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Noise Requirement for IMC QPDs

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Scope

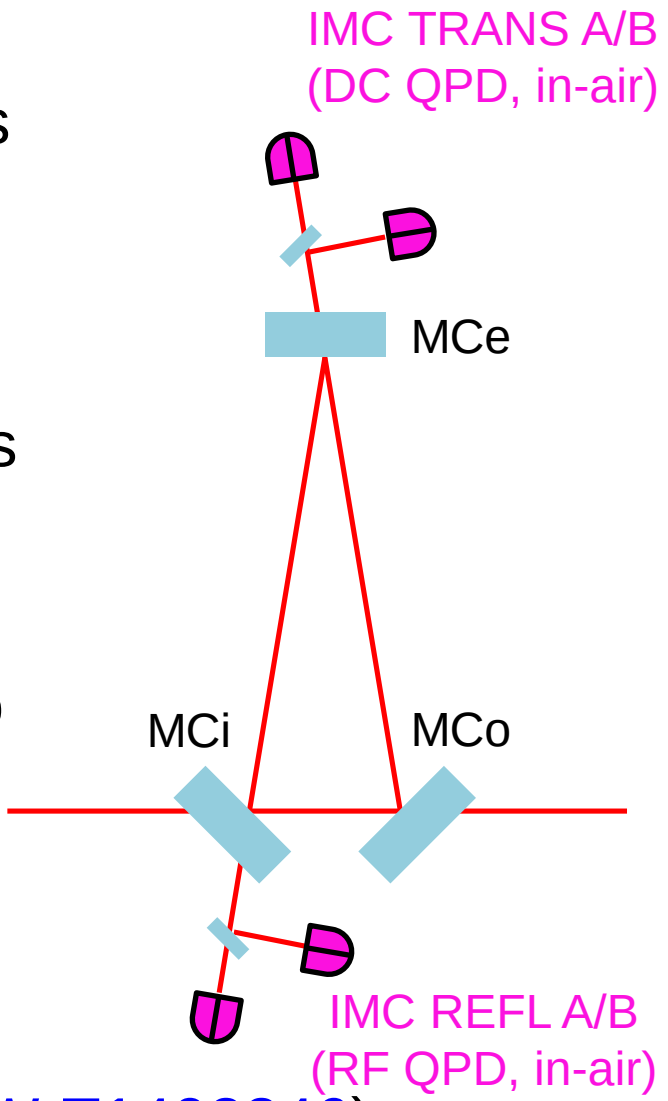
- Derive noise requirements for QPDs used for IMC ASC
- Show if the current design meets the requirement or not
  We may have to put IMC TRANS DC QPDs in vacuum

- Related documents:
  - JGW-T1402346 (requirement calculation for arm TMS)
  - JGW-T1402481 (IMC alignment sensing matrix calclation)
  - 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

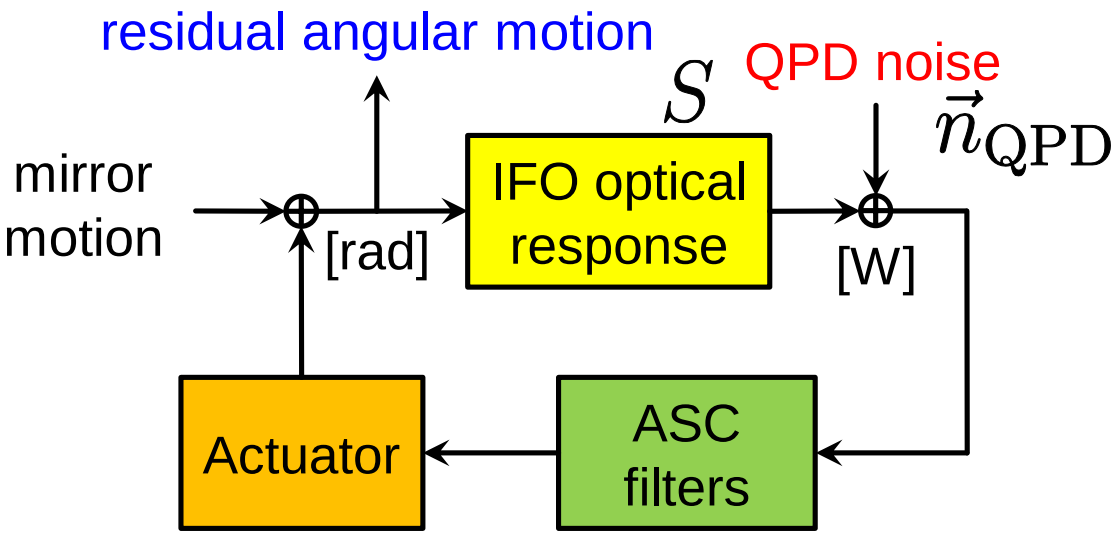
- IMC is used for the laser frequency stabilization servo (FSS), and there is a requirement for IMC length noise
- Shot noise, seismic noise, etc. on QPDs will fake IMC alignment signal, and thus IMC ASC shakes the mirrors
- Angle to length (A2L) coupling result in the IMC length noise
- This noise should be small enough to meet the IMC length noise requirement

