

Noise Requirement for IMC QPDs

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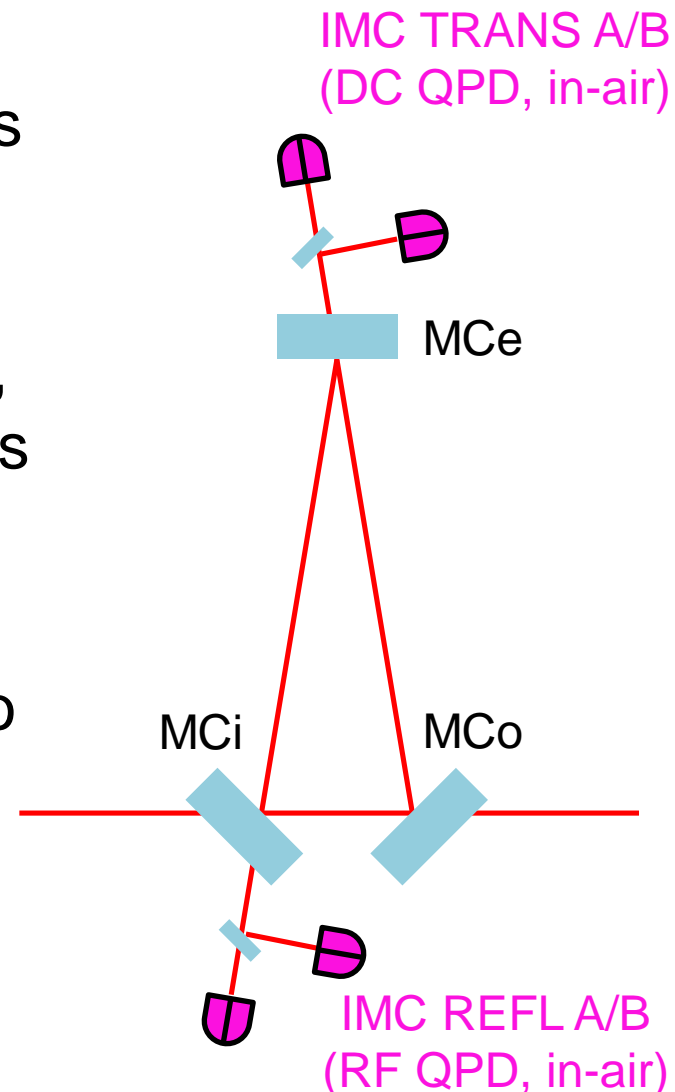
Scope

- Derive noise requirements for QPDs used for IMC ASC
- Show if the current design meets the requirement or not
 - We may have to put IMC TRANS DC QPDs in vacuum**
- Related documents:
 - [JGW-T1402346](#) (requirement calculation for arm TMS)
 - [JGW-T1402481](#) (IMC alignment sensing matrix calculation)
 - [JGW-D1402411](#) (oplev QPD schematic)
 - [JGW-G1402375](#) (oplev QPD noise calculation)
 - [JGW-G1402961](#) (oplev QPD noise measurement)
 - [JGW-T1200913](#) (IMC length noise requirement from MIF; Fig. 4.6, 4.7)
 - [JGW-G1301747](#) (beam jitter requirement)

Noise Requirement from Angle to Length Coupling

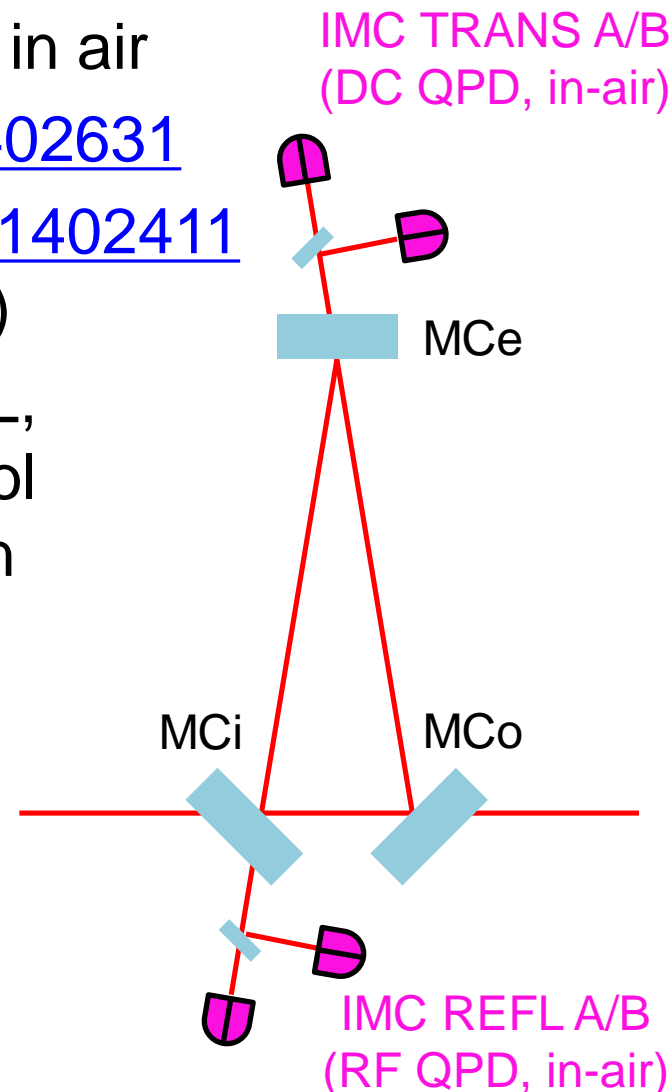
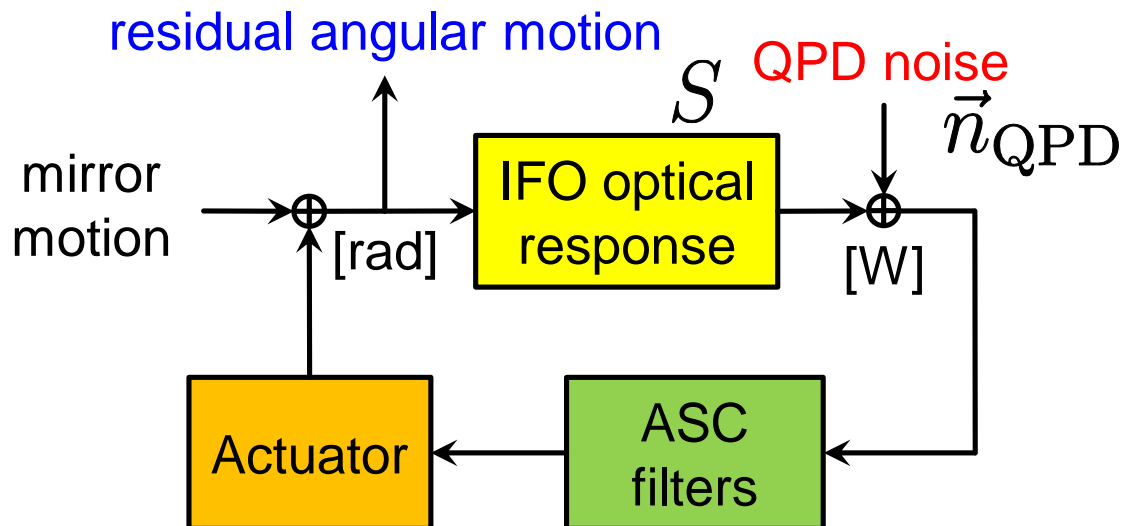
Requirement Derivation

