Rogowski Beam Position Monitor

Workshop on Polarized Sources Targets and Polarimetry 2022

Rahul Suvarna, 27 September 2022

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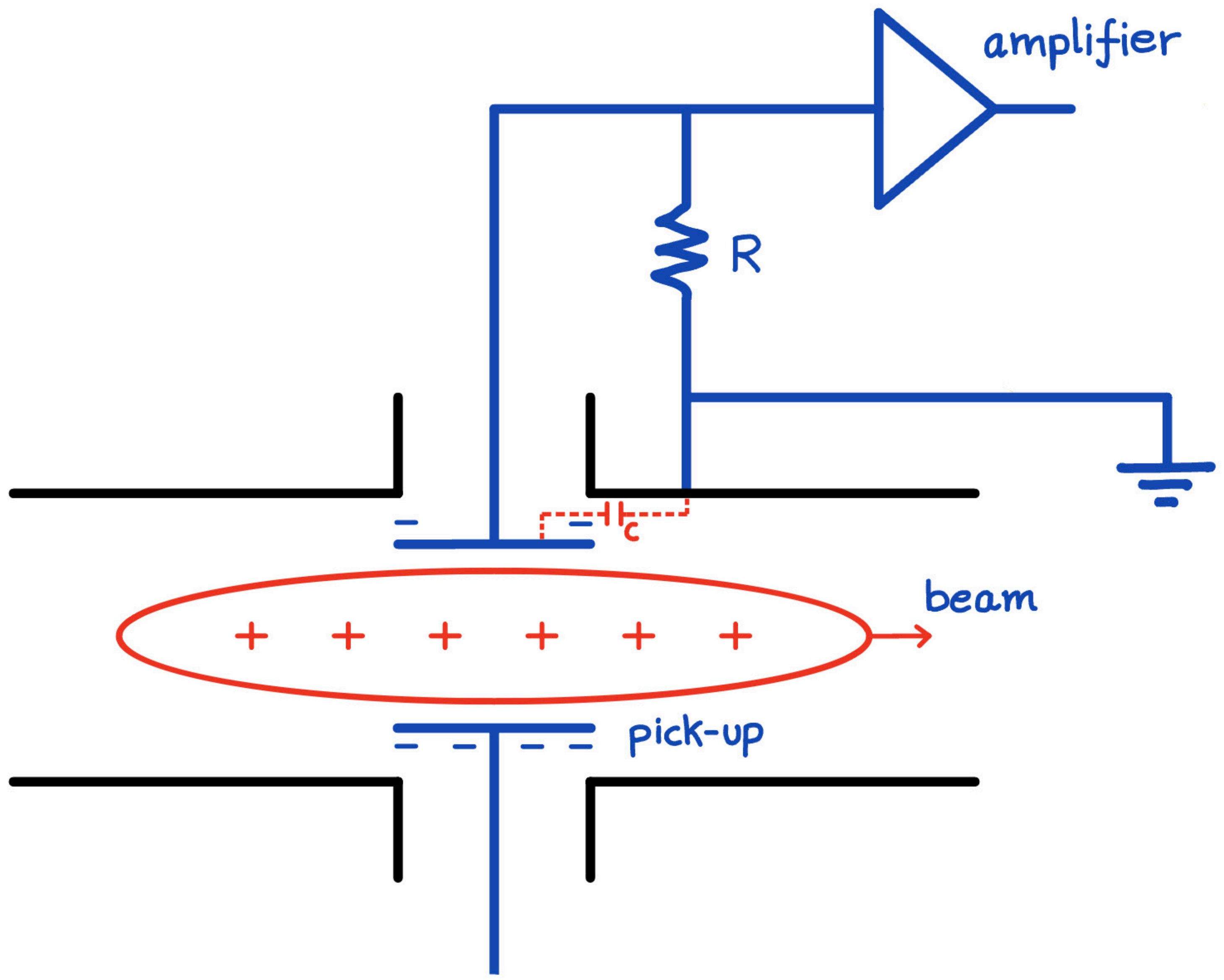
Introduction

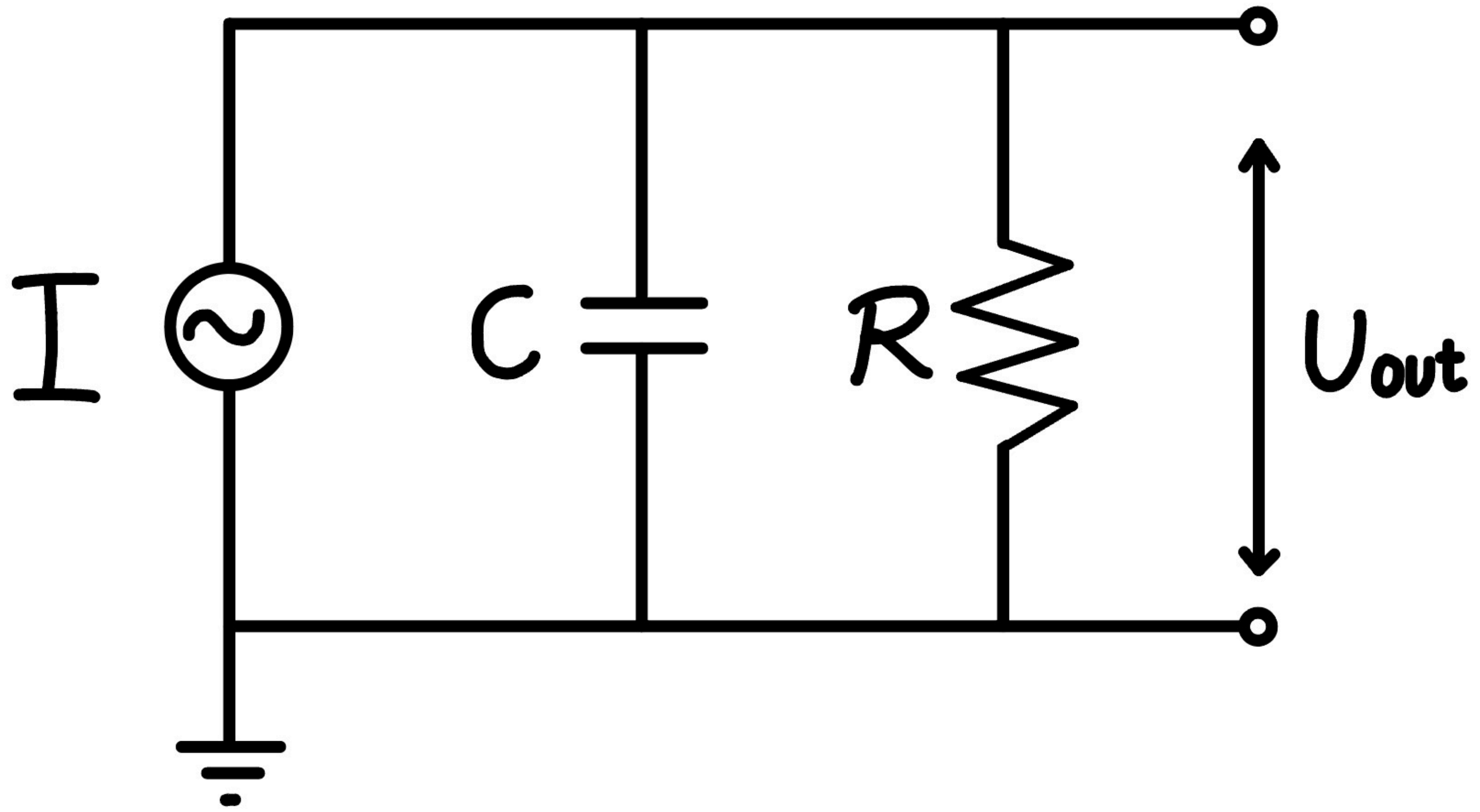
Beam Position Monitors

Beam Position Monitors

- Beam Position Monitors (BPM) are diagnostic tools used to locate the beam during a run.
- A well known example of a BPM is a Capacitive Pick-up BPM.
- A charge, proportional to the beam current and it's distance, is produced on the pick-up plates which is then used to interpret the beam position.



Capacitive Pick-up BPM



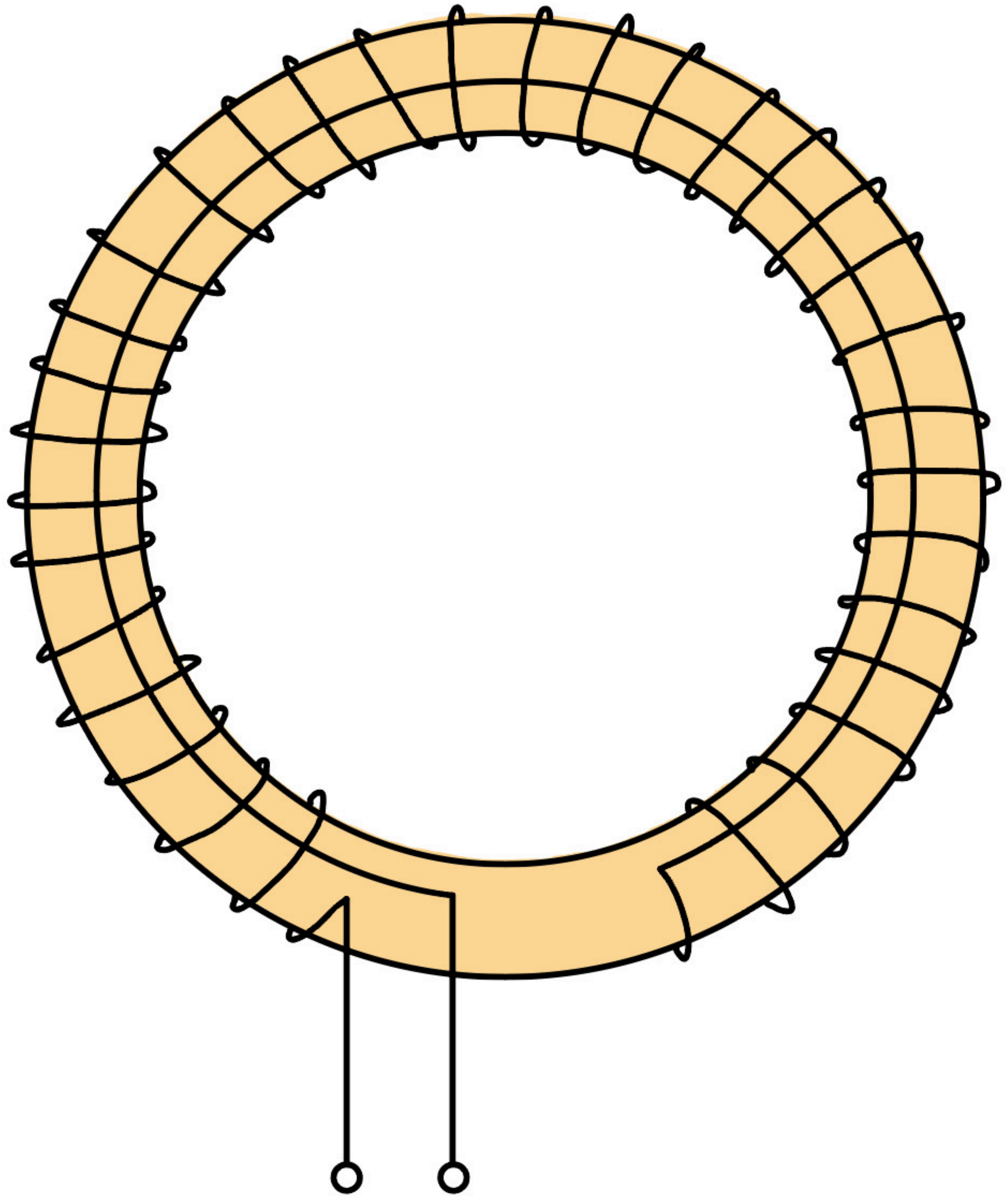
Equivalent circuit

Rogowski Beam Position Monitor

Rogowski Beam Position Monitor

- A Rogowski coil is a toroidal coil wound around a non-conducting core.
- It works on the principle of induction.
- When a beam passes through the Rogowski coil, a signal is induced in it.

