Closed Loop Noise Propagation Simulation in Finesse3

UF LIGO

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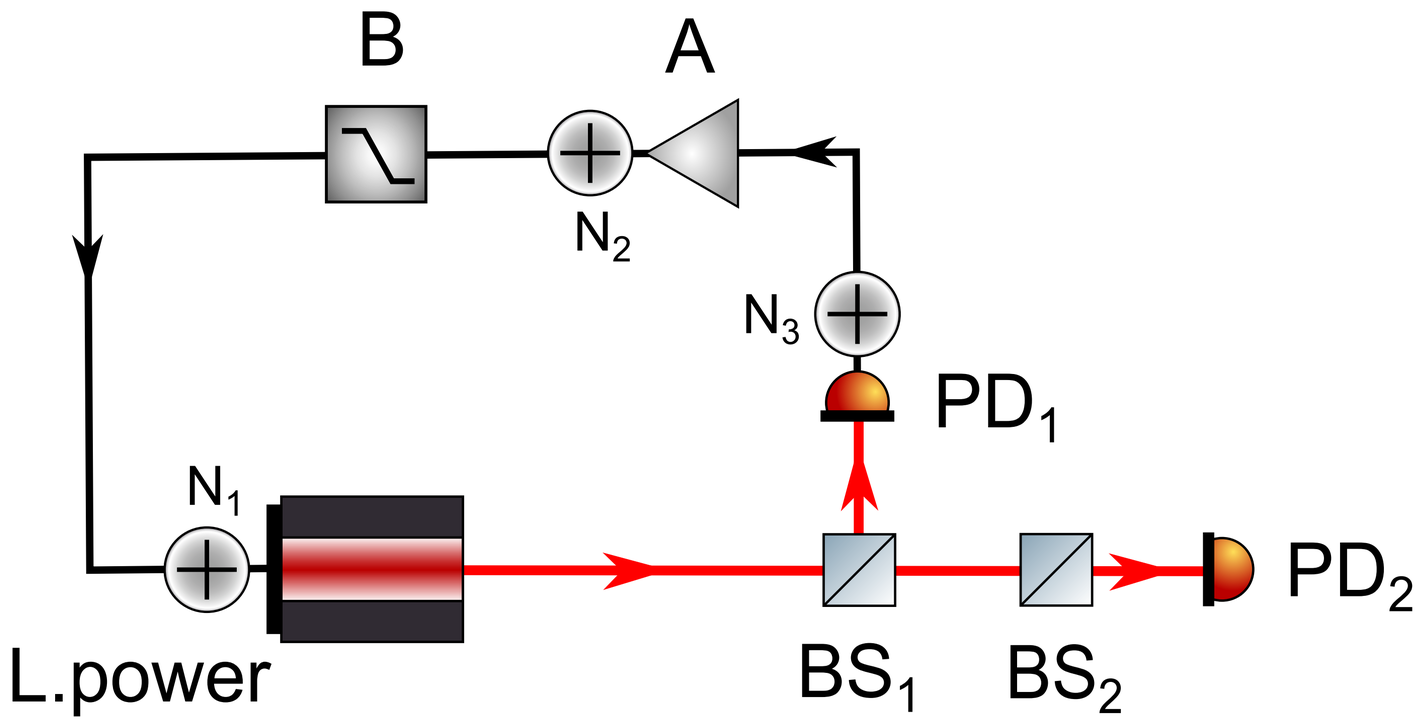
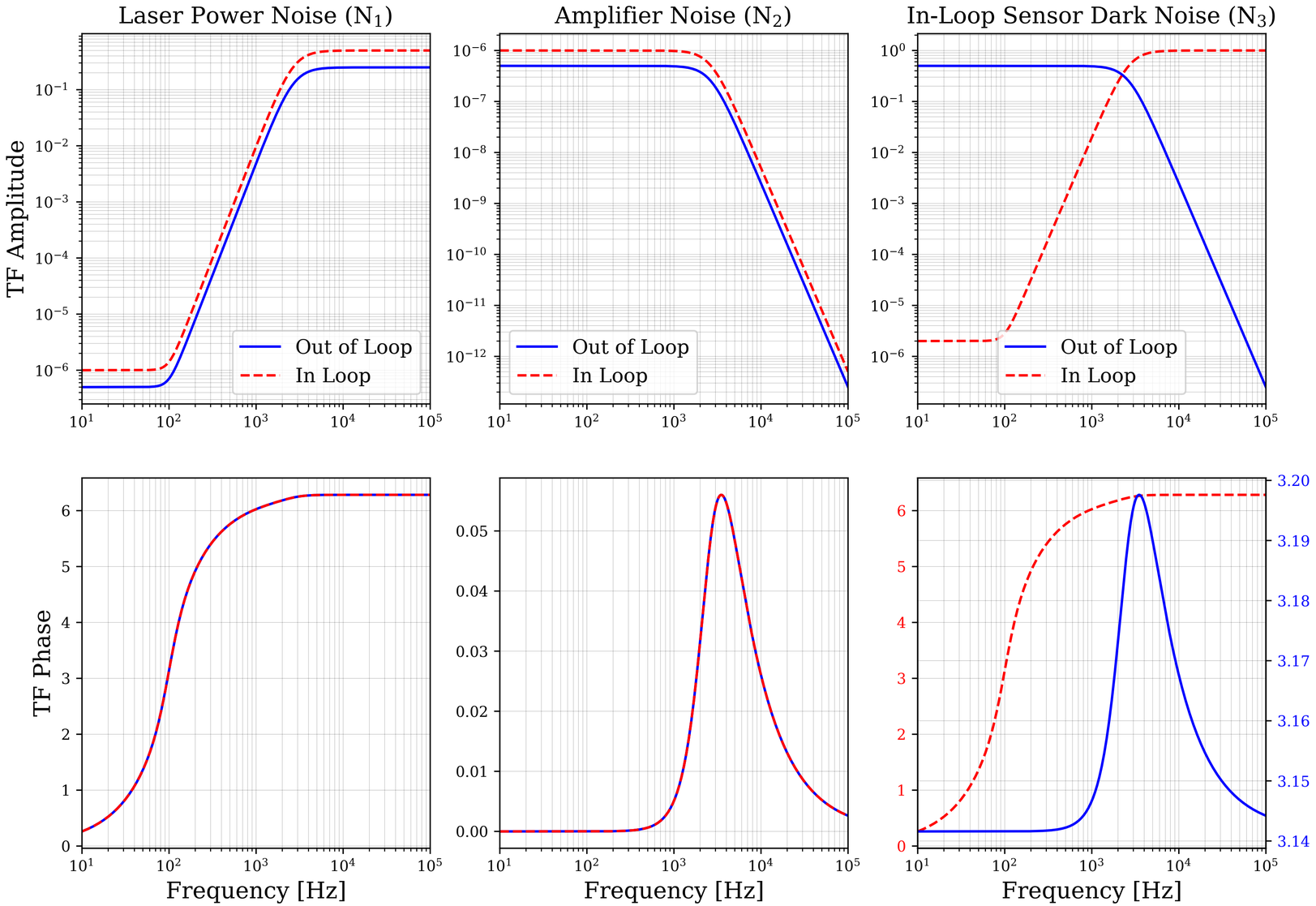
Simple Control Loop Example