- IMC is used for the laser frequency stabilization servo (FSS), and there is a requirement for IMC length noise
- Shot noise, seismic noise, etc. on QPDs will fake IMC alignment signal, and thus IMC ASC shakes the mirrors
- Angle to length (A2L) coupling result in the IMC length noise
- This noise should be small enough to meet the IMC length noise requirement
- Requirement derivation is similar to what we have done for the arms ([JGW-T1402346](#))



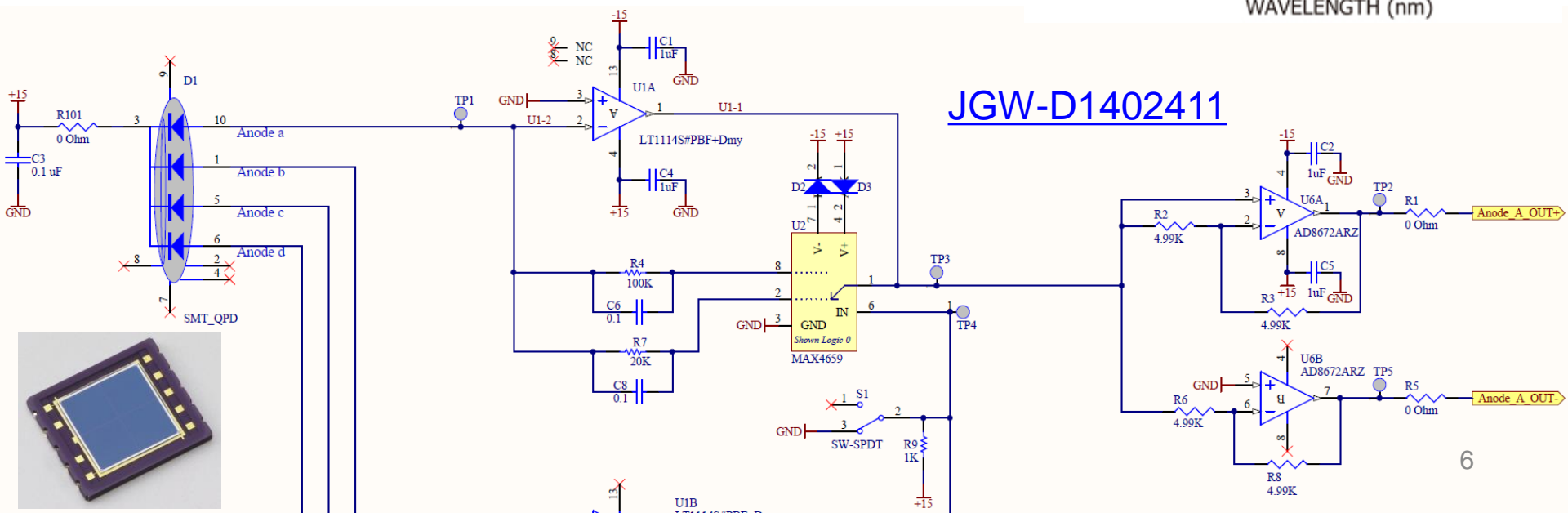
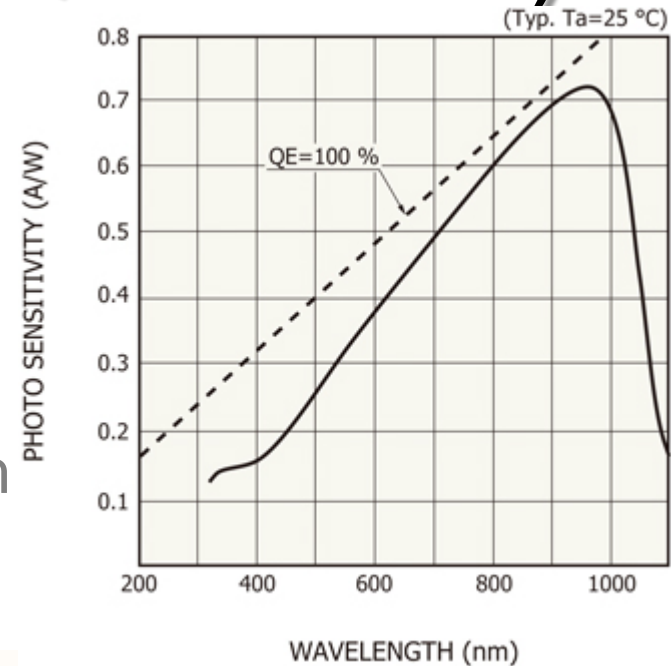
Current IMC ASC Design

- QPDs are put on non-isolated tables in air
- REFL RF QPD schematic: [JGW-D1402631](#)
- TRANS DC QPD schematic: [JGW-D1402411](#)
(same as the QPD used for oplevs)
- use two alignment signals from REFL, and one signal from TRANS to control three mirrors (we name two QPDs on each port as A and B)



Oplev QPD (ISC DC QPD in-air)

- Si diode, Hamamatsu [S5981](#)
 area 10 x 10 mm, gap 0.03 mm
 ~0.30 A/W @ 1064 nm (QE=36%)
 ~0.30 A/W @ 532 nm (QE=70%)
 ~0.47 A/W @ 680 nm (QE=85%)
 ↗ oplev wavelength
- transimpedance = 20 k Ω (or 100 k Ω)



Expression and Assumptions

- A2L from QPD noise should be smaller than the length noise requirement

$$\delta L(f) = \vec{k} \cdot d^{\text{RMS}} \frac{G(f)}{1 + G(f)} S^{-1} \vec{n}_{\text{QPD}}(f) < L_{\text{req}}(f)$$

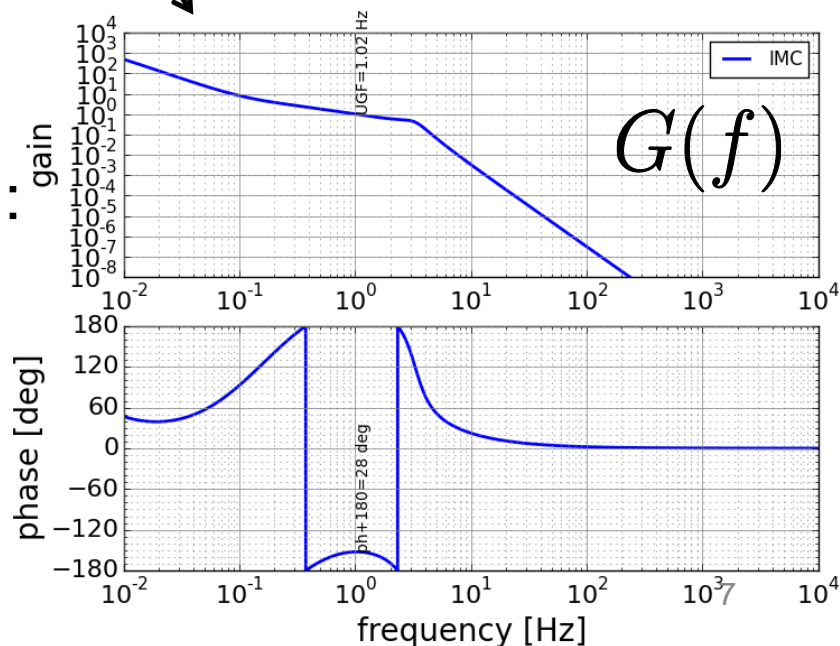
$\delta L(f)$ [m/rtHz] (A2L)
 \vec{k} coupling for each mirror
 d^{RMS} beam mis-centering on mirrors [m]
 $G(f)$ sensing matrix [W/rad]
 S^{-1} ASC OLTF
 $\vec{n}_{\text{QPD}}(f)$ QPD noise [W/rtHz]
 $L_{\text{req}}(f)$ length noise requirement [m/rtHz]