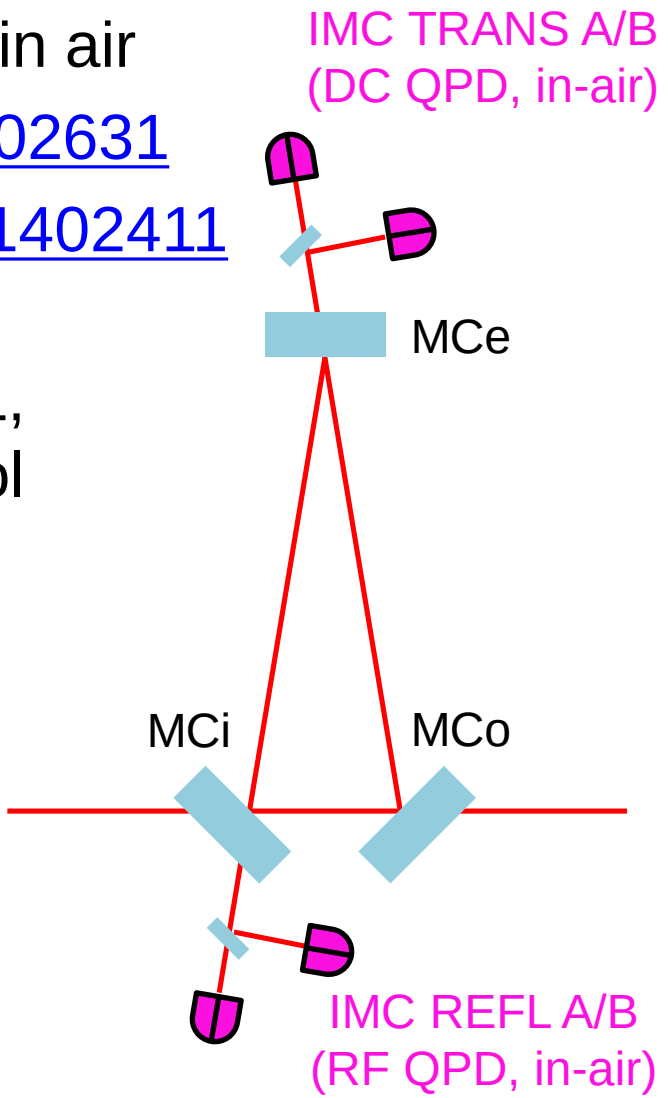


- Requirement derivation is similar to what we have done for the arms (JGW-T1402346)

Current IMC ASC Design

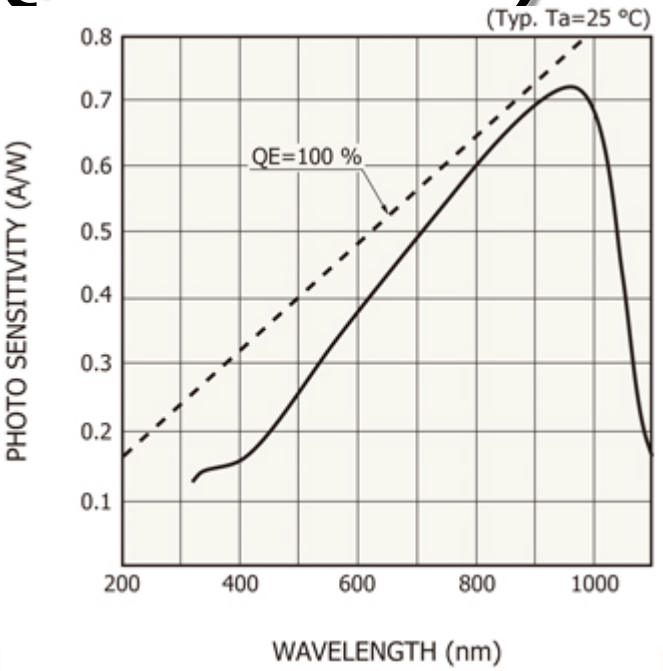
- QPDs are put on non-isolated tables in air
- REFL RF QPD schematic: JGW-D1402631
- TRANS DC QPD schematic: JGW-D1402411
  (same as the QPD used for oplevs)
- use two alignment signals from REFL, and one signal from TRANS to control three mirrors (we name two QPDs on each port as A and B)

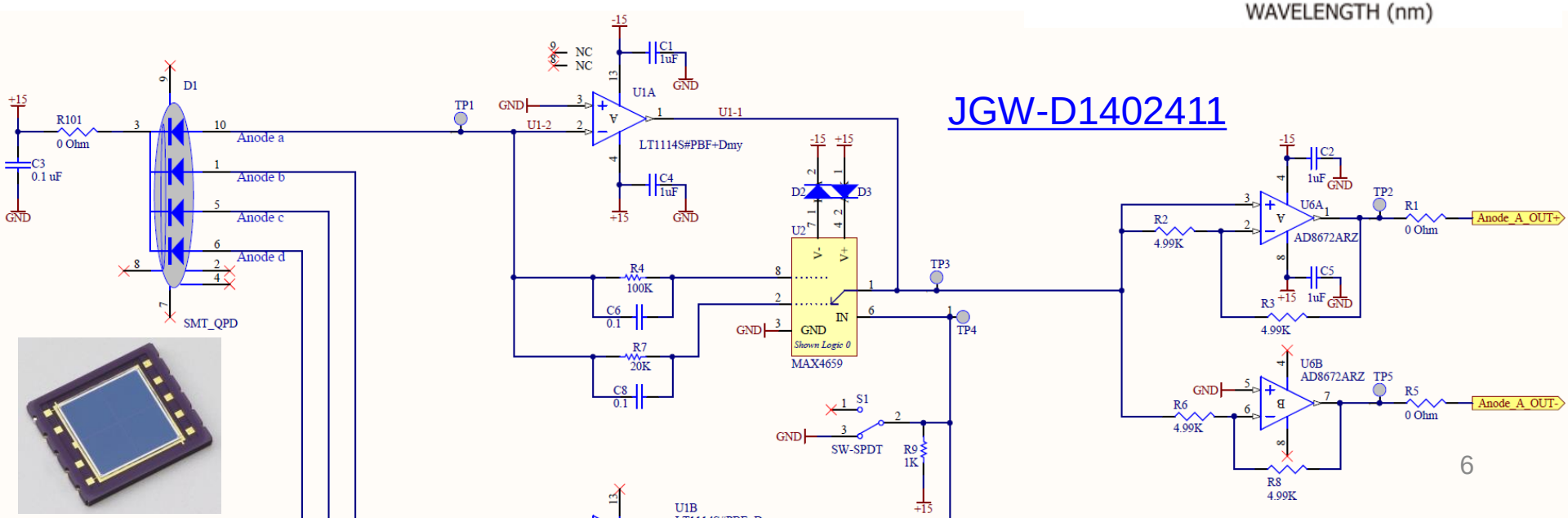




Oplev QPD (ISC DC QPD in-air)

- 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 kΩ (or 100 kΩ)





Expression and Assumptions

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

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

A2L [m/rtHz]

coupling for each mirror

beam mis-centering on mirrors [m]

