TES Simulation

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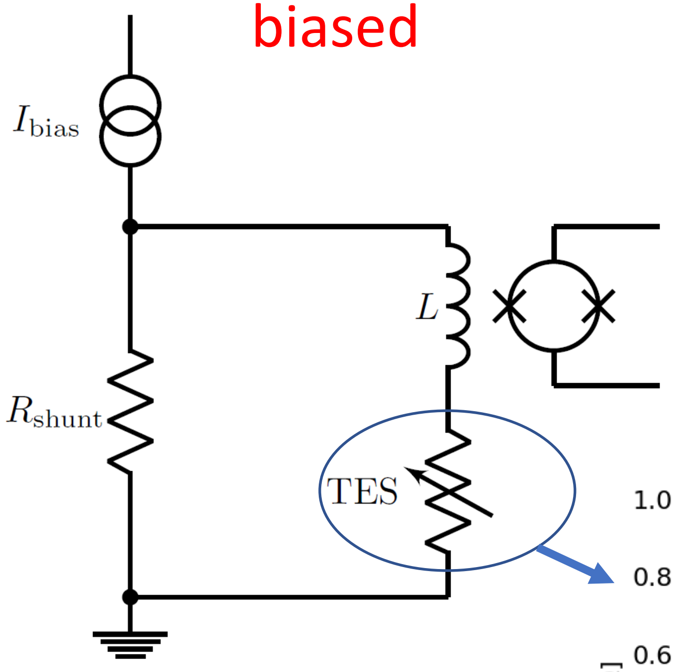
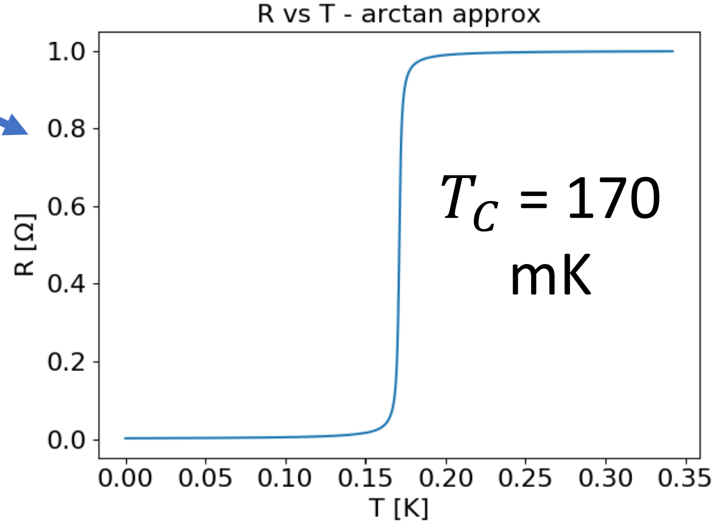
TES Model (Minimal complexity)