$$\vec{k} = 2 \cos \vec{\theta}_i$$

$\vec{\theta}_i$ incident angle for each mirror

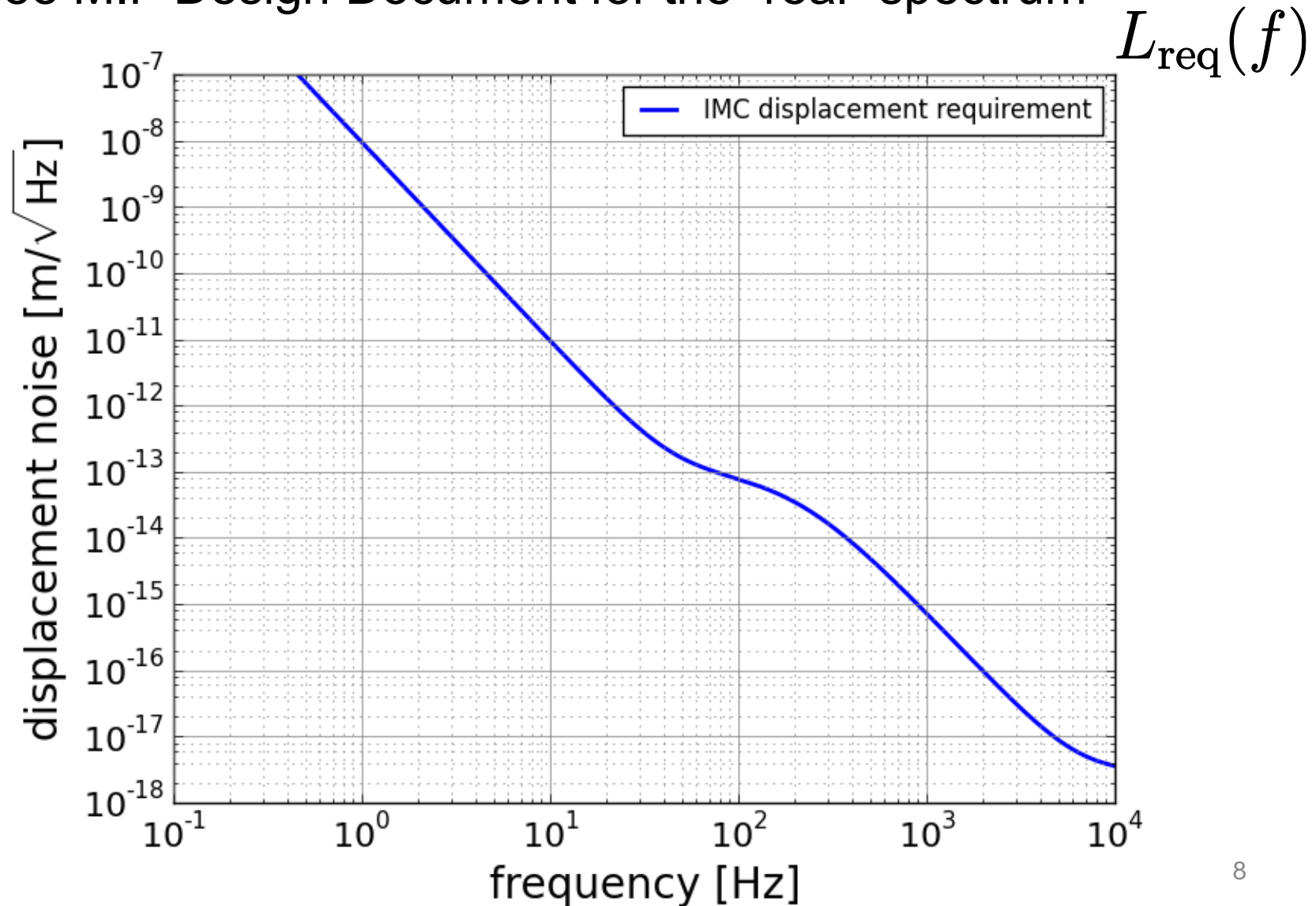
- Assumptions for the calculation:

- 1 mW on each QPD
- 0.2 mm beam radius on each QPD
- $d^{\text{RMS}} = 0.1$ mm
- IMC ASC UGF = 1 Hz



IMC Length Noise Requirement

- See MIF Design Document for the “real” spectrum



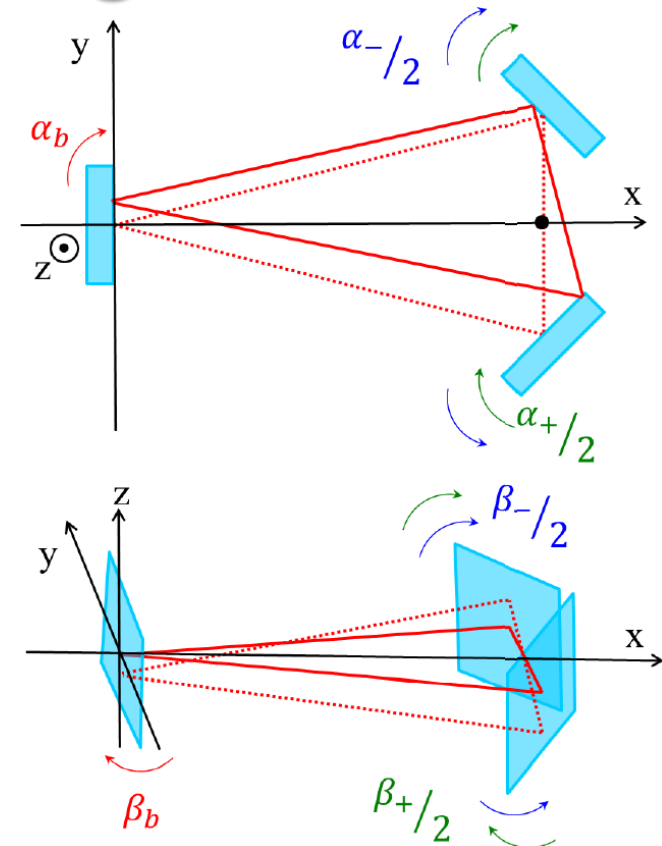
IMC Alignment Sensing Matrix

- DOF basis

	yaw			Pitch		
	α_b	α_+	α_-	β_b	β_+	β_-
REFL A	-39.2	-11.5	0	0	7.9	-7.9
REFL B	0	0	17.5	24.8	0	0
TRANS A	-12.6	0.32	0	-13.4	8.2	0
TRANS B	-14.3	0.26	-17.6	0	6.9	0.08

- Mirror basis

	yaw			pitch		
	MCi	MCo	MCE	MCi	MCo	MCE
REFL A	-11.5	-11.5	-39.2	15.8	0	0
REFL B	-17.5	17.5	0	0	0	24.8
TRANS A	0.32	0.32	-12.6	8.2	8.2	-13.4
TRANS B	17.8	-17.3	-14.3	6.8	7.0	0