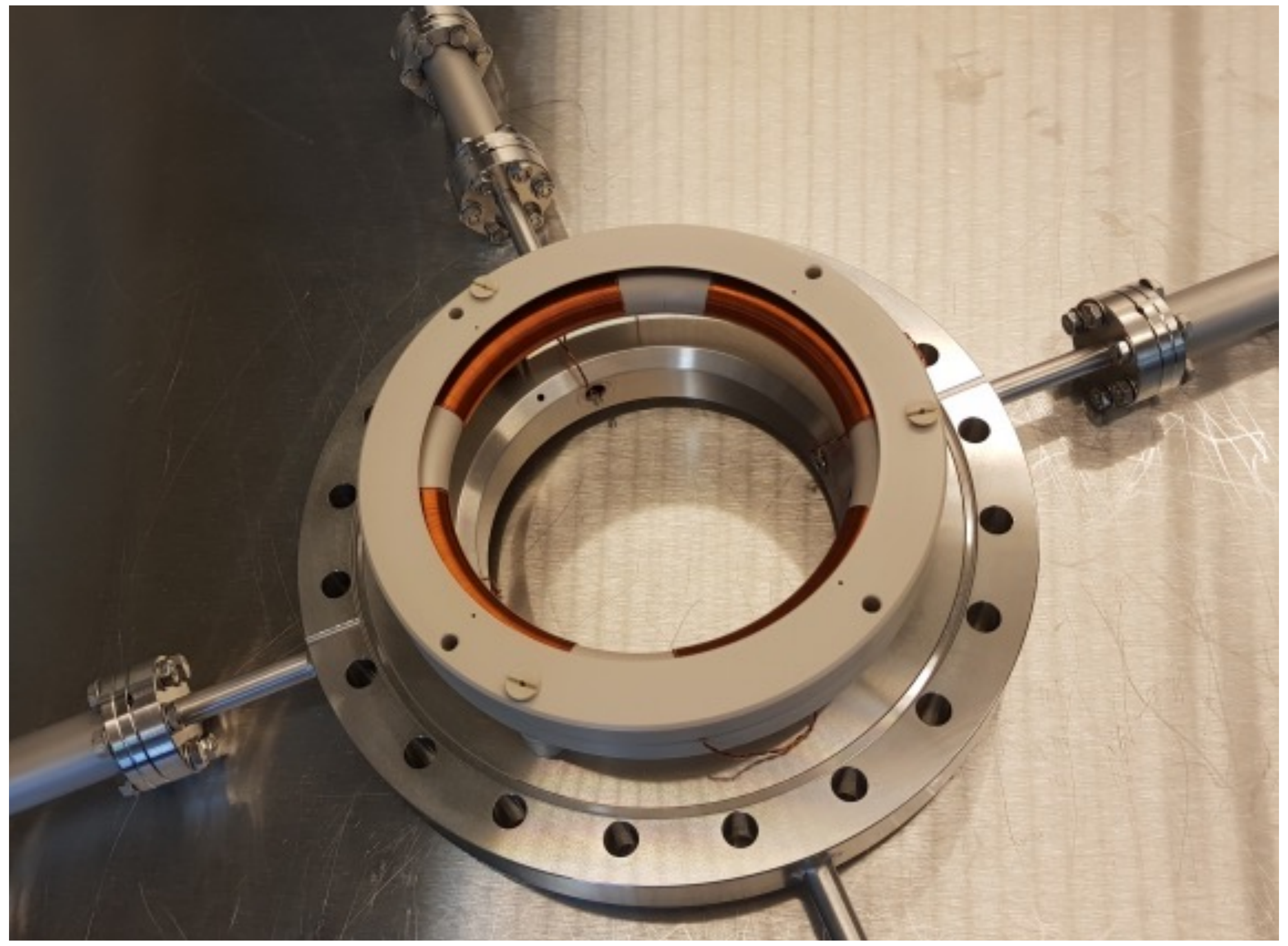
$$U(t) \propto -\frac{dI(t)}{dt}$$



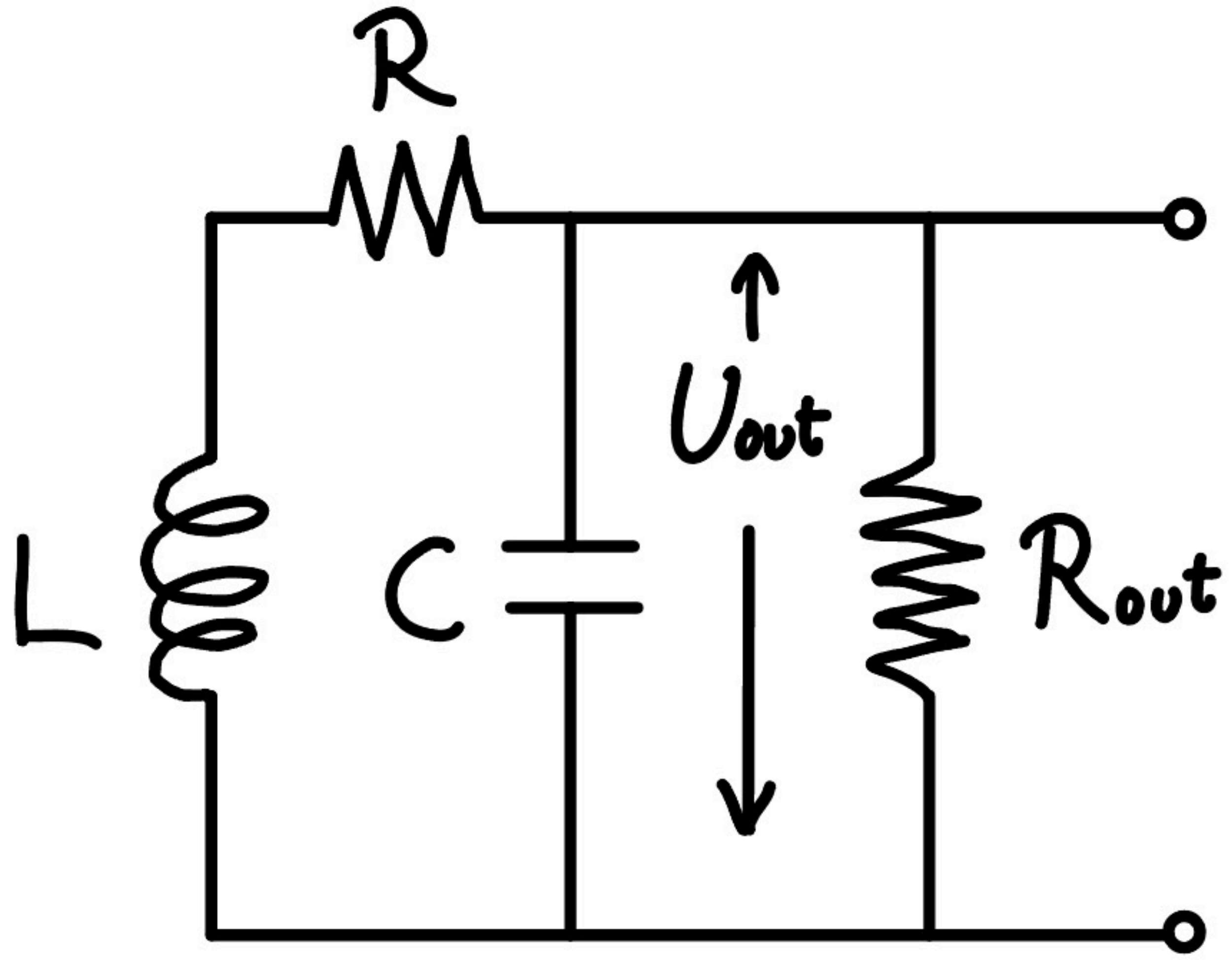
Rogowski Coil

Rogowski Beam Position Monitor

- The Rogowski BPM is made of four Rogowski coil segments acting as the four quadrants.
- The Rogowski BPM is compact, highly sensitive, is easy to produce and has a very basic construction, making it cost effective.
- The coils are highly sensitive towards a certain frequency.
- Study the performance of the Rogowski BPM in comparison to other BPM types for example, Superconducting Quantum Interference Device (SQUID) based BPM.



