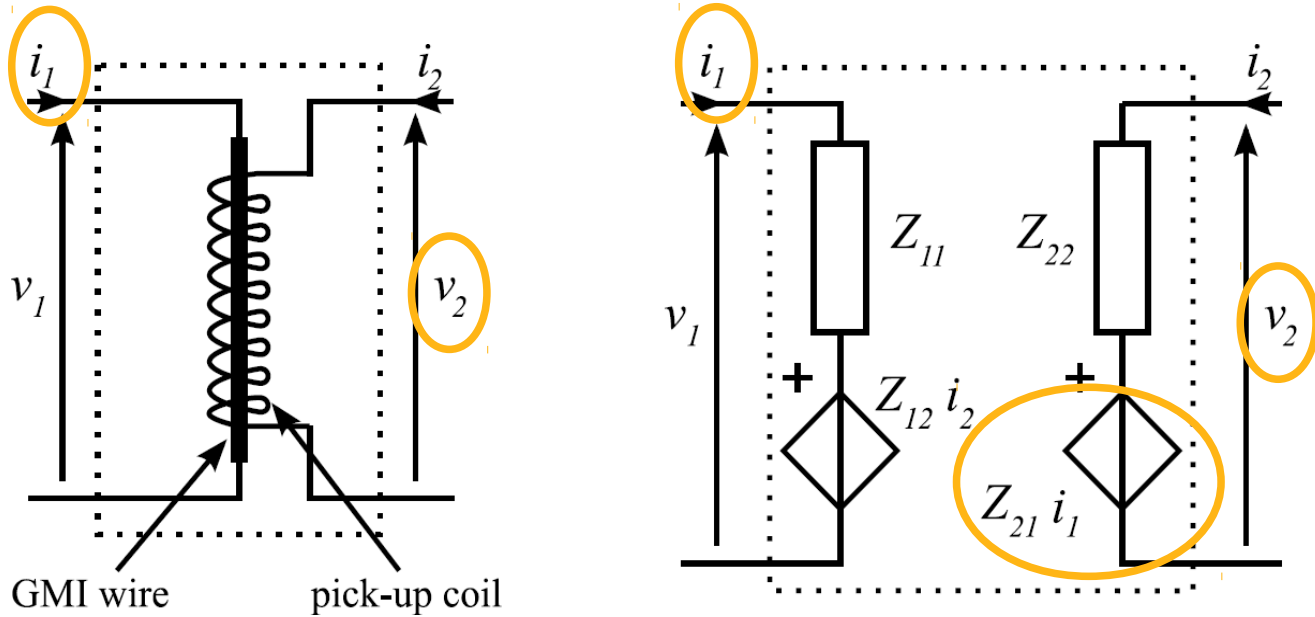
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Impedance matrix of the two ports network :

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- Physical model
- Measurement

- Electrical model of the sensing element :

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Impedance matrix of the two ports network :

- **Physical model**

Surface impedance tensor¹

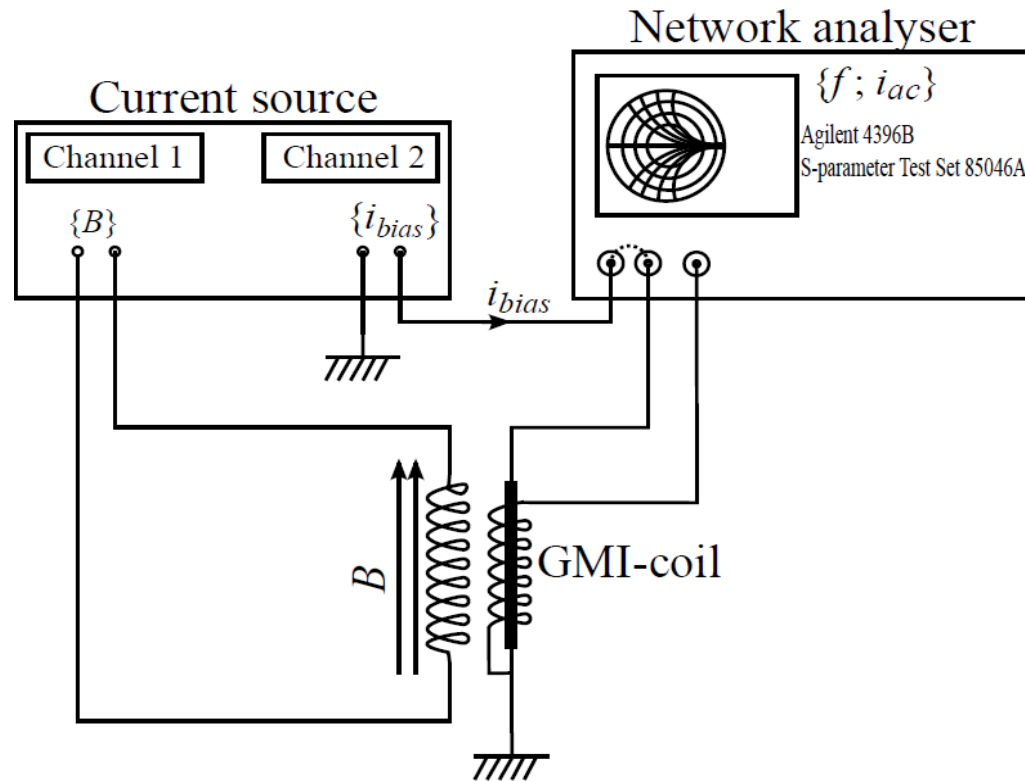
$$\begin{pmatrix} e_{\varphi} \\ e_z \end{pmatrix} = \begin{pmatrix} Z_{\varphi z} & Z_{\varphi\varphi} \\ Z_{zz} & Z_{z\varphi} \end{pmatrix} \begin{pmatrix} h_{\varphi} \\ h_z \end{pmatrix}$$

¹D. P. Makhnovskiy, L. V. Panina, and D. J. Mapps, « Field-dependent surface impedance tensor in amorphous wires with two types of magnetic anisotropy : helical and circumferential », *Physical Review B*, vol. 63, no. 14, 2001

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Impedance matrix of the two ports network :

■ Measurement



- Electrical model of the sensing element :

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- **Characterization**

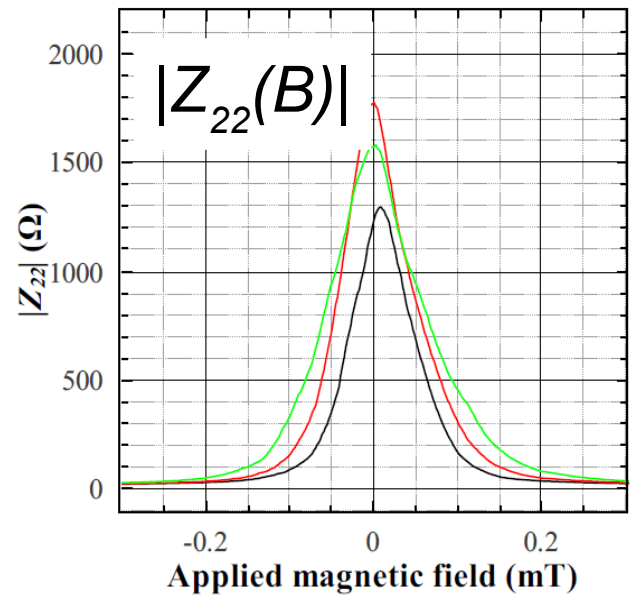
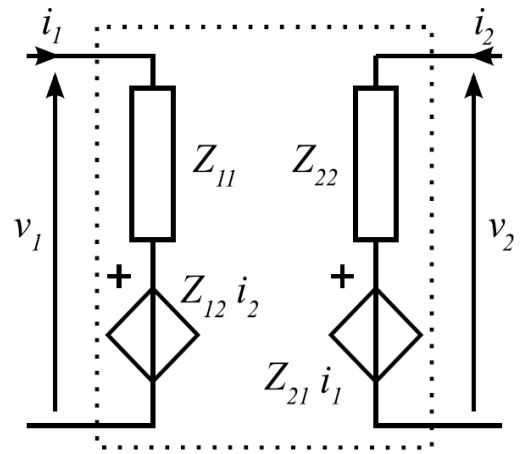
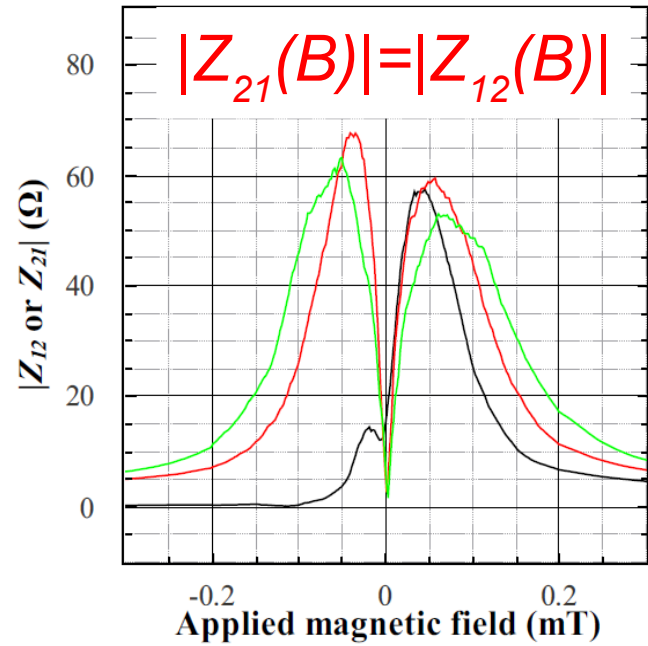
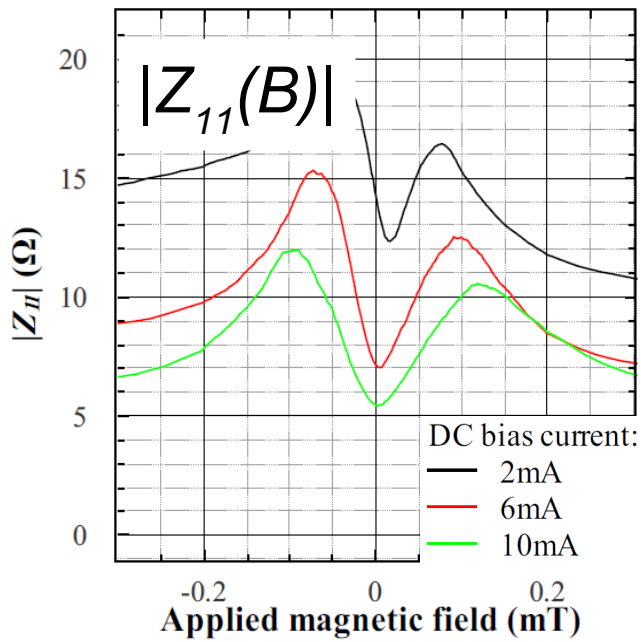
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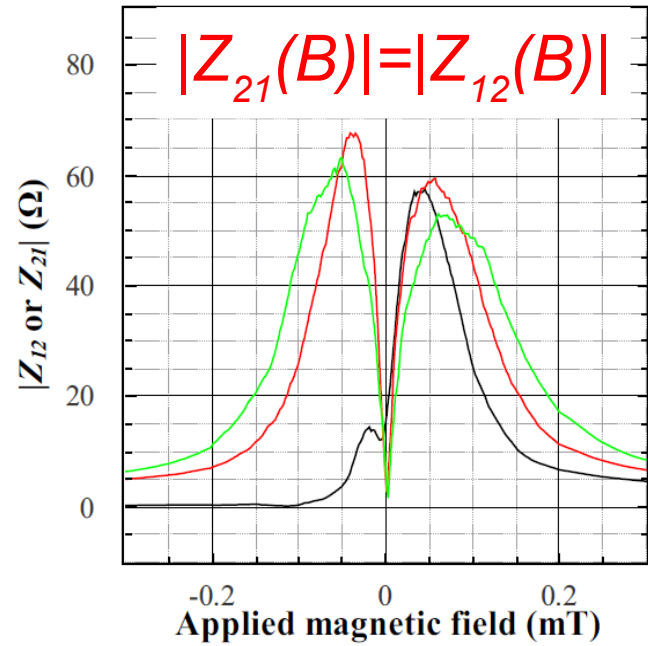
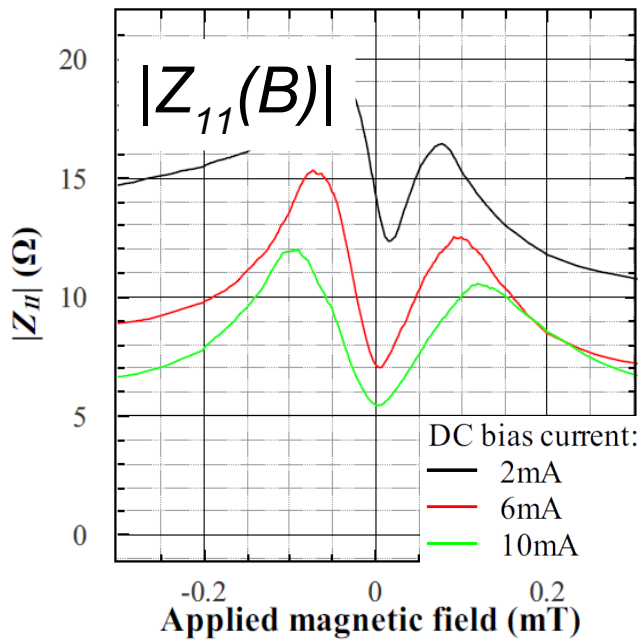
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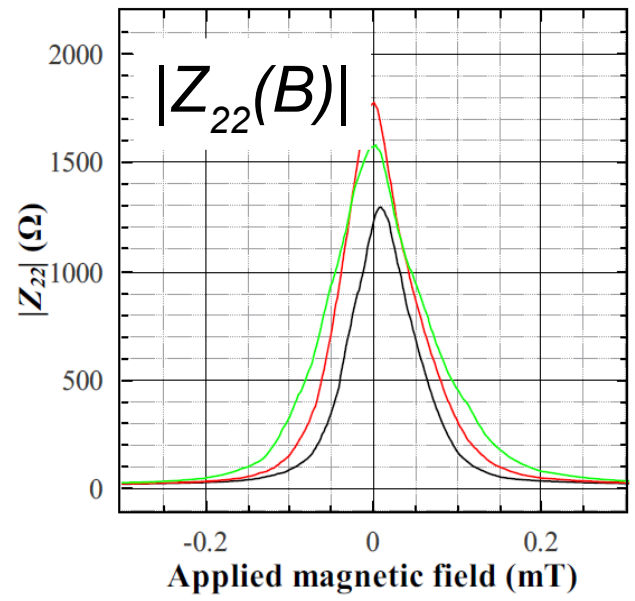
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Static working point:

$$B = B_0 + b(t)$$



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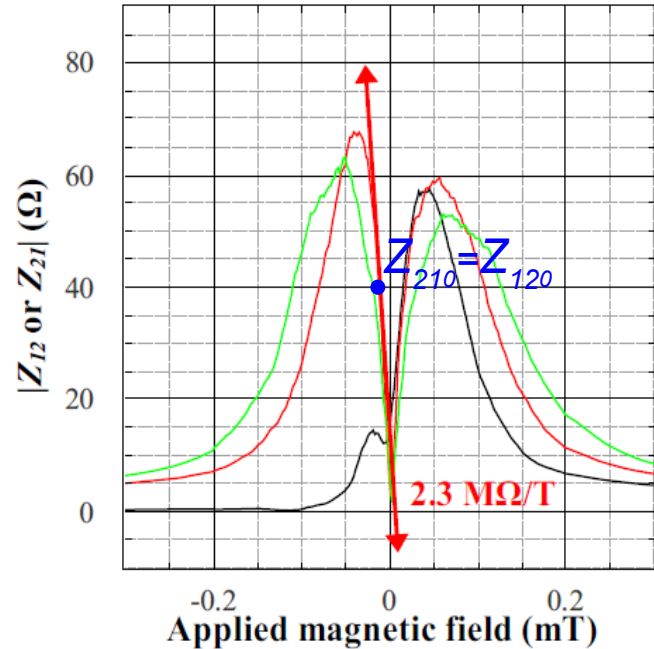
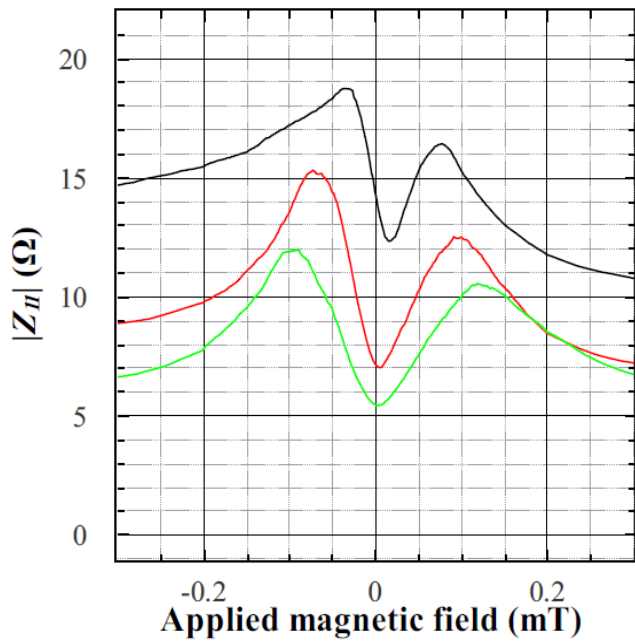
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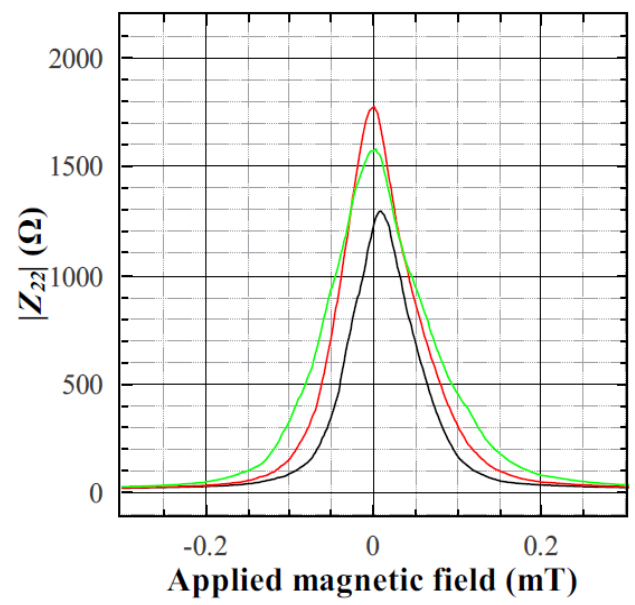
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Field locked loop :

$$B = B_0 + b(t)$$

$$Z_{21}(B) = Z_{210} - \left. \frac{\partial Z_{21}}{\partial B} \right|_{B=B_0} \cdot b(t)$$



Electronic conditioning circuitry

•Electrical model of the sensing element :

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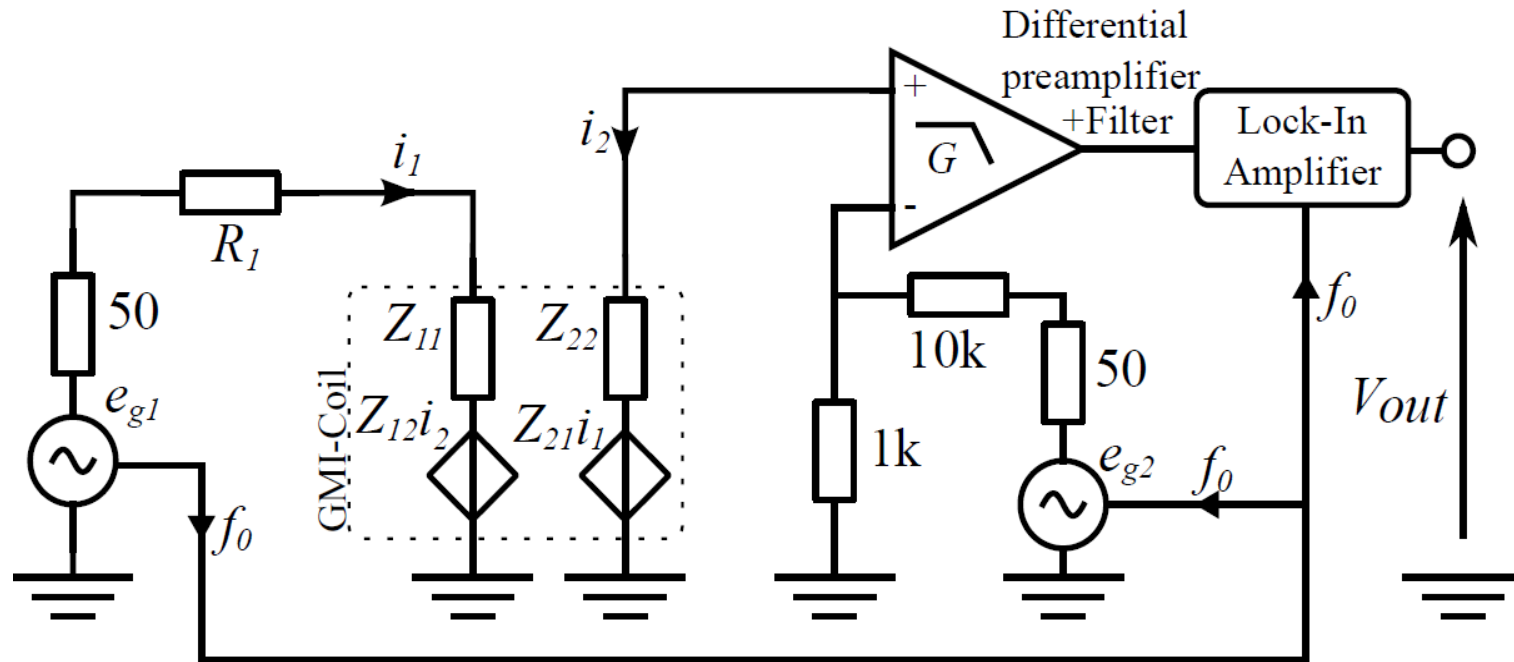
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$$f_0 = 300 \text{ kHz}$$

