Op-amp Stability: Measurements and Modeling

14th Power Analysis & Design Symposium 2025

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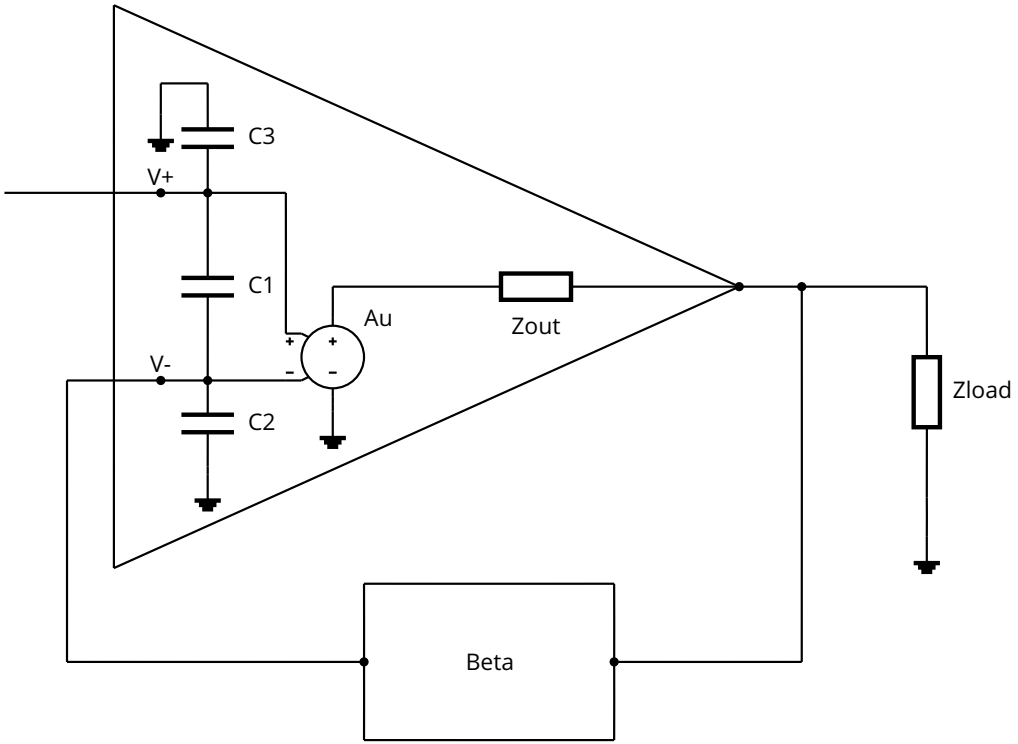
What & Why

- I'll show you how to measure:
  - Open loop gain
  - Open loop output impedance
  - Input capacitance
- What to watch out when measuring
- And how to turn the measurements into stability model
- Why?
  - Feedback system = instability risk
  - Simulation speeds up development

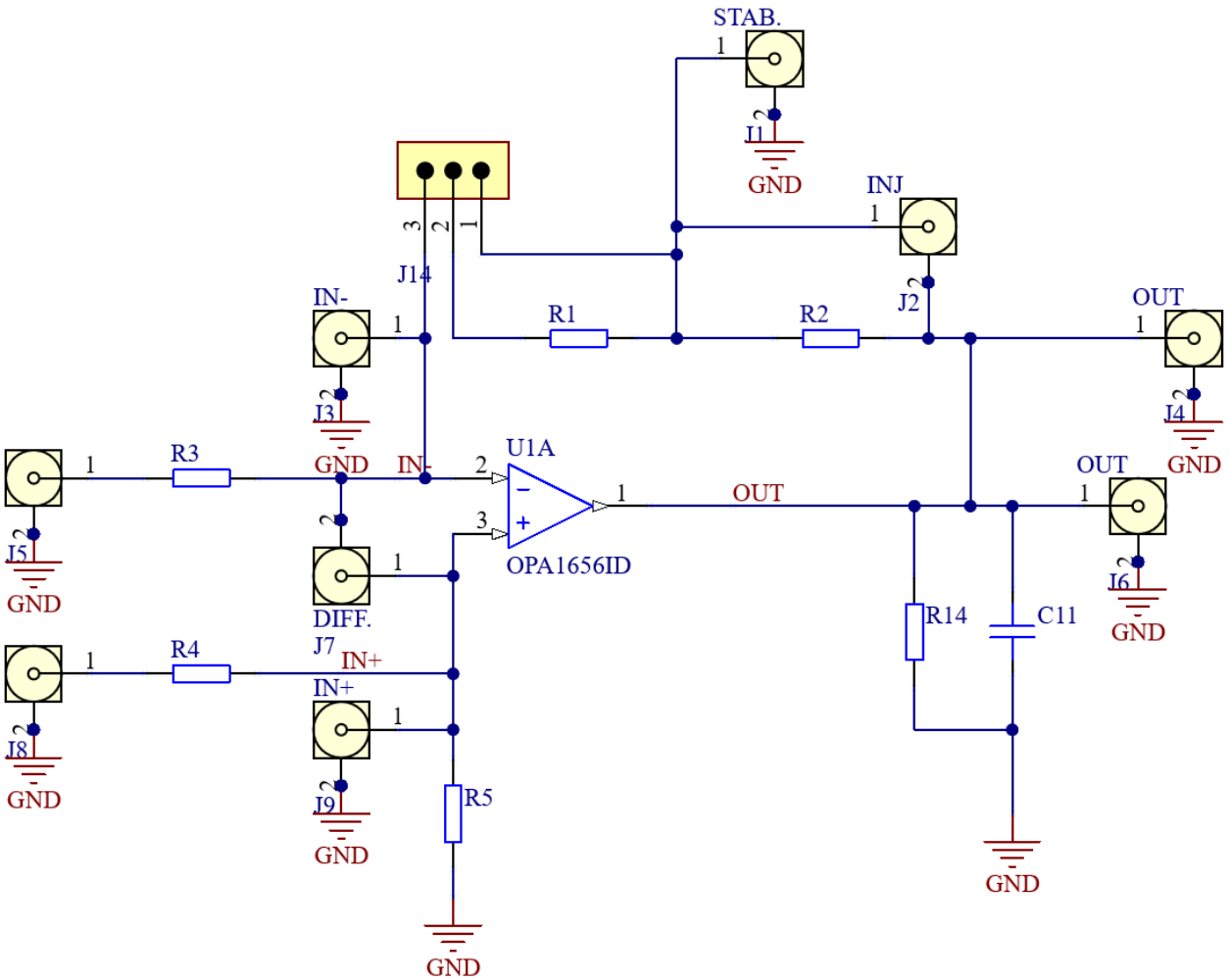
Operationa Amplifier



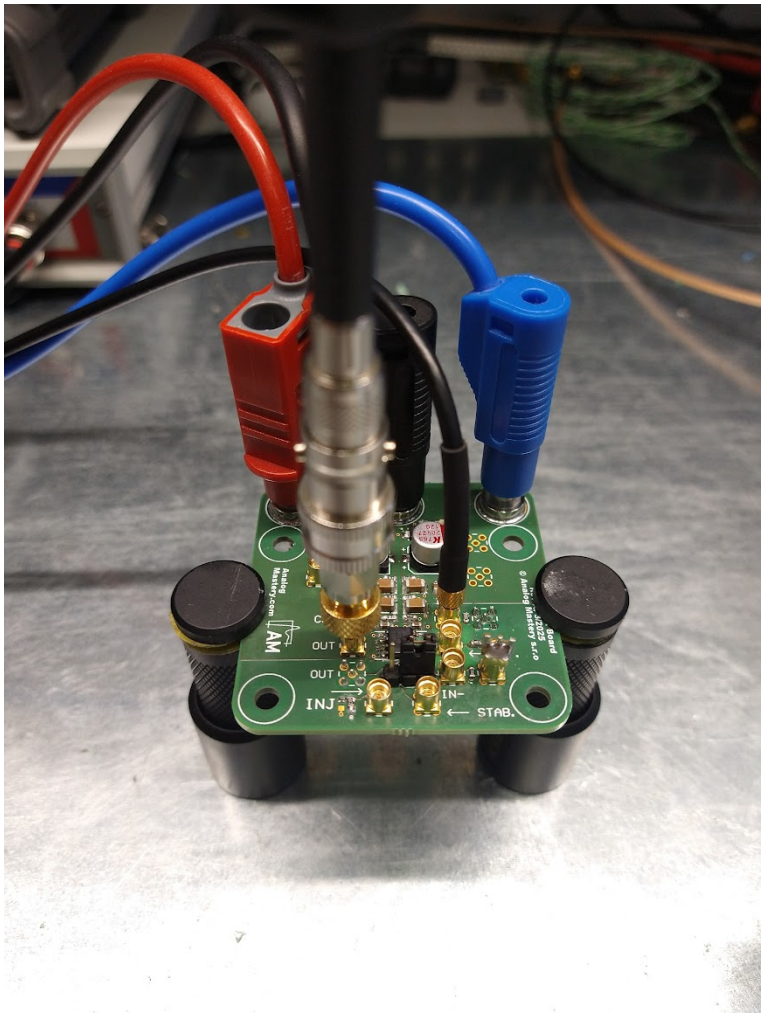
Test board

- A dedicated test board
  - All required test points
  - Multiple device configuration possible
  - Onboard load
  - GND removed from under inputs
  - All required connection points
- MMCX connectors
  - Hand free connection
  - Universal - Bode, SA, Oscilloscope
  - Rugged, cheap, great signal fidelity
- Board parasitic are part of your model
- Speeds up testing by a LOT