ASC OLTF

sensing matrix [W/rad]

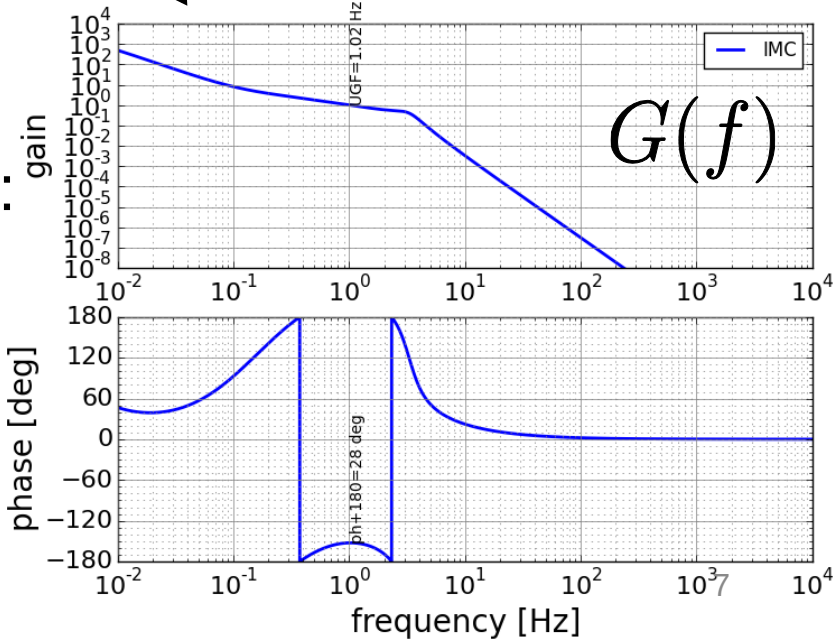
QPD noise [W/rtHz]

length noise requirement [m/rtHz]

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

incident angle for each mirror

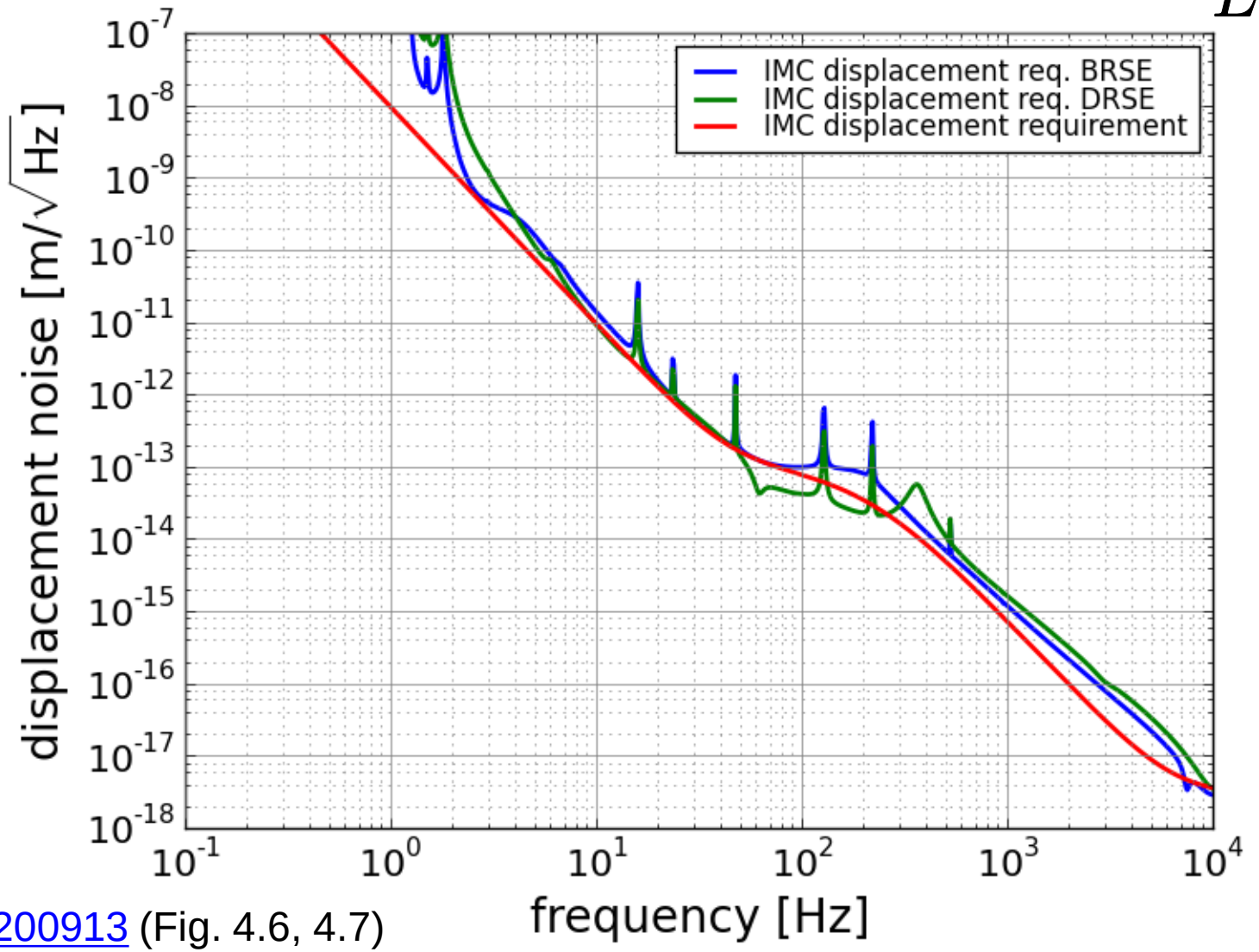
- Assumptions for the calculation:
  - 1 mW on each QPD
  - 0.2 mm beam radius on each QPD
  - $d^{\mathrm{RMS}} = 0.1$ mm
  - IMC ASC UGF = 1 Hz