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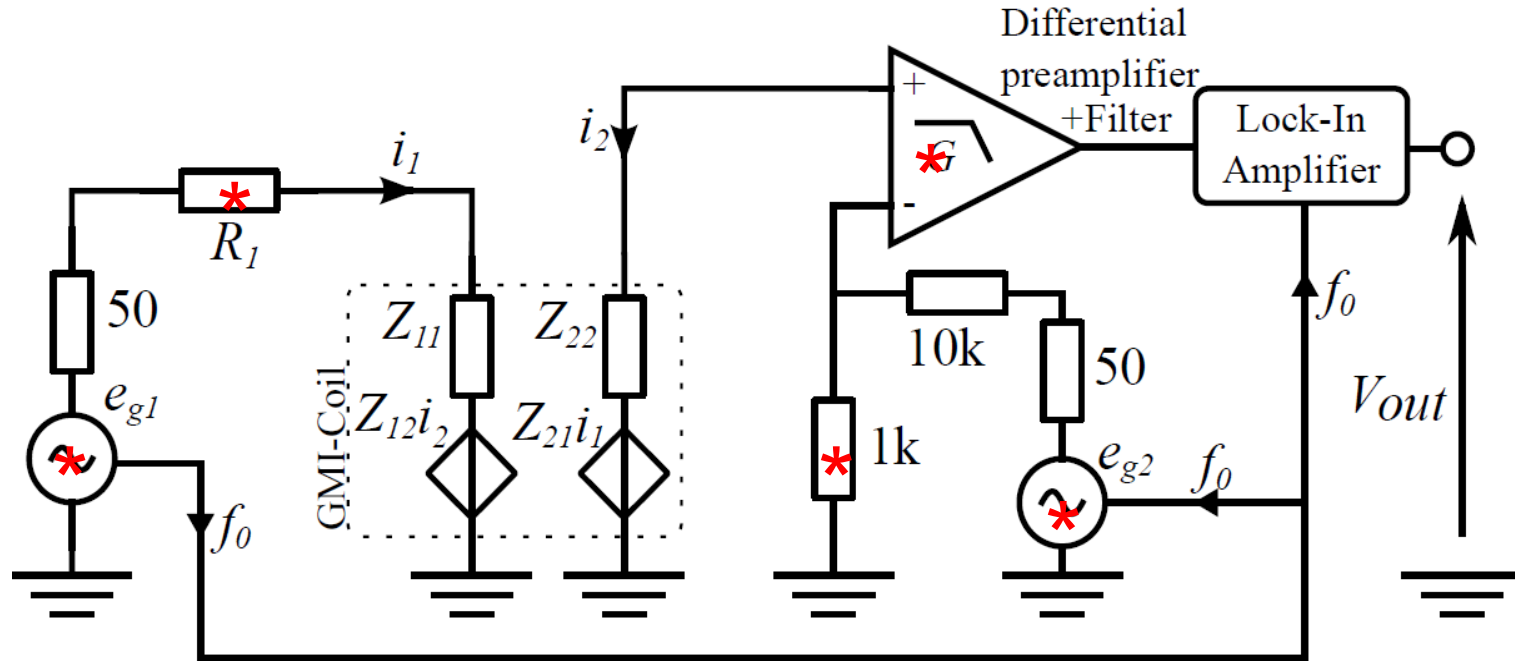
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$$e_{n21}^2 =$$

$$\frac{|Z_{210}(f_0)|^2}{(R_1 + 50 + |Z_{110}(f_0)|)^2} \left[2e_{ng1}^2 + e_{nR1}^2 \right] + e_{nR=1000}^2 + |Z_{22}(f_0)|^2 i_{npreamp}^2 + e_{npreamp}^2$$