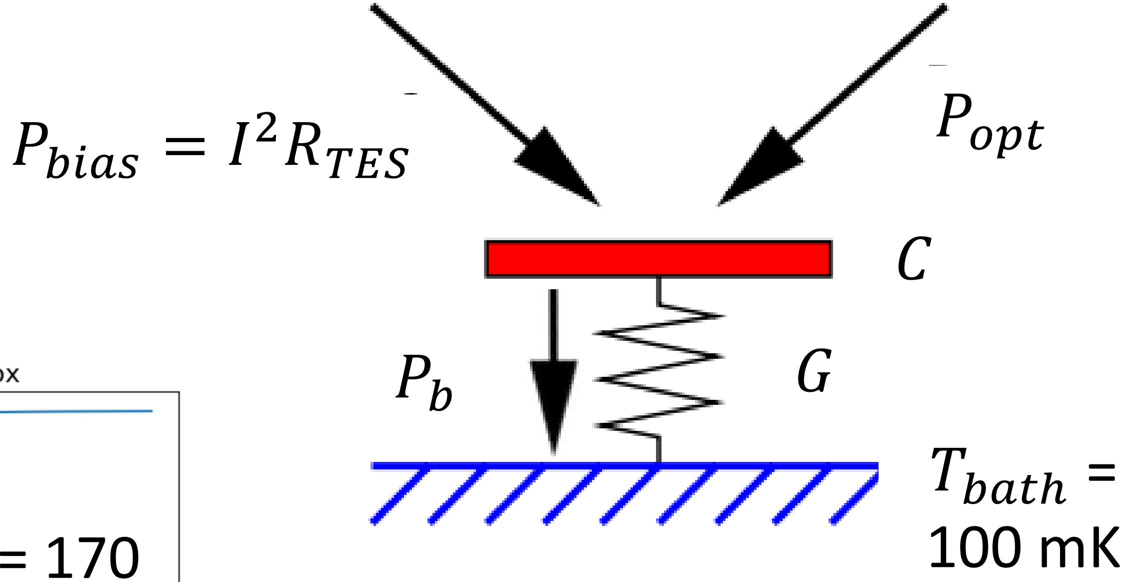
Electrical circuit – DC biased



$$L\frac{dI}{dt} = V - IR_{TES} - IR_{shunt}$$



Thermal circuit



$$C\frac{dT}{dt} = -P_b + I^2 R_{TES} + P_{opt}$$

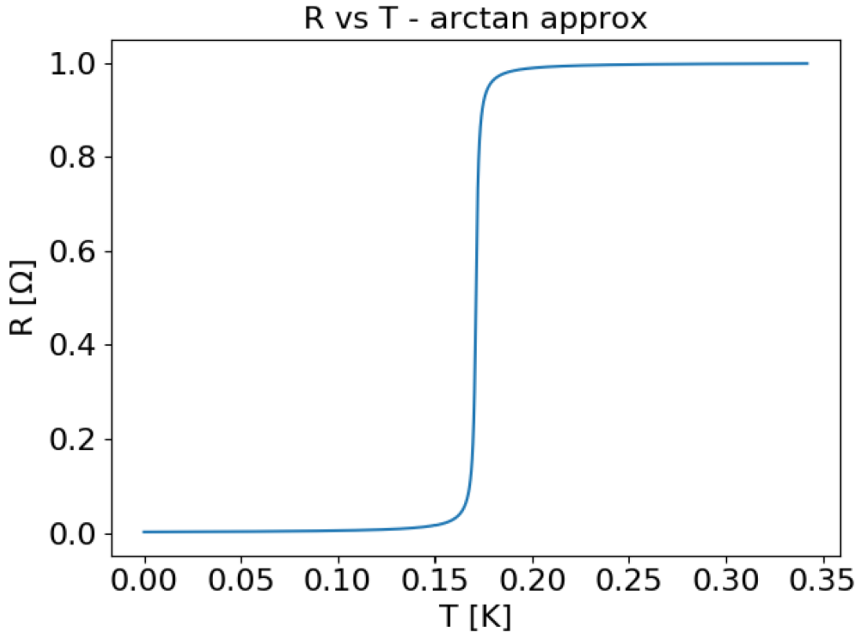
$$P_b = \frac{G}{nT^{n-1}}\left(T^n - T_{bath}^n\right)$$ with n=4