IMC Length Noise Requirement

- here, red line is used for simplicity

$L_{\mathrm{req}}(f)$

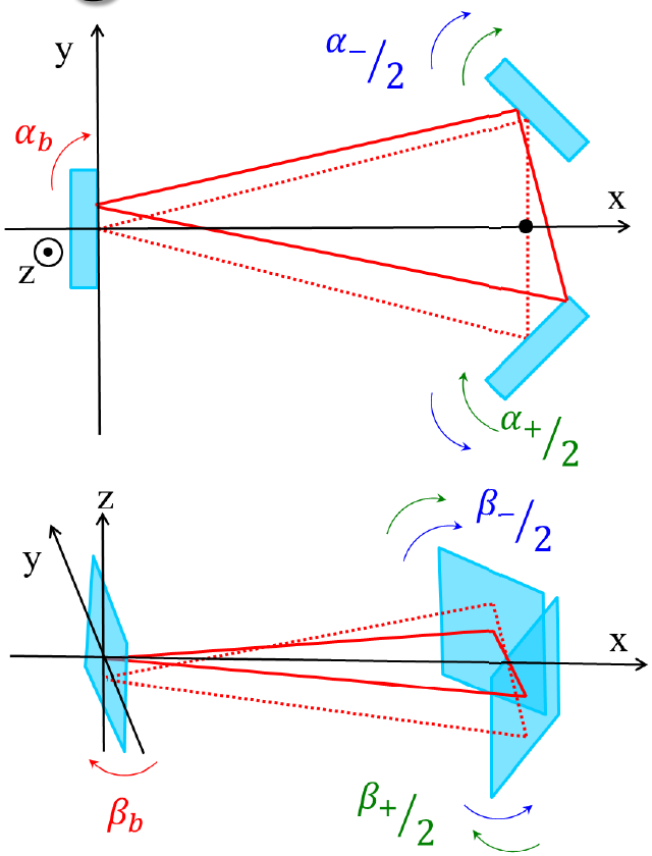


JGW-T1200913 (Fig. 4.6, 4.7)

IMC Alignment Sensing Matrix

- DOF basis

	yaw			Pitch		
	αb	α+	α-	βb	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

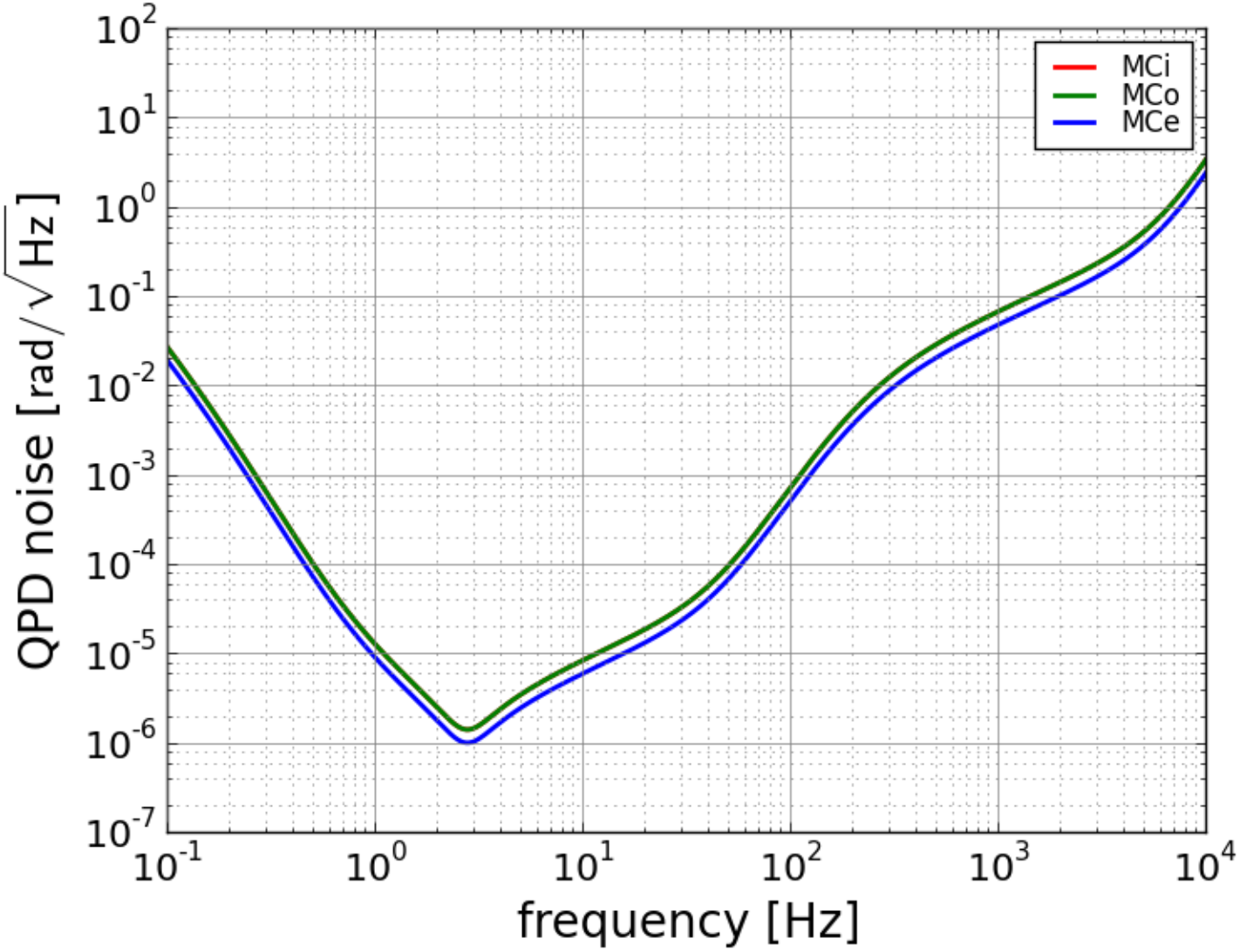
JGW-T1402481 (Table 8.1)