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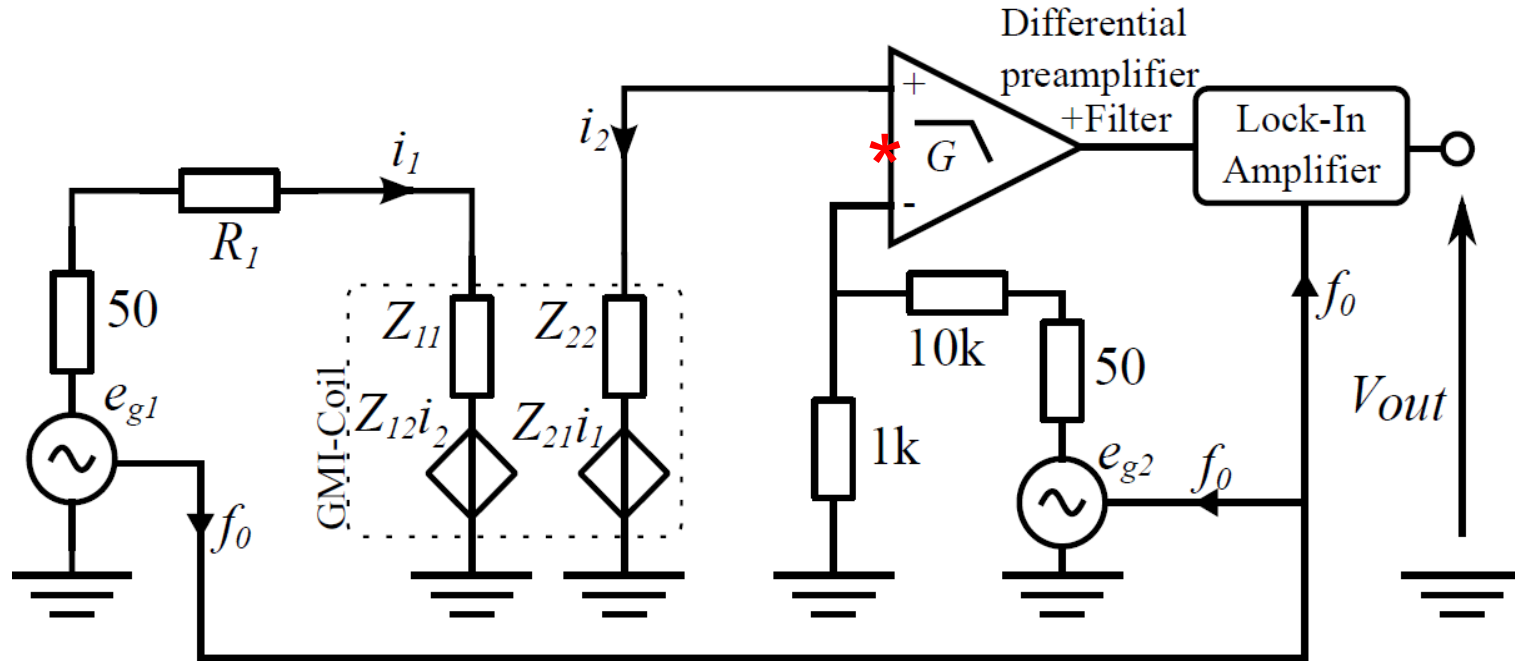
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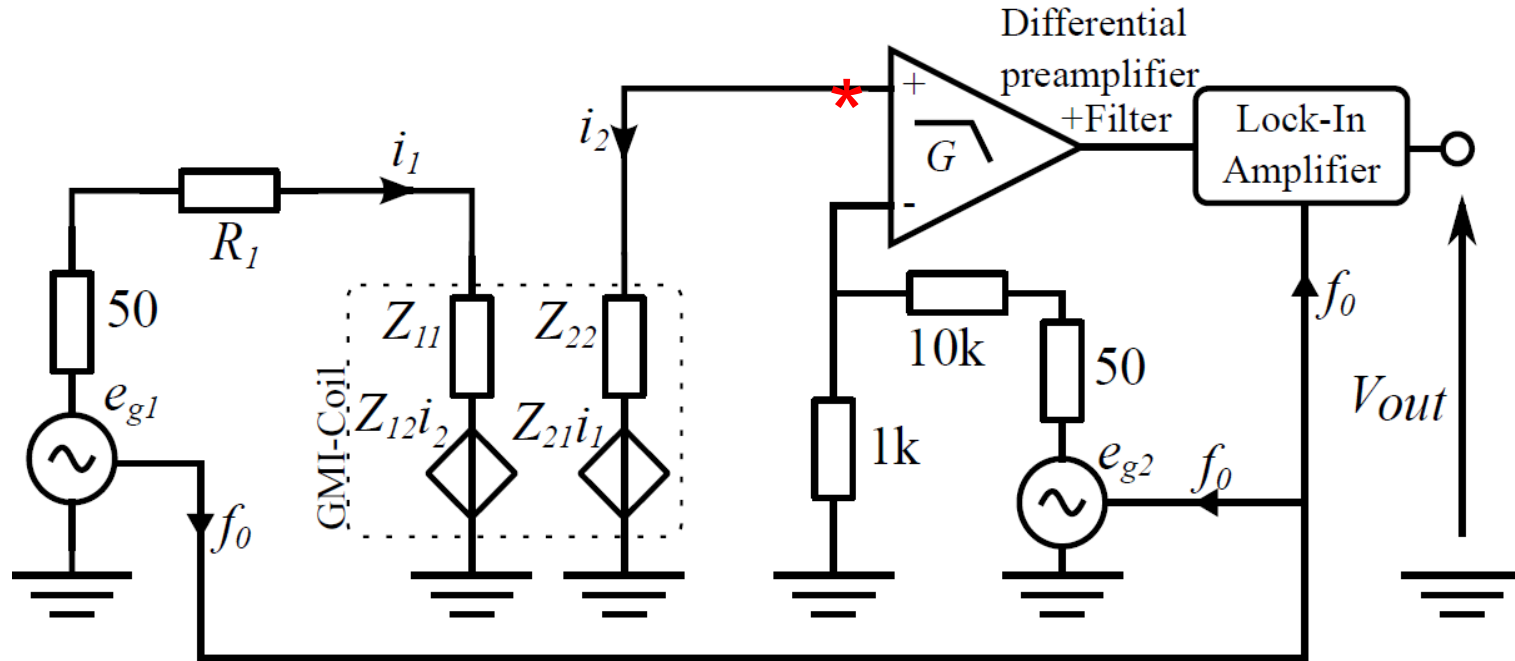
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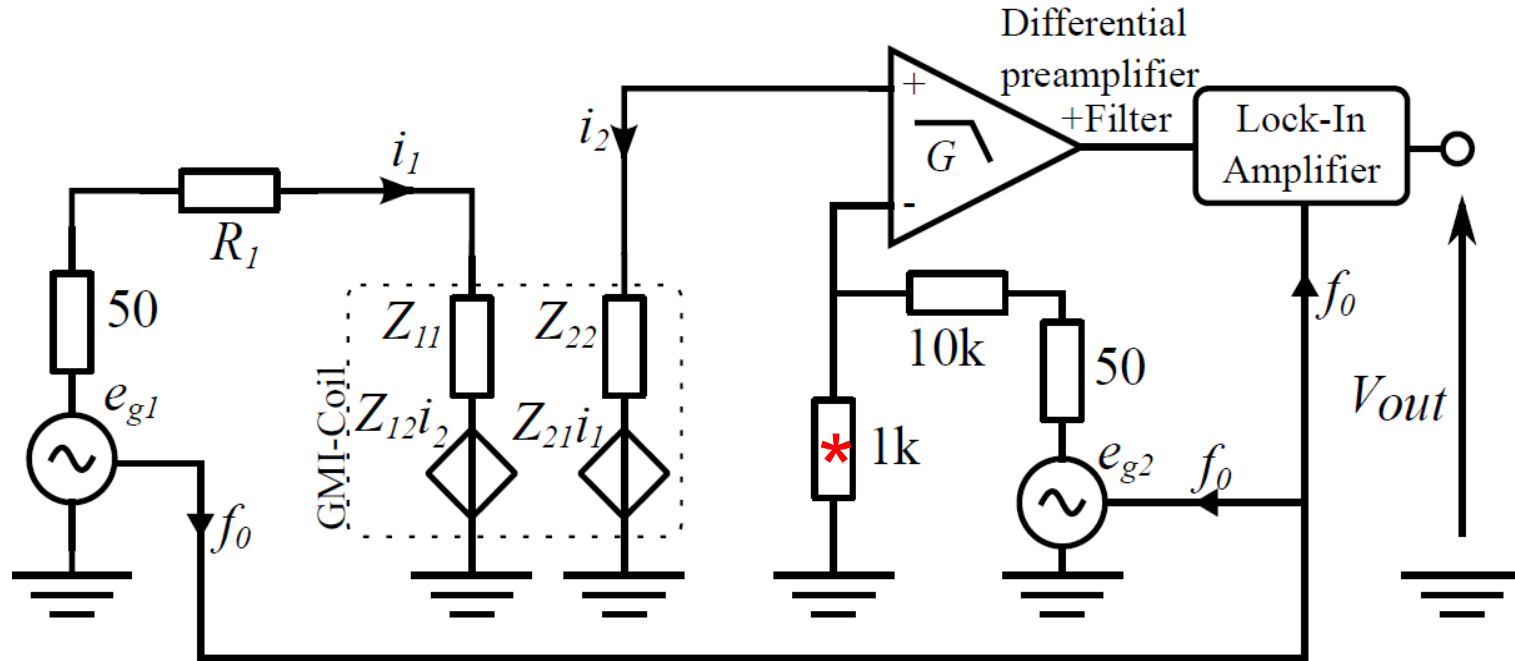
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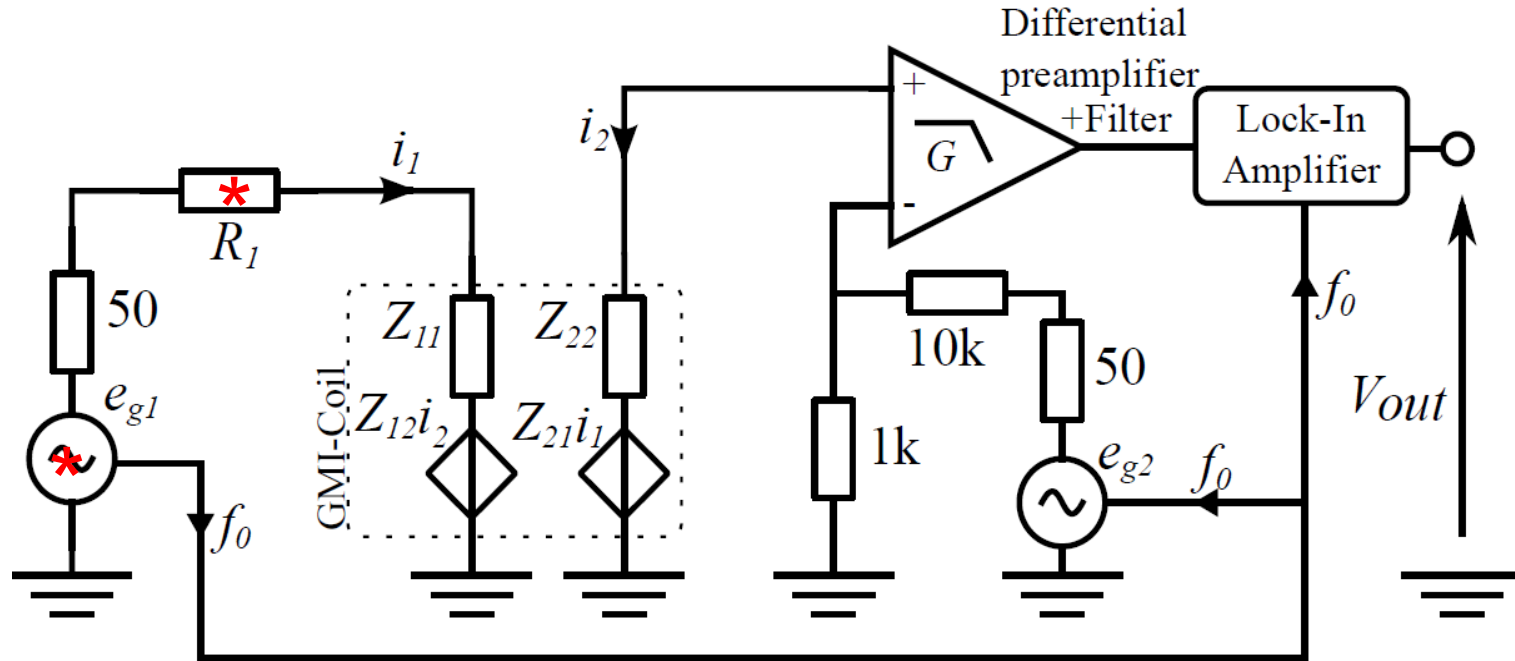
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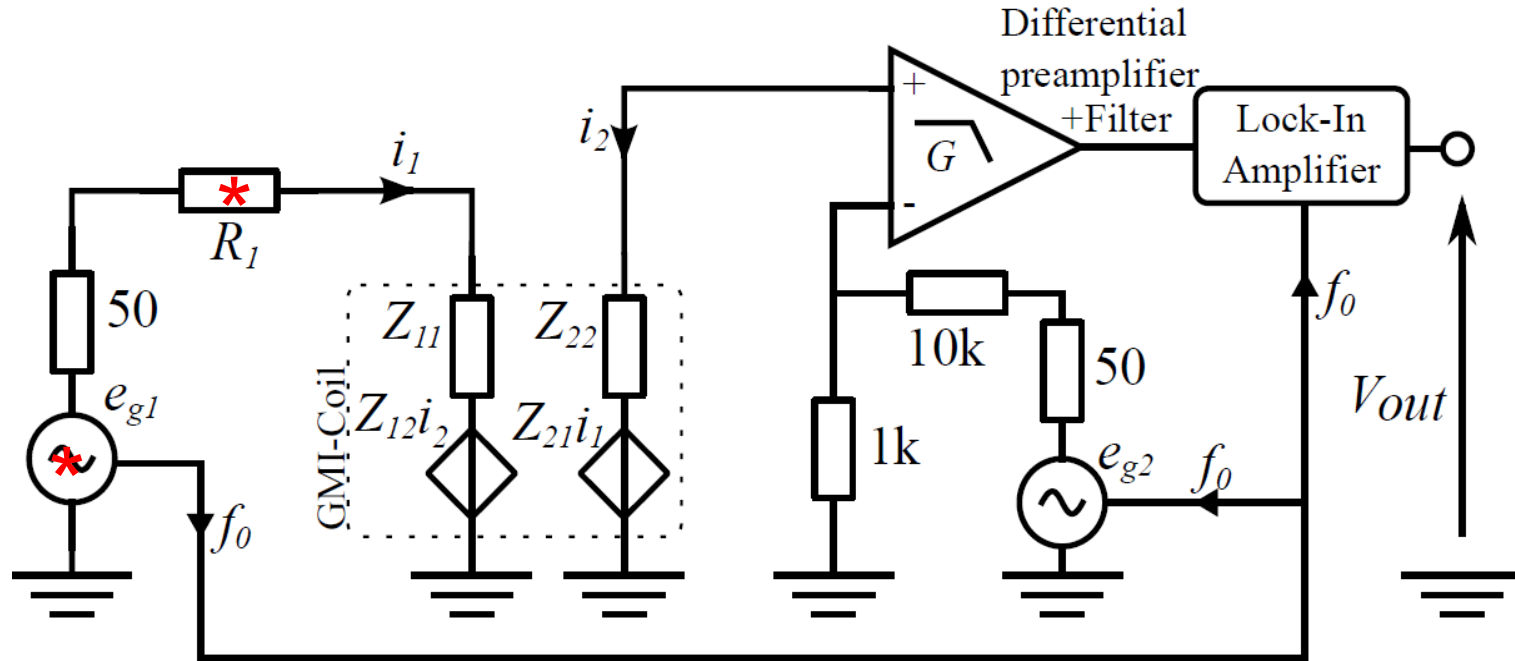
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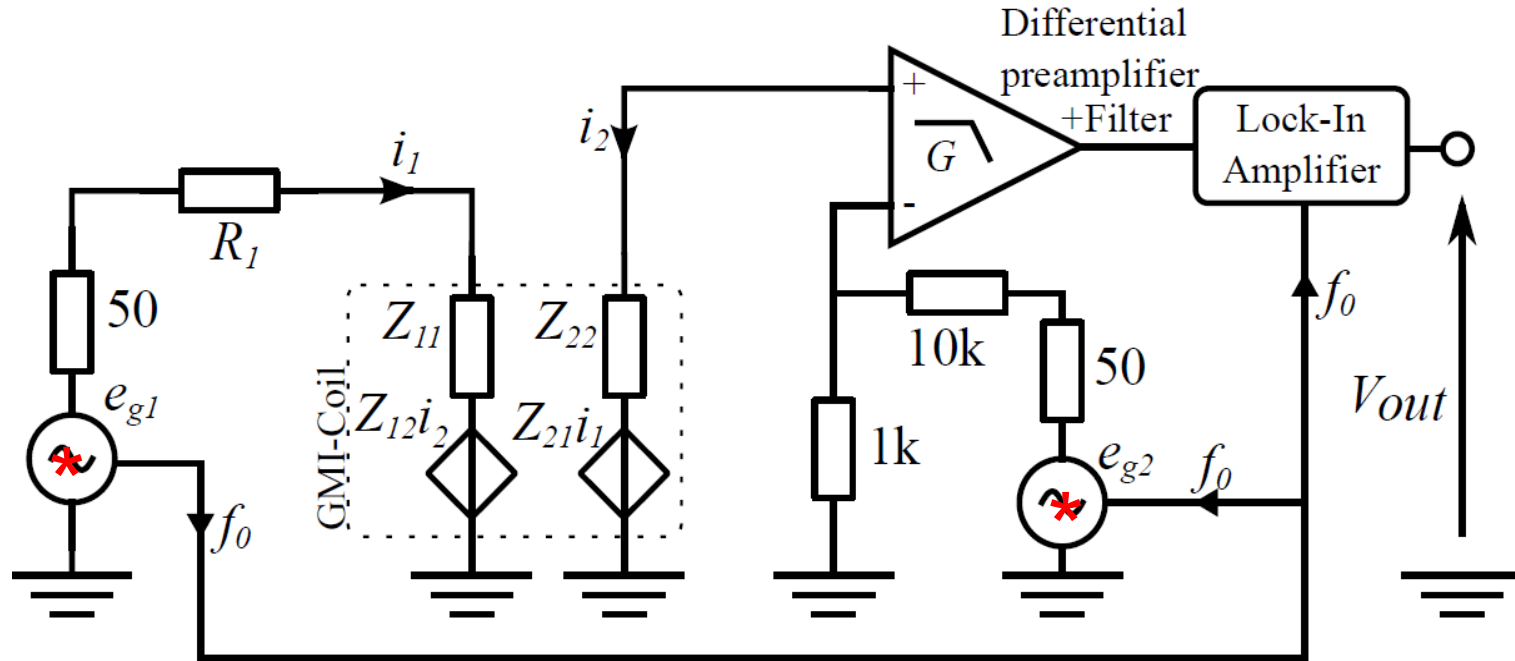
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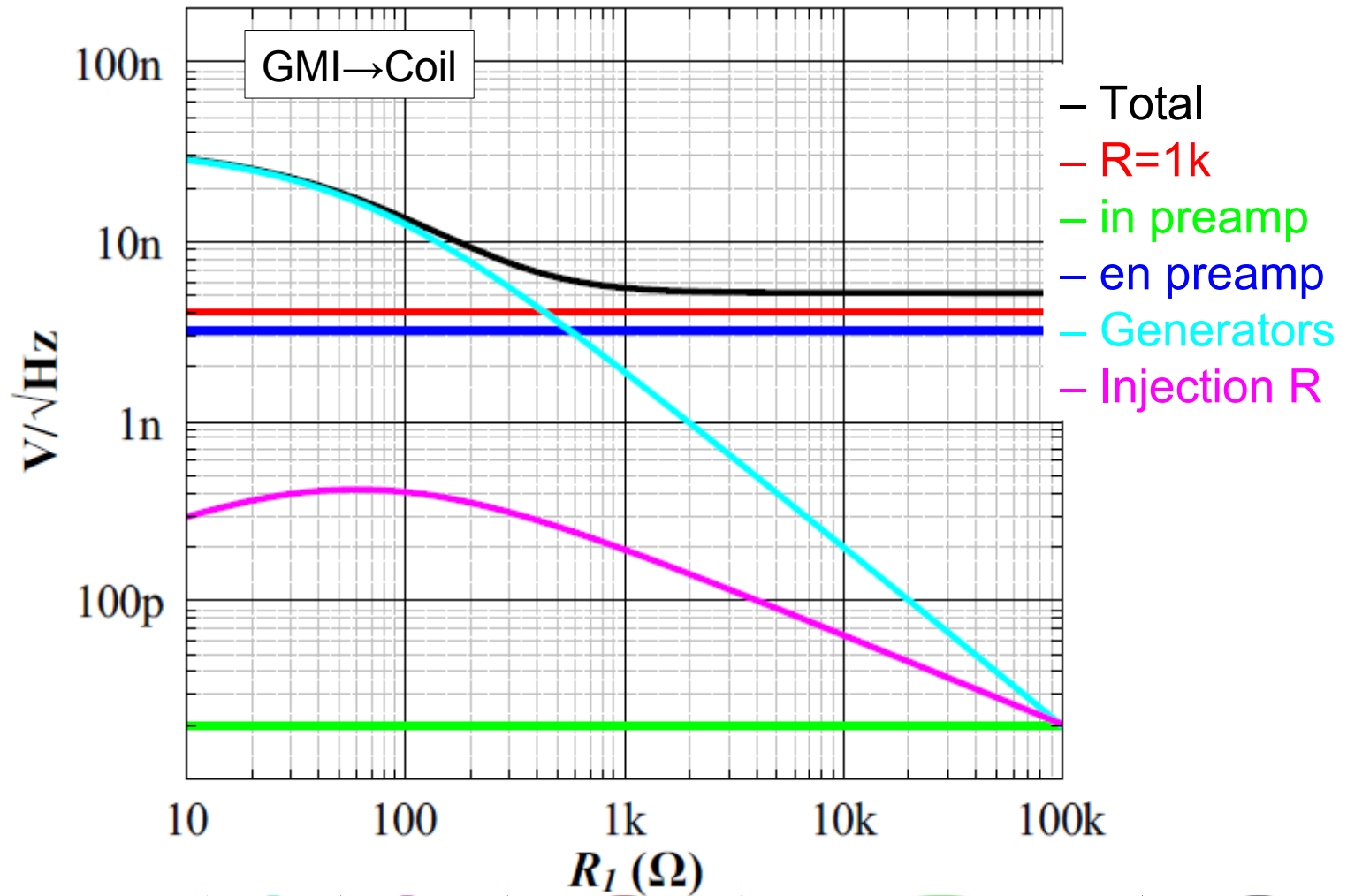
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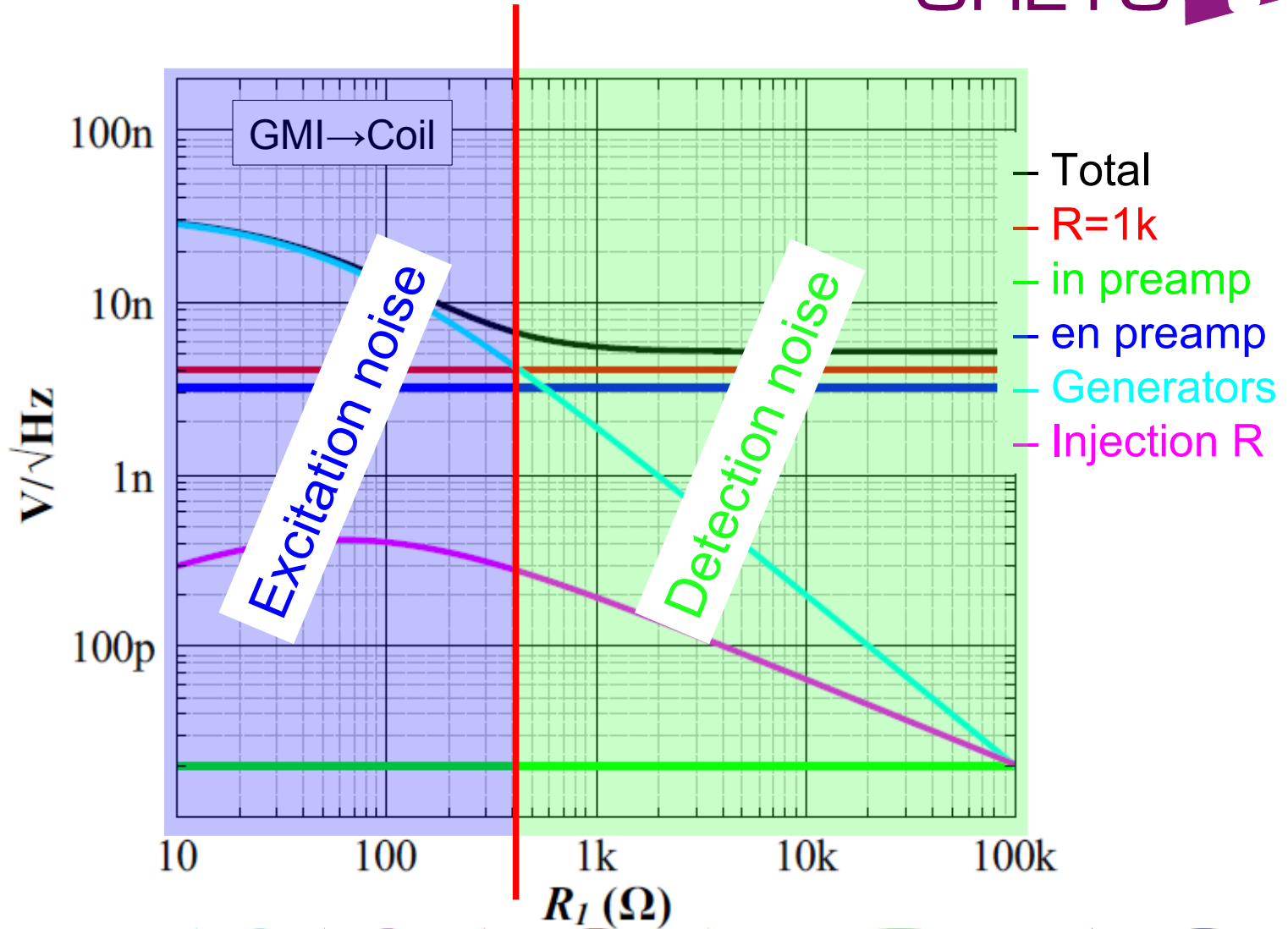
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Evaluation of the sensitivity