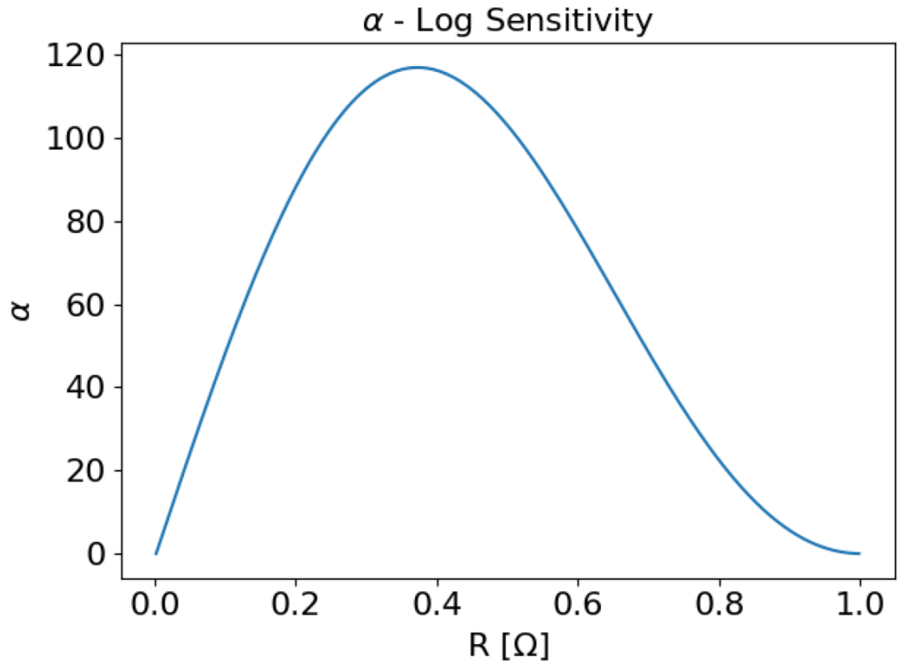
Irwin & Hilton. Transition-edge sensors, 2005: https://doi.org/10.1007/10933596_3.

Assumptions

- For LiteBIRD we expect $P_{opt} \approx 0.3 - 0.5$ pW depending on the band. For simplicity I assumed $P_{opt} = 0.5$ pW.
- Saturation power. I assumed a target $P_{sat} = 2.5 \times P_{opt}$.
- “Normal” thermal time constant $\tau_0 = \frac{C}{G}$. Target value = 33 ms.
- From expected P_{sat} and τ_0, using expression for P_b we can define $G \sim 3.3 \times 10^{-11}$W/K and $C \sim 1 \times 10^{-12}$ J/K.
- Inductor $L = 1$ nH. Small enough to have $\tau_{el} = \frac{L}{R} \ll \tau_{th}$.
- We need $R_{shunt} \ll R_{TES}$ to keep the TES voltage biased: $R_{shunt} = 0.02\ \Omega$.
- **In the Df-Mux system TES are AC biased. Since the bias frequency >> $\frac{1}{\tau_{th}}$ >> signal variations we expect the DC approx to be good enough for now. However I have an AC version of the code that can be used for more extended studies if needed.**

Assumptions





- Logarithmic responsivity: $\alpha = \frac{d\ logR}{d\ logT}$
- Loop Gain: $\mathcal{L} = \frac{\alpha P_{bias}}{GT}$
- Thermal time constant: $\tau_{th} = \frac{\tau_0}{\mathcal{L}+1}$

if $\mathcal{L} \gg 1$

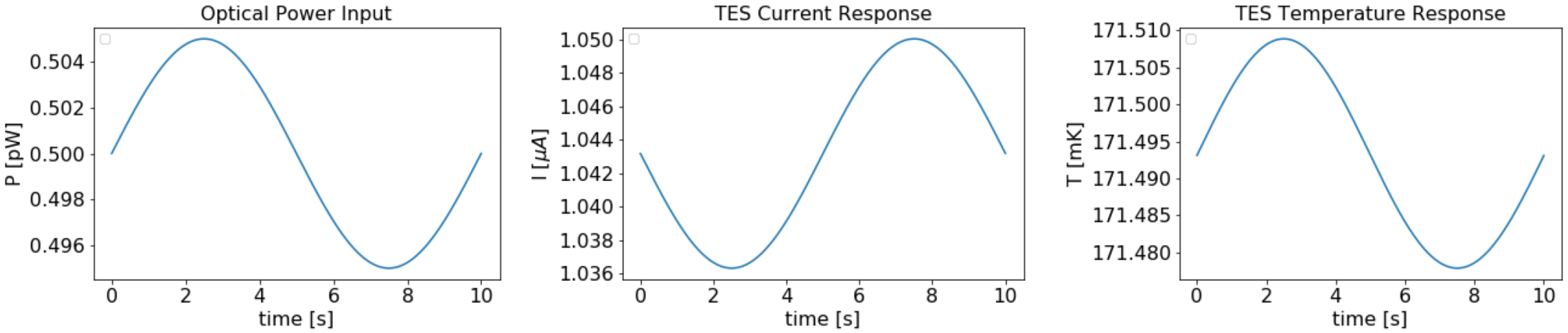
- Current responsivity: $S_I = -\frac{1}{V}\frac{\mathcal{L}}{\mathcal{L}+1}\frac{1}{1+\omega\tau_{th}}$