Test board

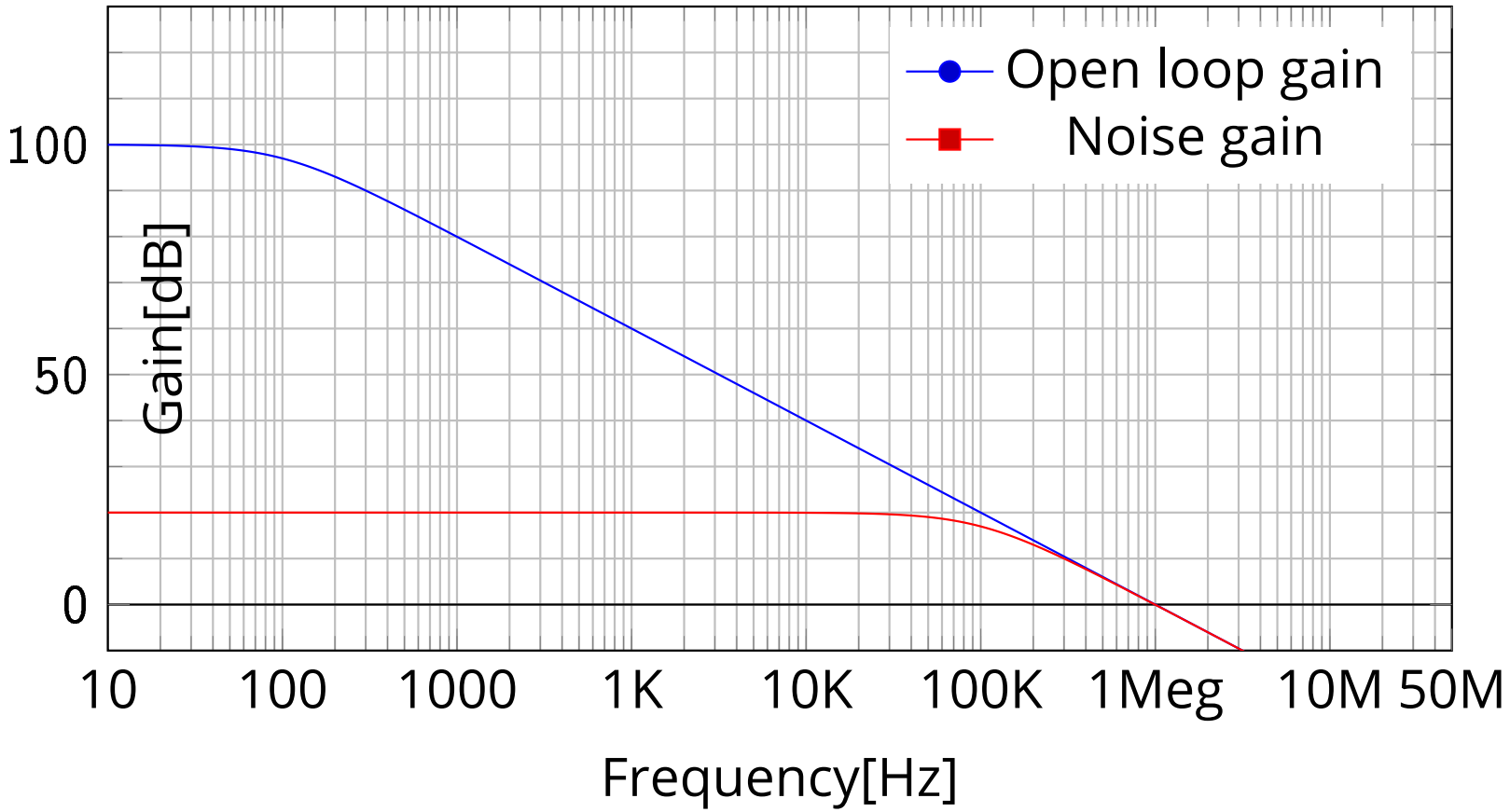


Test board



MMCX

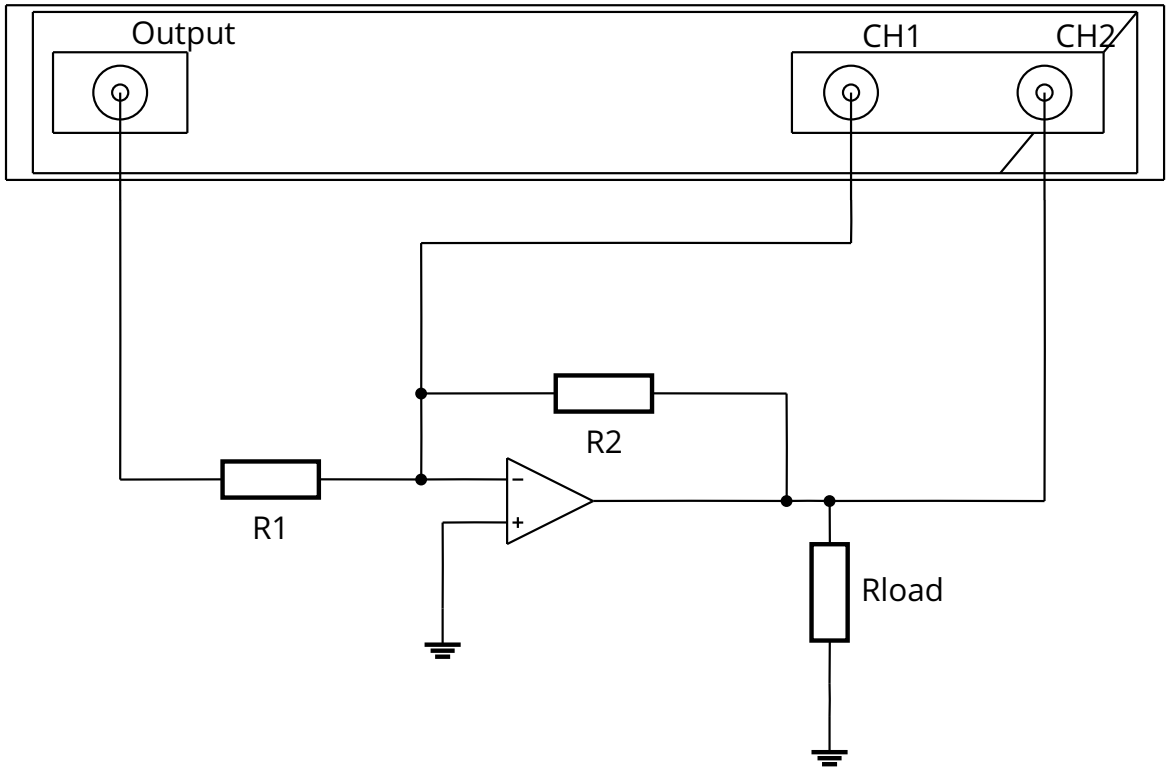
Amplifier gains



Open Loop Gain Measurement

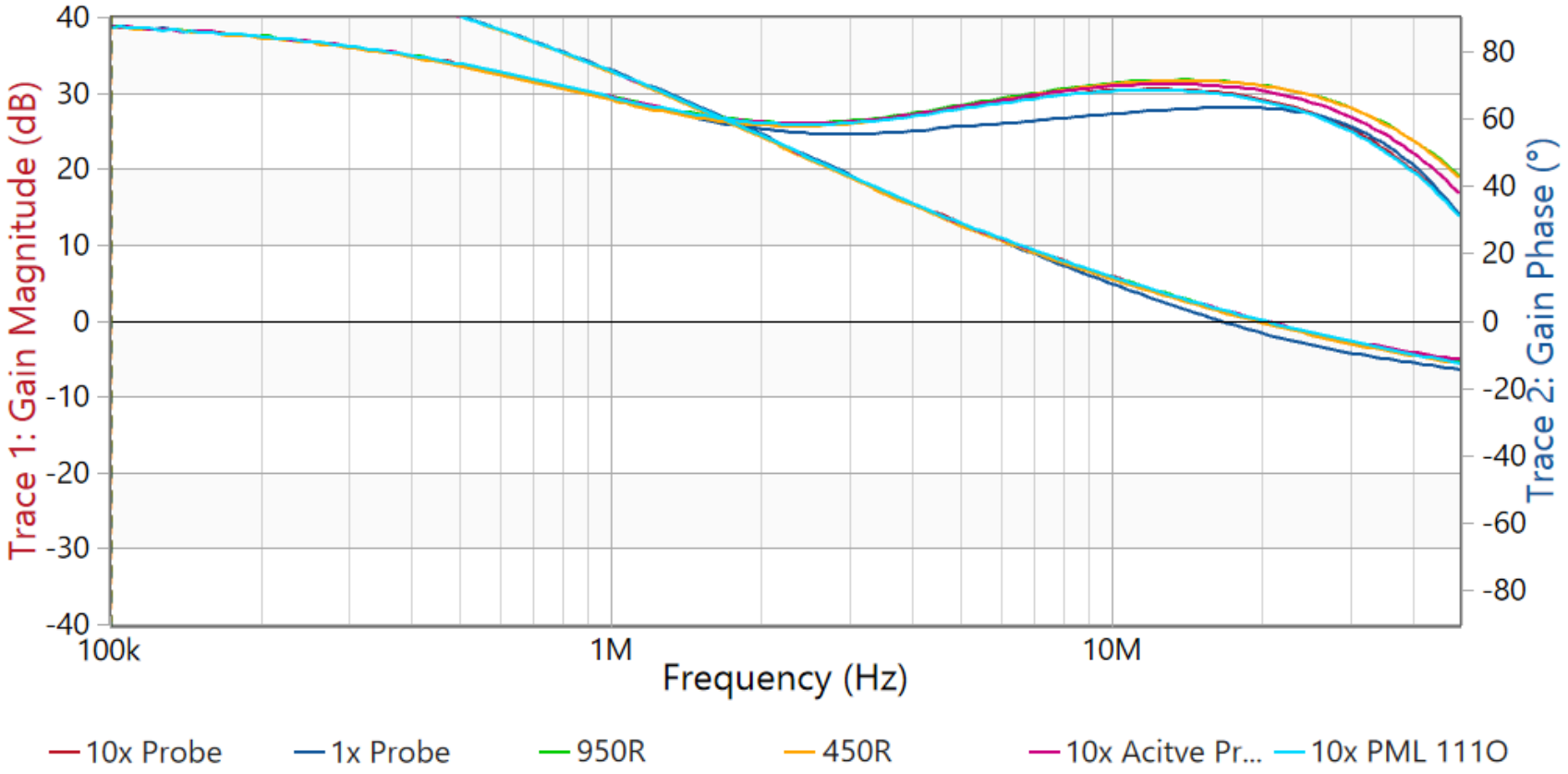
- High gain - 100dB+
- Wider bandwidth - MHz+ range
- Possible configurations:
  - Unity gain stable - FB injection
  - Non-inverting amplifier
  - Inverting amplifier