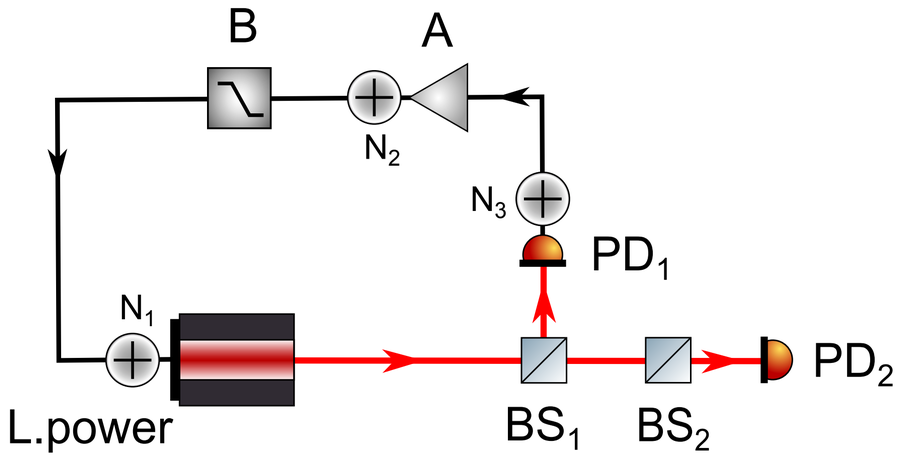
Reflected DC signal is fed to the laser power port



- **PD_1&PD_2**: In & out of loop sensors,
- **BS_1&BS_2**: 50/50 beam splitters,
- **A**: Amplifier with gain -1M,
- **B**: Butterworth low pass filter with corner freq 100 Hz and order of 4,
- ⊕ Noise injections:
  - » N_1: laser power noise
  - » N_2: amplifier noise
  - » N_3: PD_1 dark noise

First Look at the Results (Finesse3)





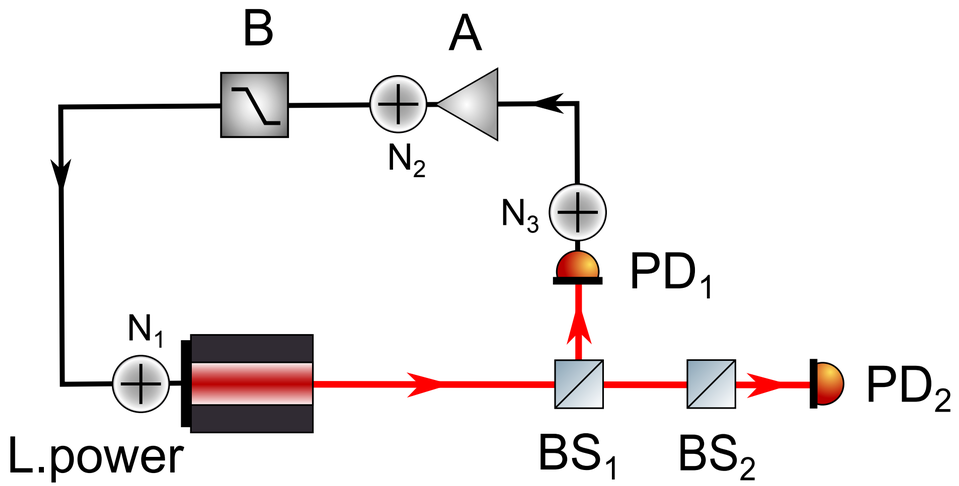
TFs (amplitude and phase) from noise injections ports $N_{1,2,3}$ to $PD_{1,2}$ calculated in Finesse3

Interpret the Results

Noise Propagation TF(N -> PD) = Closed Loop TF * Open Loop TF(N -> PD)

Closed Loop TF = 1/(1-G)
where G is the open loop TF.

G can be formulated in turns of the gains from all the constituent components in the control loop.



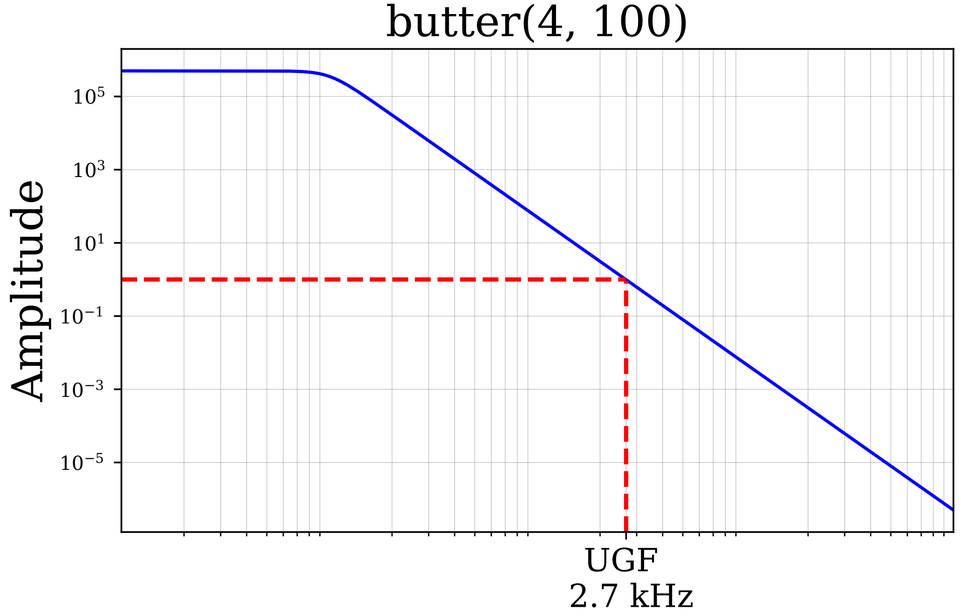
$$G = A_c[W/V] \times P_o[W/W] \times S_e[V/W] \times A_m[V/V] \times S_v[V/V]$$