Rogowski BPM installed inside a flange



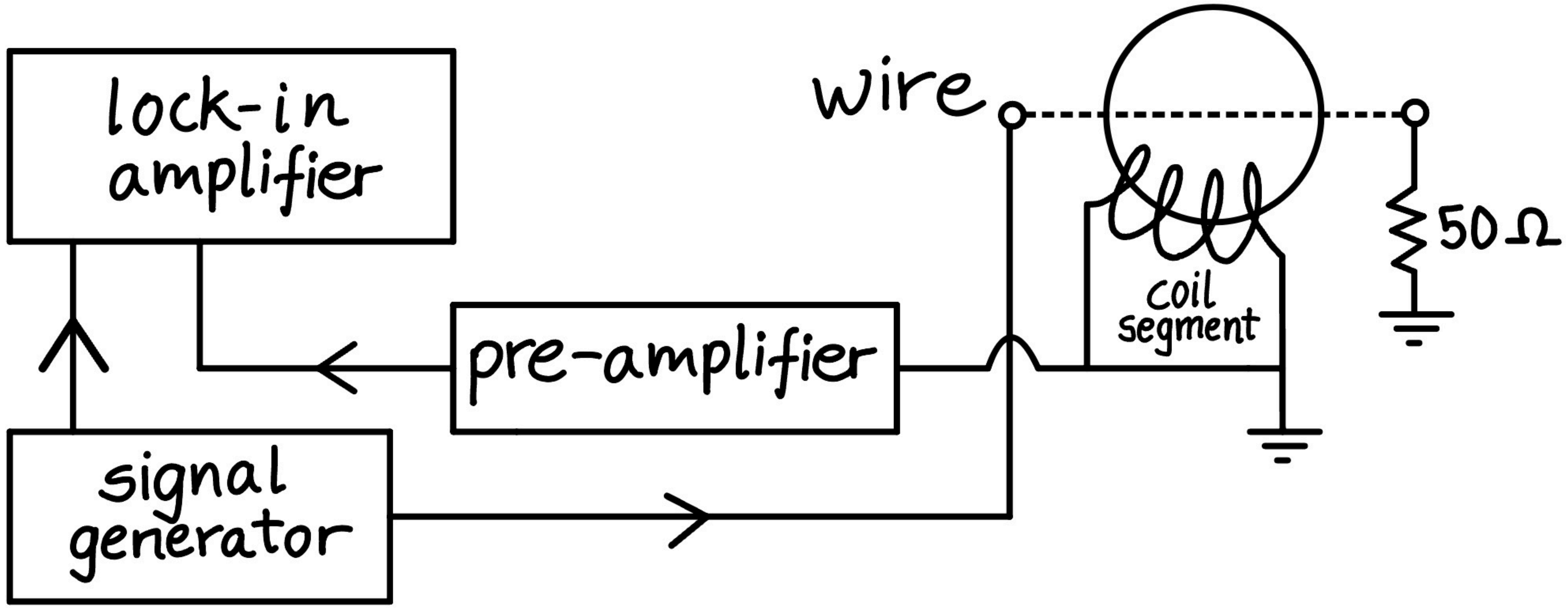
Equivalent circuit of the coil segment

Lab Experiments

General Setup

General Setup

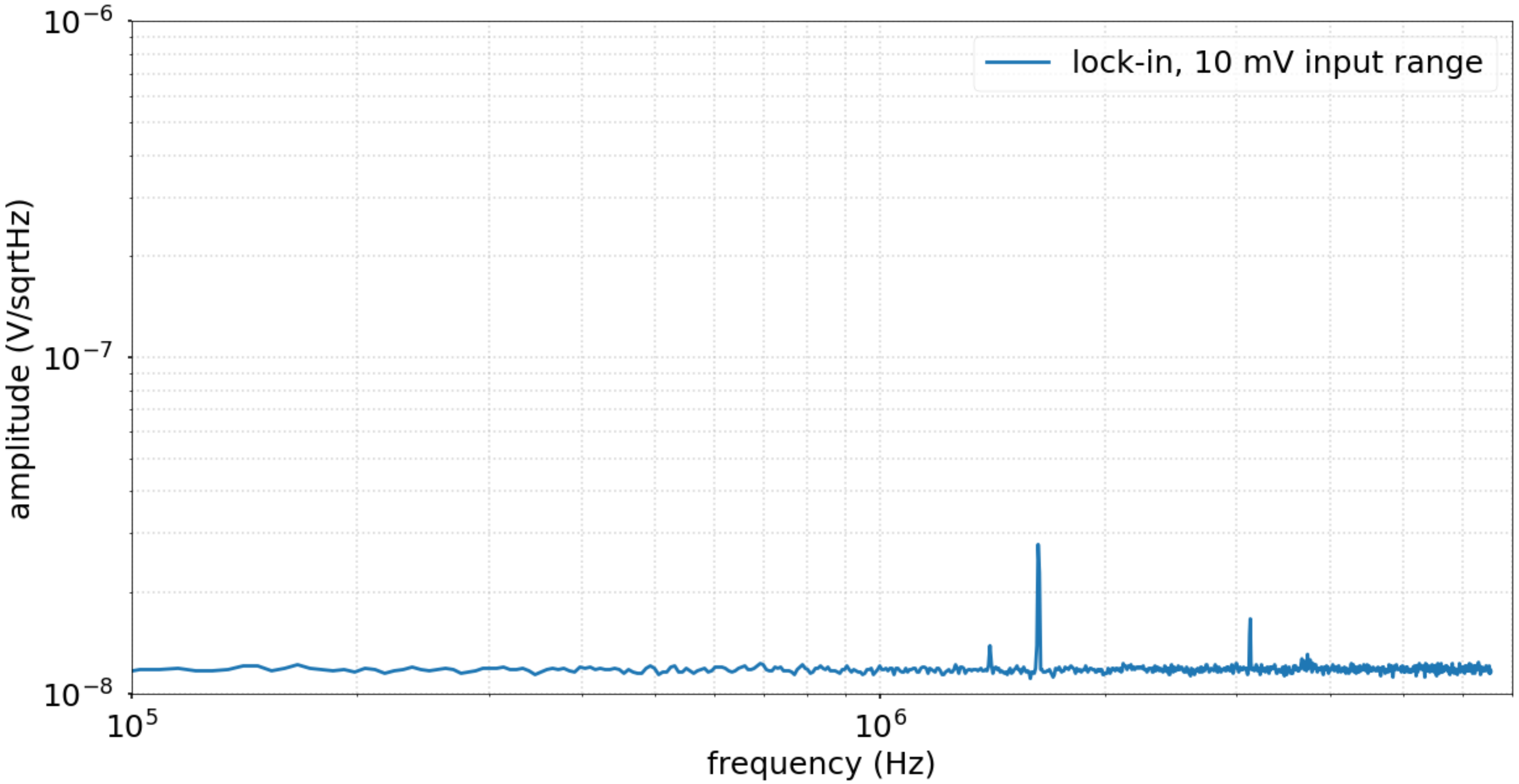
- A fixed wire is used to simulate the beam.
- Any position of the beam can be achieved by moving the coil around.
- This setup provides a controlled environment to test & calibrate the Rogowski BPM.