Measuring Open Loop Gain

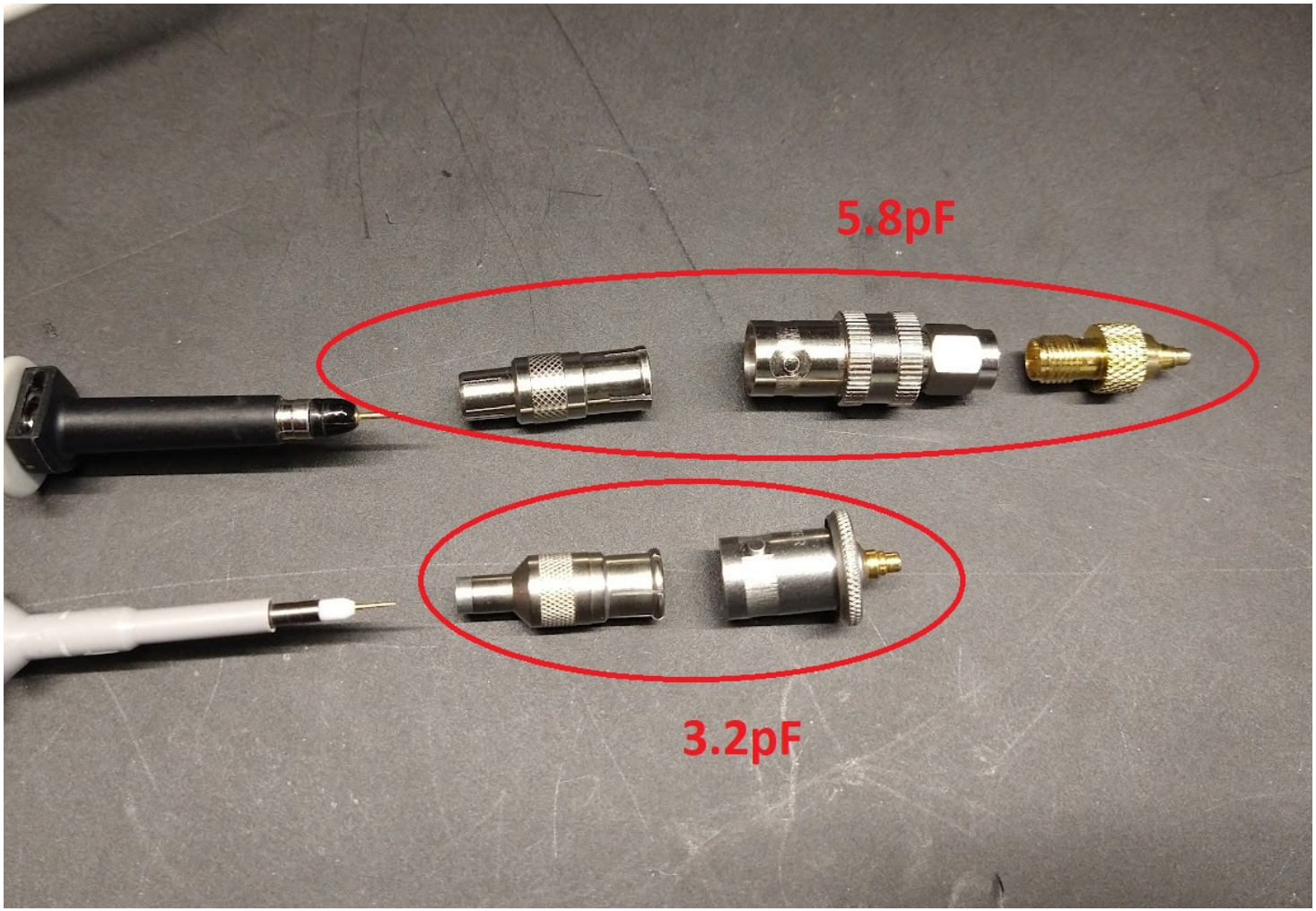


$$Vout = Au \cdot (V_+ - V_-)$$

Measurement results



Adapter capacitance



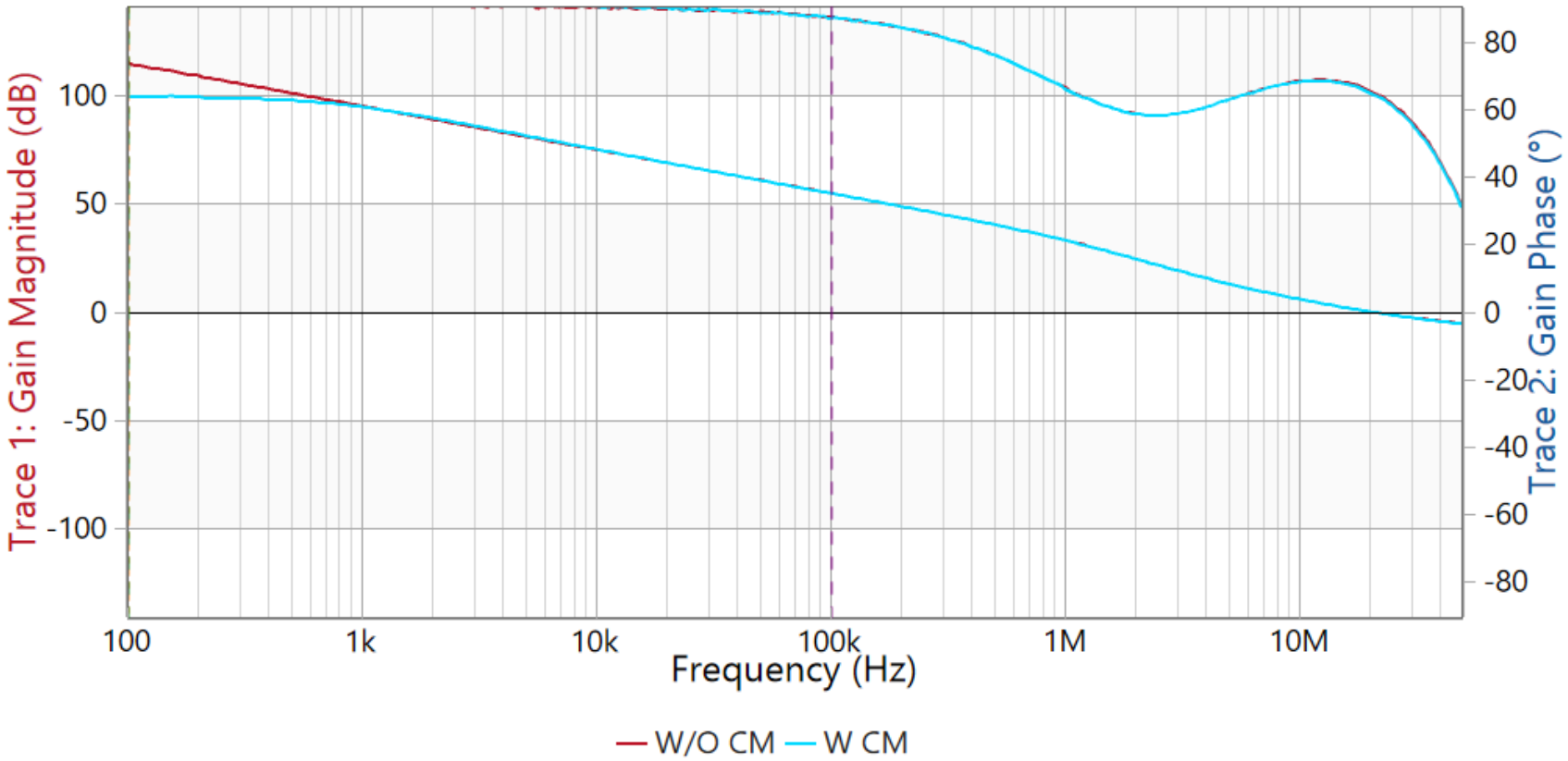
Adapter capacitance

- Minimize loading capacitance:
  - Low capacitance probes
  - No adapters
- Probe holder
- Pin receptacle
- MMCX probes
- DIY low Z probe - MMCX connector + 950 0Ω

Probe comparison

Probe	LF load	AC load	R load	Bode Termination
1x Probe	1M	100pf	1KΩ	1MΩ
10x Probe	10M	16pF	1KΩ	1MΩ
450Ω+ 50Ω cable	500Ω	2.1pF	N/A	50Ω
950Ω+ 50Ω cable	1kΩ	2.1pF	N/A	50Ω

LF measurements



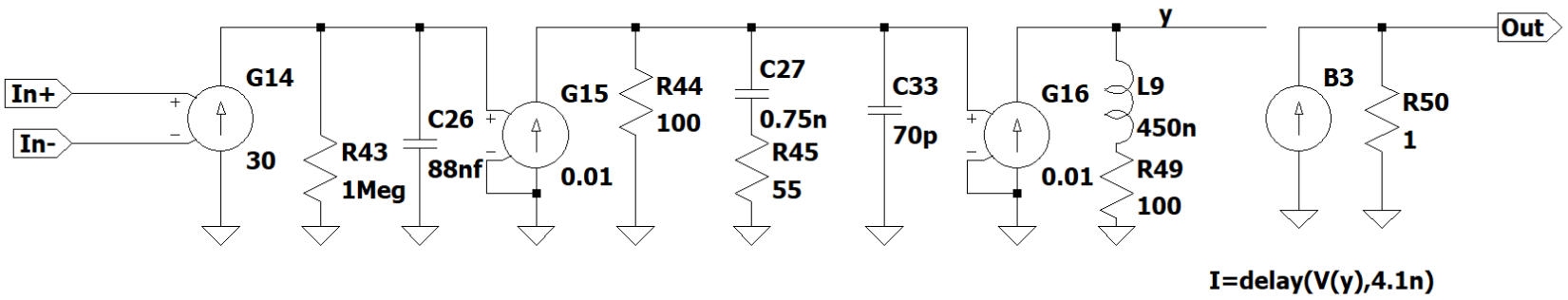
LF Error

- Caused by cable braid loops
- Same as two port shunt-through low impedance
- What can we do:
  - Use a differential probe
  - Use CM choke
  - Use injection transformer with 950Ω probes
  - Leave it as is...