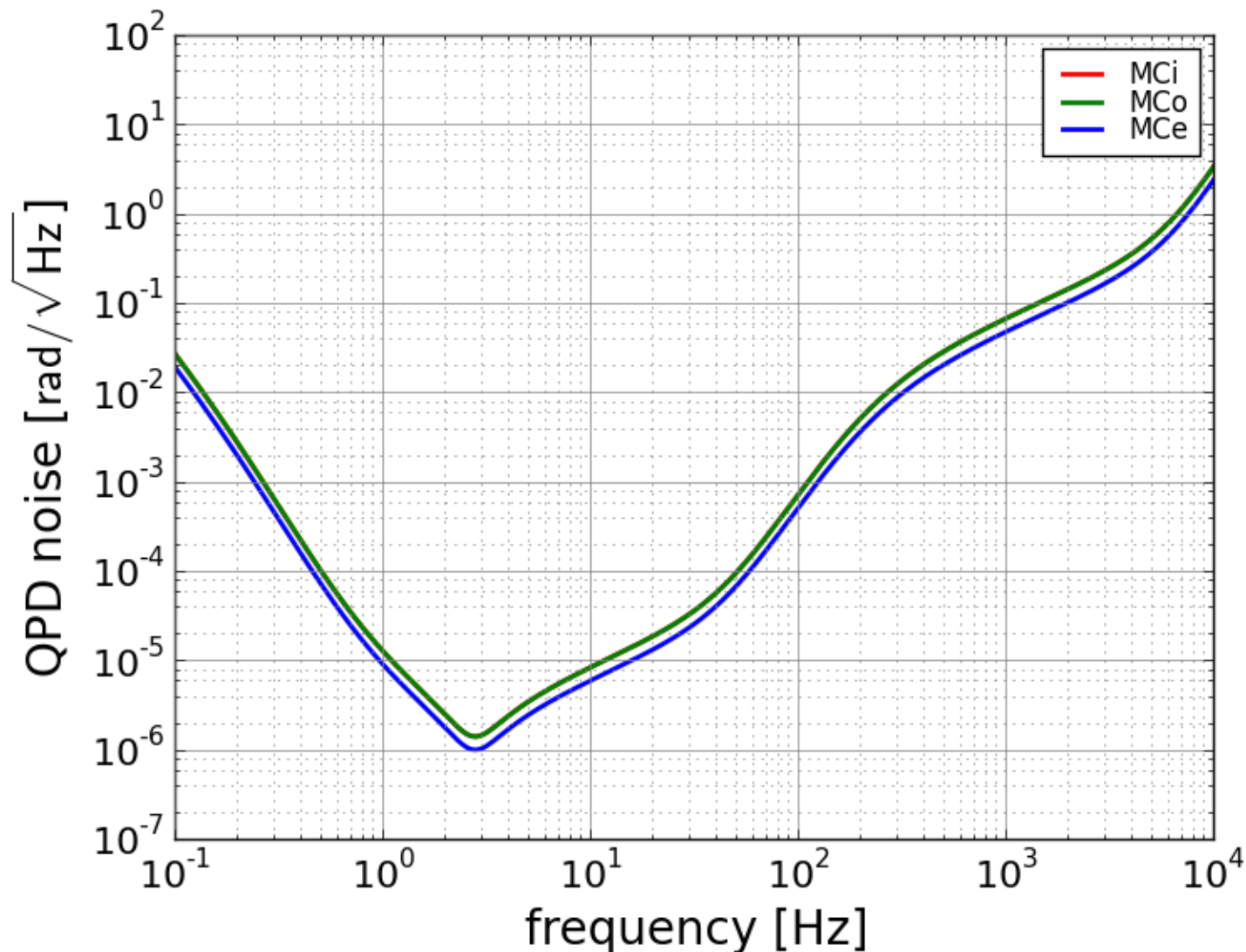
[JGW-T1402481](#)

← \mathcal{S} in p.4 (Table 8.1)

all in units of W/rad
modulation index = 0.1 9

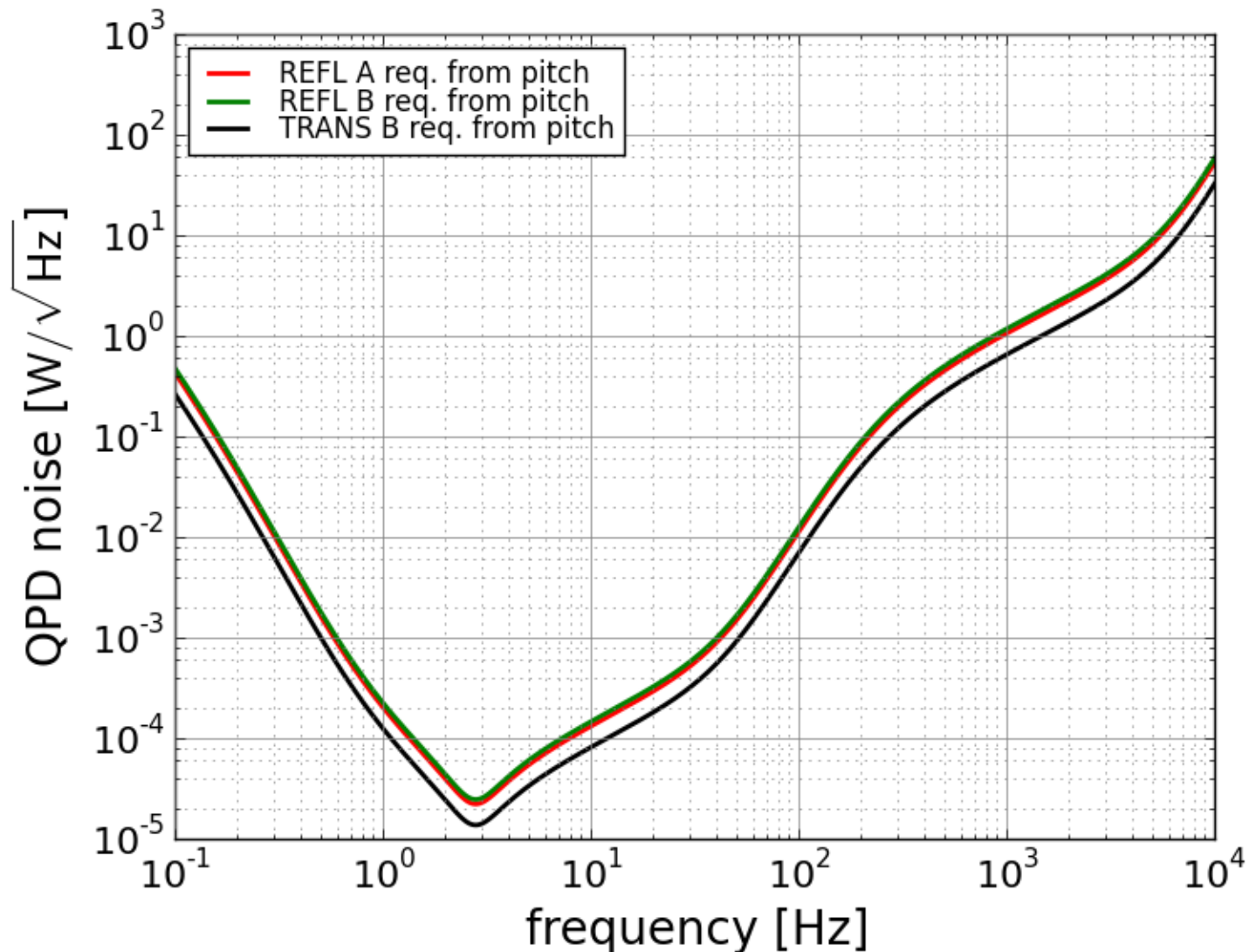
QPD Noise Requirement

- in terms of equivalent angular noise (same for pitch/yaw)