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Sensitivity

$$T_{r_{21}} = \frac{\partial V_{out}(t)}{\partial b(t)} \quad [\text{V/T}]$$

$$B = B_0 + b(t)$$

$$Z_{21}(B) = Z_{21_0} + \left. \frac{\partial Z_{21}}{\partial B} \right|_{B=B_0} \cdot b(t)$$

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Sensitivity $T_{r_{21}} = \frac{\partial V_{out}(t)}{\partial b(t)} \quad [\text{V/T}]$

$$B = B_0 + b(t)$$

$$Z_{21}(B) = Z_{21_0} + \left. \frac{\partial Z_{21}}{\partial B} \right|_{B=B_0} \cdot b(t)$$

$$T_{r_{21}}(f_0) \approx \frac{e_{g1}}{|Z_{11_0}(f_0)| + R_1 + 50} \frac{\partial |Z_{21}(f_0)|}{\partial B}$$

Equivalent magnetic noise

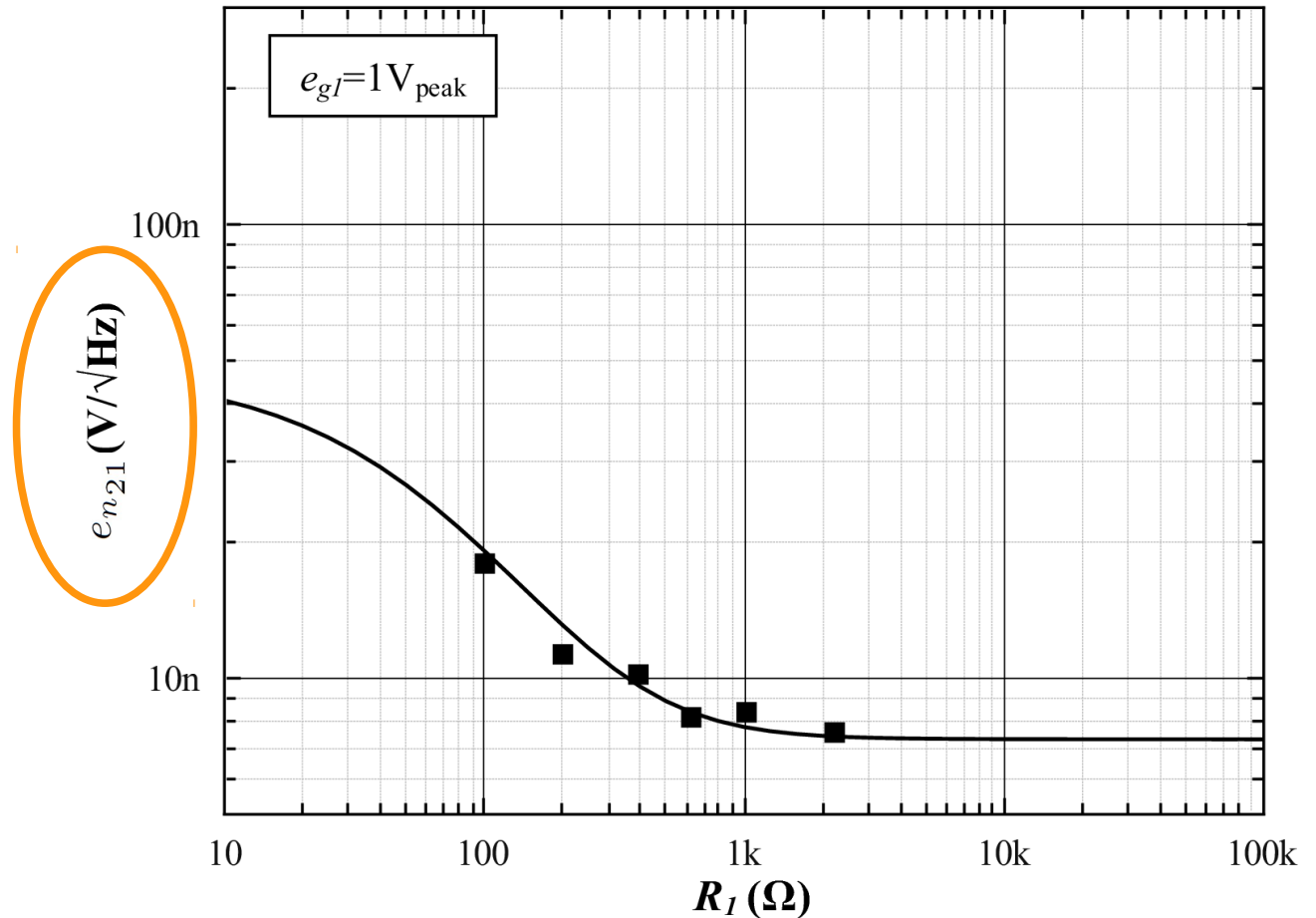


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$$b_{n_{21}} = \frac{e_{n_{21}}}{T_{r_{21}}} \quad \text{T}/\sqrt{\text{Hz}}$$