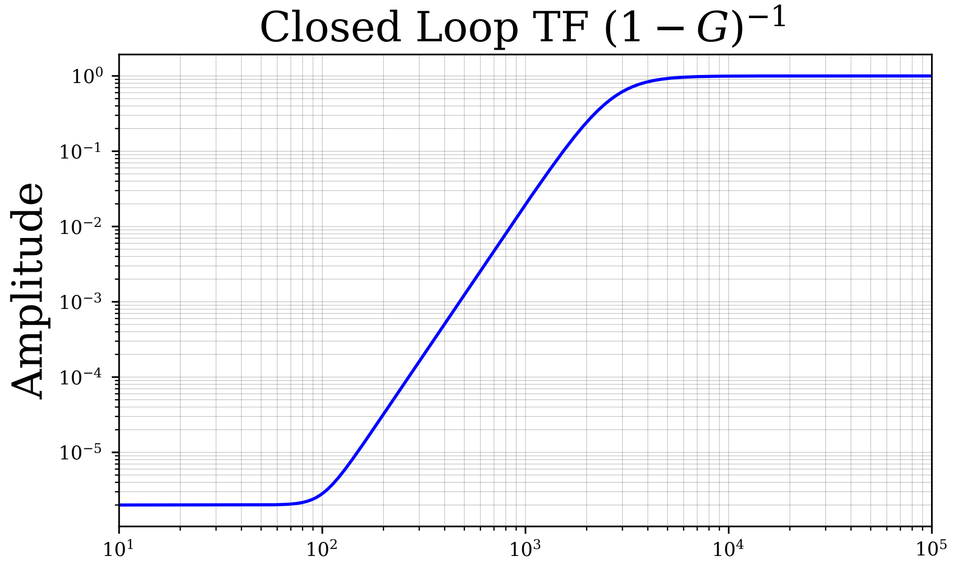
Actuator Gain=1 **Opt. Plant=0.5** **Sensor TI Gain=1** **Amplifier=-1M** **Servo Gain=butter(4, 100)**

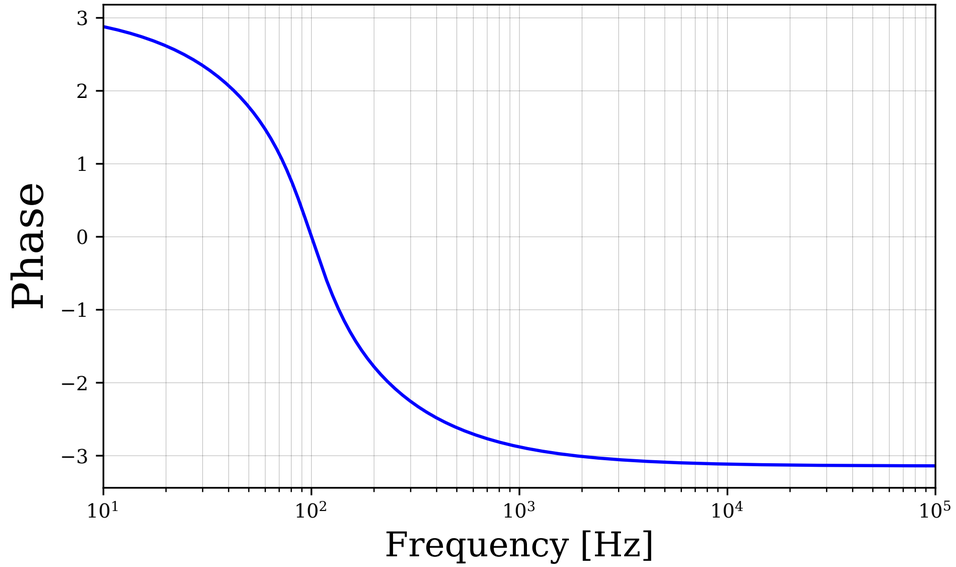
$$= -5 \cdot 10^5 \cdot \text{butter}(4, 100)$$