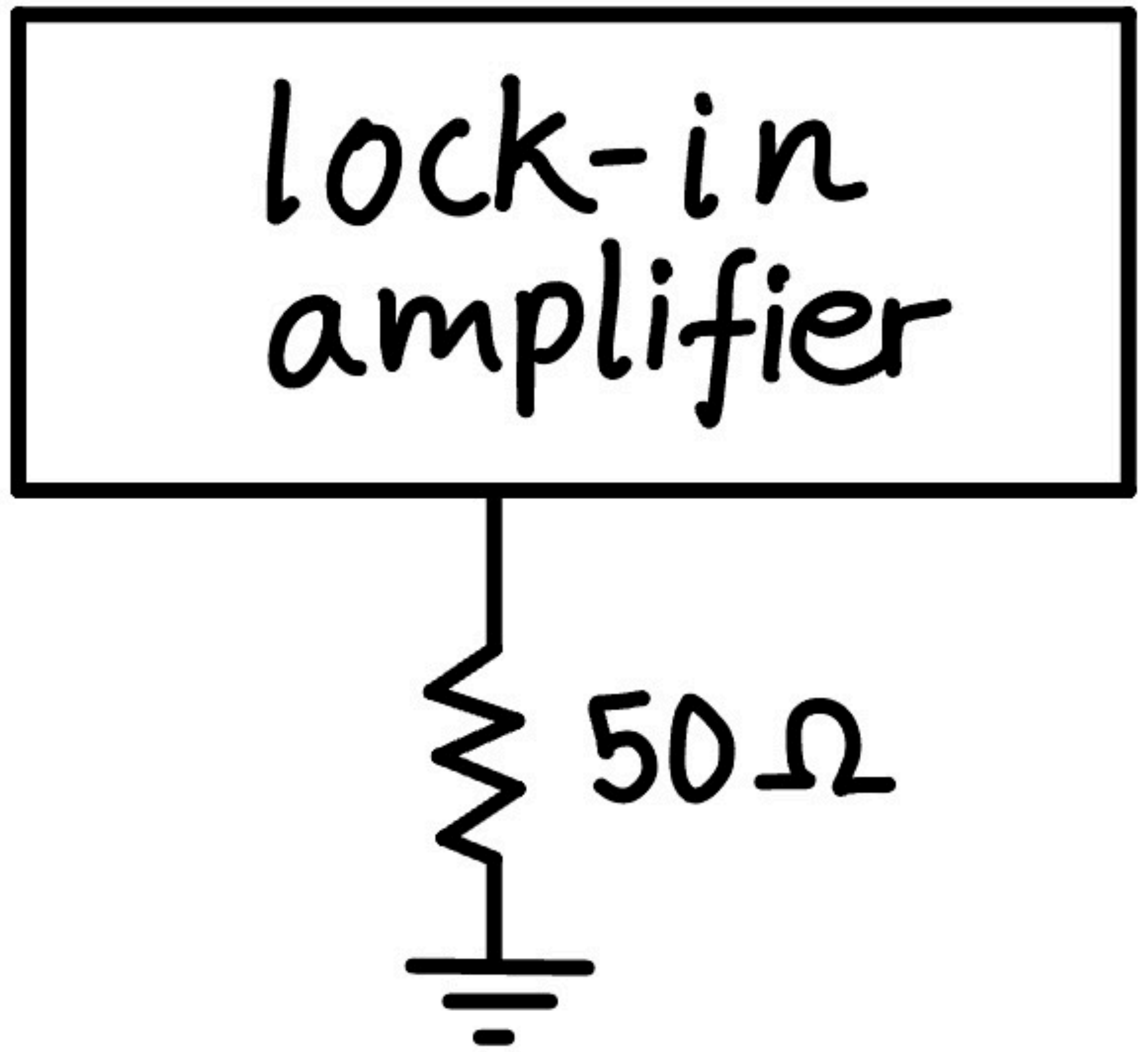
General testing setup circuit diagram

Lock-In Amplifier Noise

Lock-In Amplifier Noise



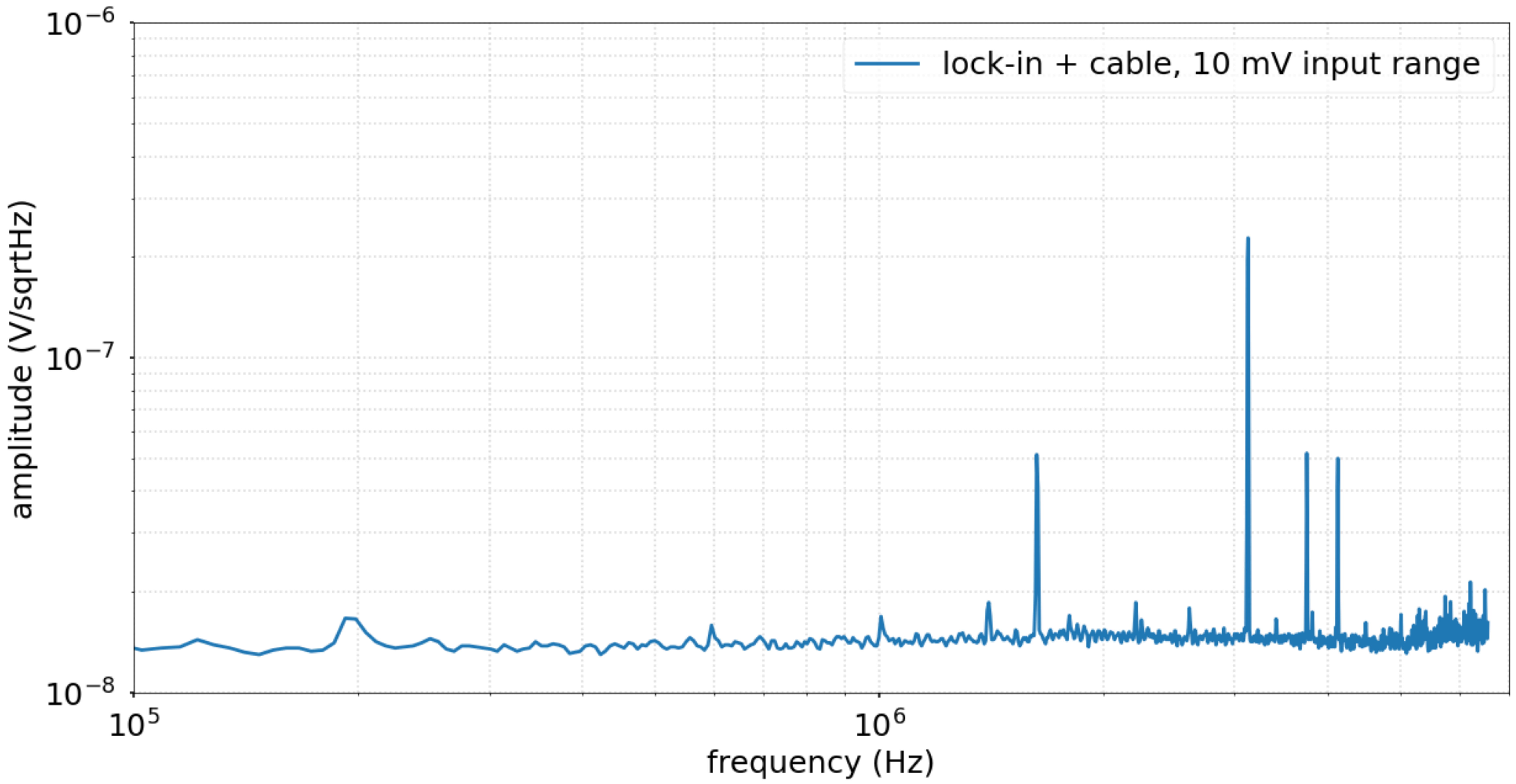
Lock-in amplifier noise characteristics



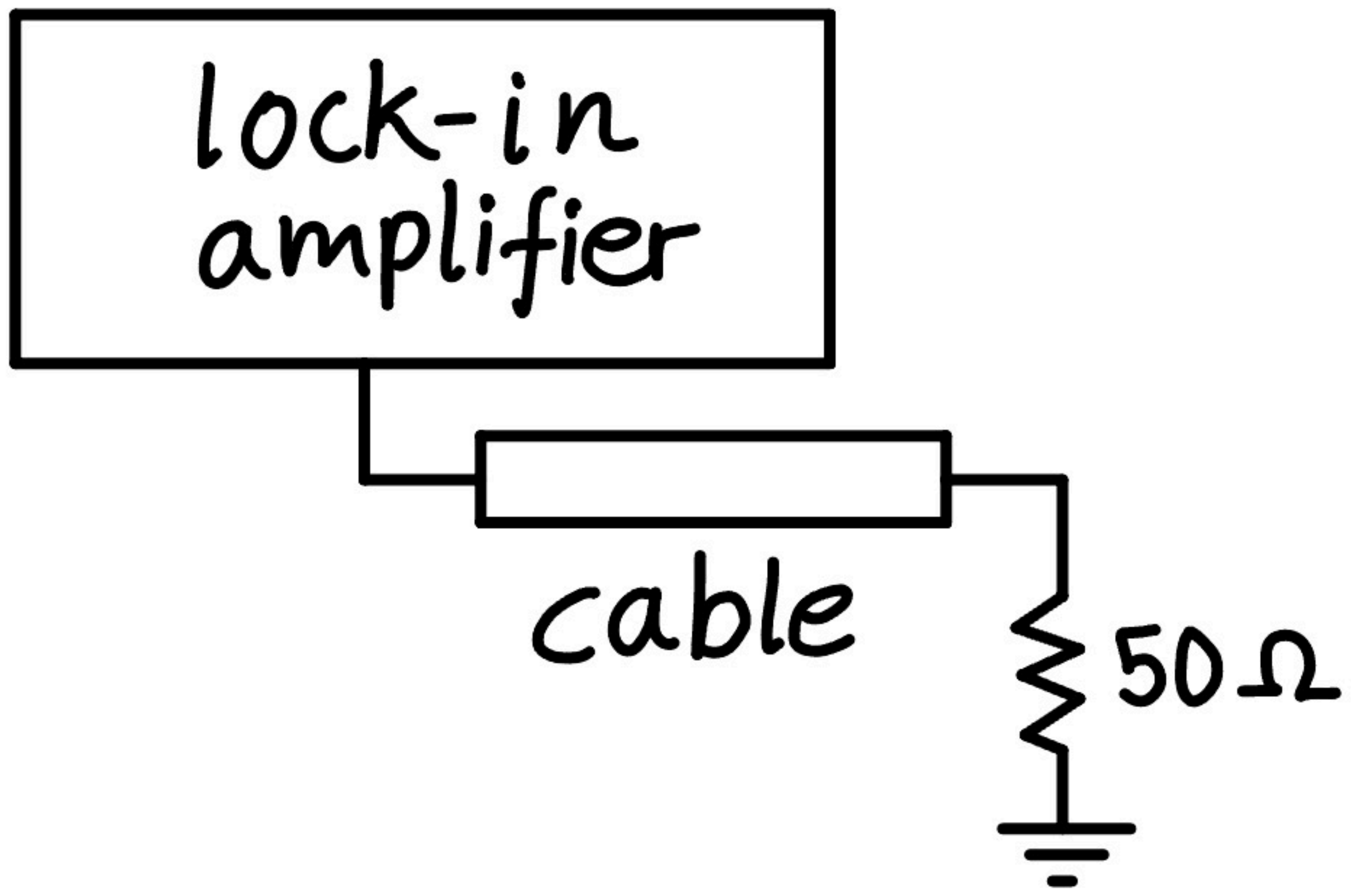
- Zurich Instruments HF2LI.
- 50Ω load at the input.
- ~12 $nV/\sqrt{Hz}$.

Cable Noise

Cable Noise



Lock-in + Cable noise characteristics

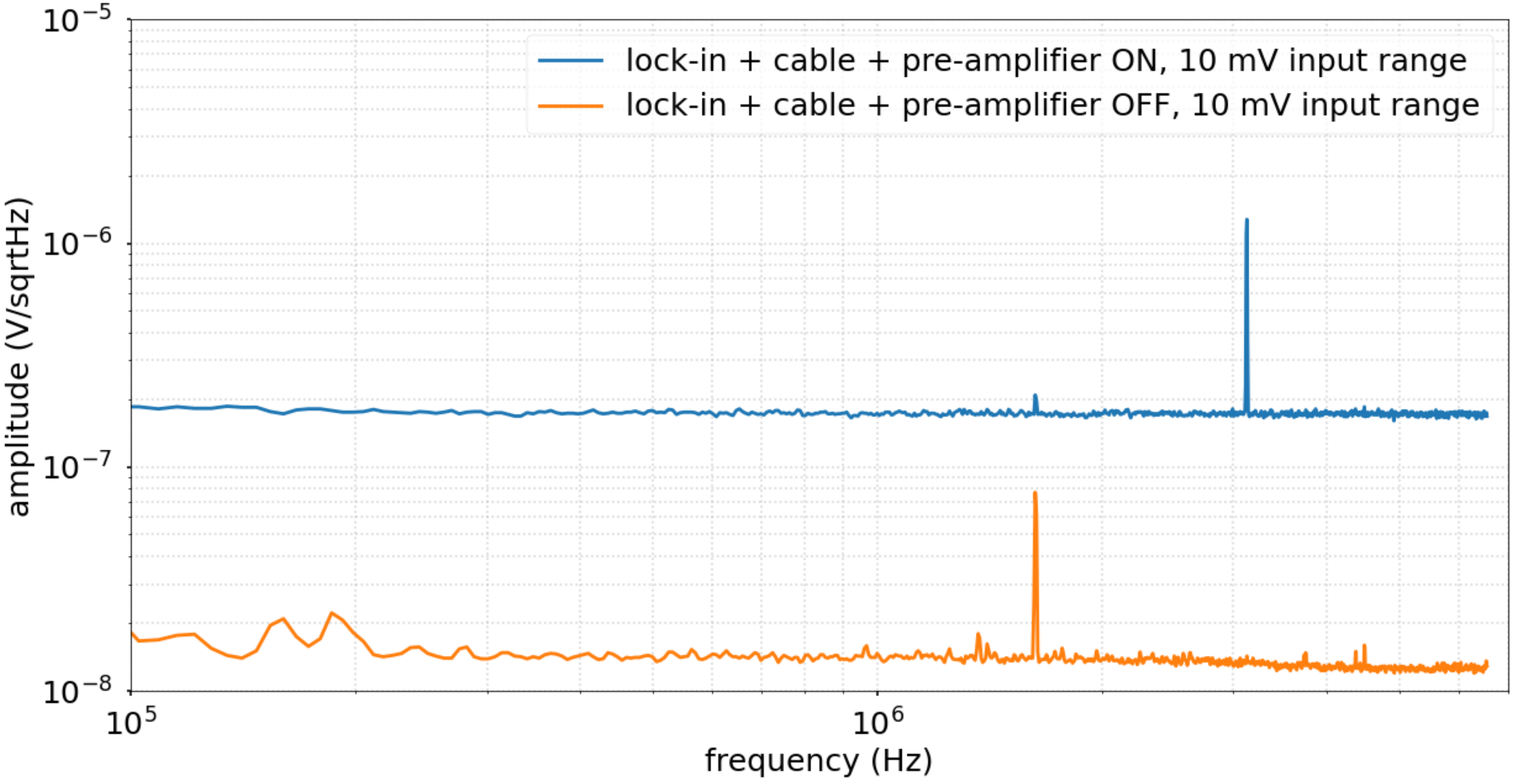


- Coaxial cable connected to the lock-in amplifier input.
- 50Ω load at the end of the cable
- ~15 $nV/\sqrt{Hz}$.