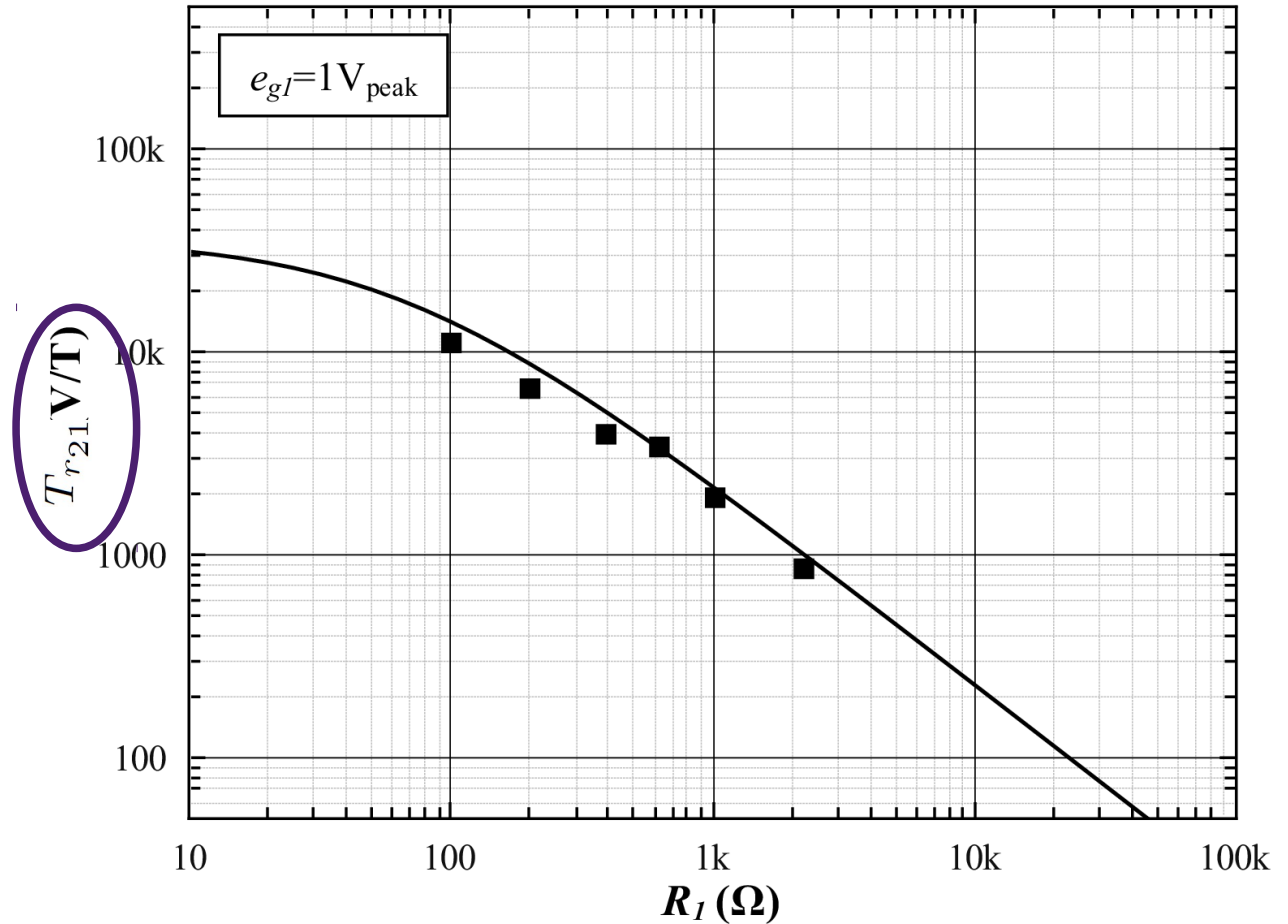
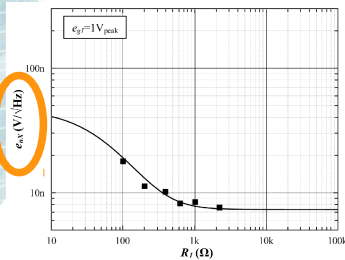
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$$b_{n_{21}} = \frac{e_{n_{21}}}{I_{r_{21}}} \quad \text{T}/\sqrt{\text{Hz}}$$



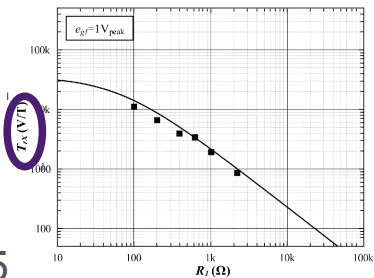
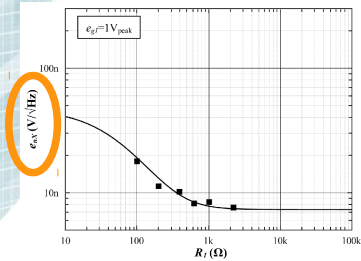
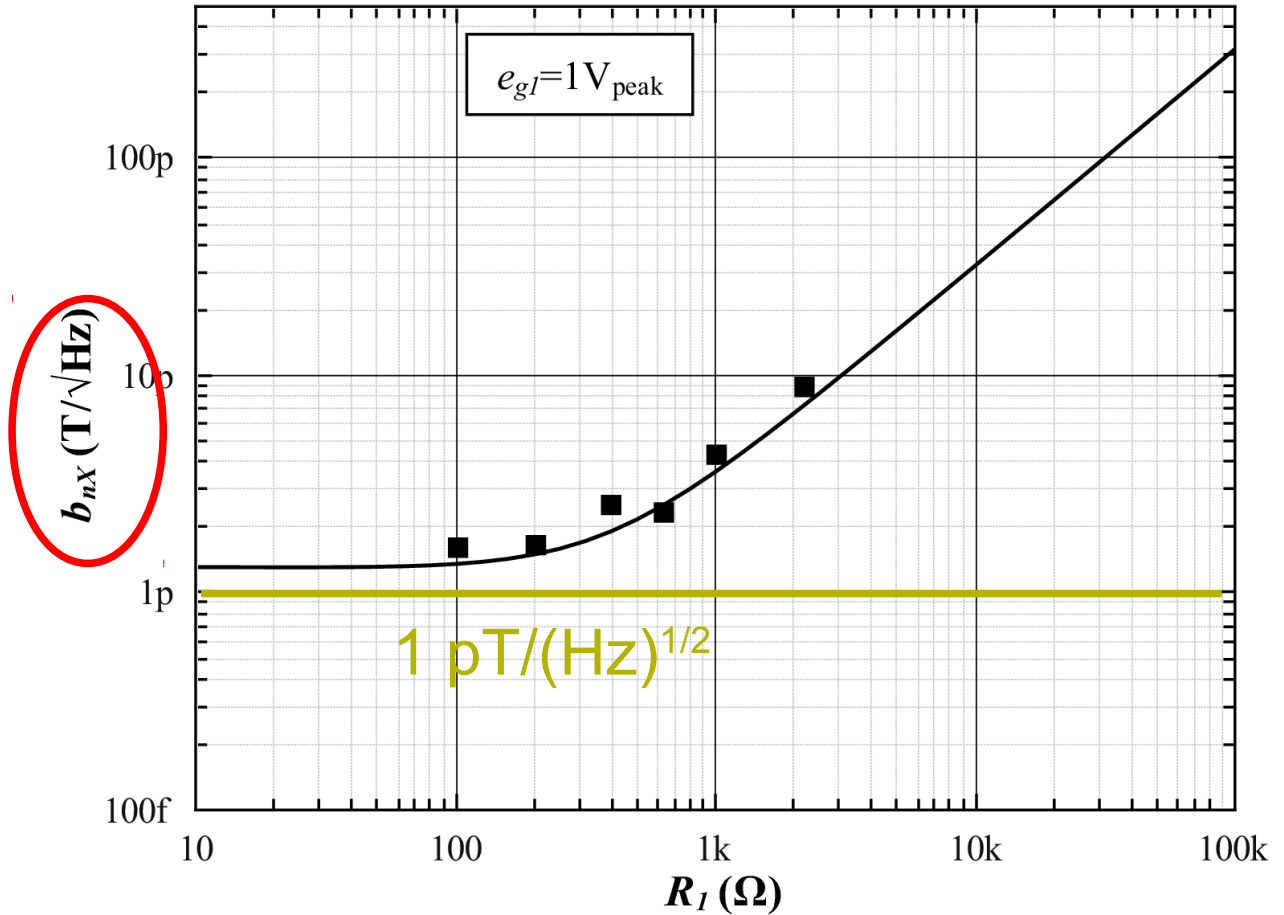
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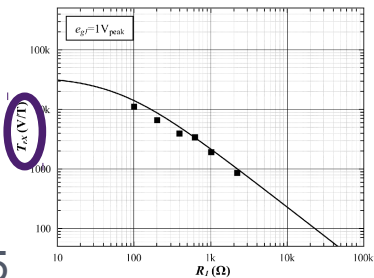
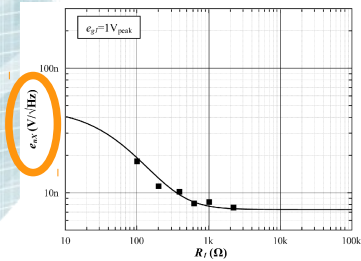
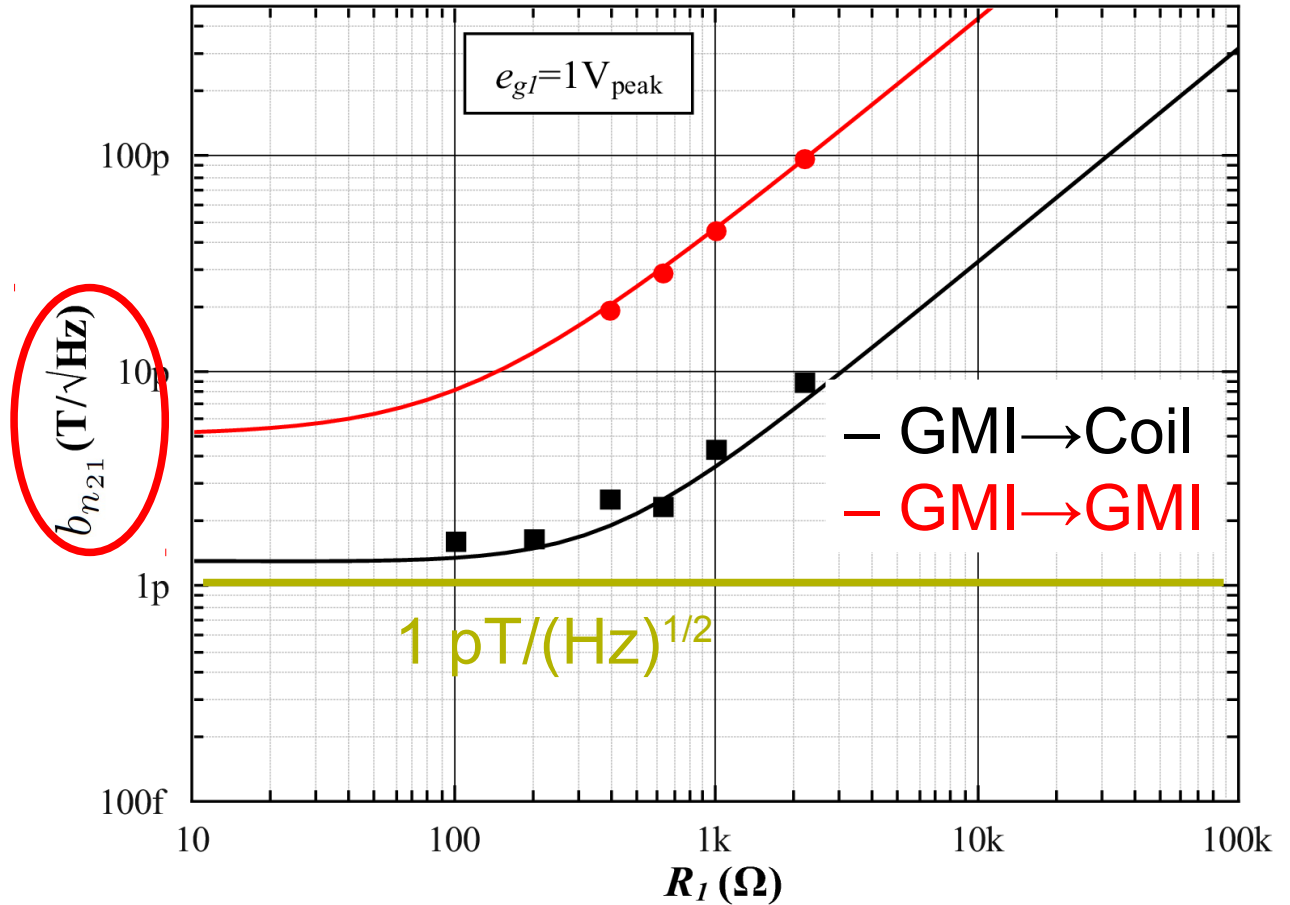
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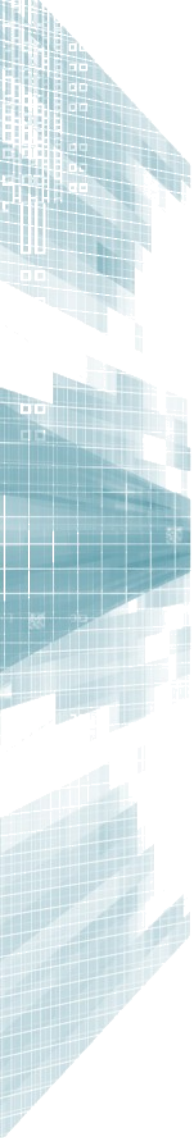
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$$b_{n21} = \frac{e_{n21}}{T r_{21}} \quad T/\sqrt{Hz}$$