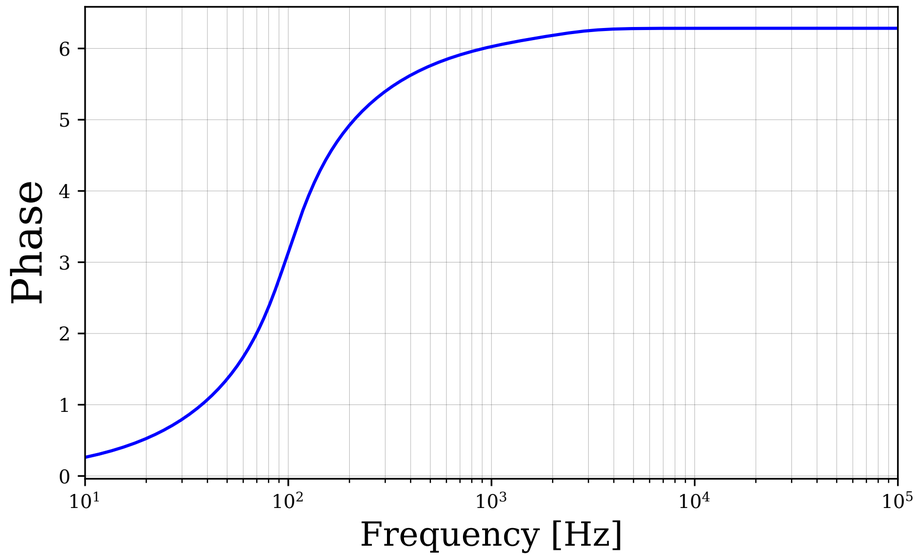
Interpret the Results

$$G = -5 \cdot 10^5 \cdot \text{butter}(4, 100)$$

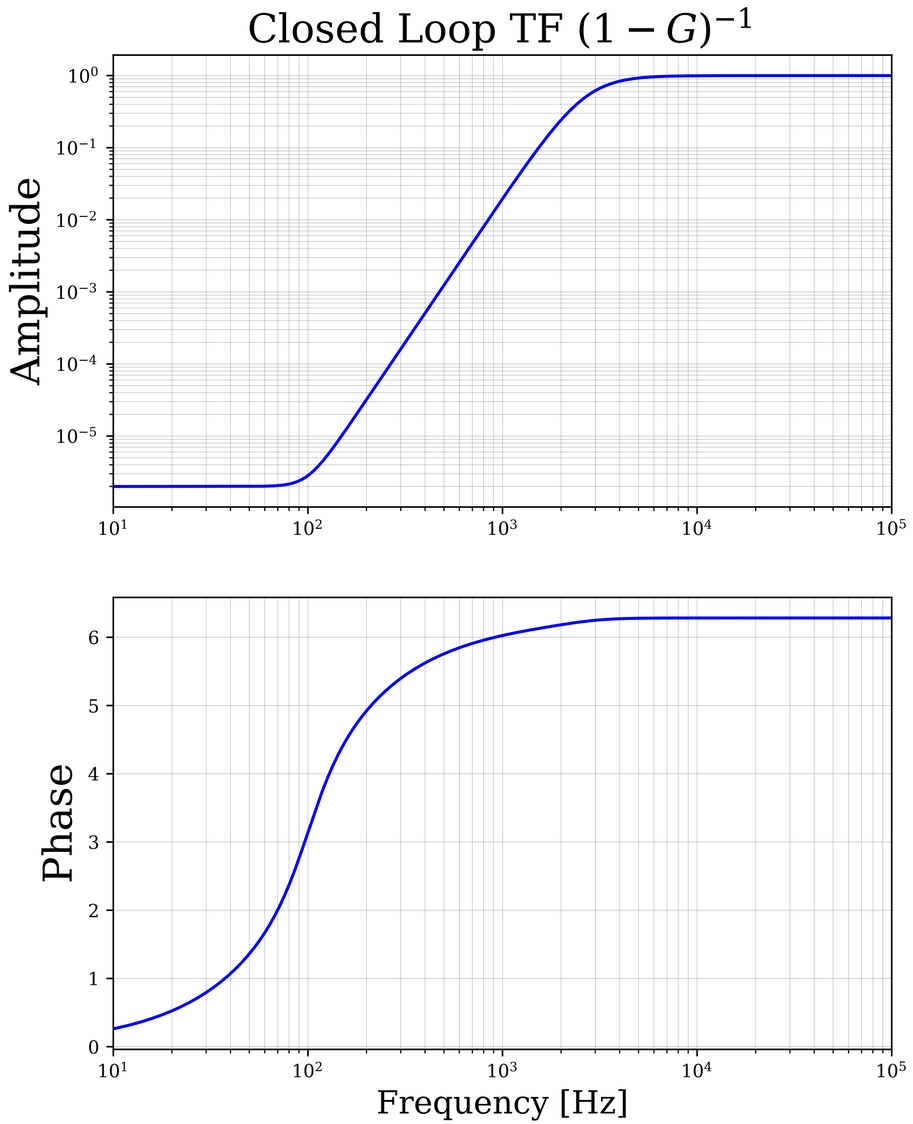


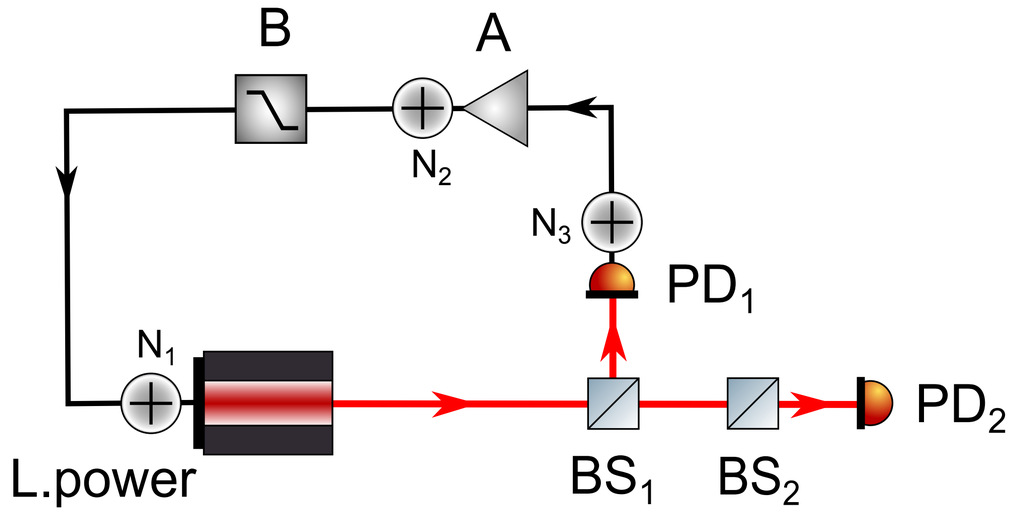






Interpret the Results





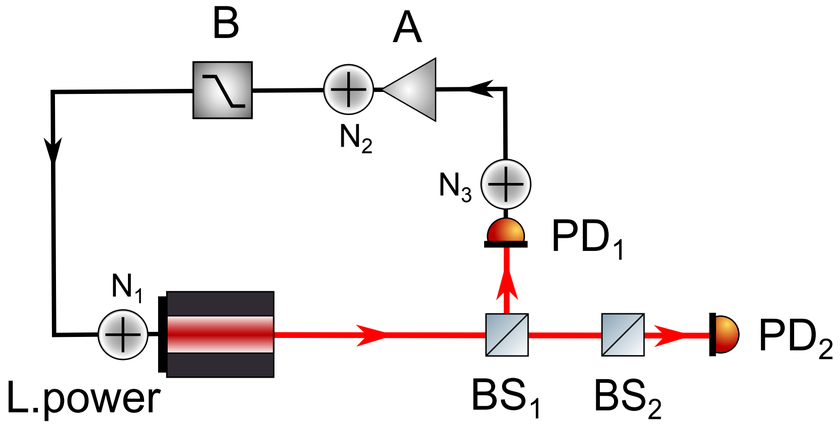
Open Loop TF(N_1 —> PD_1) = 0.5
Open Loop TF(N_1 —> PD_2) = 0.5*0.5=0.25