Target $\mathcal{L}$~$10-15 \Rightarrow \tau_{th}$~3 ms

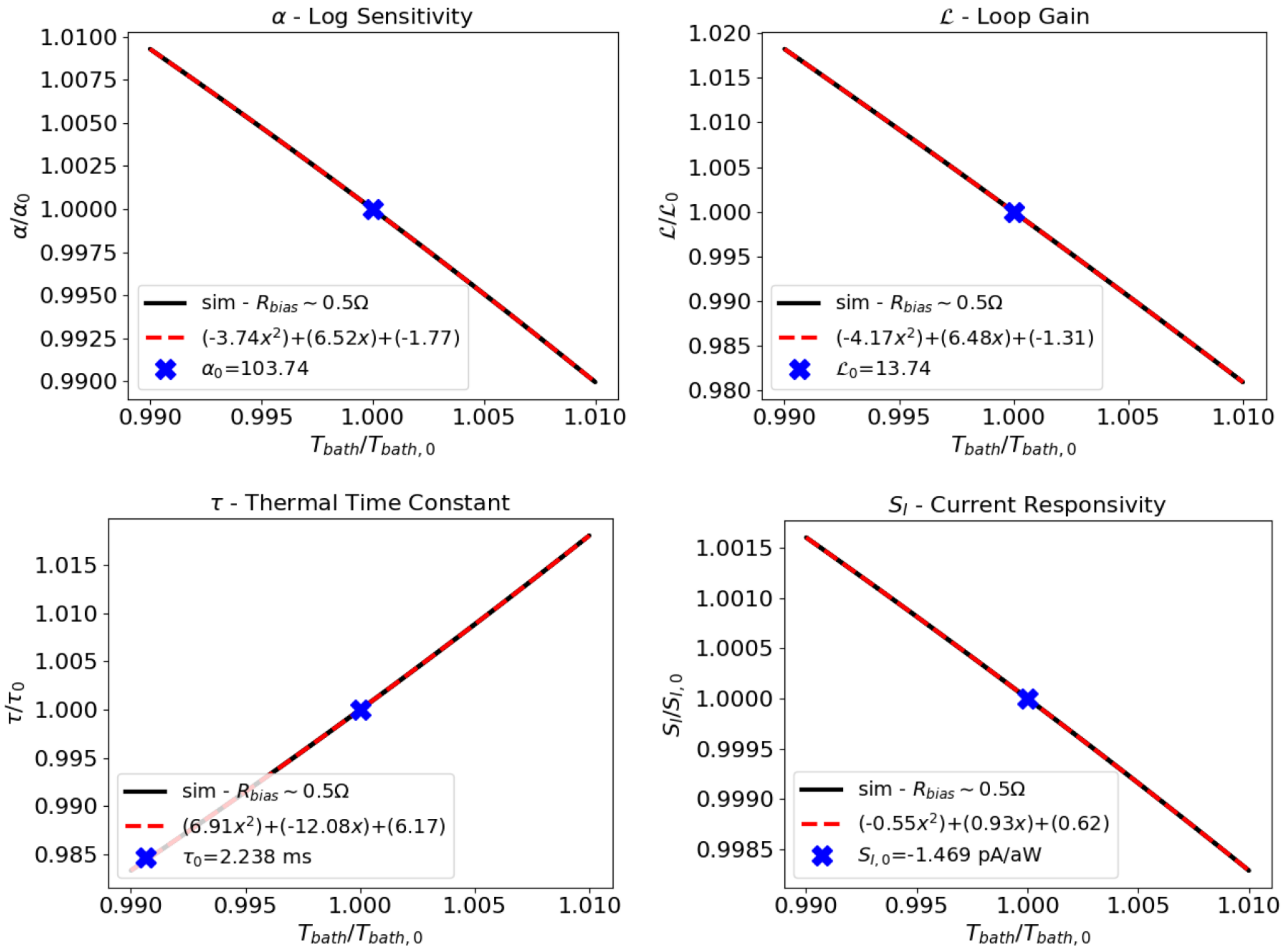
if signal is quasi-static $\omega \rightarrow 0$