- GMI-Coil configuration is a promising approach to increase noise performances of GMI based magnetometers.
- Good agreement between the model and experimental data:
 - Identify dominating noise sources.
 - Extrapolate results to other conditioning circuitry.
 - Noise floor is still due to electronic circuitry.
- $1\text{pT}/\text{Hz}^{1/2}$, leaving room for further improvements.

The amorphous wire was kindly provided by prof. H. Chiriac from National Institute of Research & Development for Technical Physics, Romania.



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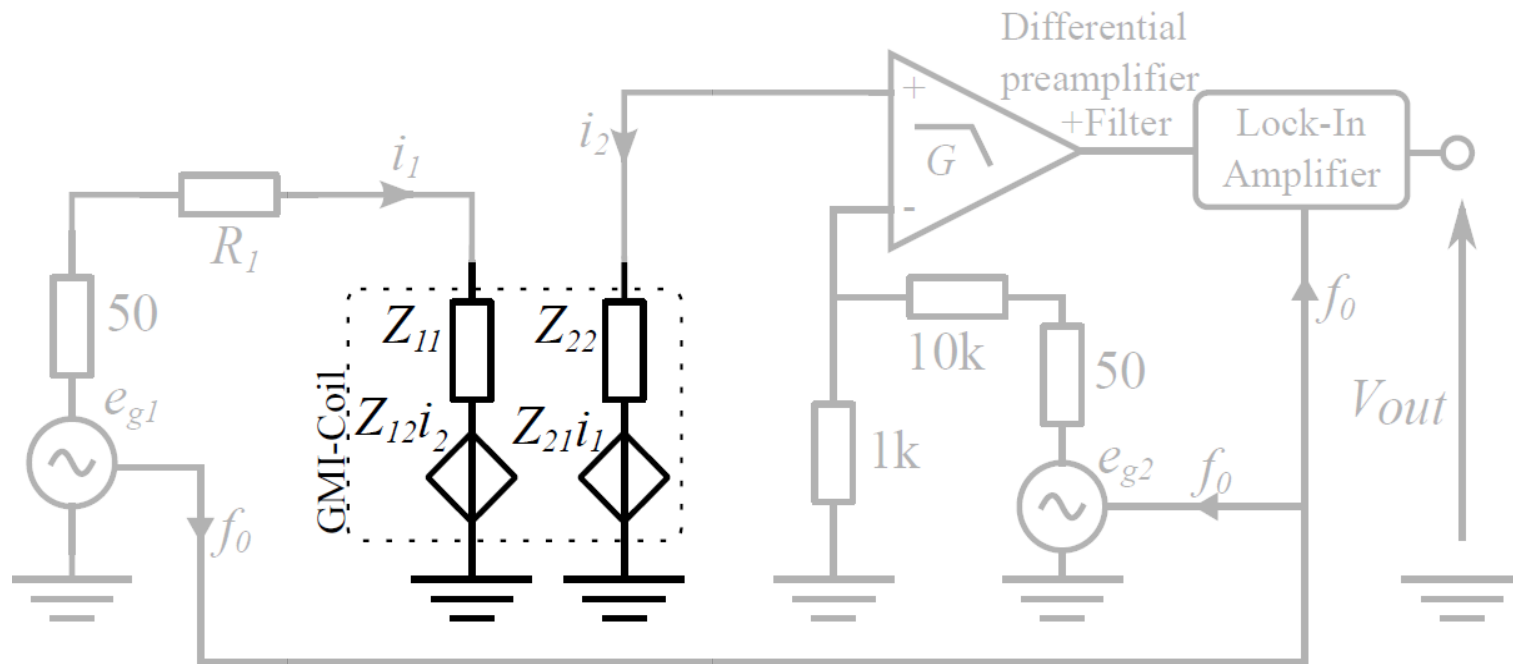
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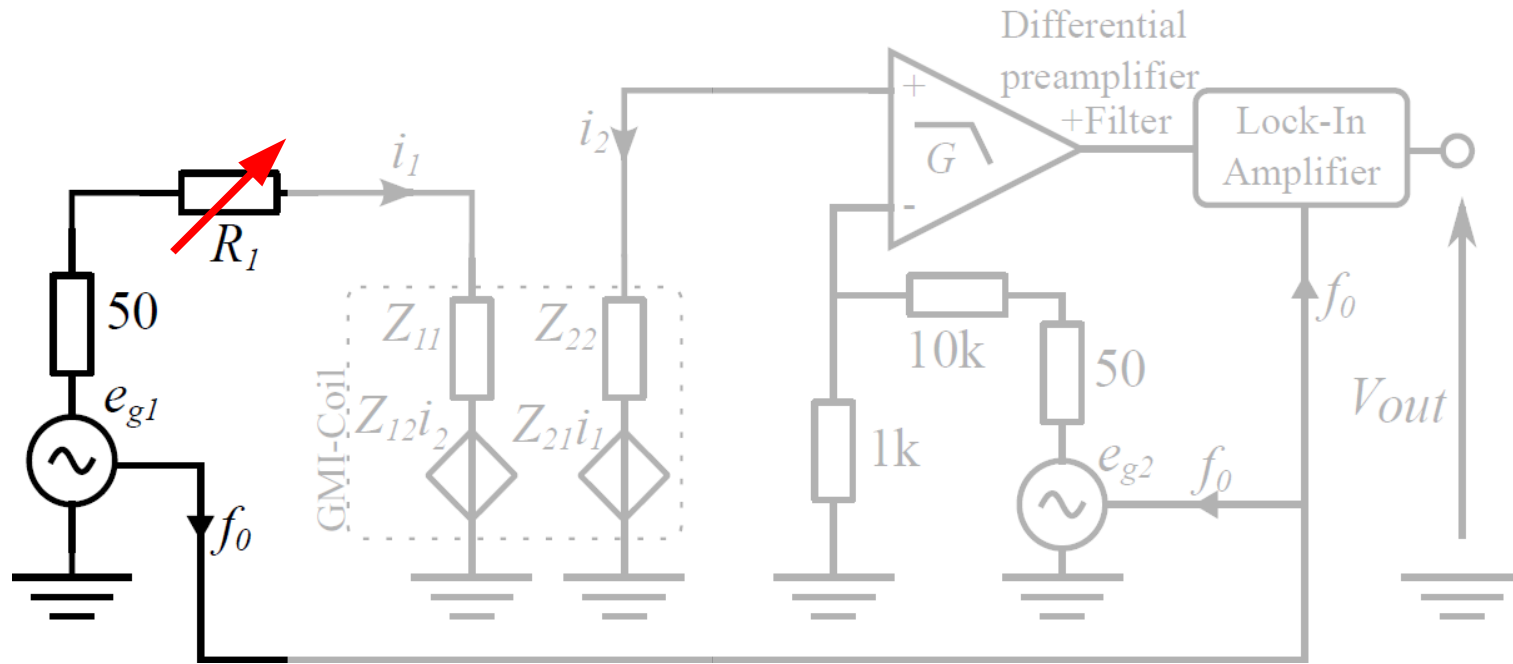
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$f_0 = 300\text{kHz}$

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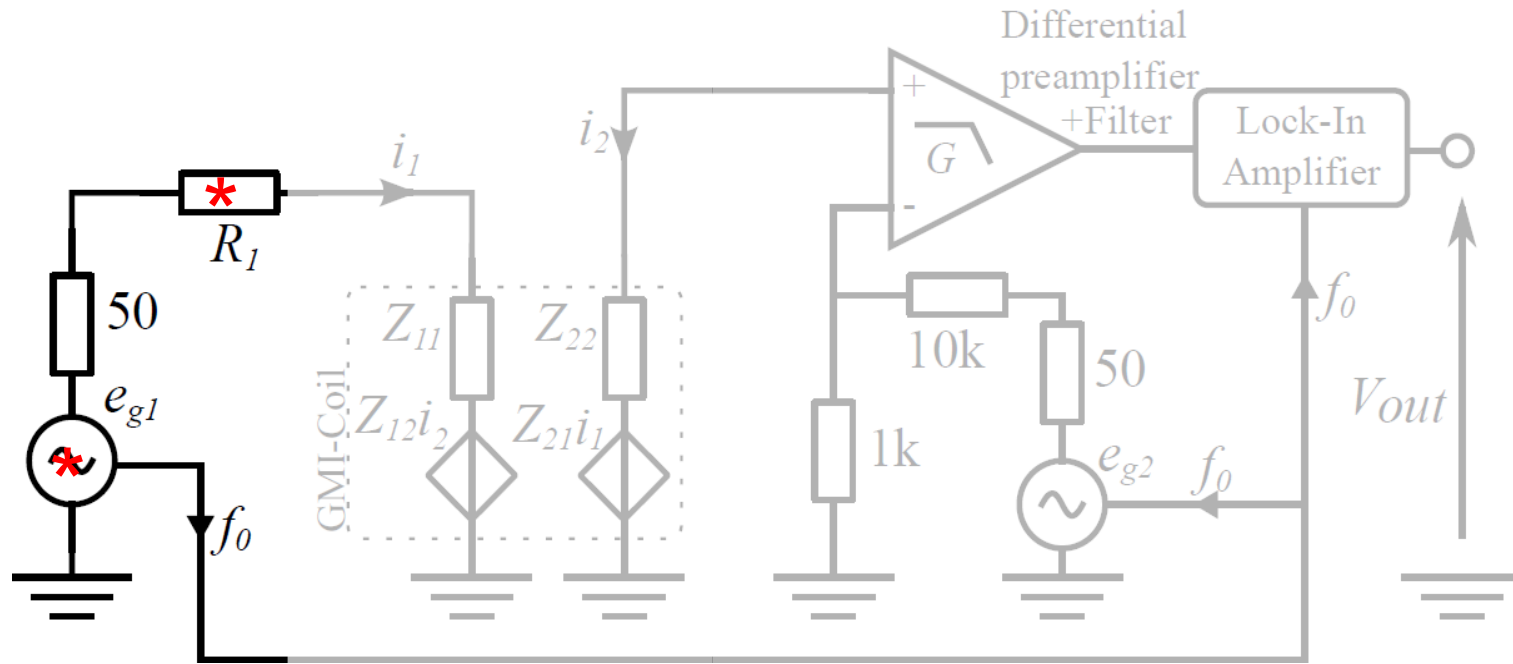
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Associated noise sources :

$$e_{ng_{1,2}}^2 = \frac{\left(\frac{e_{g_{1,2}}}{\sqrt{2}}\right)^2}{10^{148/10}} = \left(\frac{e_{g_{1,2}}}{10^{151/20}}\right)^2 \text{ [V}_{\text{rms}}^2/\text{Hz}]$$

$$e_{nR}^2 = 4k_B T R \text{ [V}_{\text{rms}}^2/\text{Hz}]$$

•Electrical model of the sensing element :