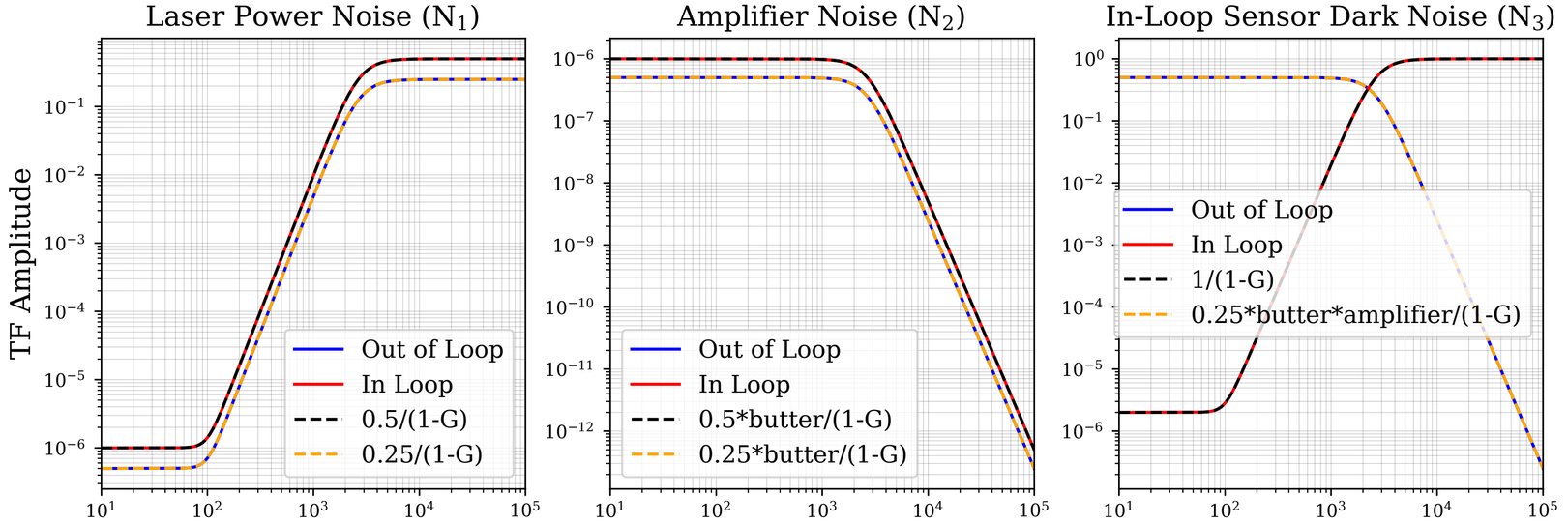
Open Loop TF(N_2 —> PD_1) = S_v[V/V]*0.5 = 0.5*butter
Open Loop TF(N_2 —> PD_2) = S_v[V/V]*0.25 = 0.25*butter

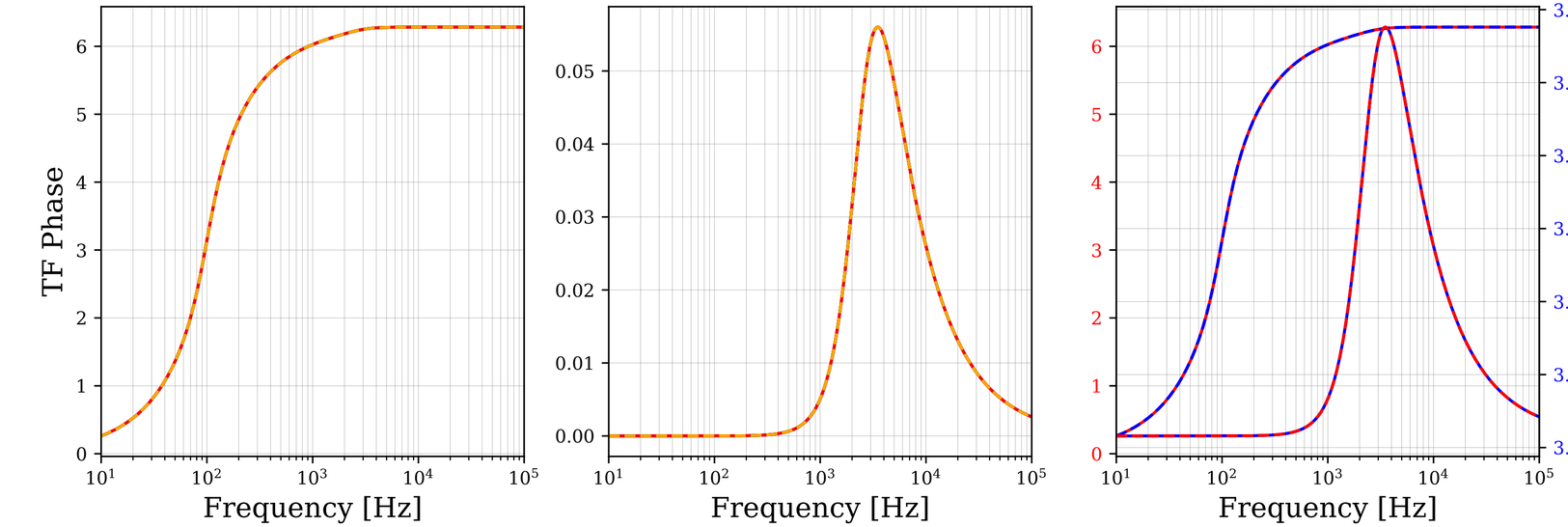
Open Loop TF(N_3 —> PD_1) = 1
Open Loop TF(N_3 —> PD_2) = A_m[V/V]*S_v[V/V]*0.25
= 0.25*butter*amplifier

Noise Propagation TF(N -> PD) = Closed Loop TF * Open Loop TF(N -> PD)