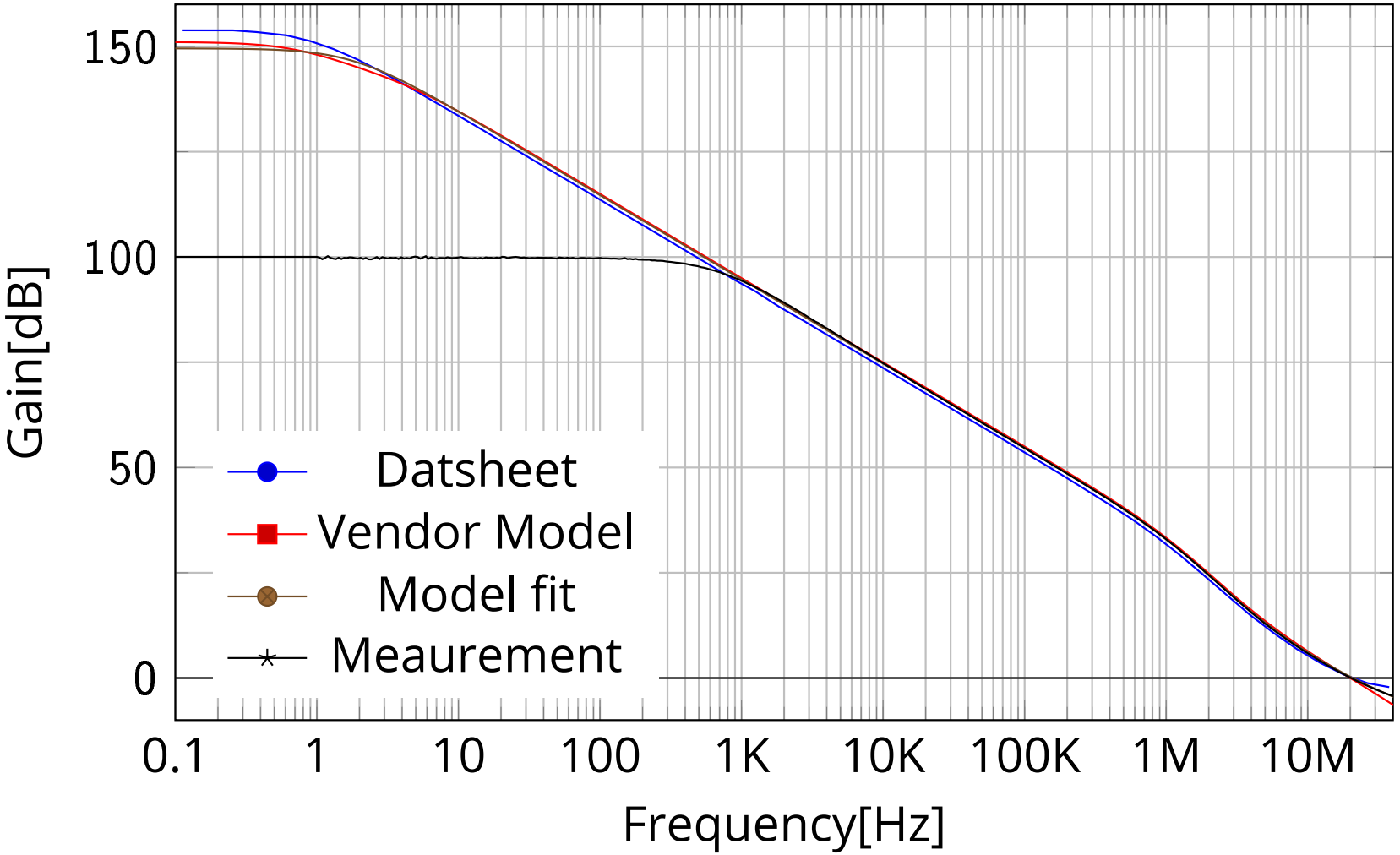
Using the data

- Use measured data as is with bode2spice utility
- Fit measured data to gain structure
- Pole zero analysis, or manual fitting
- You can correct for the braid error…