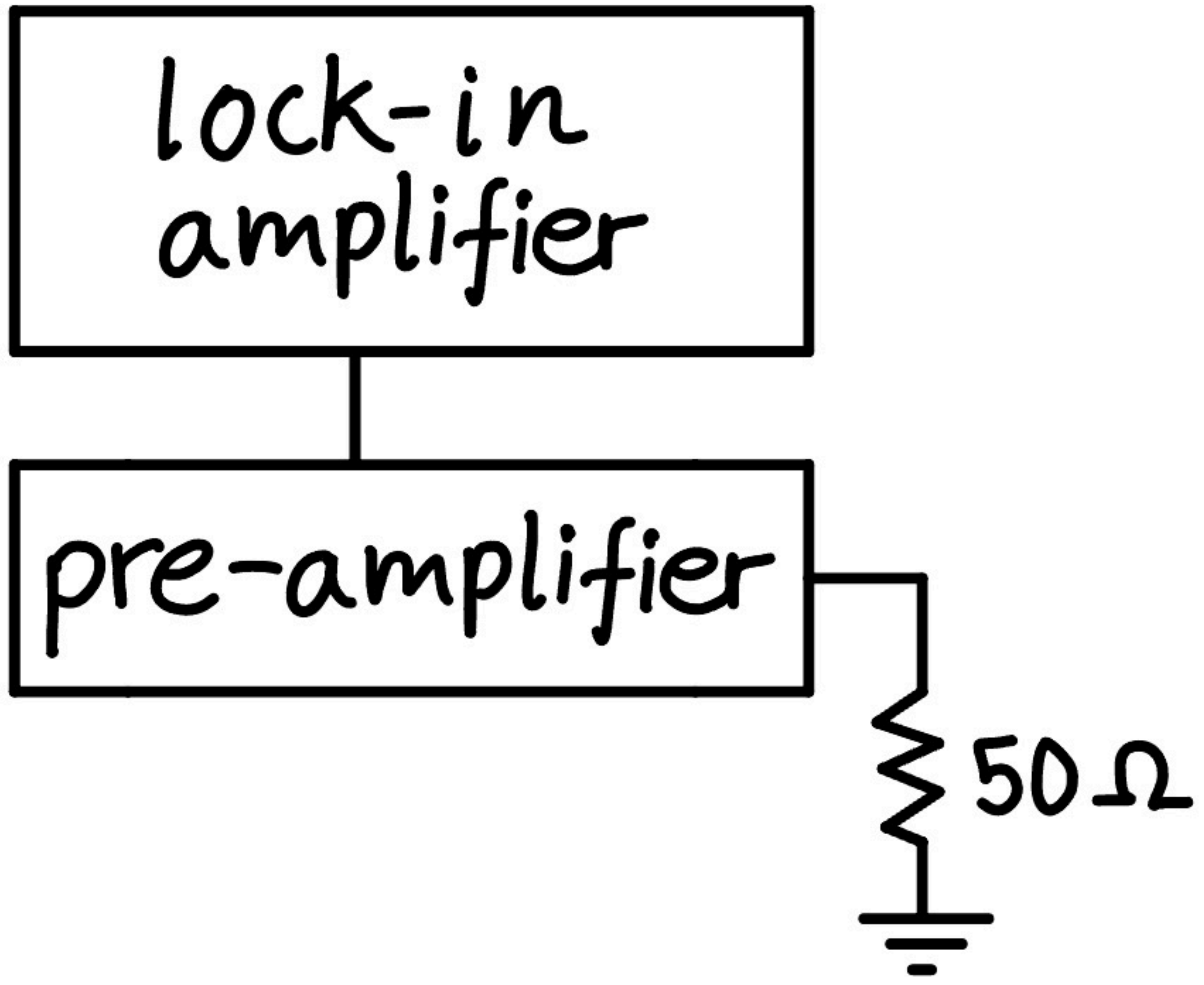
Signal-to-Noise Ratio Measurements

Pre-Amplifier Noise

Pre-Amplifier Noise



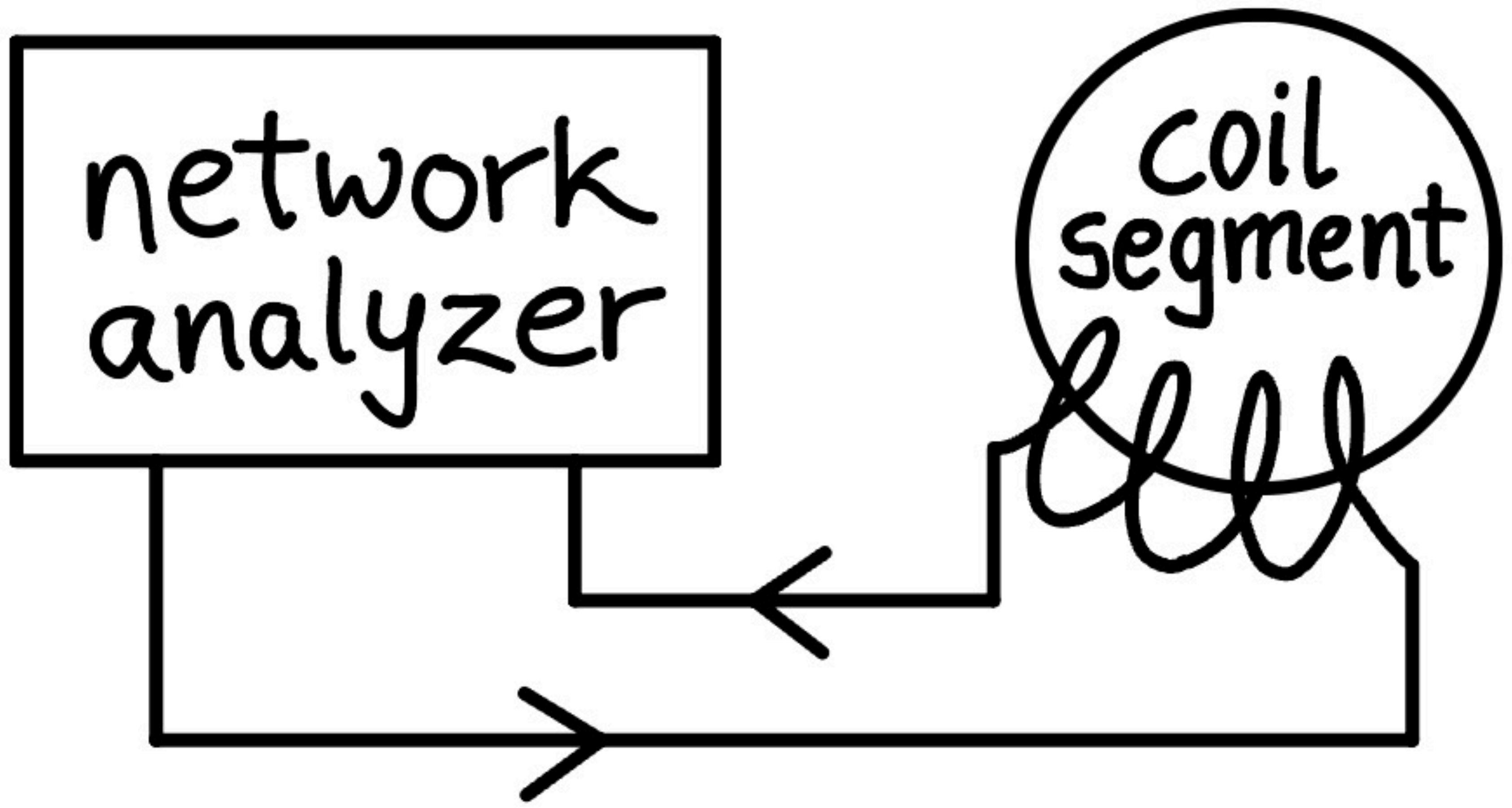
Lock-in + Cable + Pre-amplifier noise characteristics



- Pre-Amplifier with gain ~10, R_{out} = 500kΩ.
- 50Ω load at the input.
- ~15 $nV/\sqrt{Hz}$ when switched off.
- ~190 $nV/\sqrt{Hz}$ when switched on.