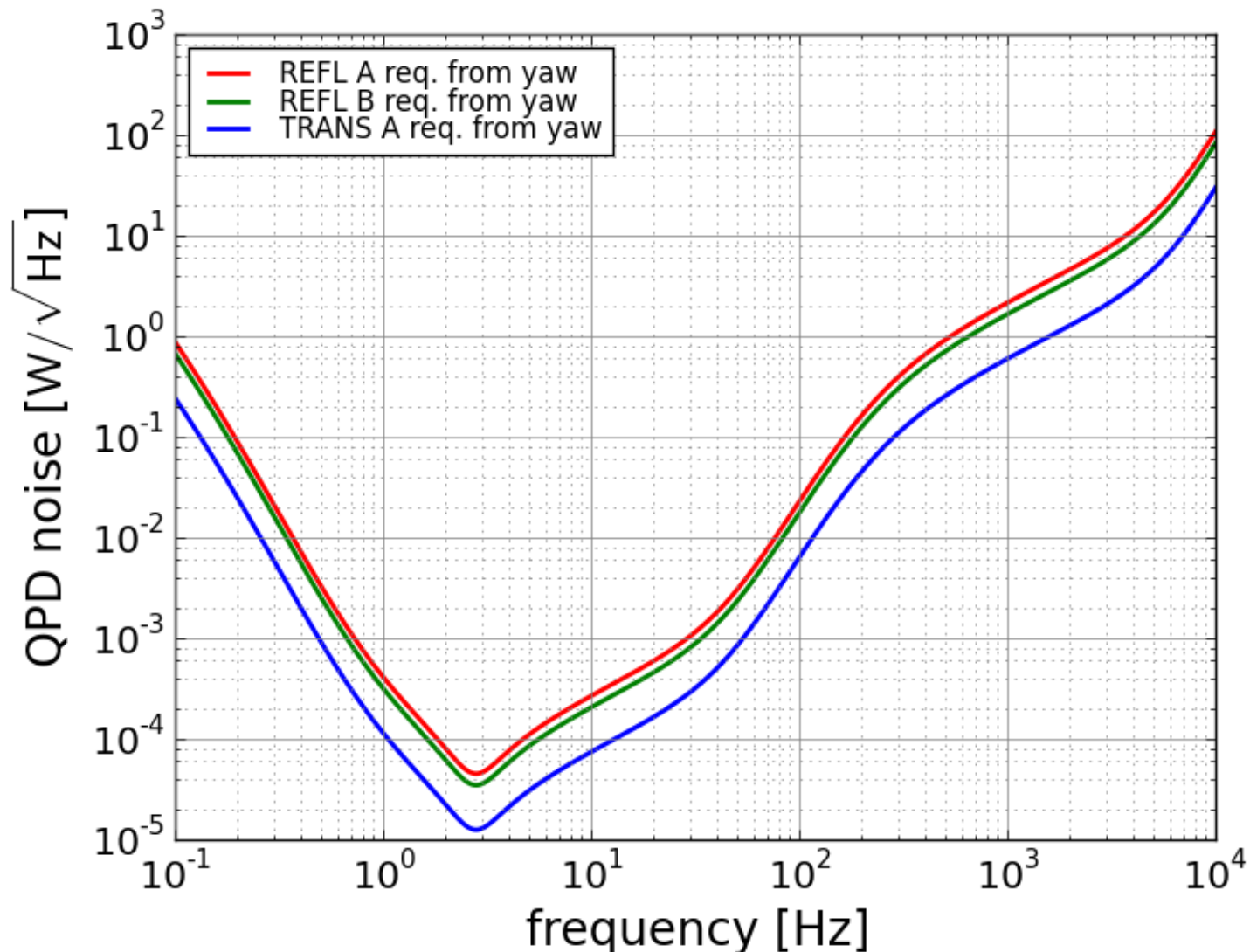
QPD Noise Requirement (pitch)

- requirement from pitch, in terms of QPD output in Watts



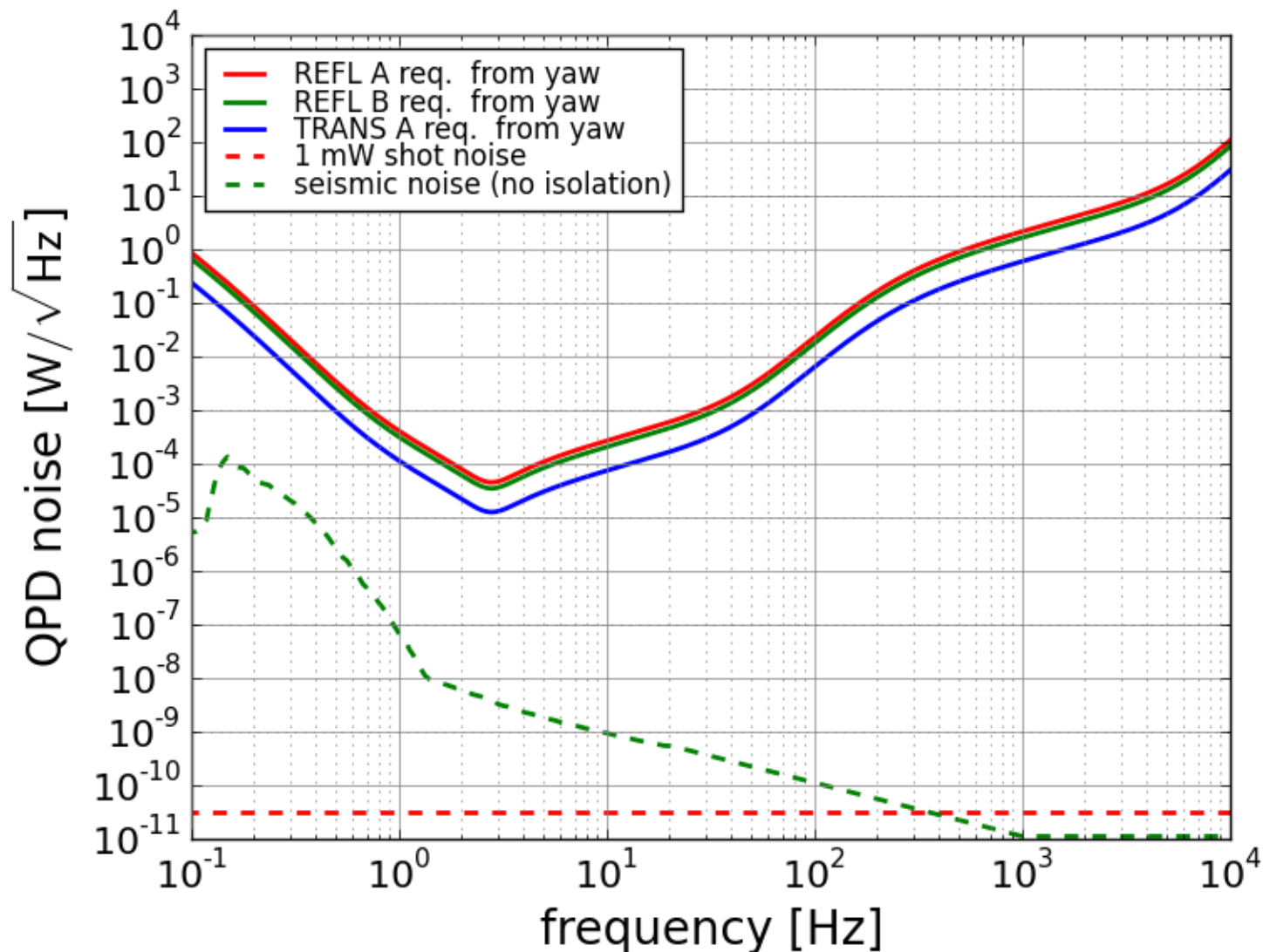
QPD Noise Requirement (yaw)