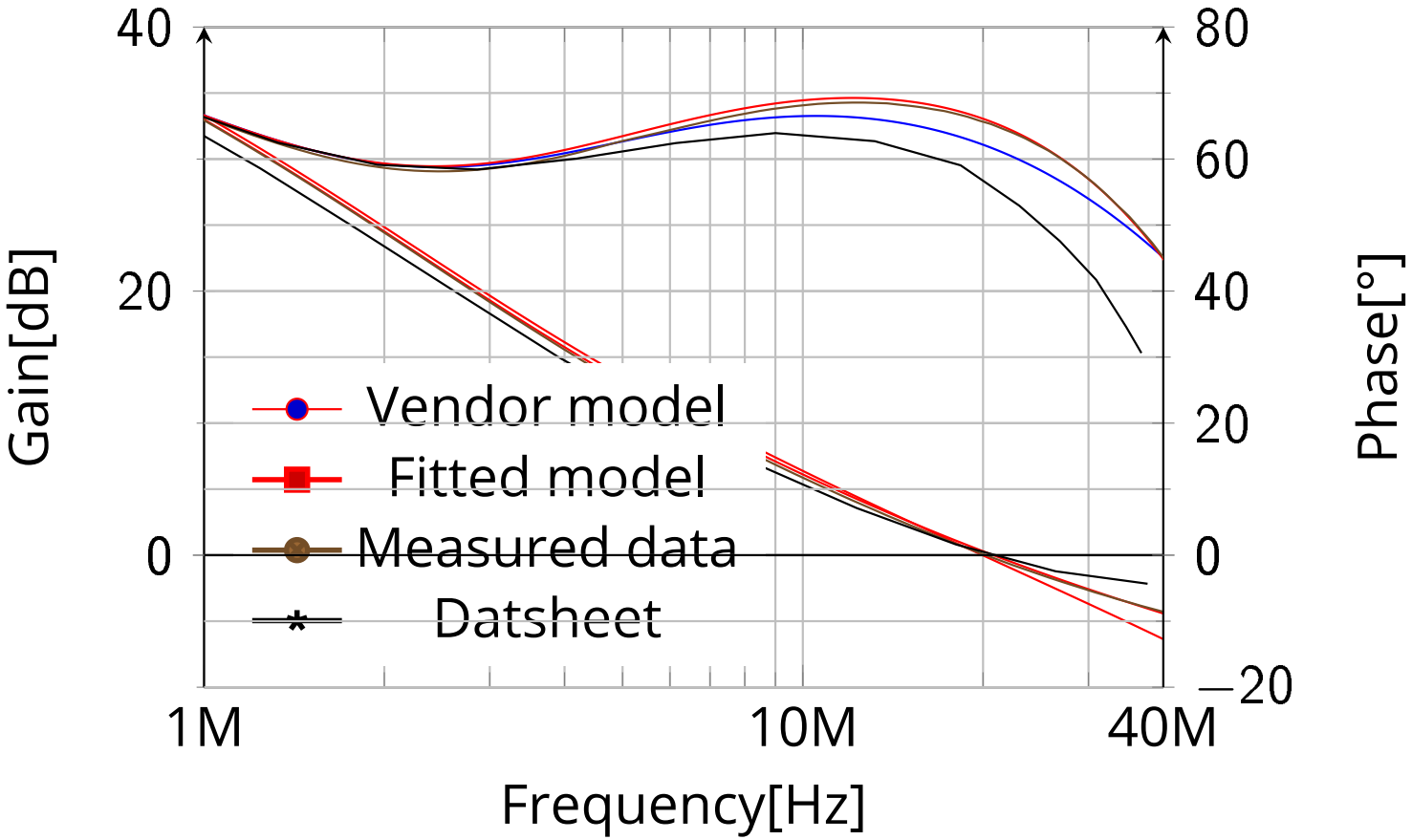
OLG model



Open Loop Gain



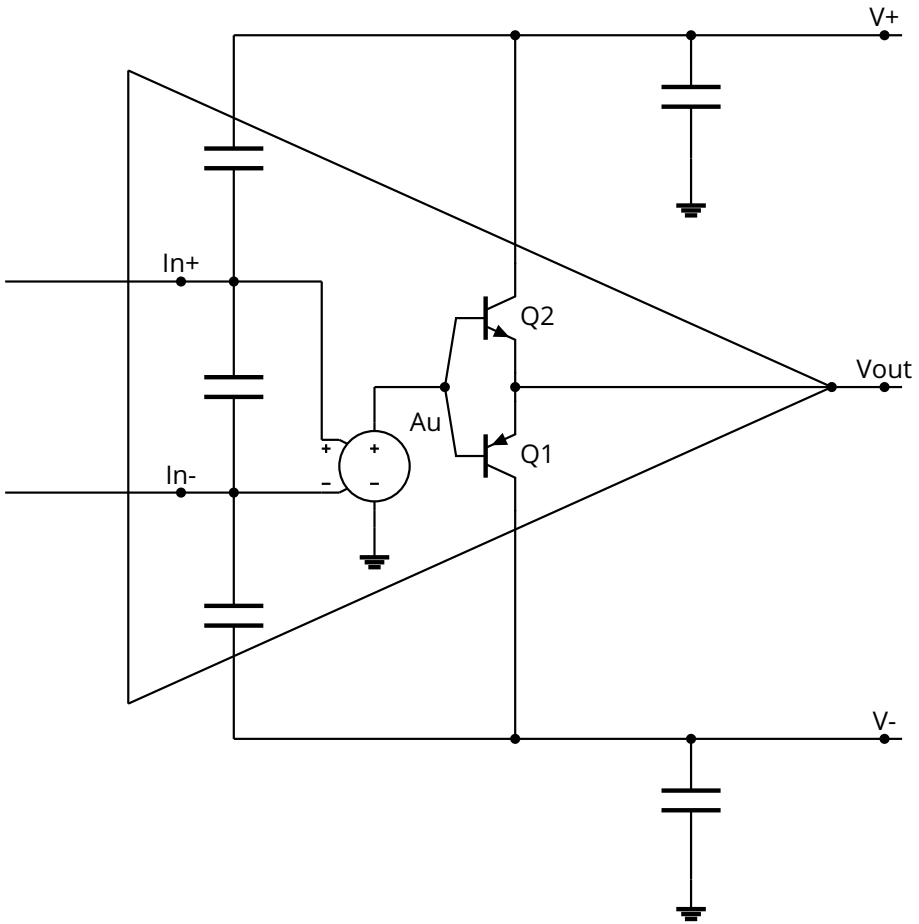
Open loop gain

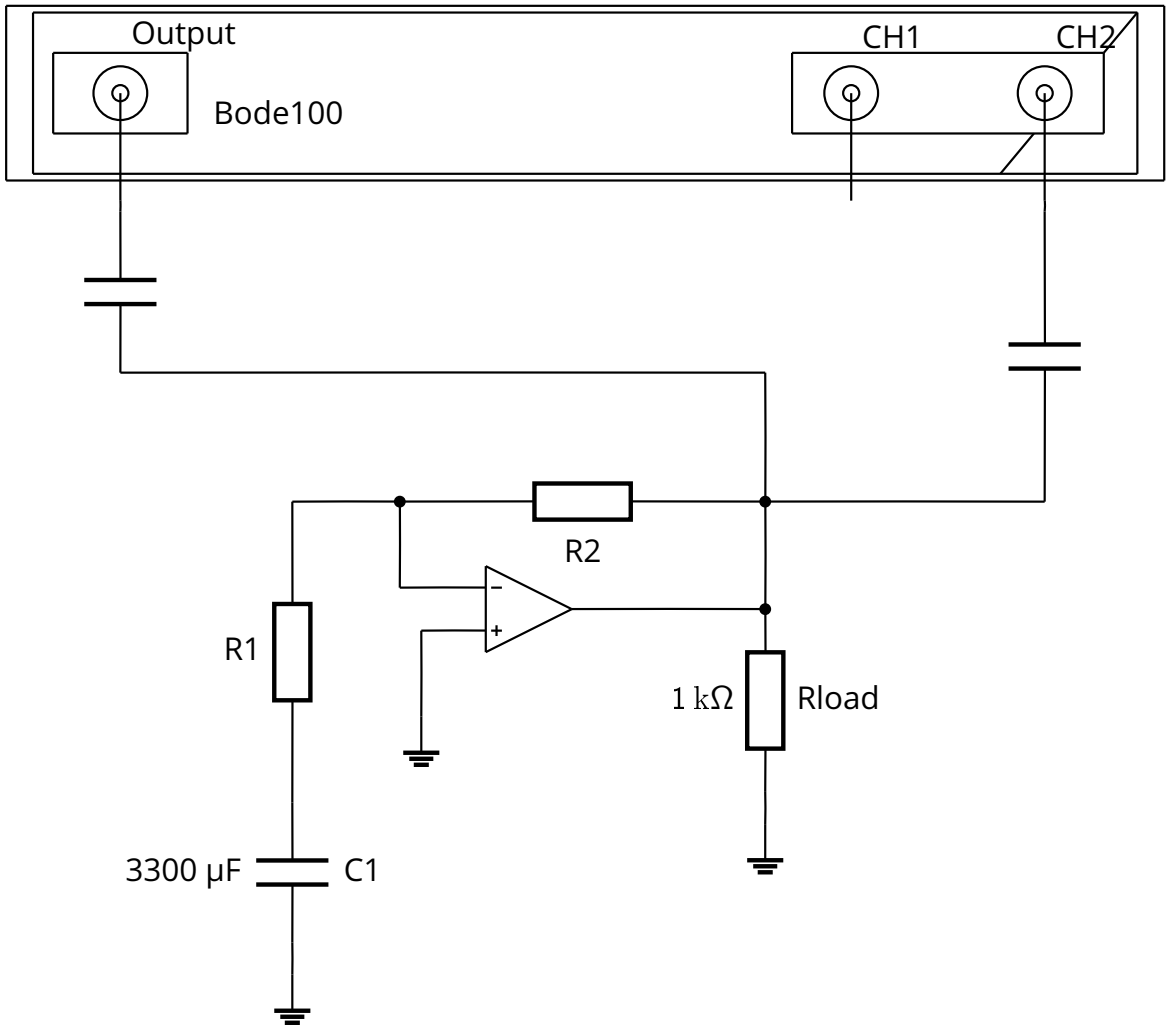


Output Impedance

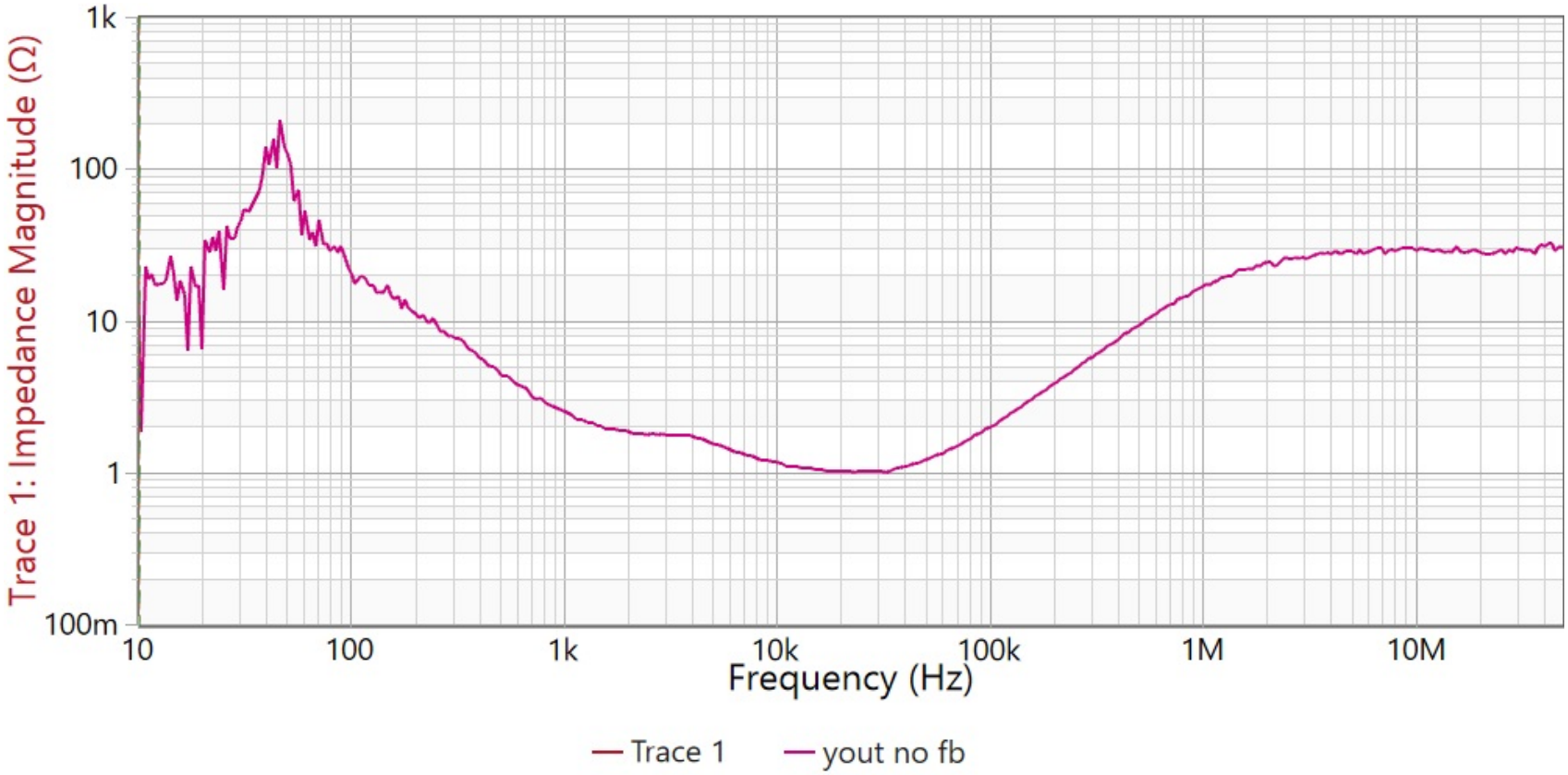
- Reduced by negative feedback
- We are interested in output impedance without feedback
- Still need feedback for defined operation point.
- RC filter to attenuate feedback
  - High impedance, watch out for offset voltages and operation point
  - Use buffer with high input bias parts

Output impedance





Output impedance



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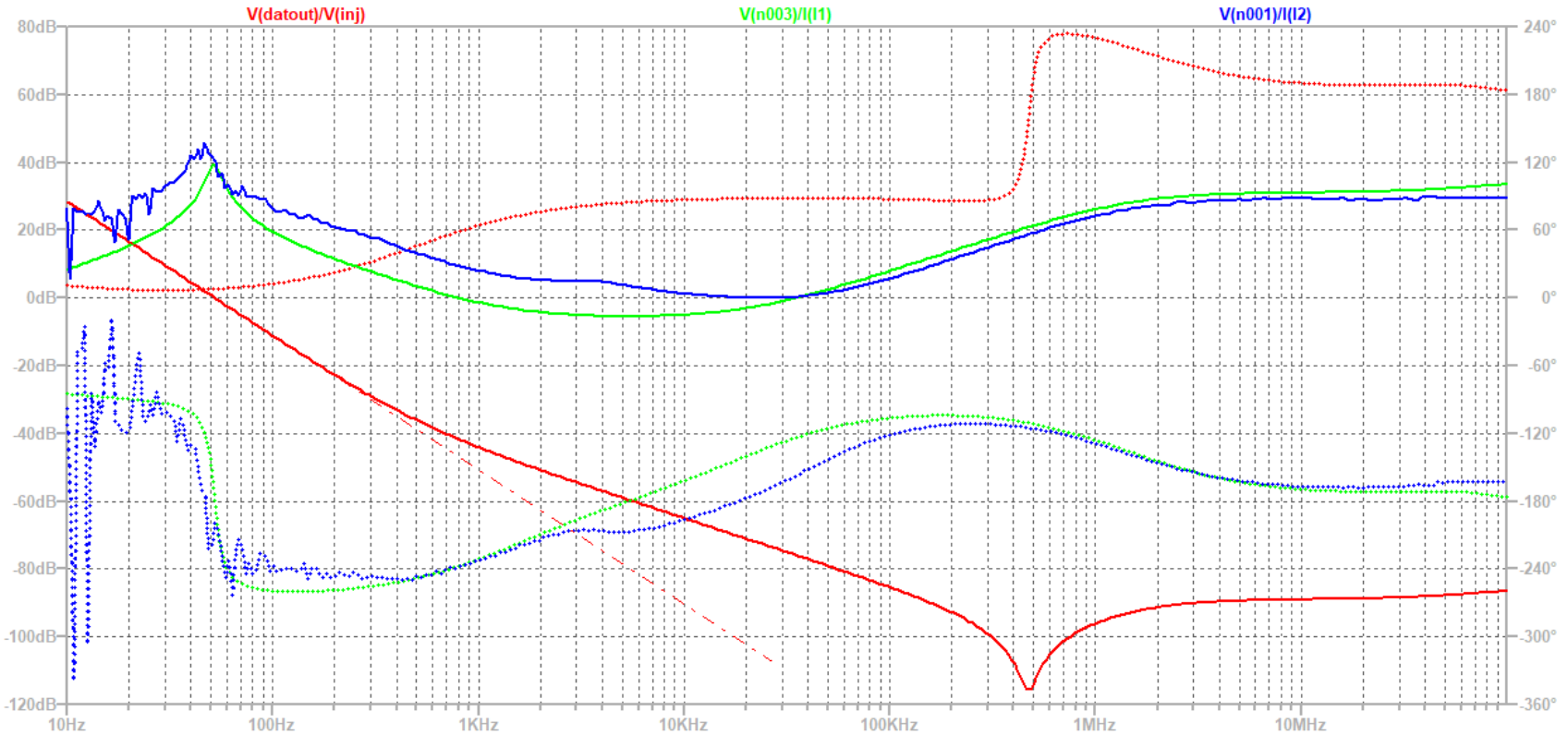