Procedure

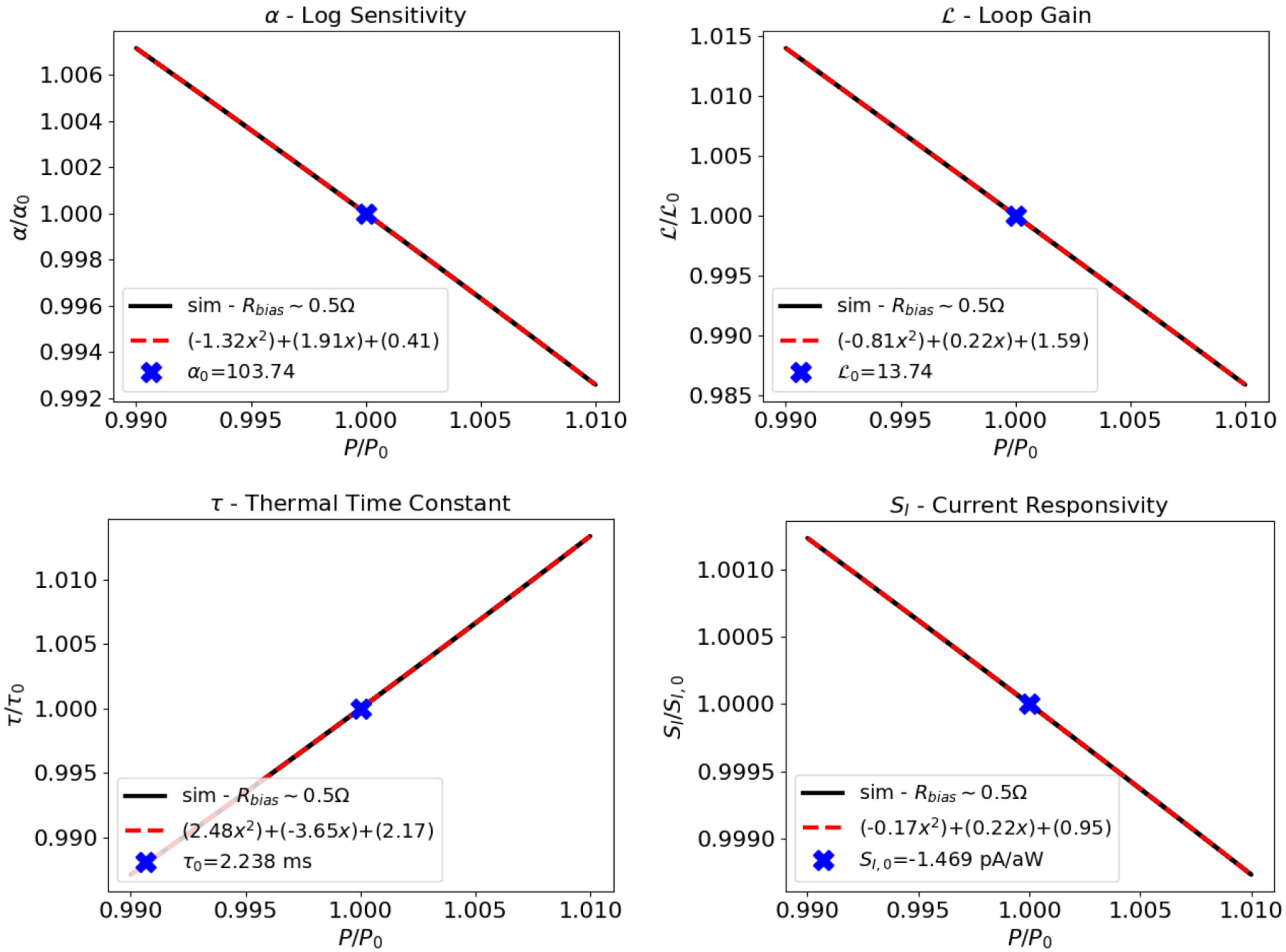
- Fix optical power input and bias current to obtain a stable response "in transition". Two case analyzed operation point: $R_{TES}\sim 0.7\ \Omega$ and $R_{TES}\sim 0.5\ \Omega$ corresponding to $\mathcal{L}\sim 7$ and $\mathcal{L}\sim 13$ for the model assumed.
- Introduce **slow** fluctuations of P_{opt}, T_{bath} or I_{bias} to study the effect on the detector response.
- Fit the result with a polynomial to obtain a formula to independently simulate response drifts. **Not applicable to fast signals like CR! Require different procedure.**