- requirement from yaw, in terms of QPD output in Watts



Estimated QPD Noise

- DC QPD on non-isolated table work



Noise Requirement from Input Pointing

Requirement Derivation

- There is a requirement for input pointing to the main interferometer
- Angular motions of IMC mirrors create beam jitter to the main interferometer
- QPD noise should be small enough so that the beam jitter created from the angular motions caused by the QPD noise meet this requirement

$$\frac{G(f)}{1 + G(f)} S^{-1} \vec{n}_{\text{QPD}}(f) < \vec{\theta}_{\text{req}}(f)$$

↖
requirement for angular motion
for each mirror [rad/rtHz]

- can be calculated from beam jitter requirement with

$$\vec{B} \vec{\theta}(f) < \epsilon_{\text{req}}$$

↖ beam jitter matrix [1/rad]

↖ beam jitter requirement [1/rtHz]

Input Pointing Requirement

- requirement for TEM01 amplitude per 1W at PRM incident is plotted (for both BRSE/DRSE cases)

- roughly

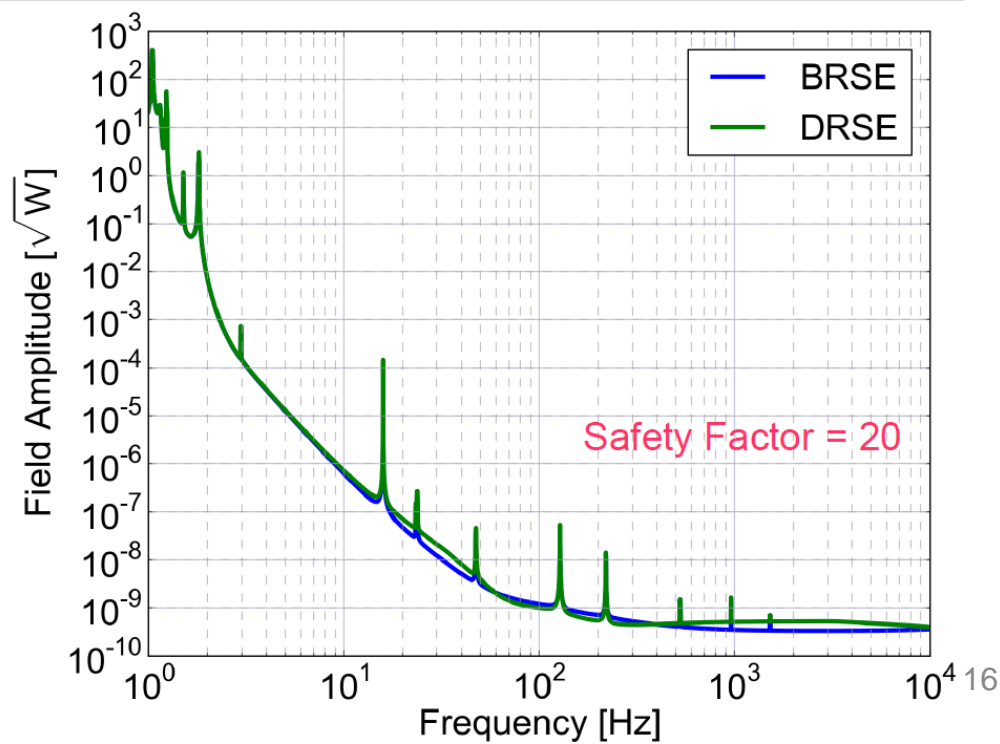
$$\sqrt{\left(\frac{\delta x}{w_0}\right)^2 + \left(\frac{\delta \theta}{\alpha_0}\right)^2} < (3 \times 10^{-10} + 3 \times 10^{-3} \text{ Hz}/f^4) / \sqrt{\text{Hz}}$$

ϵ_{req} in p.15

- see [JGW-G1301747](#)

- requirement at MCo transmission is similar
(see [JGW-T1402332](#))

入射TEM01振幅への要求値(入射パワー1W)



Beam Jitter from Angular Motion

- DOF basis

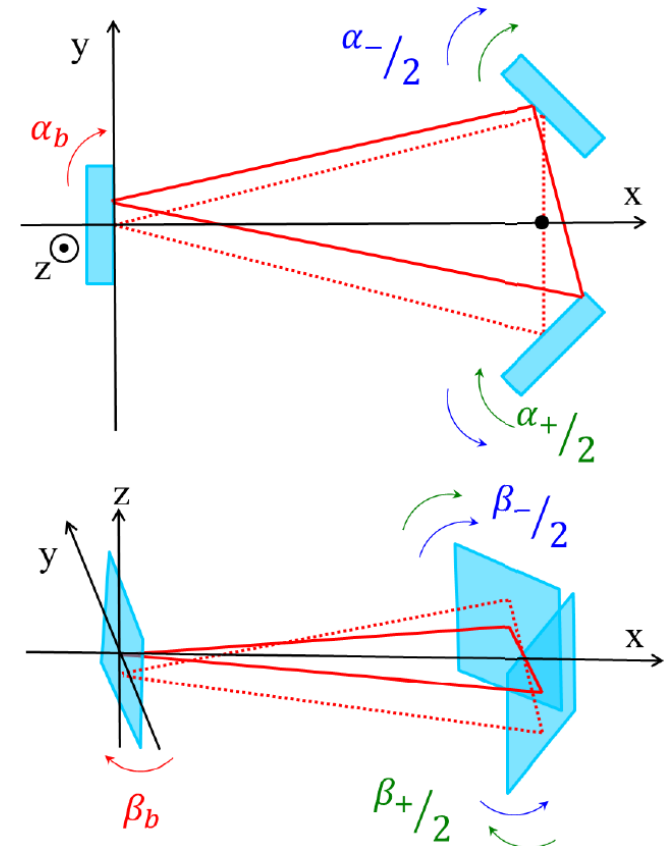
	yaw			Pitch		
	α_b	α_+	α_-	β_b	β_+	β_-
δx	0	0	-26.4	-37.3	0	0
$\delta \theta$	-3.5	-1.0	0	0	0	-0.71

δx : beam translation

$\delta \theta$: beam rotation (around cavity waist)

- Mirror basis

	yaw			pitch		
	MCi	MCo	MCE	MCi	MCo	MCE
δx	26.4	-26.4	0	0	0	-37.3
$\delta x/w_0$	11.1	-11.1	0	0	0	-15.6
$\delta \theta$	-1.0	-1.0	-3.5	-0.71	-0.71	0
$\delta \theta/w_0$	-7.2	-7.2	-24.7	5.0	-5.0	0



[JGW-T1402481](#)

← B in p.15 (Table 4.1)