Interpret the Results







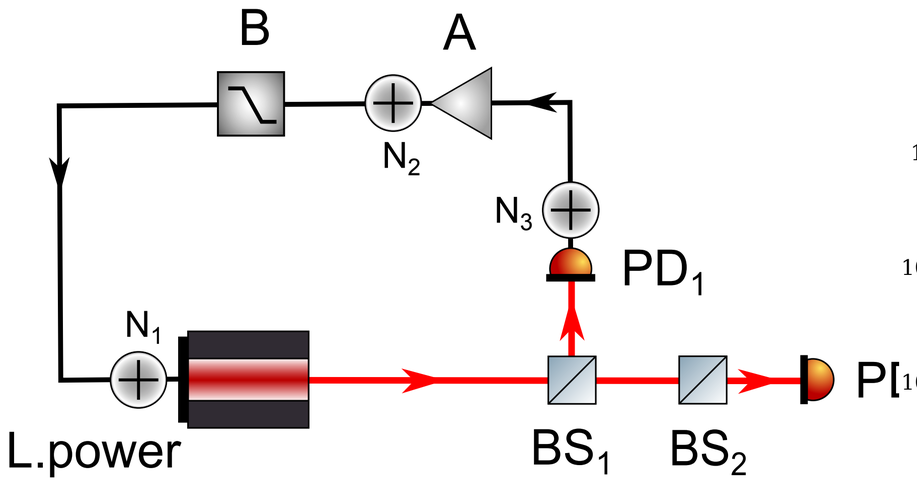
Open Loop TF(N_1 —> PD_1) = 0.5
Open Loop TF(N_1 —> PD_2) = 0.5*0.5=0.25

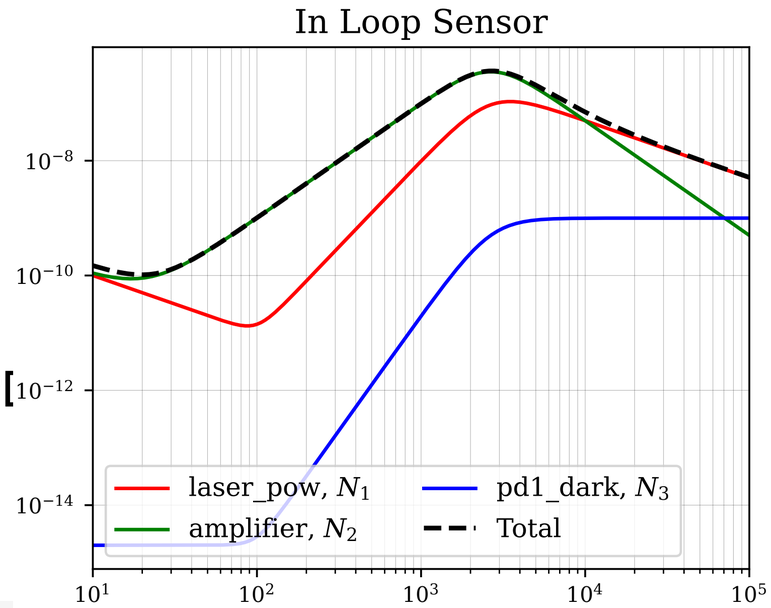
Open Loop TF(N_2 —> PD_1) = 0.5*butter
Open Loop TF(N_2 —> PD_2) = 0.25*butter

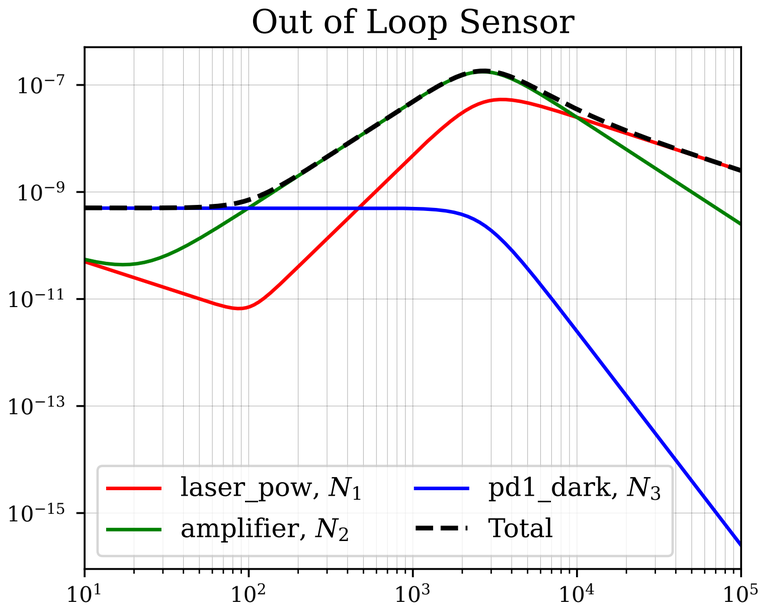
Open Loop TF(N_3 —> PD_1) = 1
Open Loop TF(N_3 —> PD_2) = 0.25*butter *amplifier

Noise Propagation TF(N -> PD) = Closed Loop TF * Open Loop TF(N -> PD)

Total Noise Level








```
3  kat1 = kat.deepcopy()
4  kat1.parse("""
5  noise laser_pow l1.amp.i 1m/fsig # N1
6  noise amplifier A.p2.o (1m/fsig + 0.1u*fsig**2) # N2
7  noise pd1_dark pd1.DC.o 1n # N3
8
9  noise_projection(
10 geomspace(10, 1e5, 1000),
11
12 pd2.DC, # out of loop
13 pd1.DC # in loop
14 )
15 """)
16 out1 = kat1.run()
```