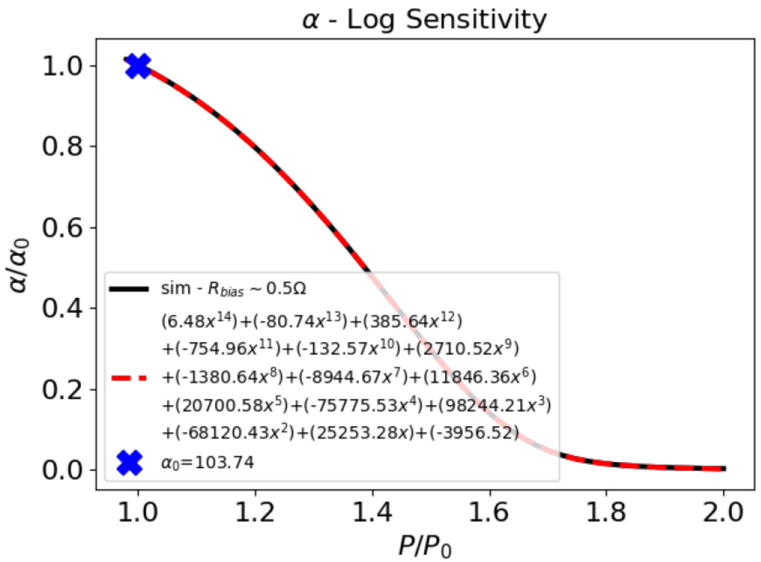
R = 0.5 Ω – 1% T_{bath} fluctuations

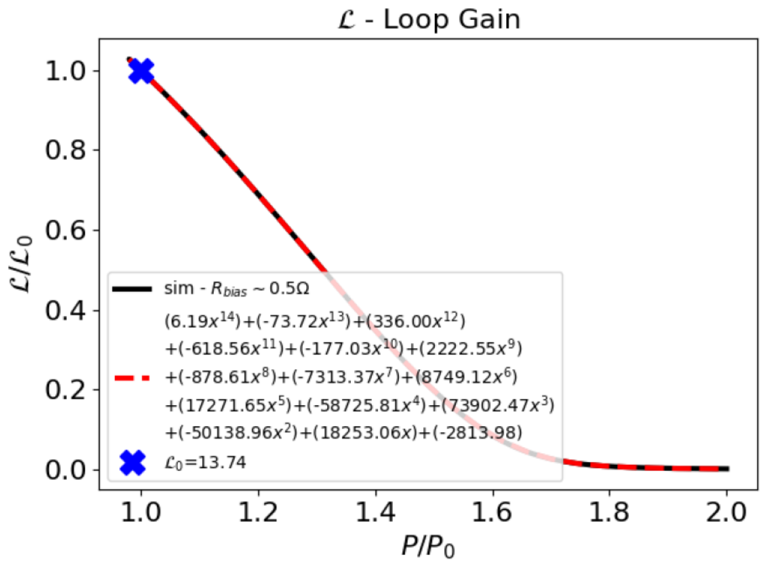


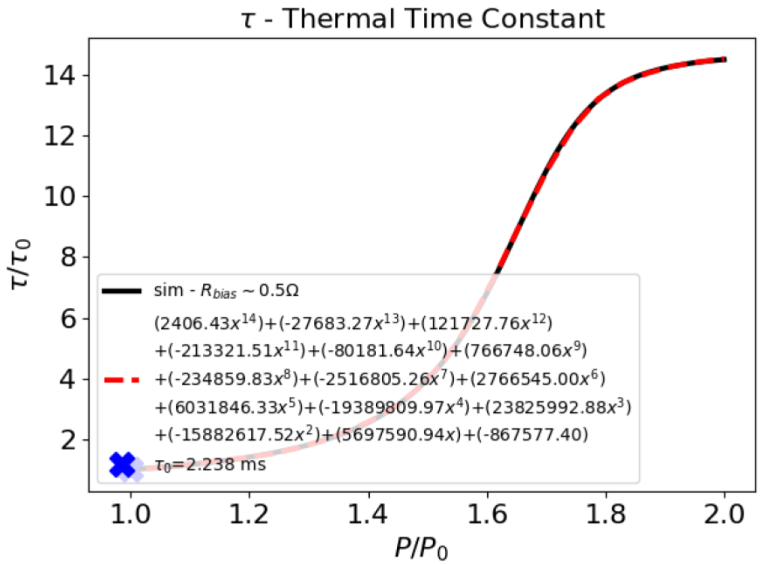