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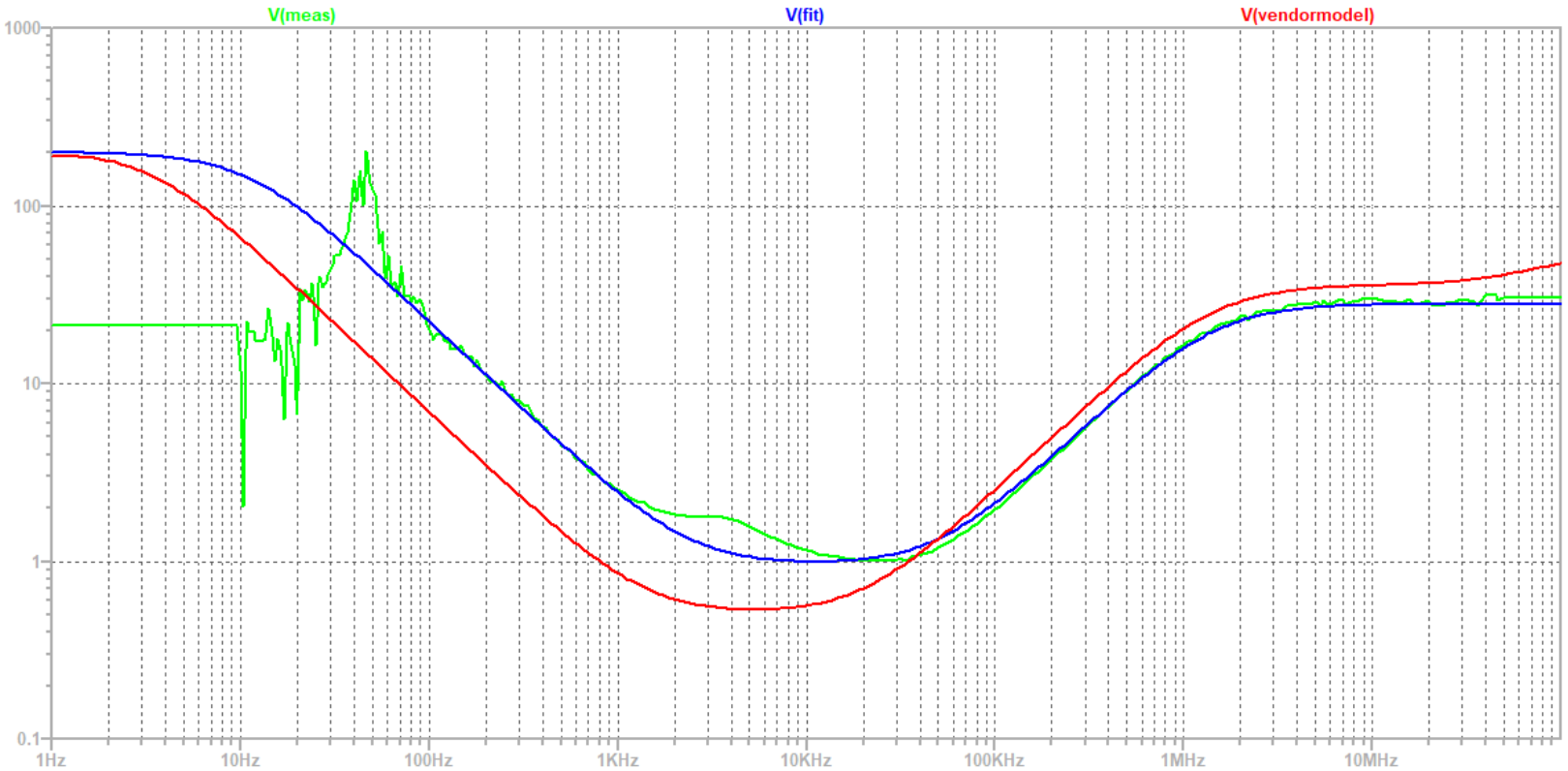
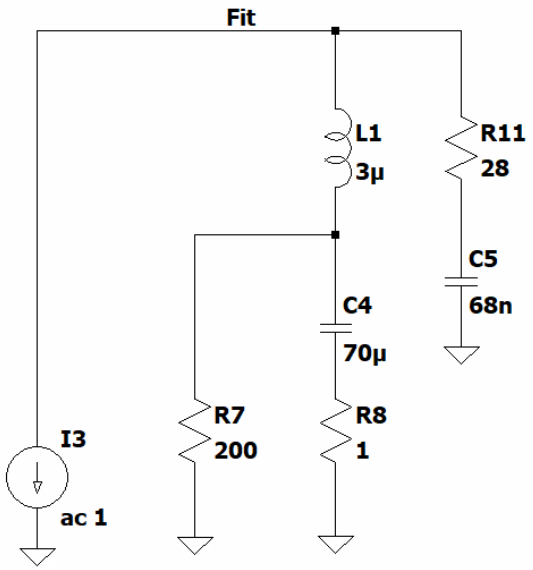
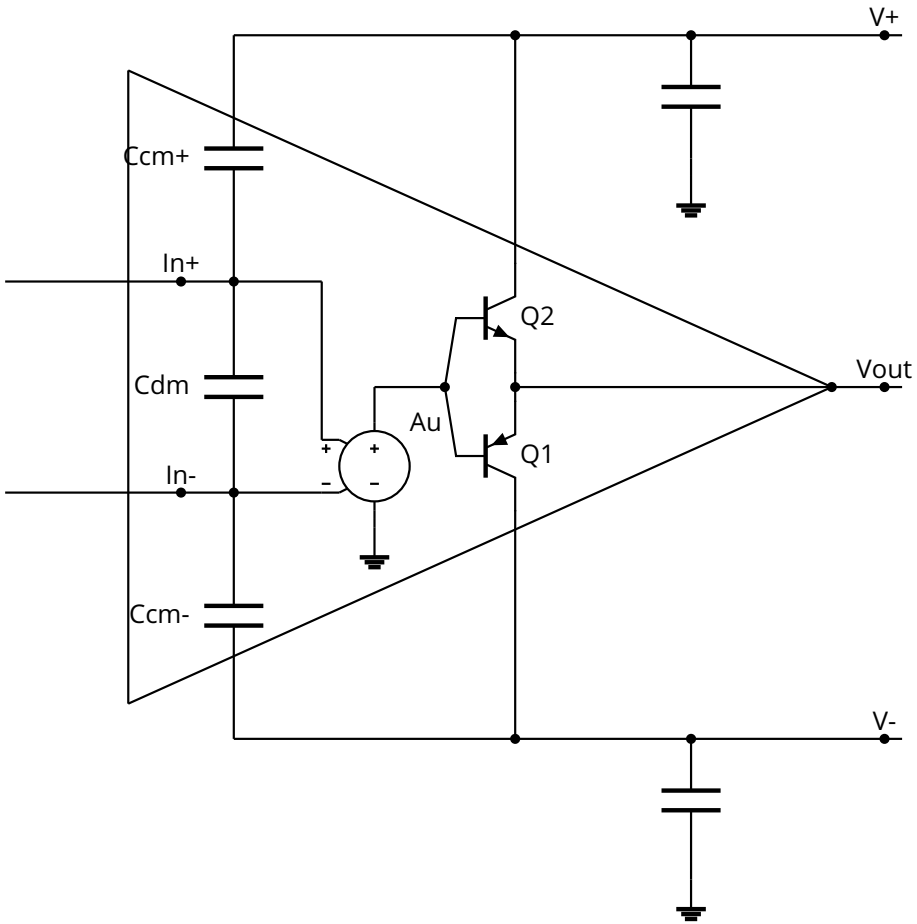


Output impedance - model

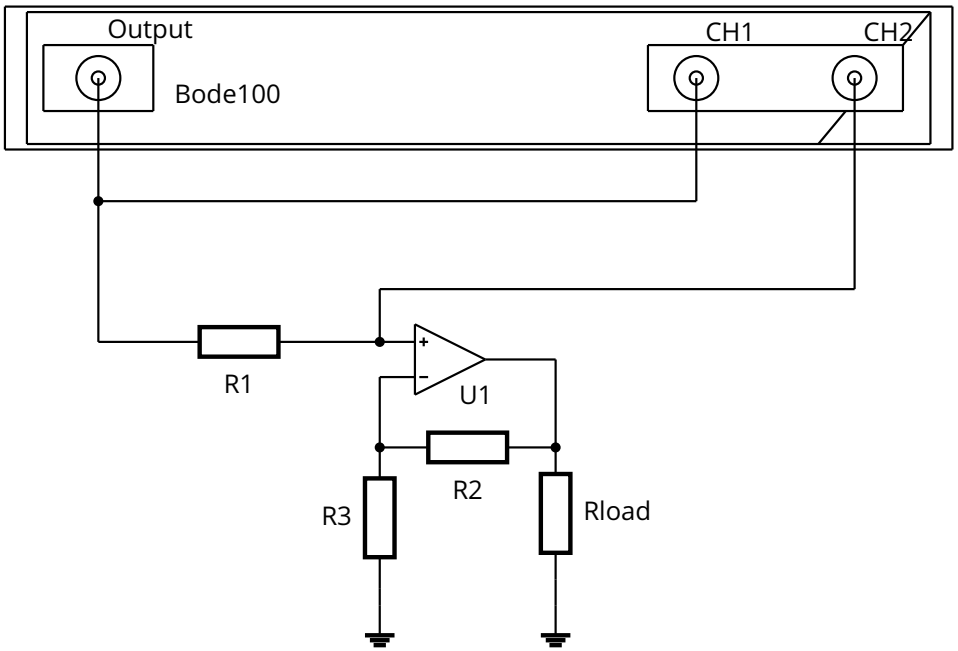


- Great resource about output impedance modeling slyt677

Input Impedance



CM Capacitance



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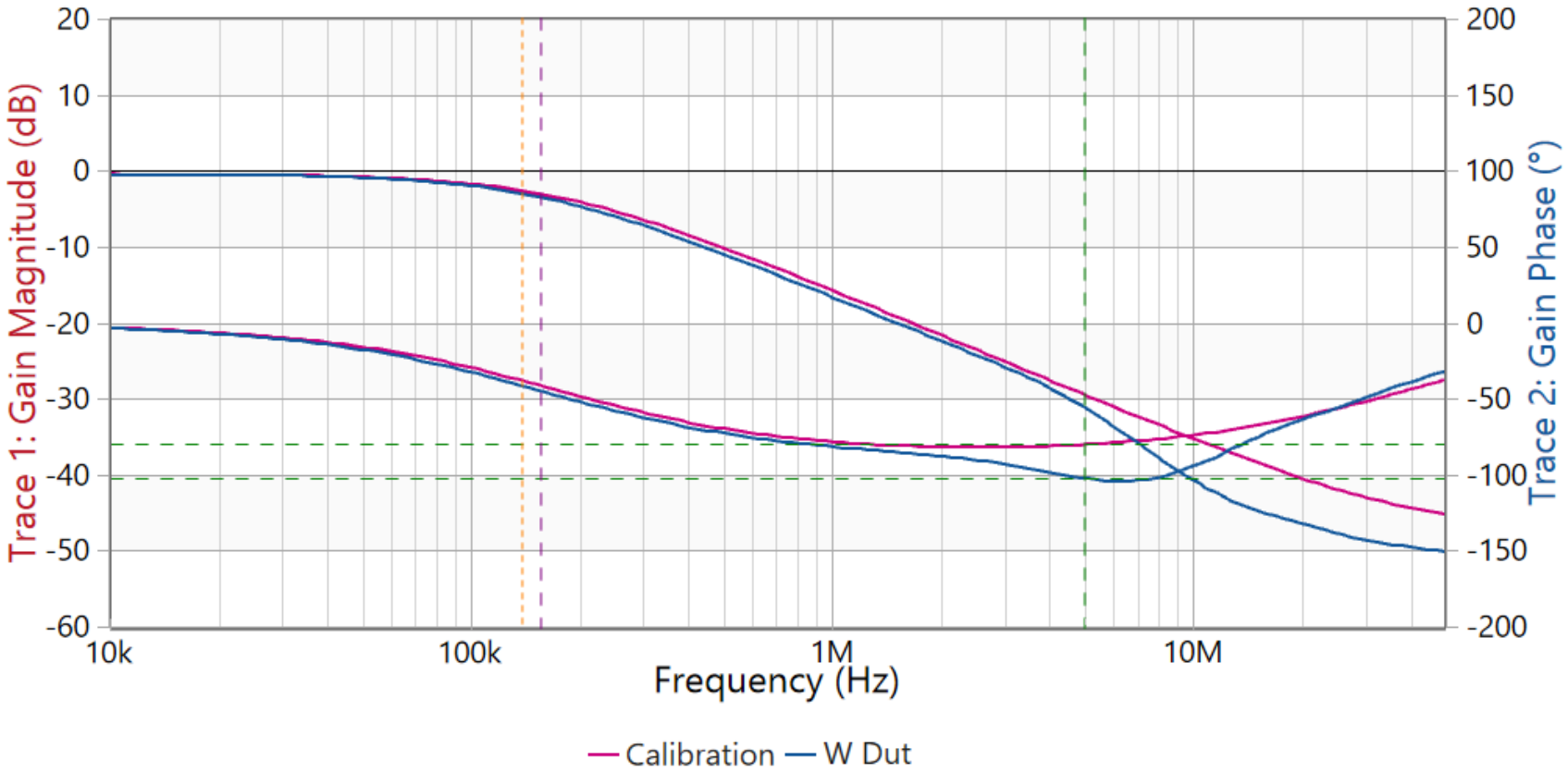
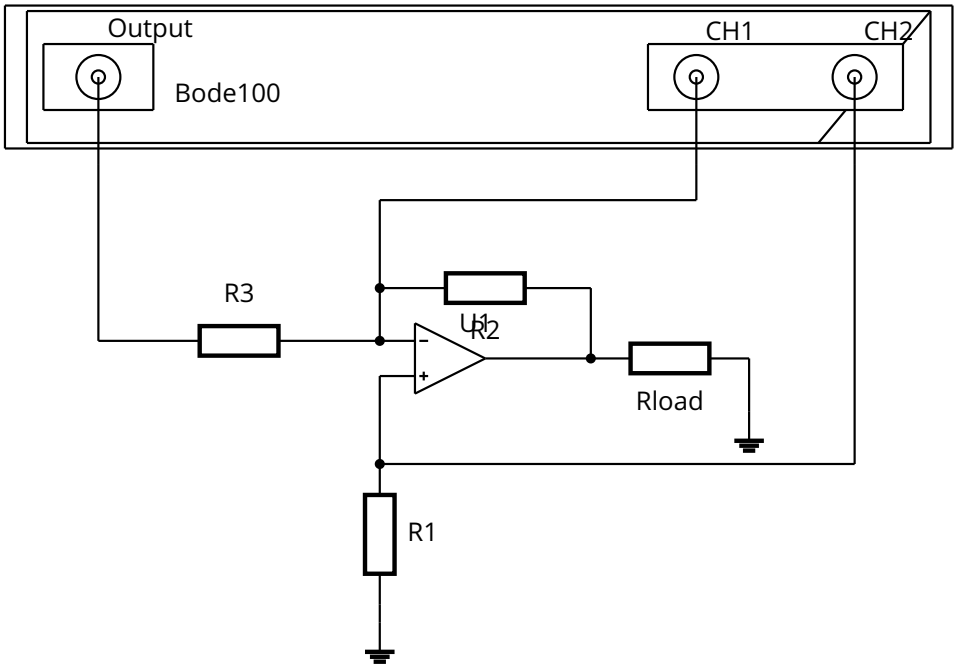