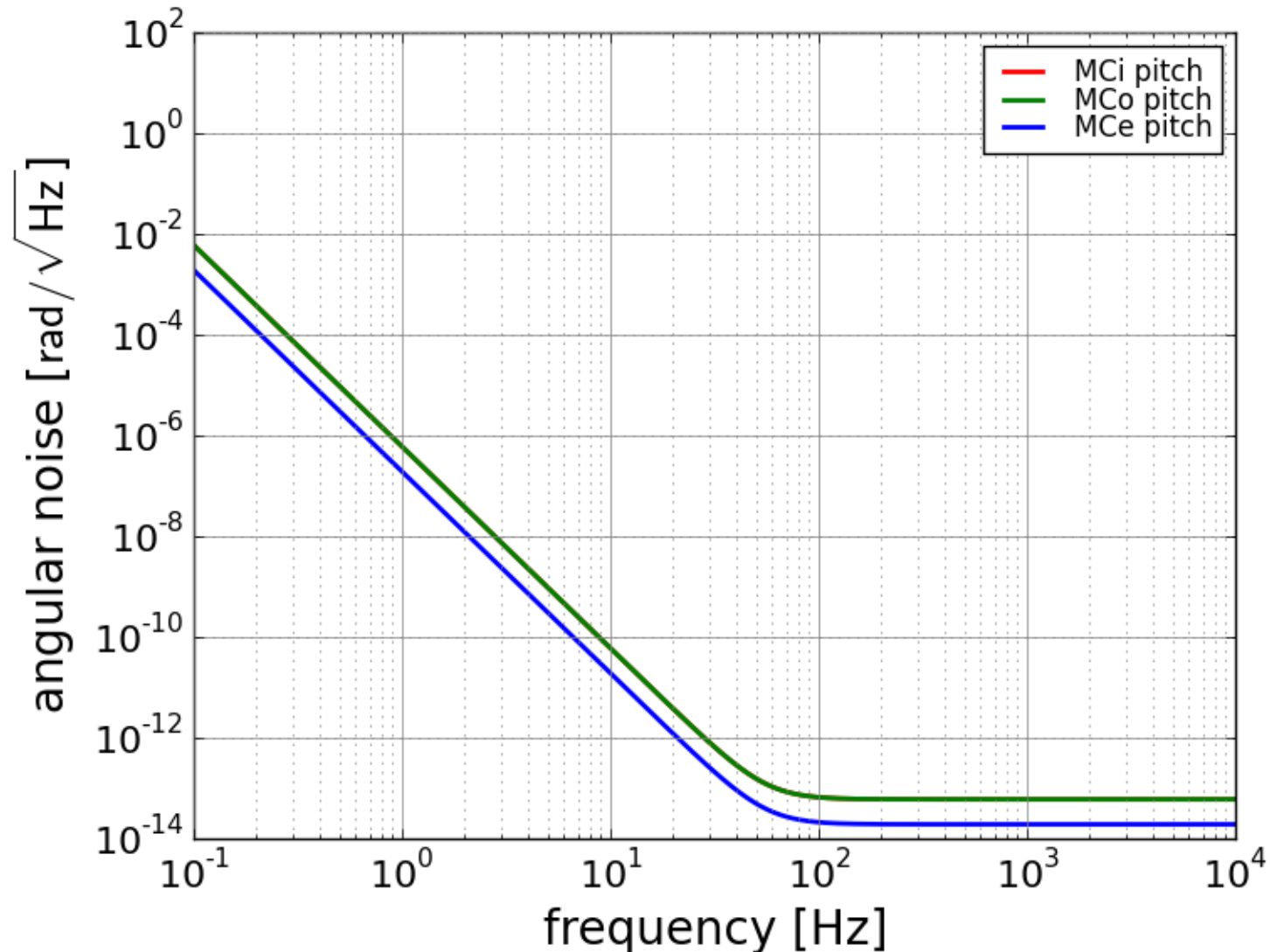
δx and $\delta \theta$ in units of
m/rad and rad/rad