R = 0.5 Ω – 1% P_{opt} fluctuations

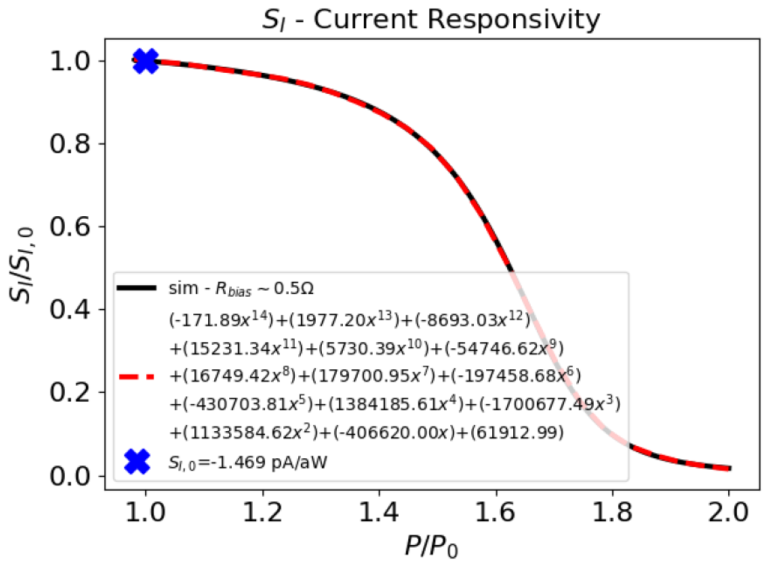


R = 0.5 Ω – 100% P_{opt} fluctuations









R = 0.5 Ω – 1% I_{bias} fluctuations