DM impedance



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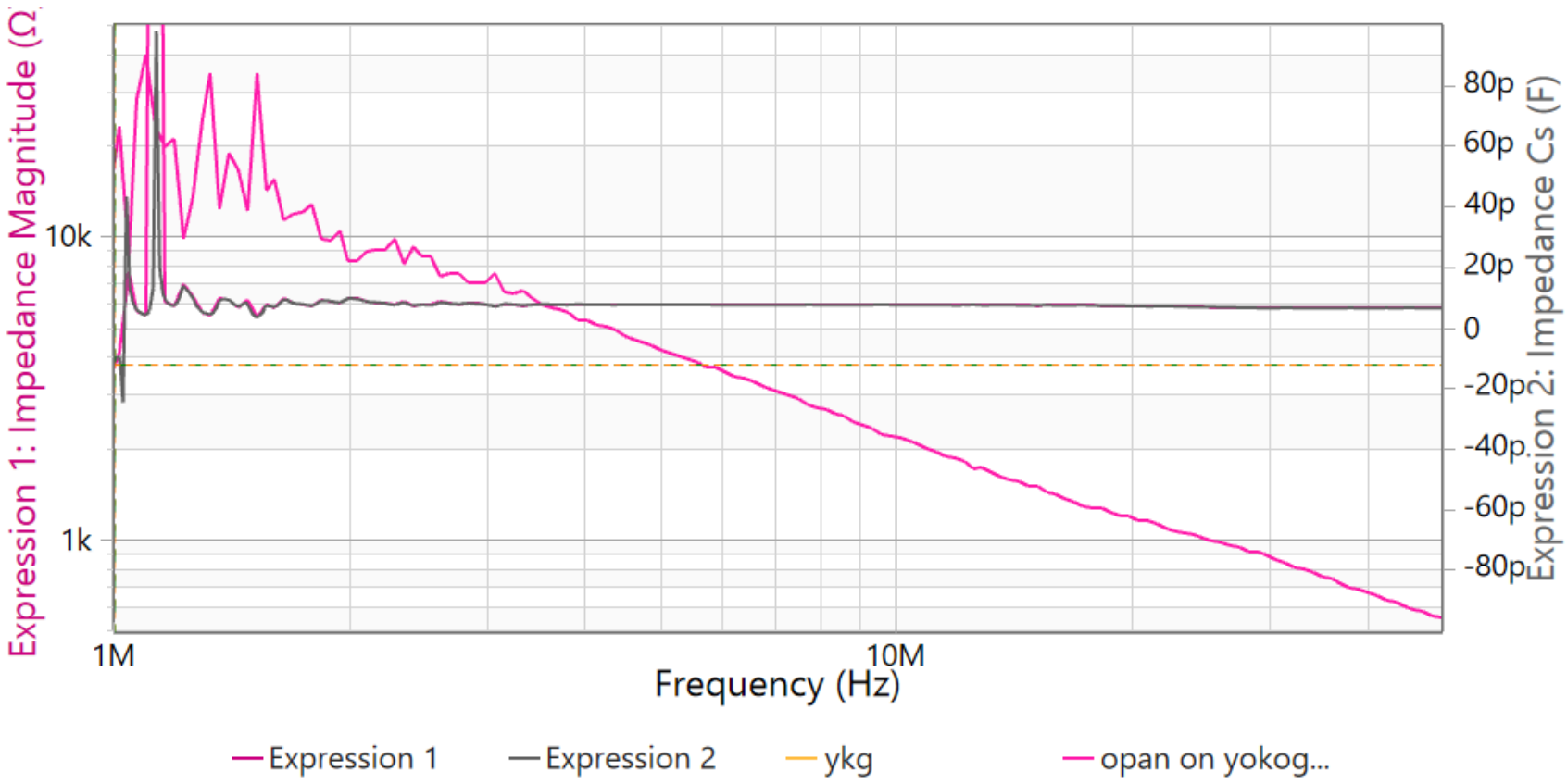
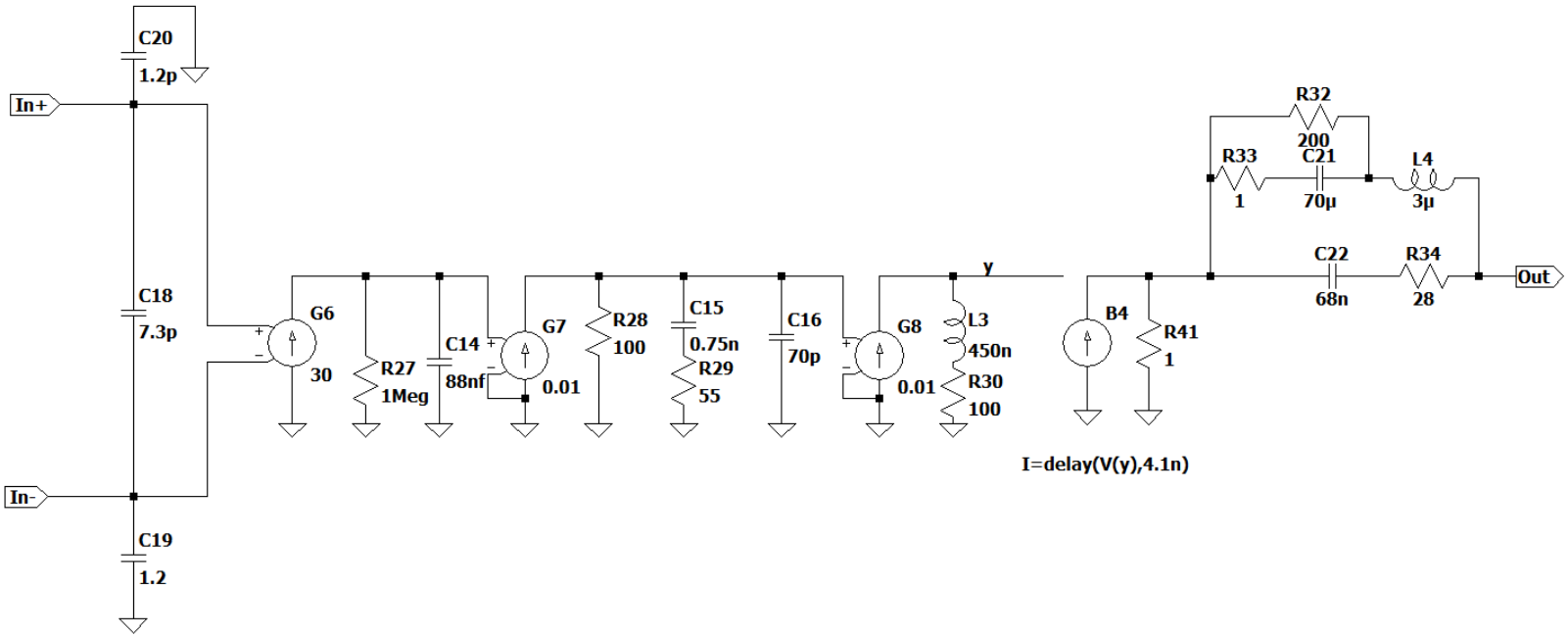
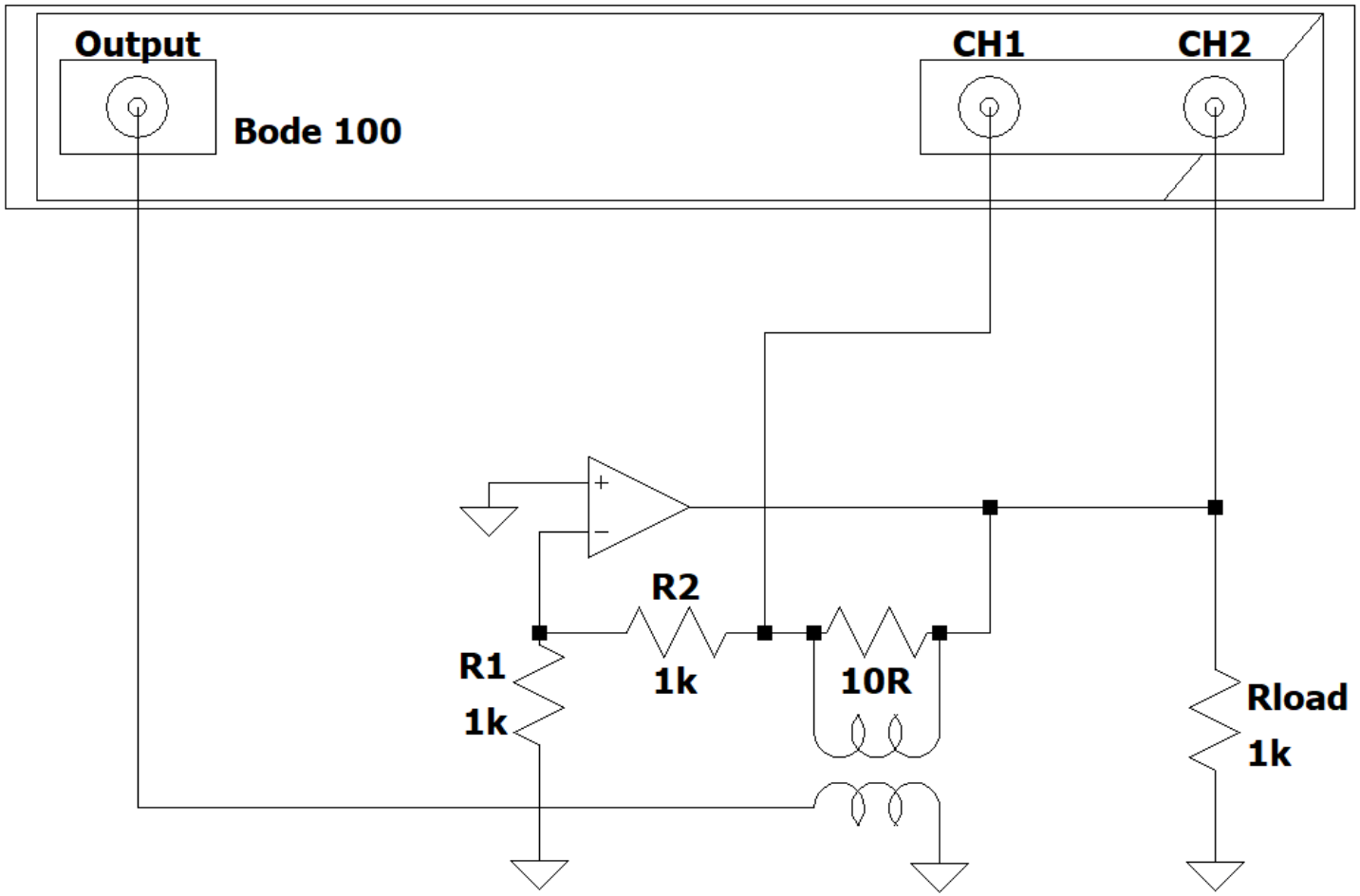