$\delta x/w_0$ and $\delta \theta/\alpha_0$ in units of
1/mrad and 1/mrad

Requirement for Angular Motion

- requirement for pitch

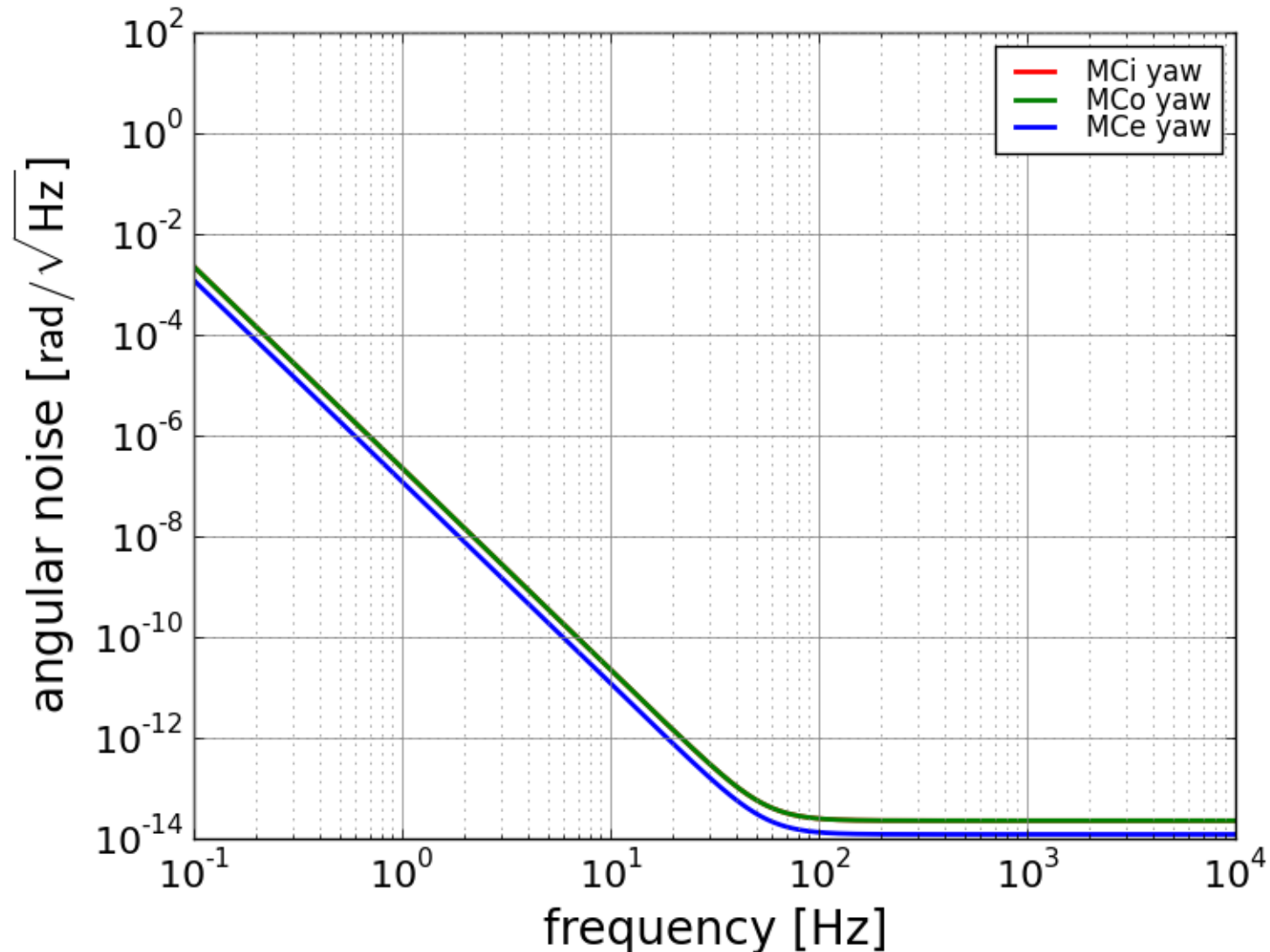
$$\vec{\theta}_{\text{req}}(f)$$



Requirement for Angular Motion

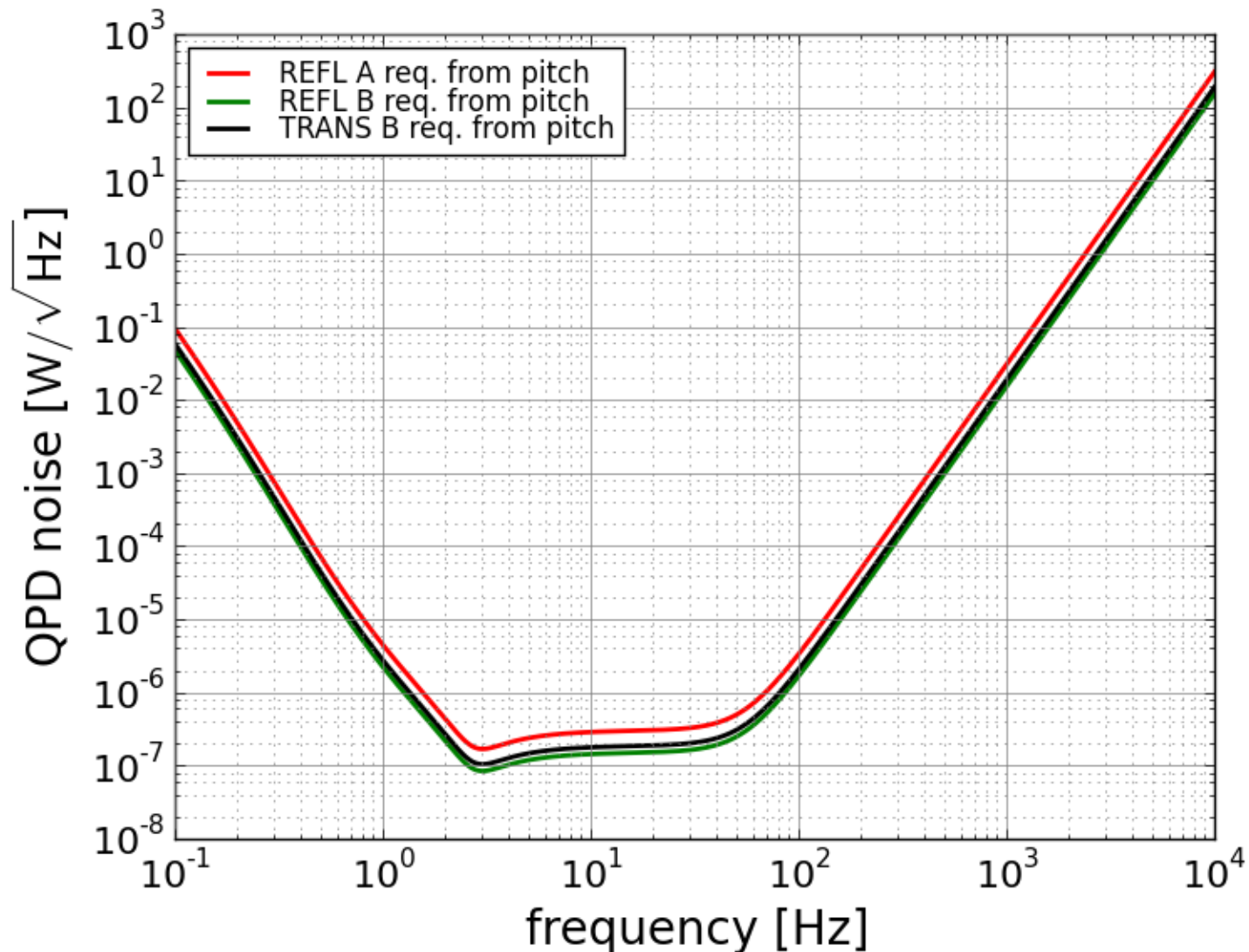
- requirement for yaw

$$\vec{\theta}_{\text{req}}(f)$$



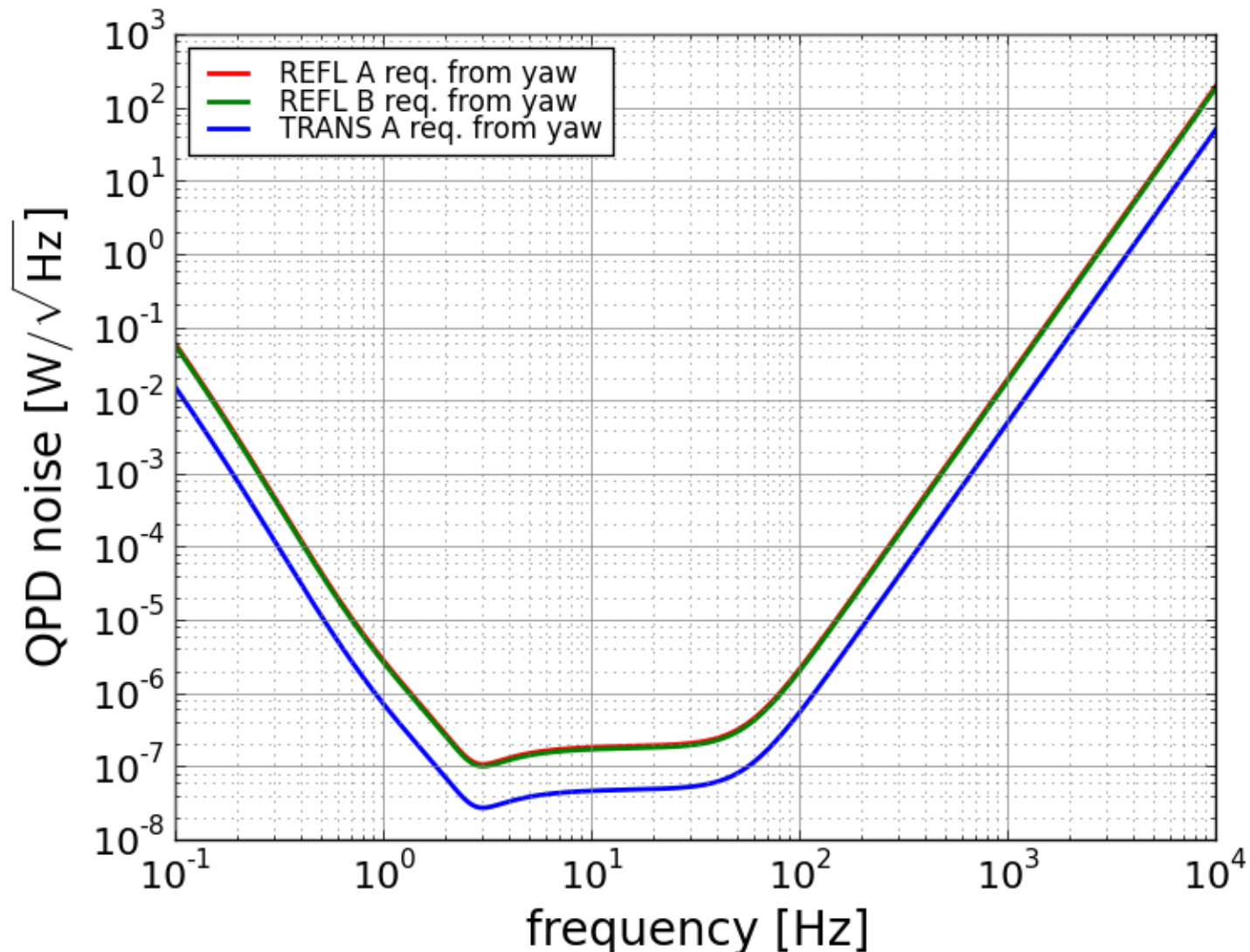
QPD Noise Requirement (pitch)

- requirement from pitch, in terms of QPD output in Watts



QPD Noise Requirement (yaw)

- requirement from yaw, in terms of QPD output in Watts



Estimated QPD Noise

- considering motions of DC QPDs in-air are larger than the seismic ground motion, **we may have to put them in-vacuum**