← S in p.4

all in units of W/rad
modulation index = 0.1

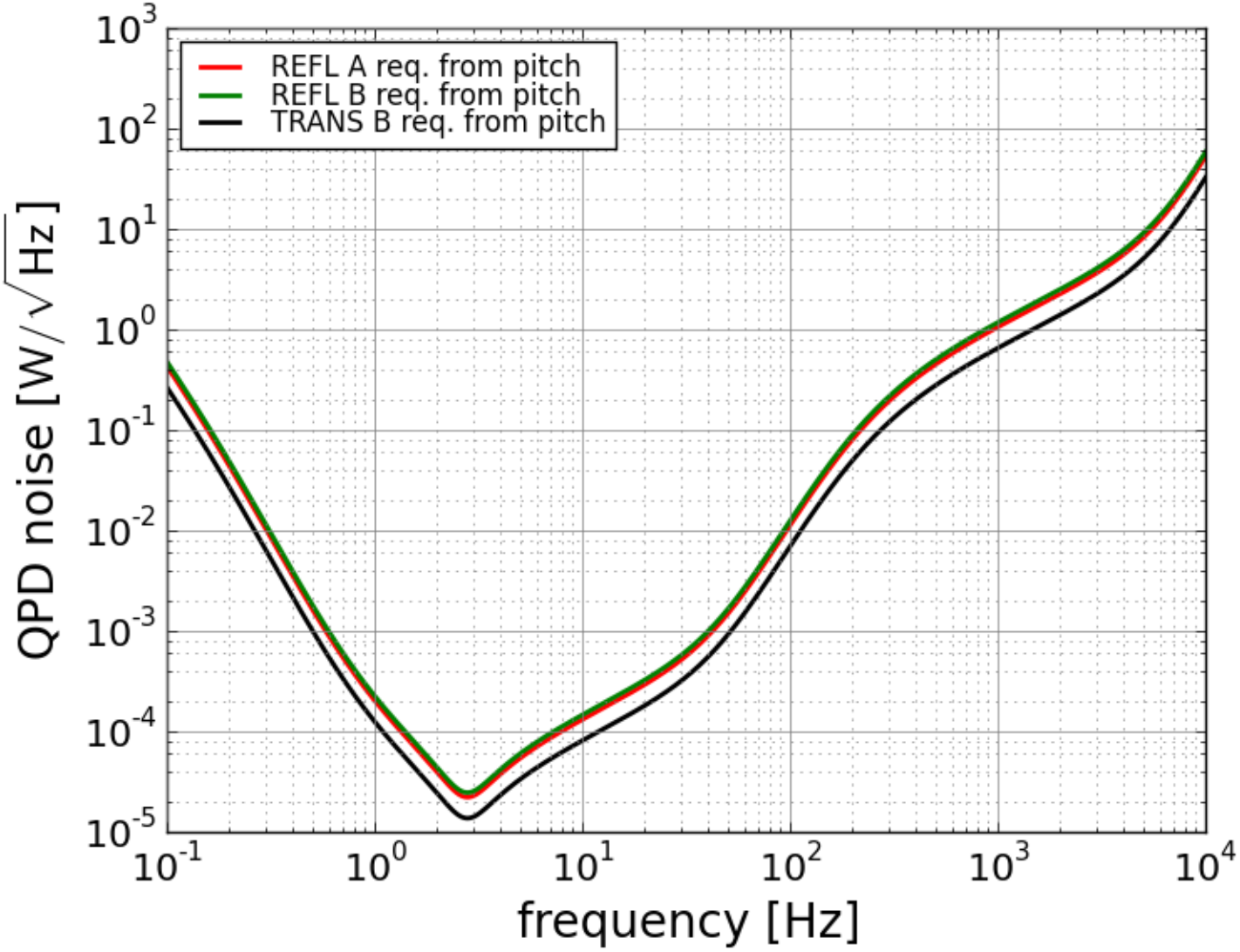
QPD Noise Requirement

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



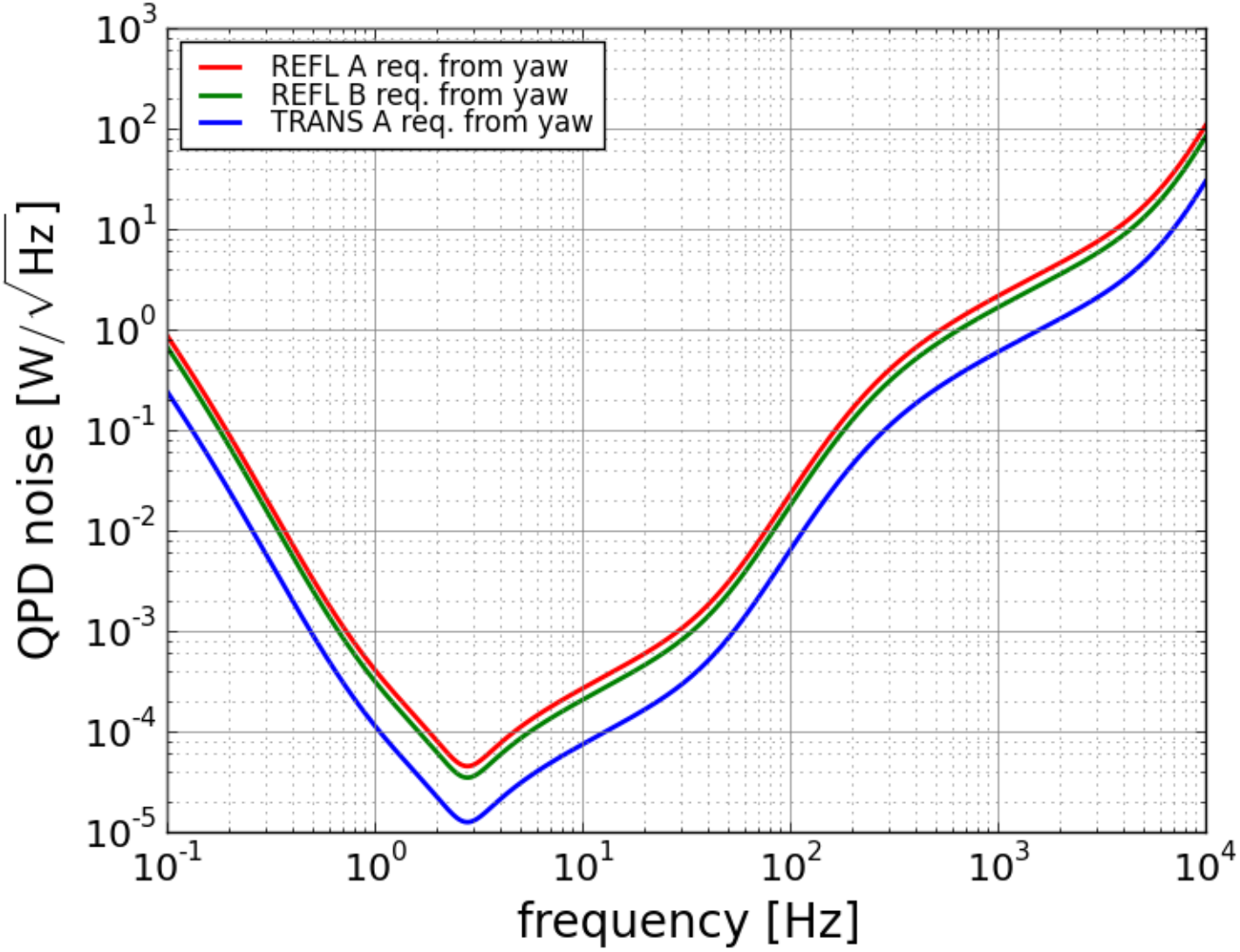
QPD Noise Requirement (pitch)