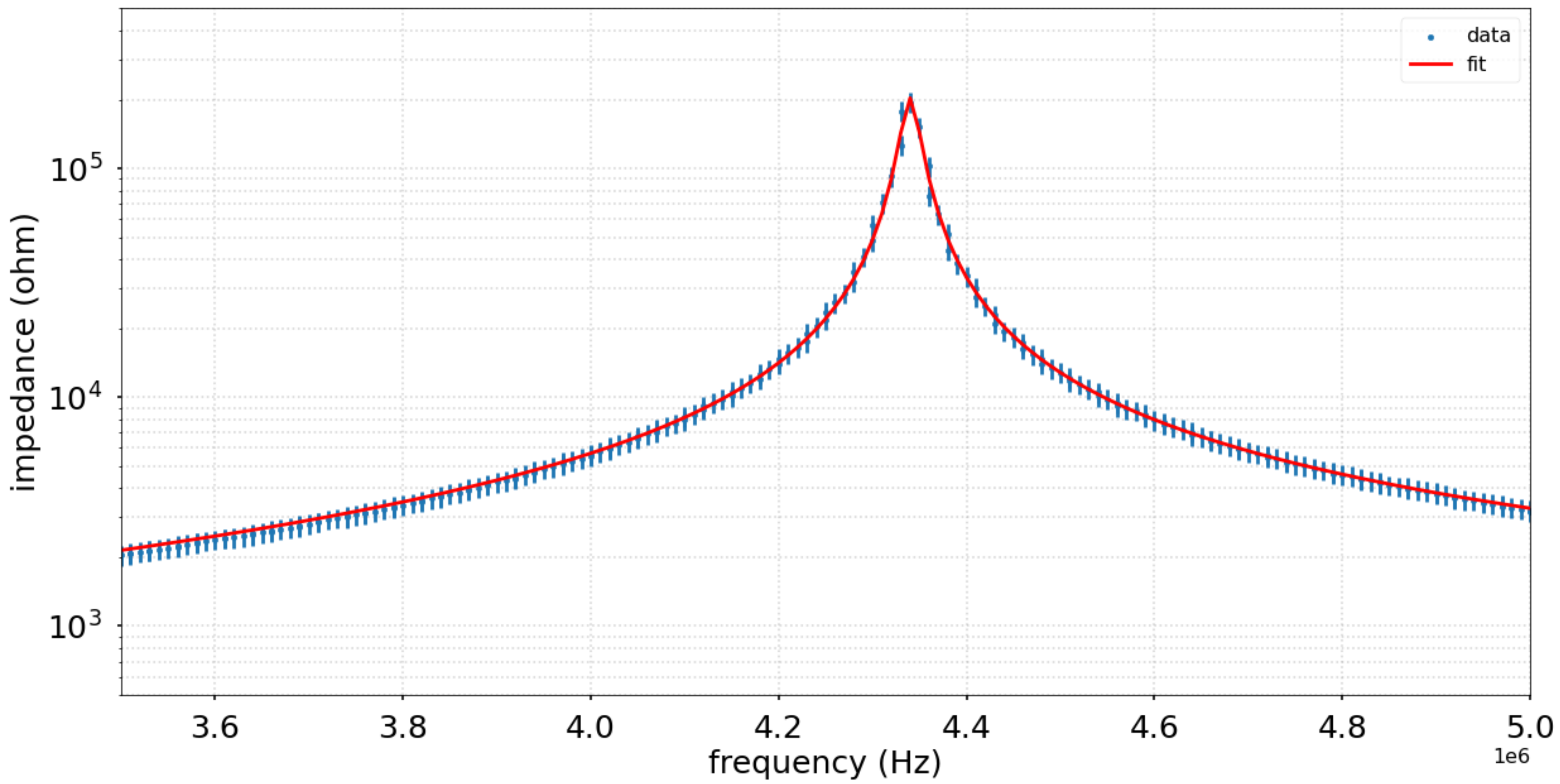
Coil Impedance

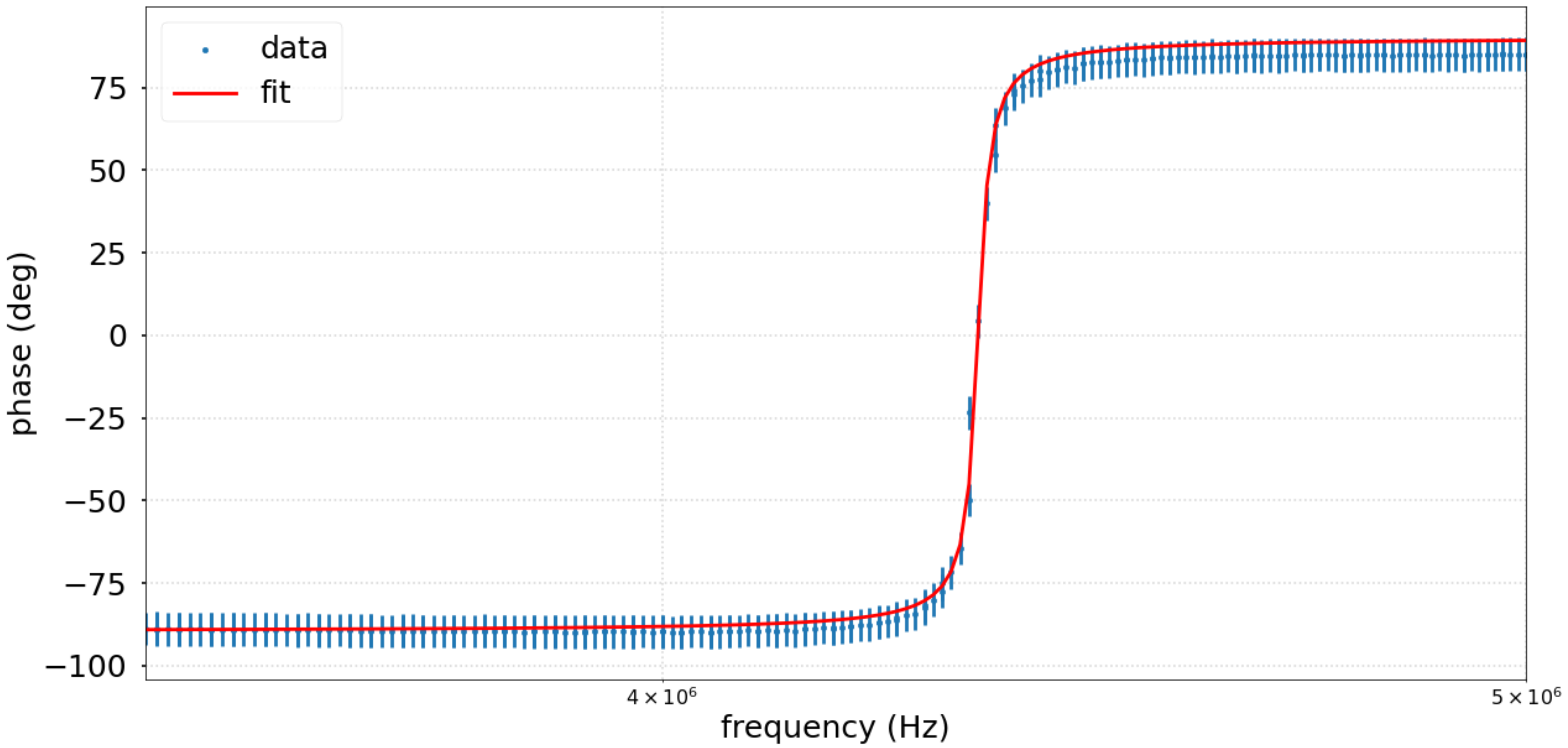
Coil Impedance



parameter	value
R [Ω]	4.26 ± 0.24
L [μH]	34.09 ± 1.97
C [pF]	39.45 ± 2.28

Siglent SVA 1032X





Coil Impedance (top) and Phase (bottom) measurements

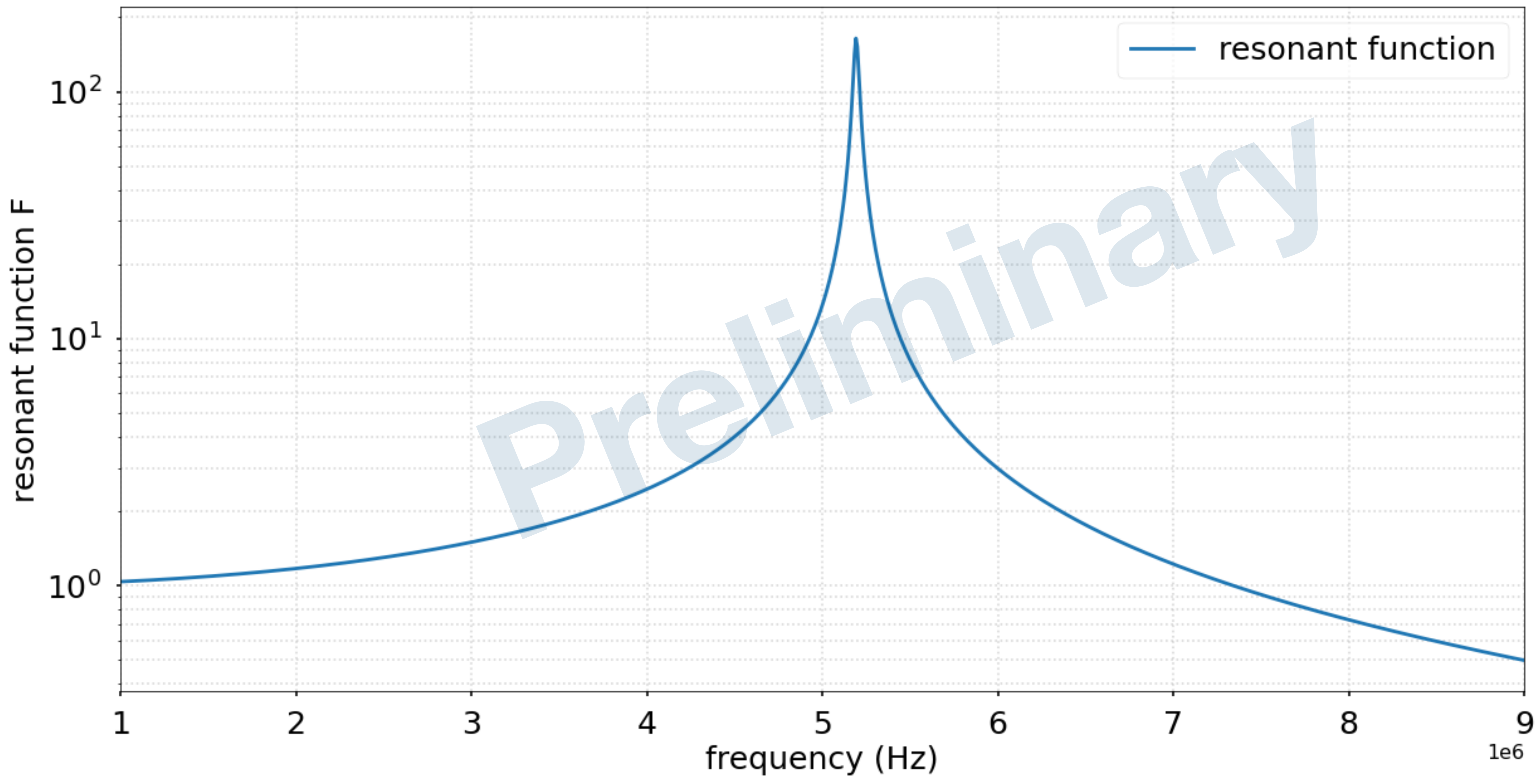
Noise Model

Noise Model

parameter	value
R [Ω]	4.26
L [μH]	34.09
C [pF]	27.55

Resonant function

$$F(\omega) = \frac{1}{\sqrt{\left(1 - \omega^2 LC + \frac{R}{R_{out}}\right)^2 + \left(\frac{\omega L}{R_{out}} + \omega RC\right)^2}}$$