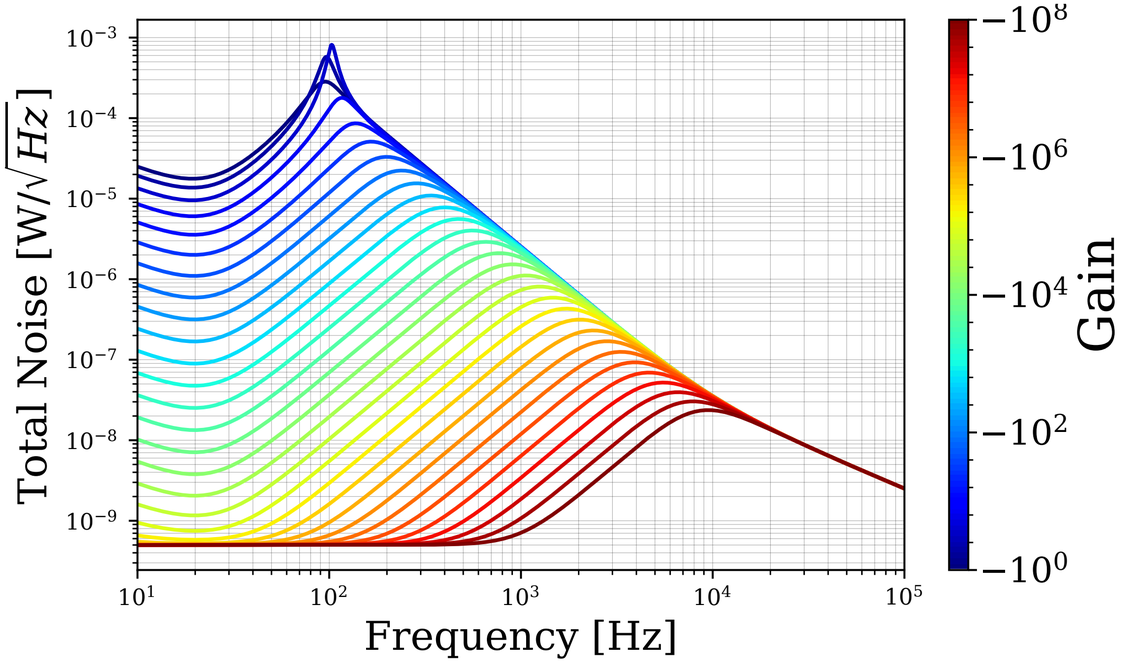
Inject input noise ASD in Finesse3

Total Noise (summed noise in quadrature):

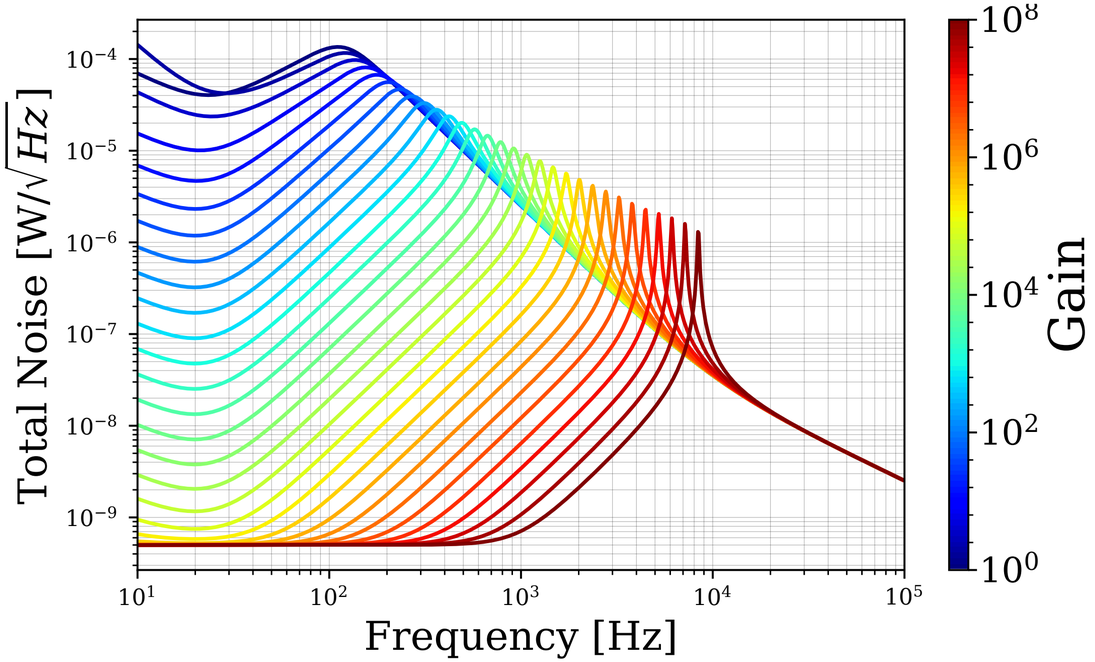
$$\mathrm{T.N.} = \sqrt{\mathrm{N}_1^2 + \mathrm{N}_2^2 + \mathrm{N}_3^2}$$