Final Model



Loop Gain measurement



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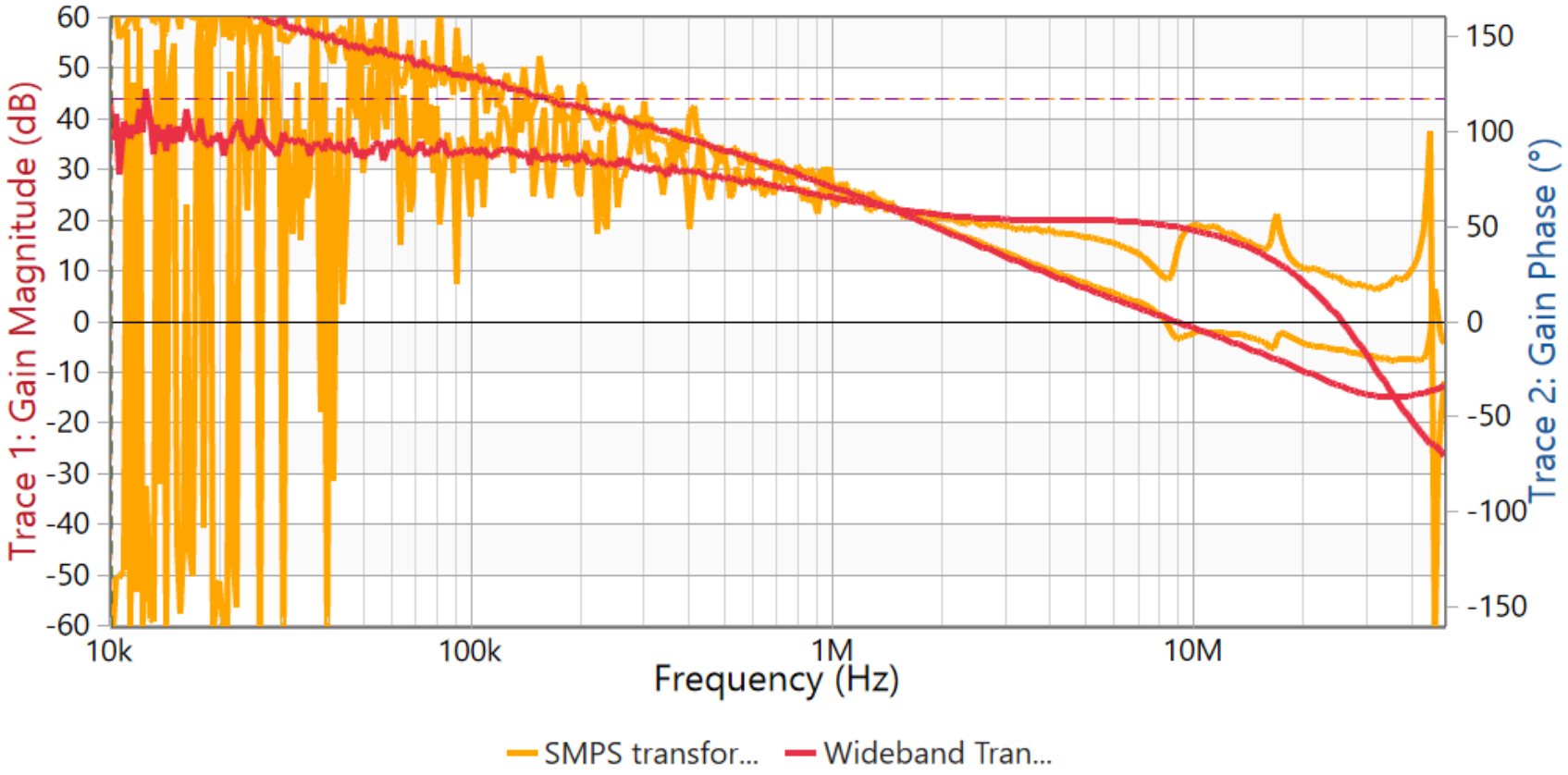
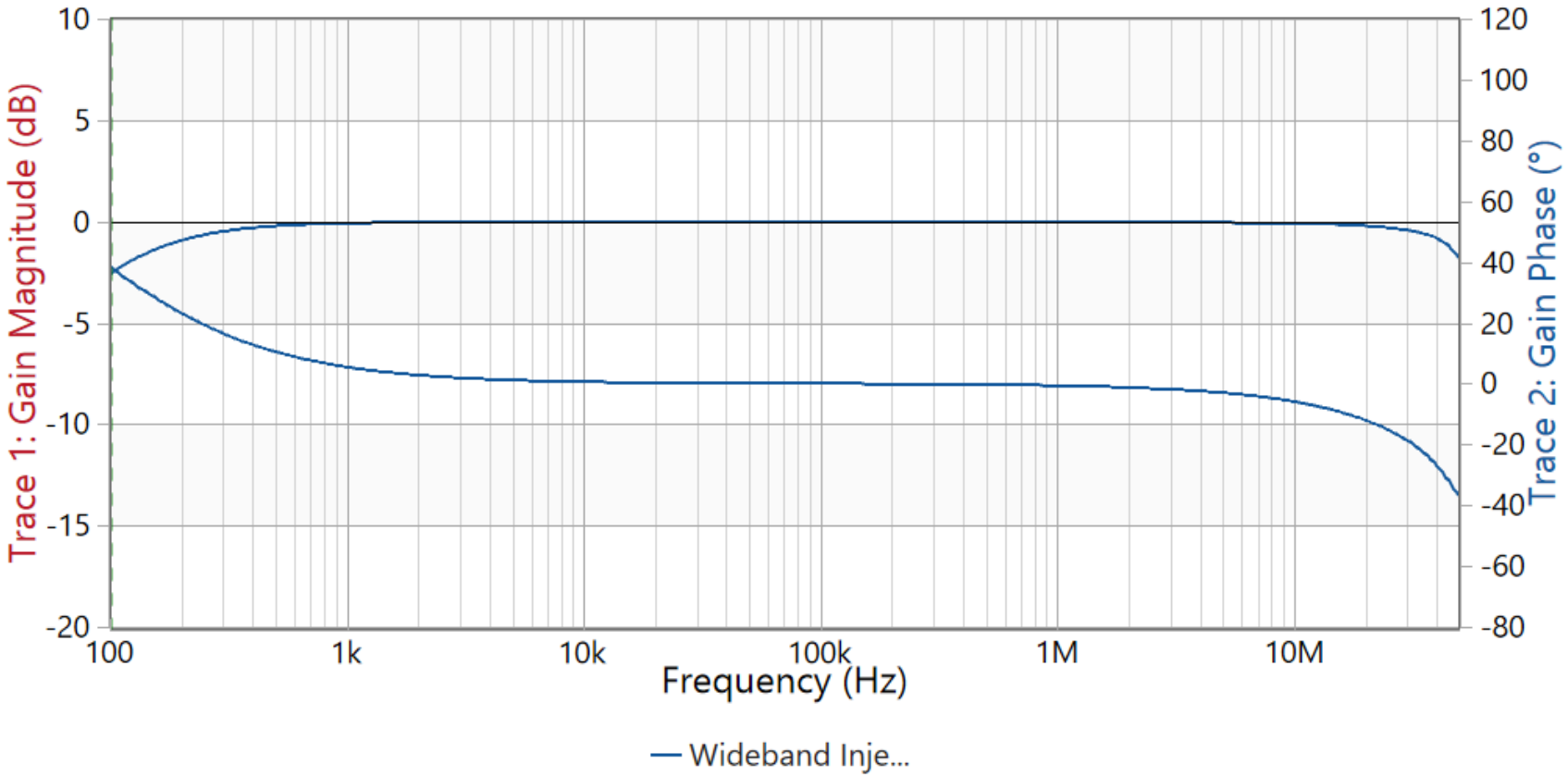


Wideband Injection Transformer



Summary

- You know how to measure:
  - Open loop gain
  - Open loop output impedance
  - Input capacitance
- What to watch out when measuring
- And how to turn the measurements into model

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