Resonant function

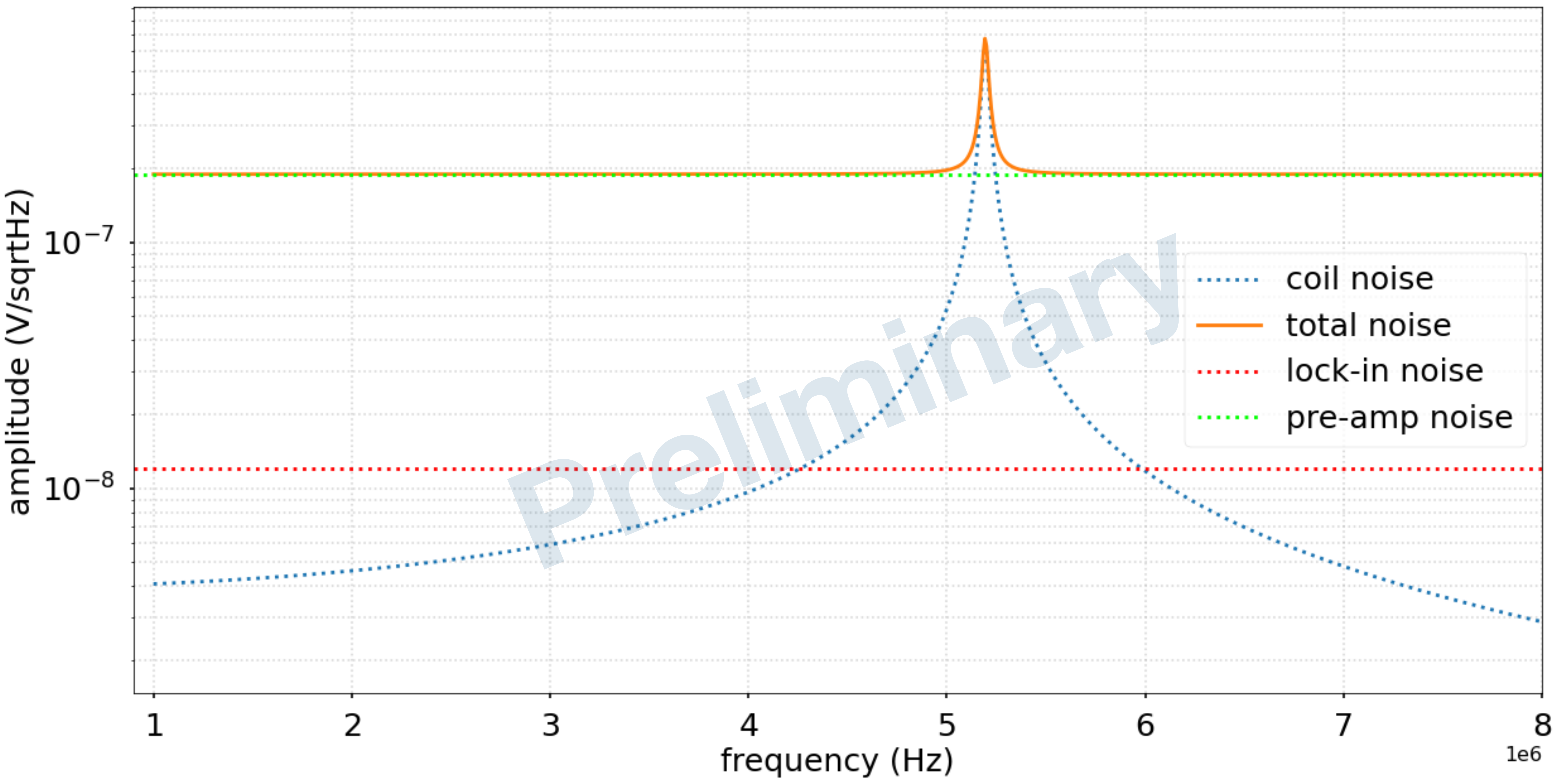
Noise Model

$$U^{noise}_{lock-in} = 12\,nV/\sqrt{Hz}$$

$$U^{noise}_{pre-amplifier} = 189\,nV/\sqrt{Hz}$$

$$U^{noise}_{coil} = F(\omega)\sqrt{4k_BTR}$$

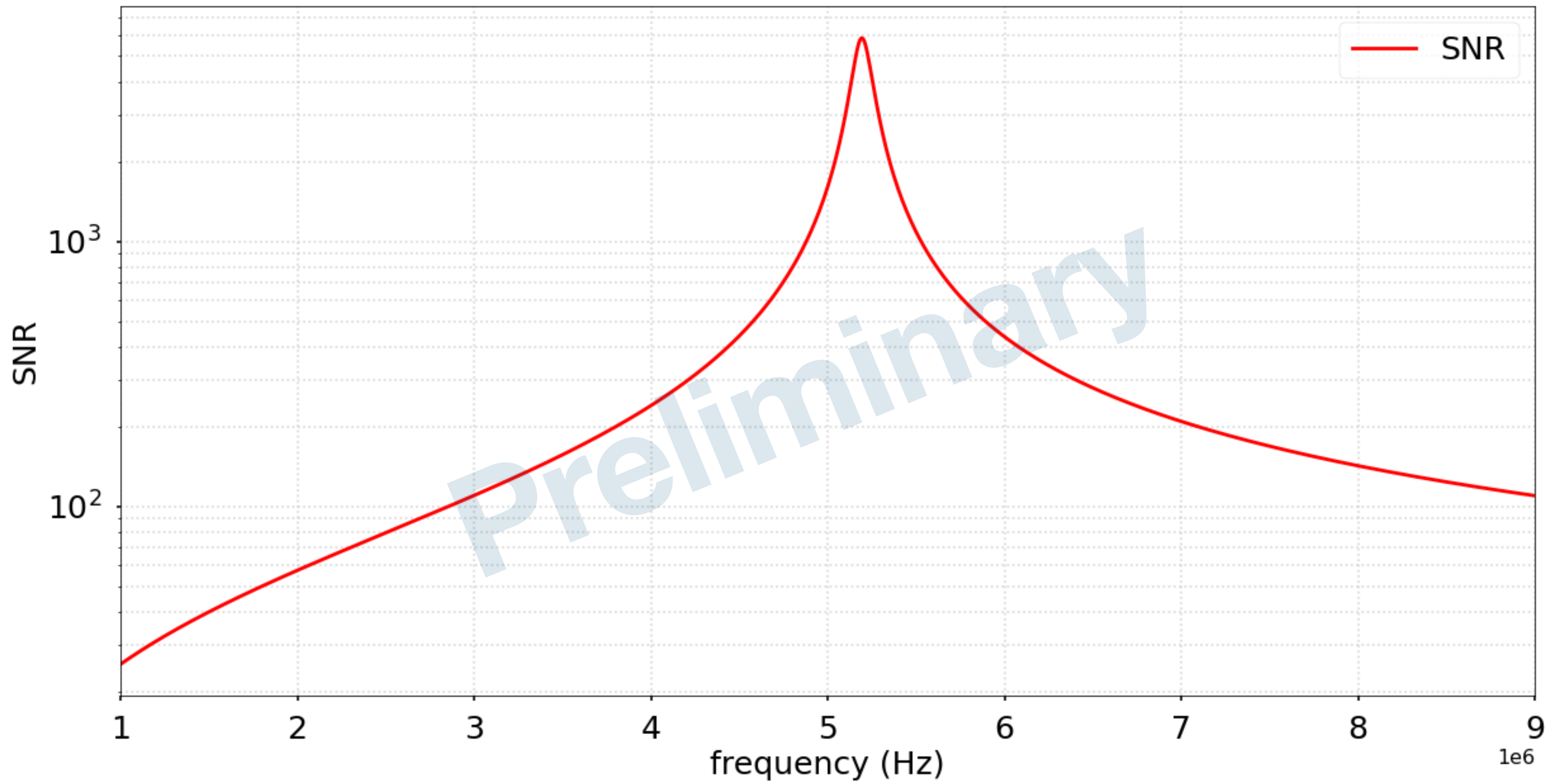
$$U^{noise}_{total} = \sqrt{{U^{noise}_{lock-in}}^2 + {U^{noise}_{pre-amplifier}}^2 + g^2 {U^{noise}_{coil}}^2}$$



Noise contributions

Noise Model

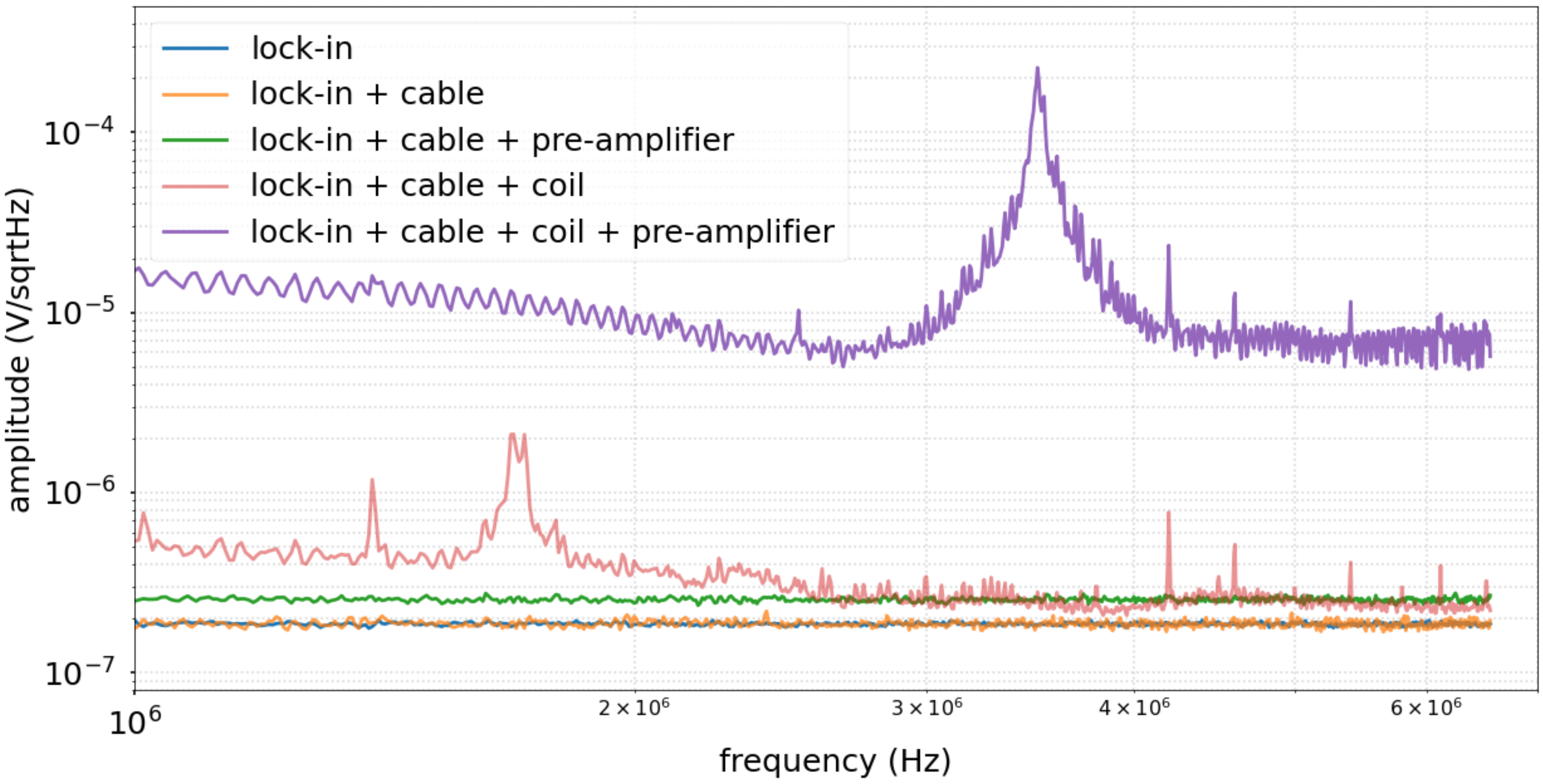
$$SNR = \frac{U(a_0, \omega)}{U^{noise}_{total}\sqrt{2\Delta f}}$$