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



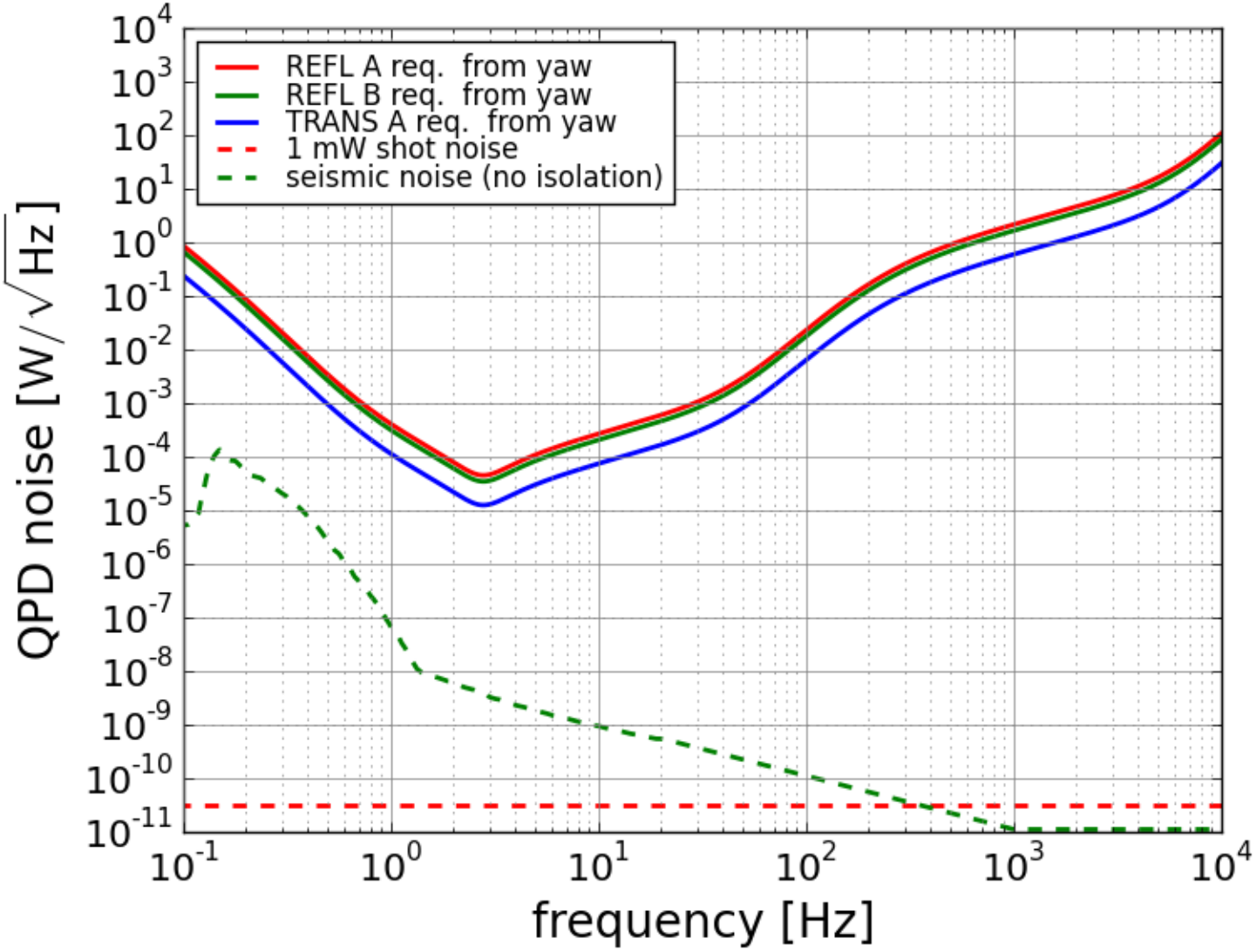
QPD Noise Requirement (yaw)