- Description
- Characterization

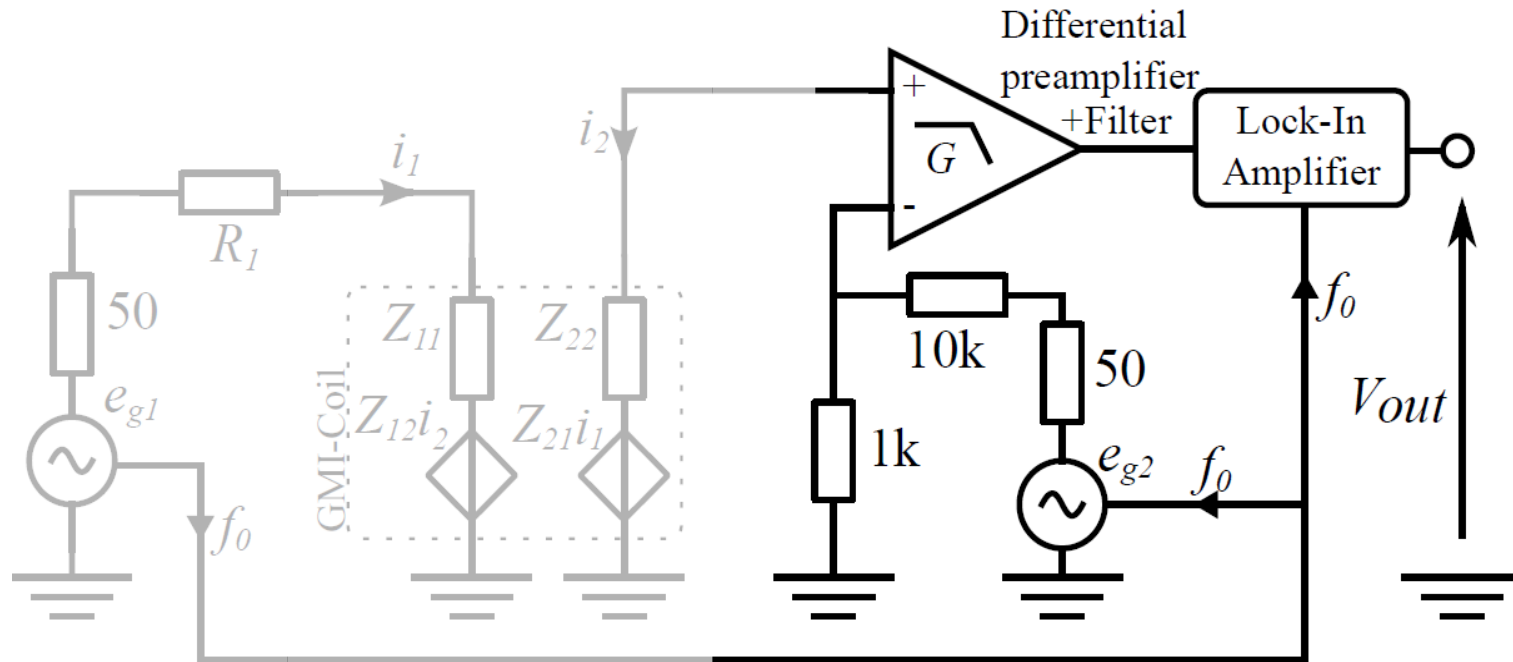
•Electronic conditioning

- Description
- Noise sources

•Sensitivity evaluation

•Equivalent magnetic noise level

•Conclusion



•Electrical model of the sensing element :

- Description
- Characterization

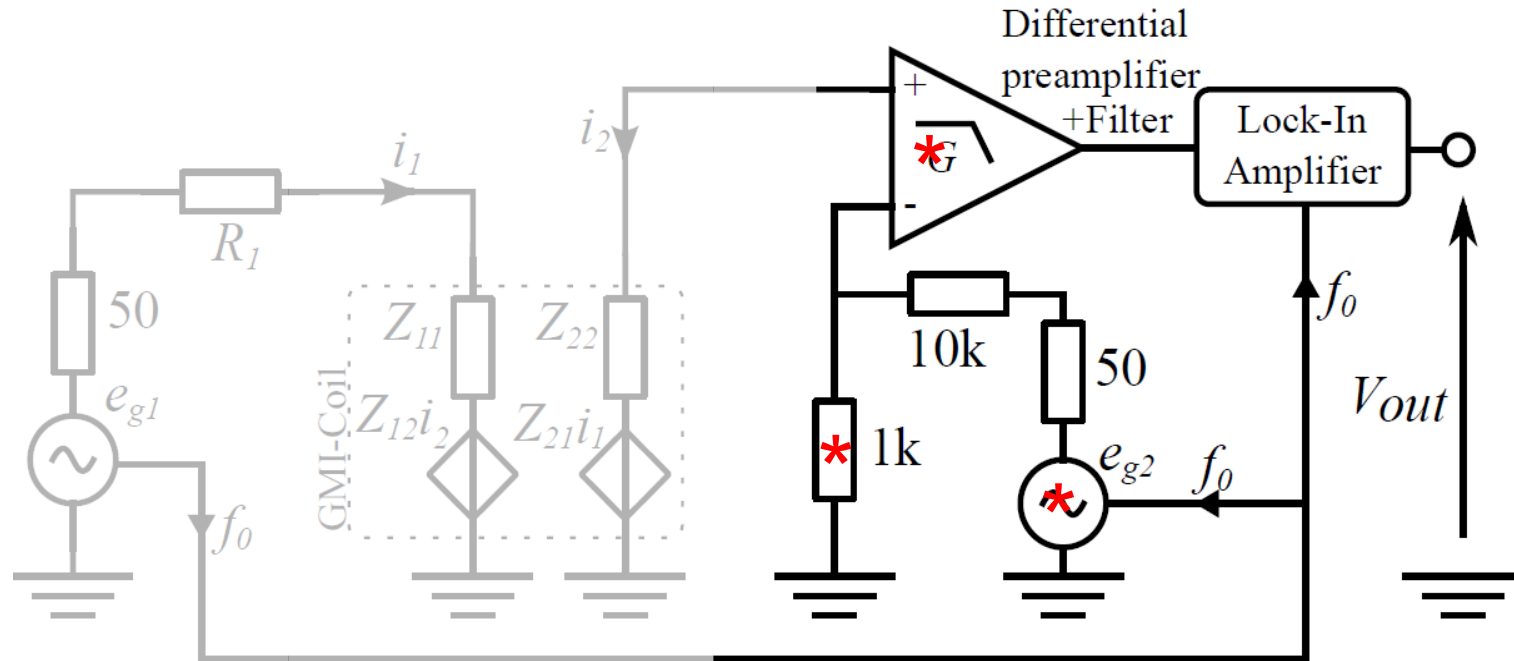
•Electronic conditioning

- Description
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•Conclusion



Associated noise sources :

$$e_{nR}^2 = 4k_B T R \text{ [V}_{\text{rms}}^2/\text{Hz]}$$

$$e_{ng_{1,2}}^2 = \frac{\left(\frac{e_{g_{1,2}}}{\sqrt{2}}\right)^2}{10^{148/10}} = \left(\frac{e_{g_{1,2}}}{10^{151/20}}\right)^2 \text{ [V}_{\text{rms}}^2/\text{Hz]}$$

(e_n, i_n) preamplifier

•Electrical model of the sensing element :

- Description
- **Characterization**

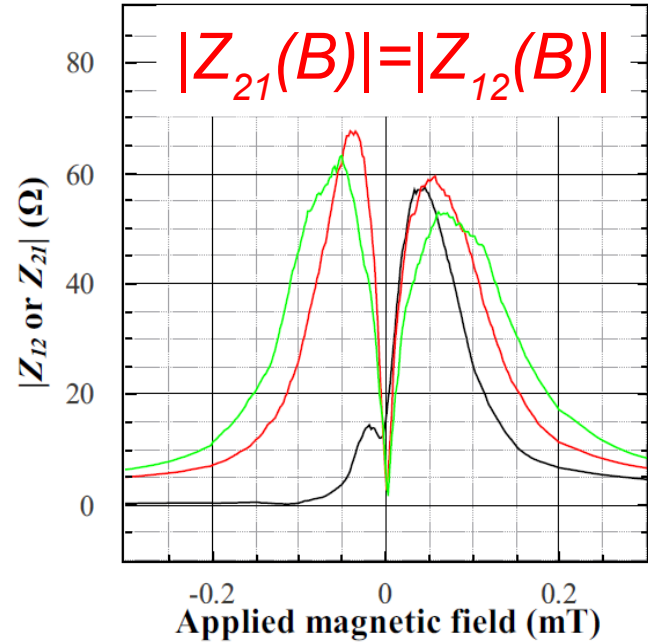
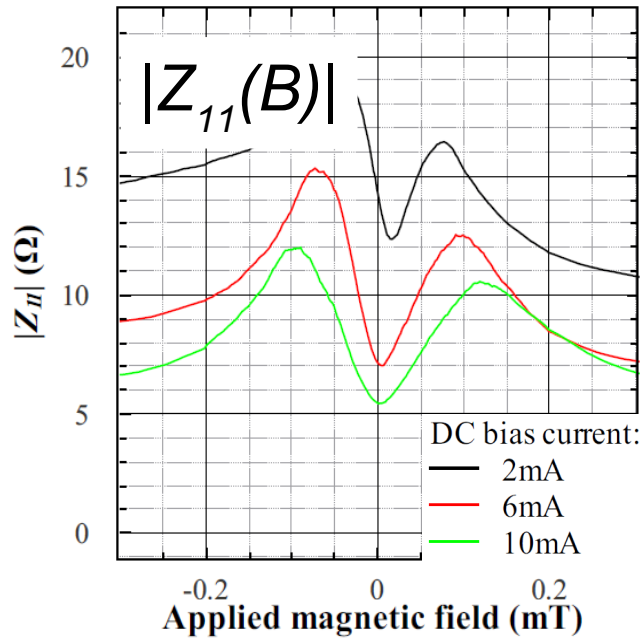
•Electronic conditioning

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Field locked loop :

$$B = B_0 + b(t)$$

$$Z_{21}(B) = \underbrace{Z_{21}|_{B=B_0}}_{Z_{210}} + \left. \frac{\partial Z_{21}}{\partial B} \right|_{B=B_0} \cdot b(t)$$