Signal-to-Noise Ratio

Noise at 1V Input Range

Noise at 1V Input Range



Noise characteristics comparison at 1V input range

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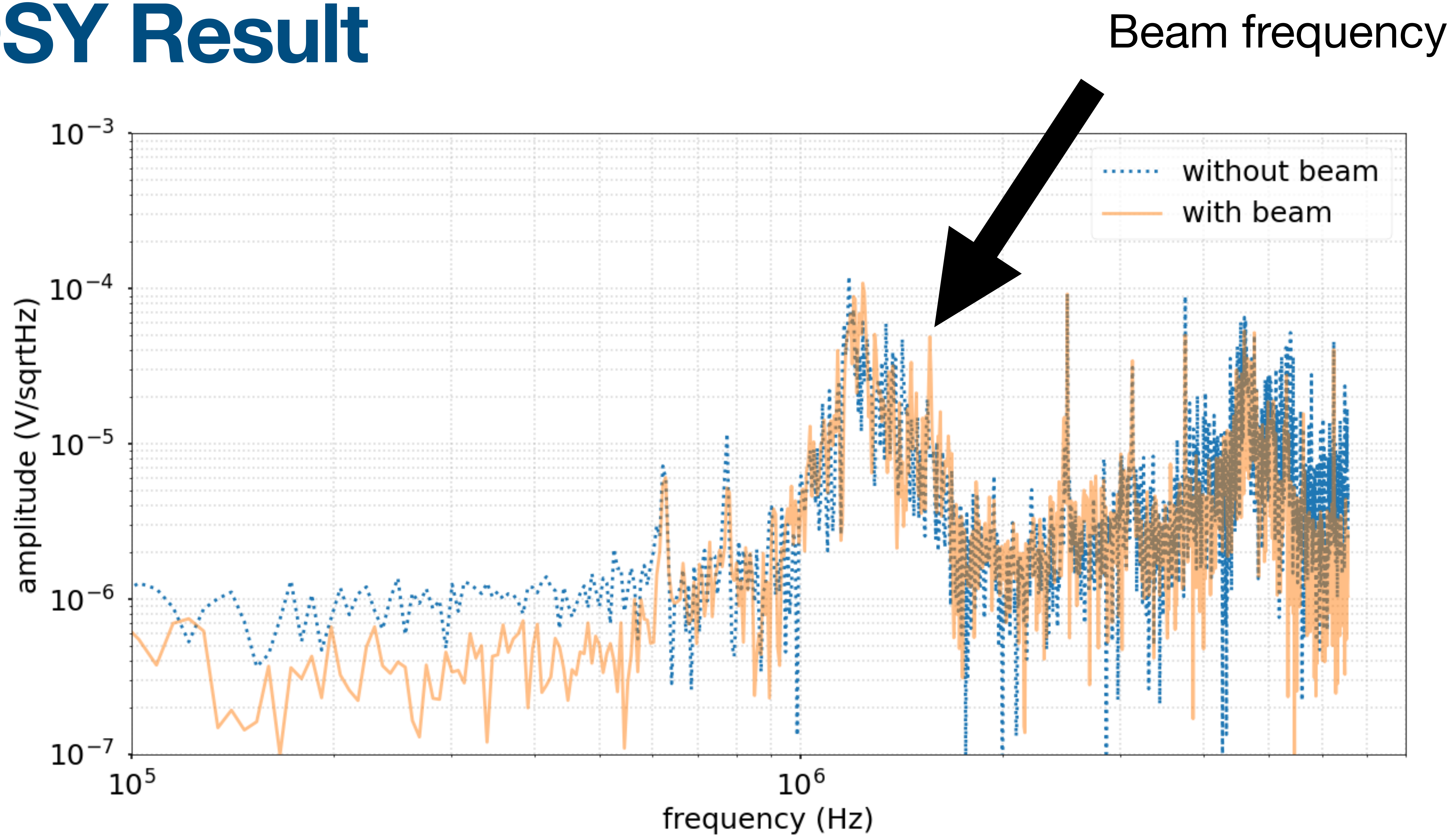
COSY Result

COSY Result



Output of the BPM coil when the beam is running (orange) vs when the beam is absent (blue), beam frequency = 1.559 MHz

Conclusion

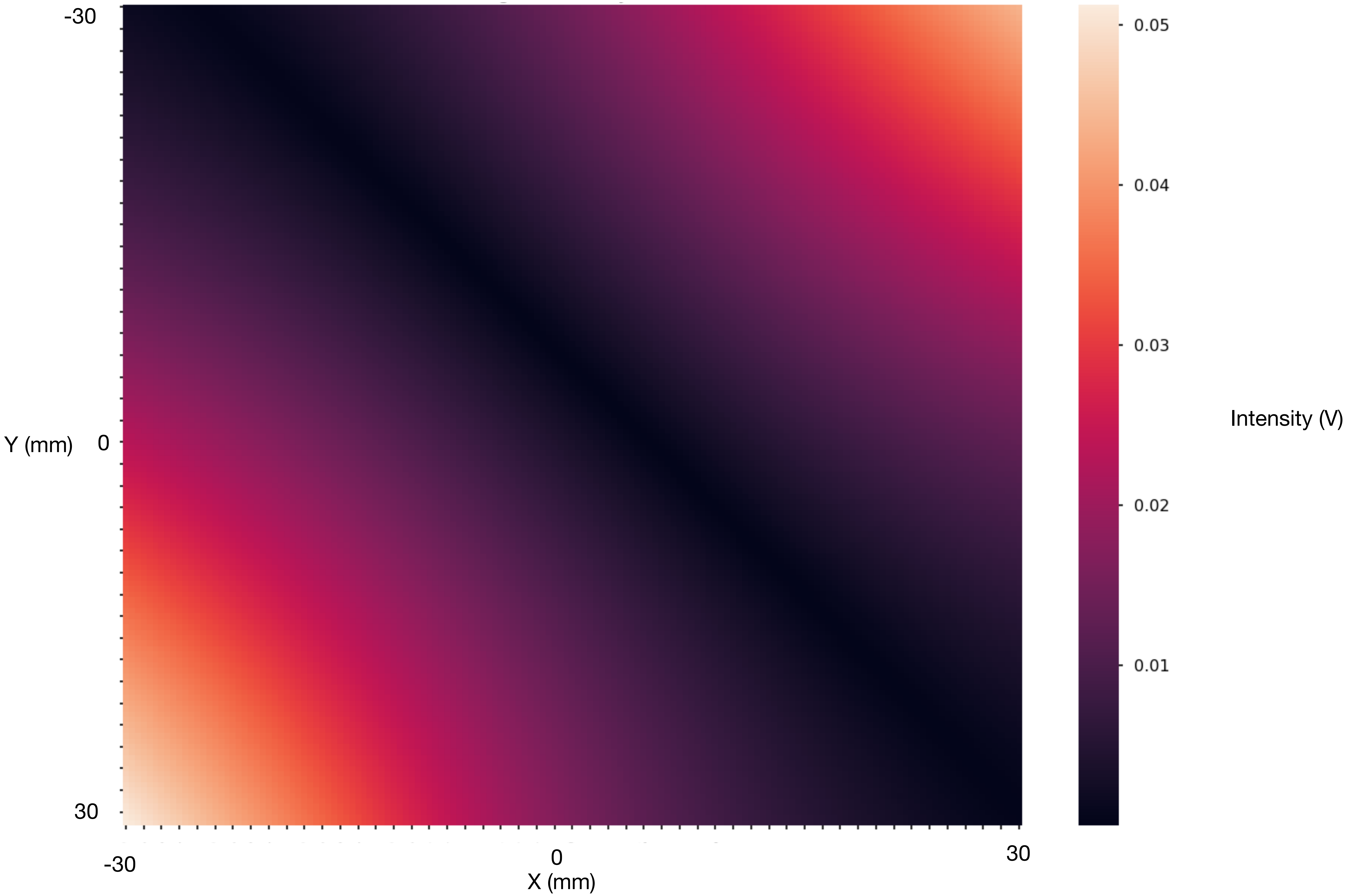
Conclusion

- The *Rogowski BPM* is a new type of *diagnostic tool* based on the principle of *Electromagnetic Induction*.
- A study of the Signal-to-Noise Ratio (SNR) of the Rogowski BPM was performed.
- The *SNR* is found to be the *best* at and around the *resonant frequency* of the coil.
- The *coils* can be *tuned* to have the *resonant frequency* equal to the *revolution frequency* of the beam for optimum results.

Thank You

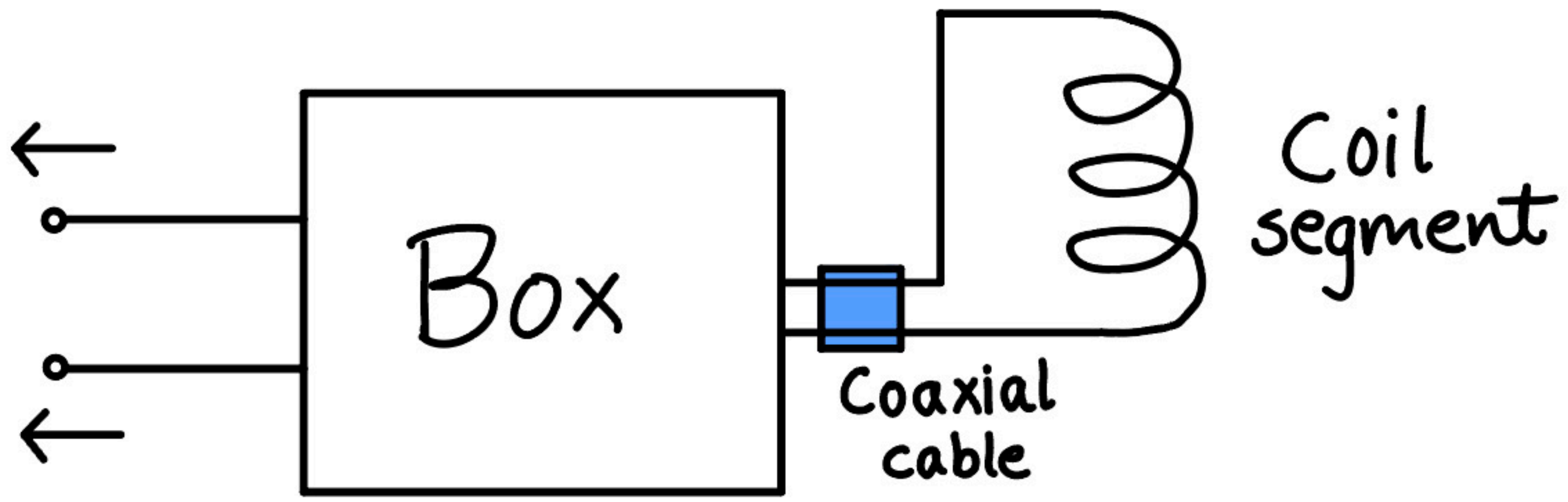
Backup

Backup



Backup

- The *box* has capacitance of ~11.9 pF.
- We subtract it from the capacitance value that was obtained using the SVA to account for the box capacitance.



Backup

$$\Phi(x,y) = -\frac{2\mu_0 a I N_w}{\pi b}\left(\frac{1}{\sqrt{1-b^2}} - 1\right)\left(\frac{x+y}{R_t}\right)$$

$$U(a_0,\omega) = g\,.\,\omega\,.\,F(\omega)\left[-\Phi\left(\frac{a_0}{\sqrt{2}},\frac{a_0}{\sqrt{2}}\right) + \Phi\left(\frac{-a_0}{\sqrt{2}},\frac{-a_0}{\sqrt{2}}\right)\right]$$

$$SNR = \frac{U(a_0,\omega)}{U_{total}^{noise}\sqrt{2\Delta f}}$$

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Backup

Welch's method

Beam frequency