- 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

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

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

- can be calculated from beam jitter requirement with

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

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

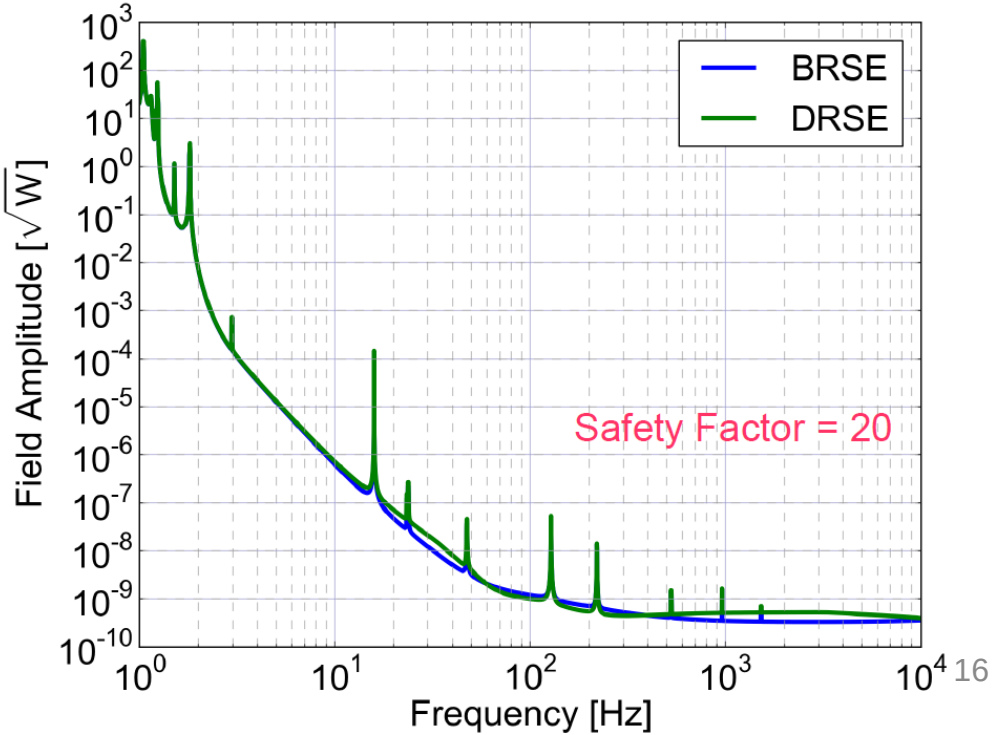
$$\sqrt{\left(\frac{\delta x}{w_0}\right)^2 + \left(\frac{\delta\theta}{\alpha_0}\right)^2} < (3\times10^{-10} + 3\times10^{-3}\ \mathrm{Hz}/f^4)\ /\sqrt{\mathrm{Hz}}$$

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)

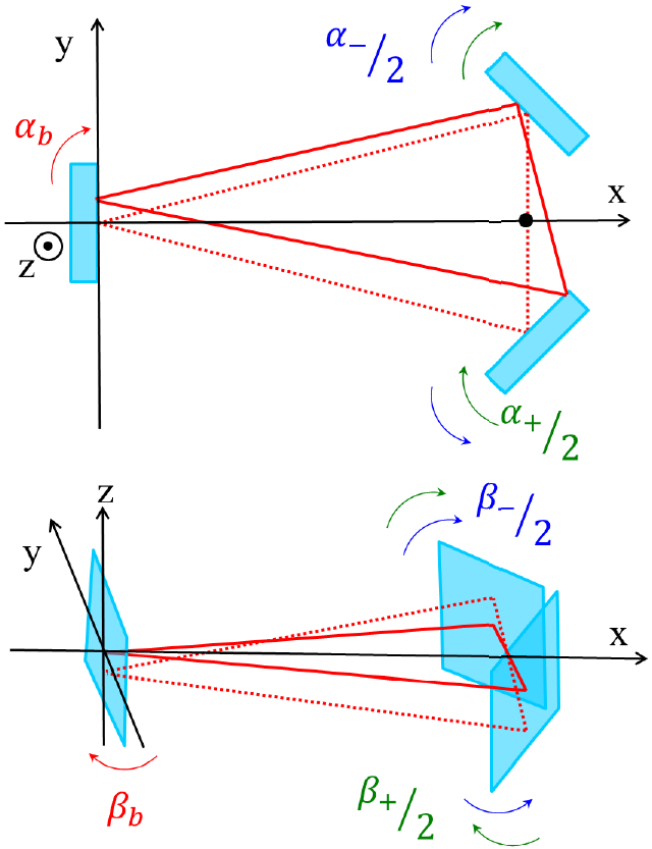


Beam Jitter from Angular Motion

- DOF basis

	yaw			Pitch		
	αb	α+	α-	βb	β+	β-
δx	0	0	-26.4	-37.3	0	0
δθ	-3.5	-1.0	0	0	0	-0.71

δx: beam translation
δθ: 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
δx/w0	11.1	-11.1	0	0	0	-15.6
δθ	-1.0	-1.0	-3.5	-0.71	-0.71	0
δθ/w0	-7.2	-7.2	-24.7	5.0	-5.0	0