$$\text{where } \mathrm{N} = \mathrm{N}_{\mathrm{input}} \cdot \mathrm{TF}$$

Total Noise at PD_2 vs. Amplifier Gain



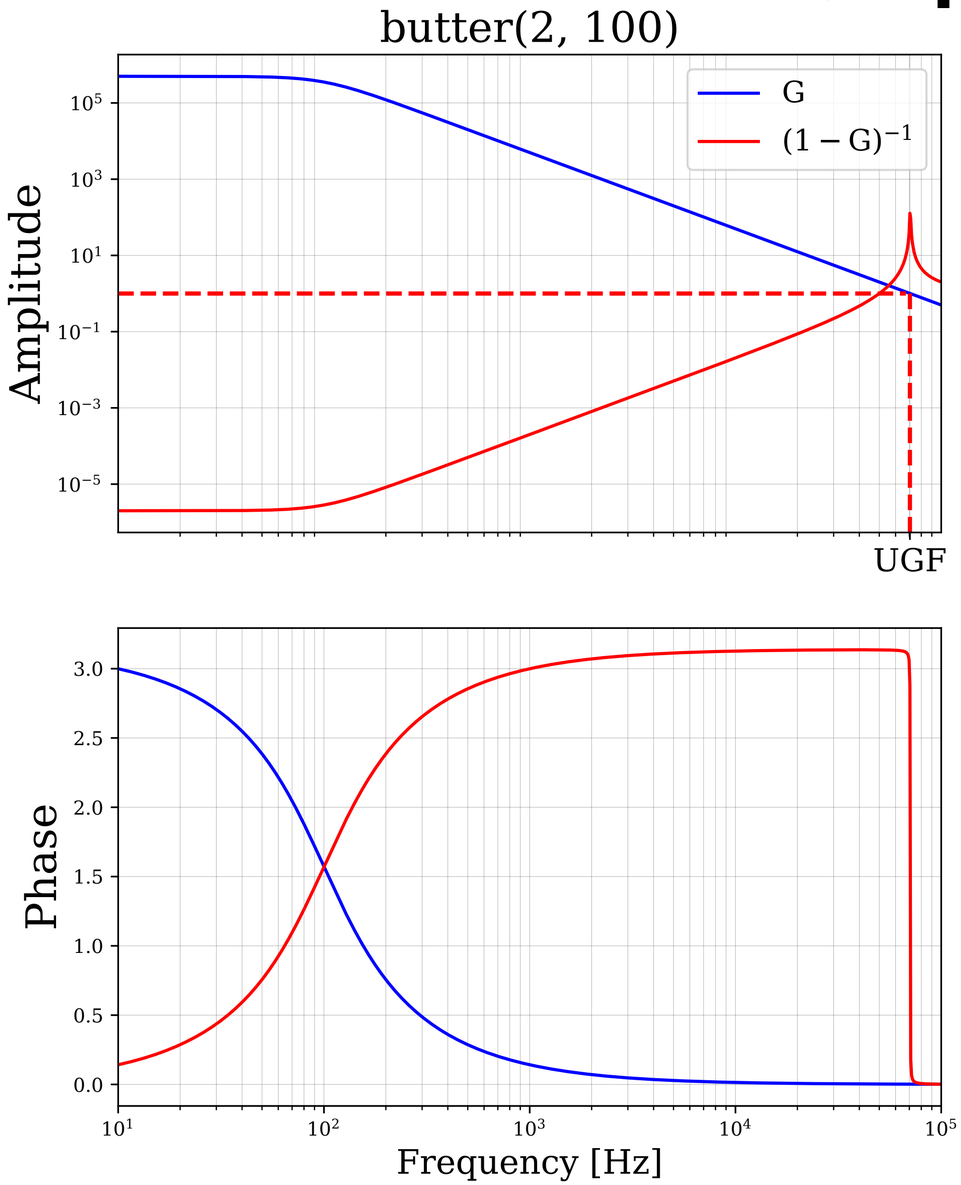
The total noise level gets suppressed more and more as we increase the gain



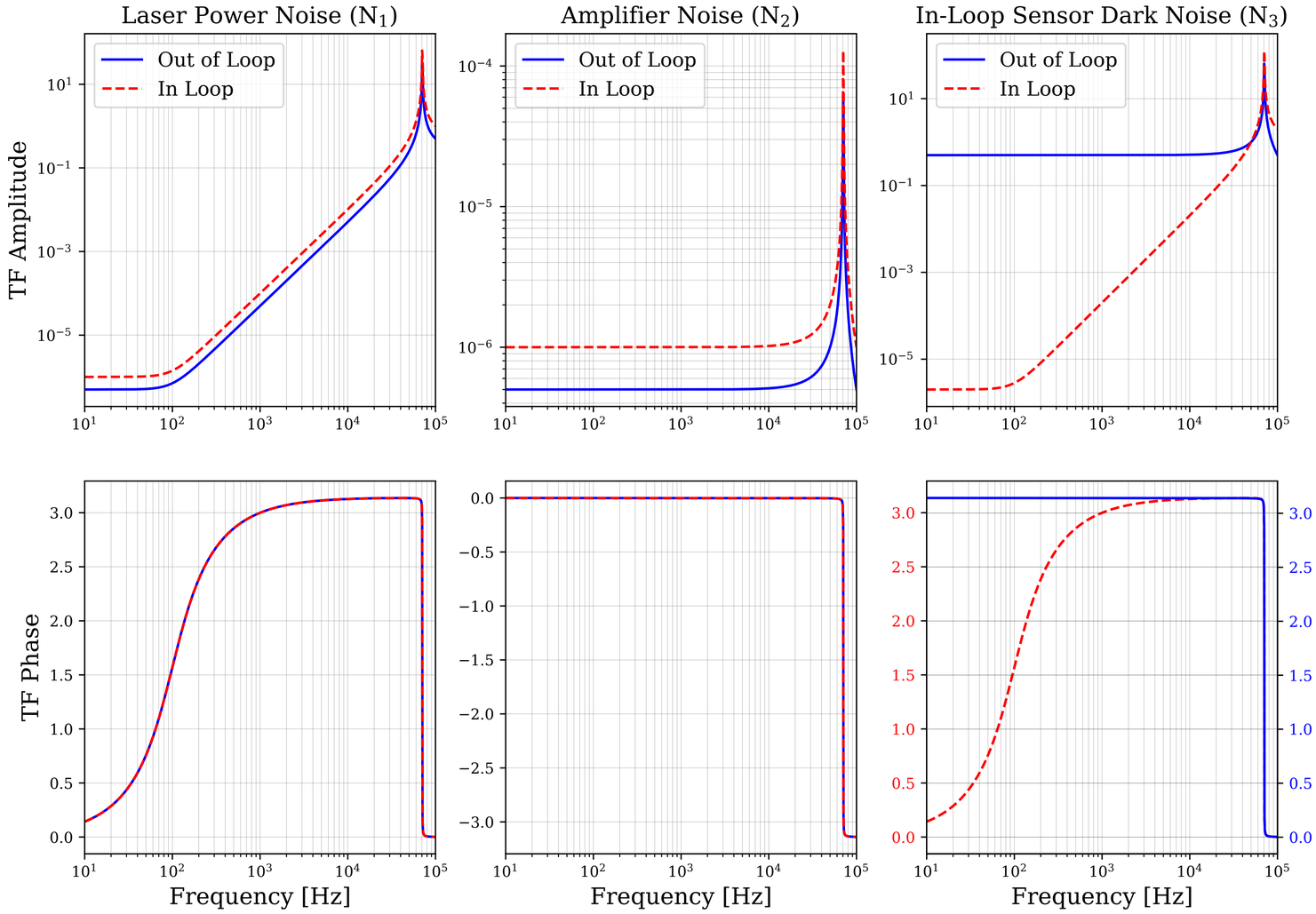
Avoid specific gains for better performances at specific frequency bands

Evaluate and optimize the control loop performances

Example on Unstable Control Loop



We have all sorts of peaks in the noise propagation TFs



Loop goes unstable when open-loop transfer function G becomes 1

Carefully design control loops to avoid any instabilities

Thank you