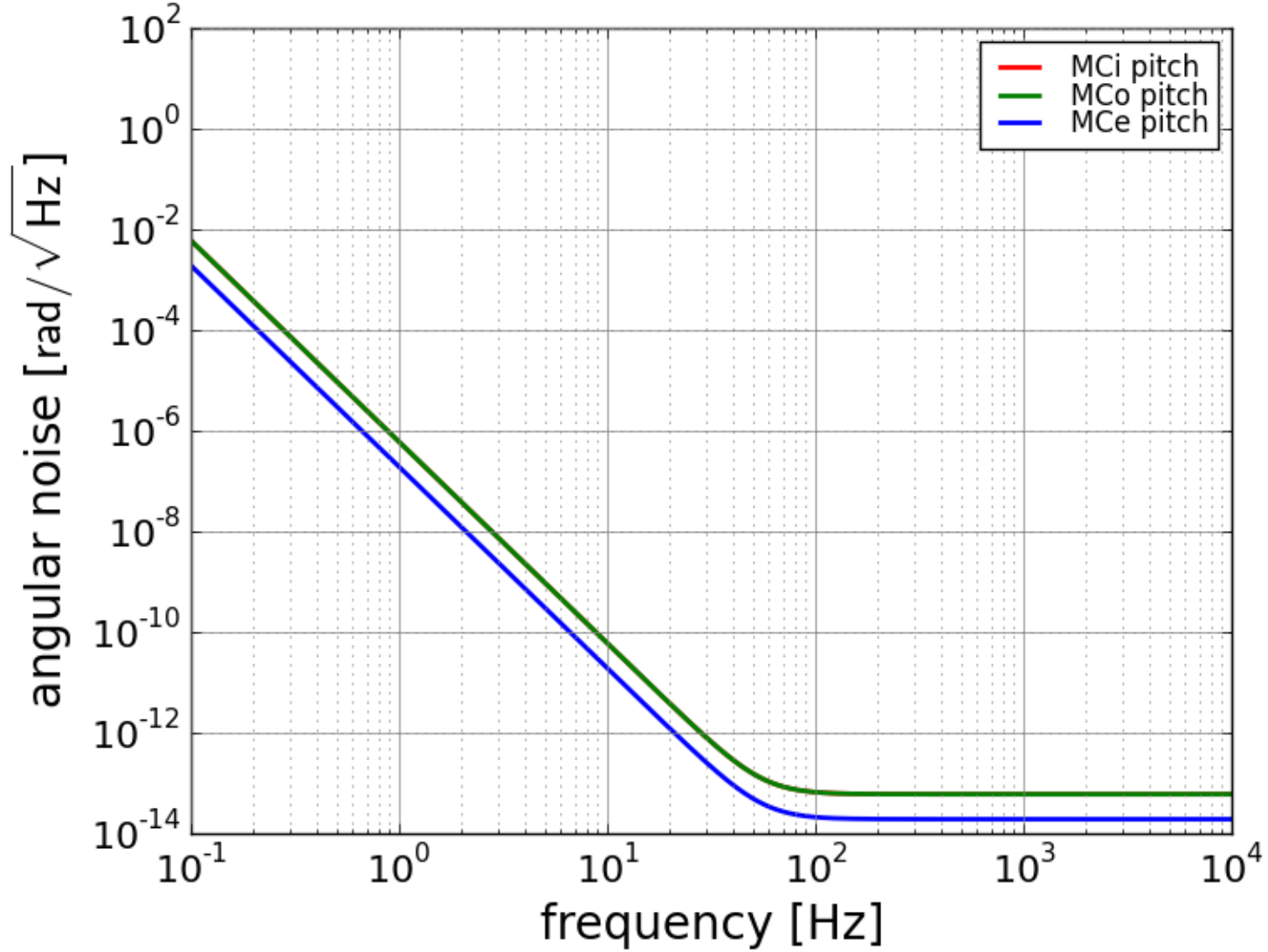
JGW-T1402481

← B in p.15 (Table 4.1)

δx and δθ in units of
m/rad and rad/rad
δx/w0 and δθ/α0 in units of
1/mrad and 1/mrad

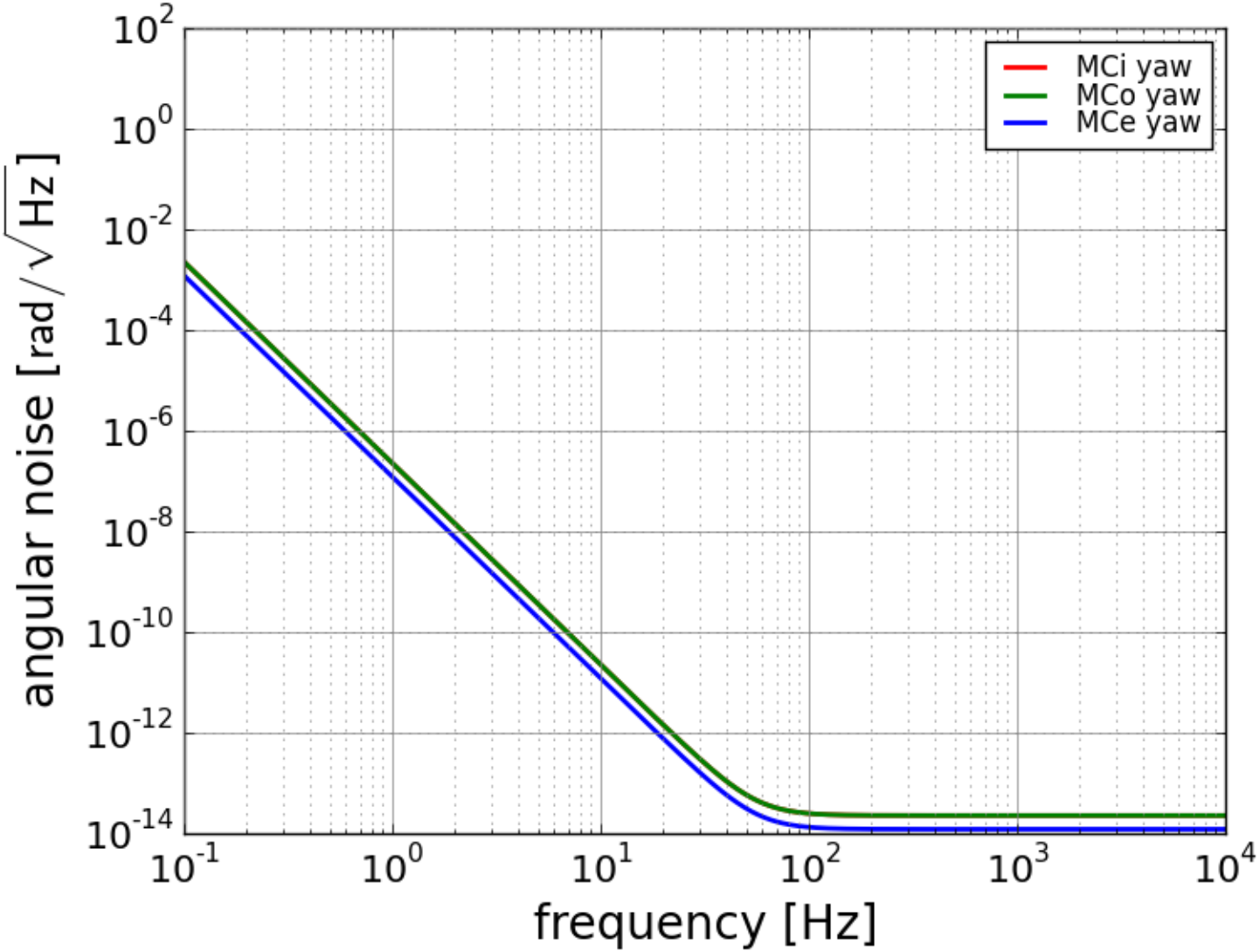
Requirement for Angular Motion

- requirement for pitch $\vec{\theta}_{\mathrm{req}}(f)$



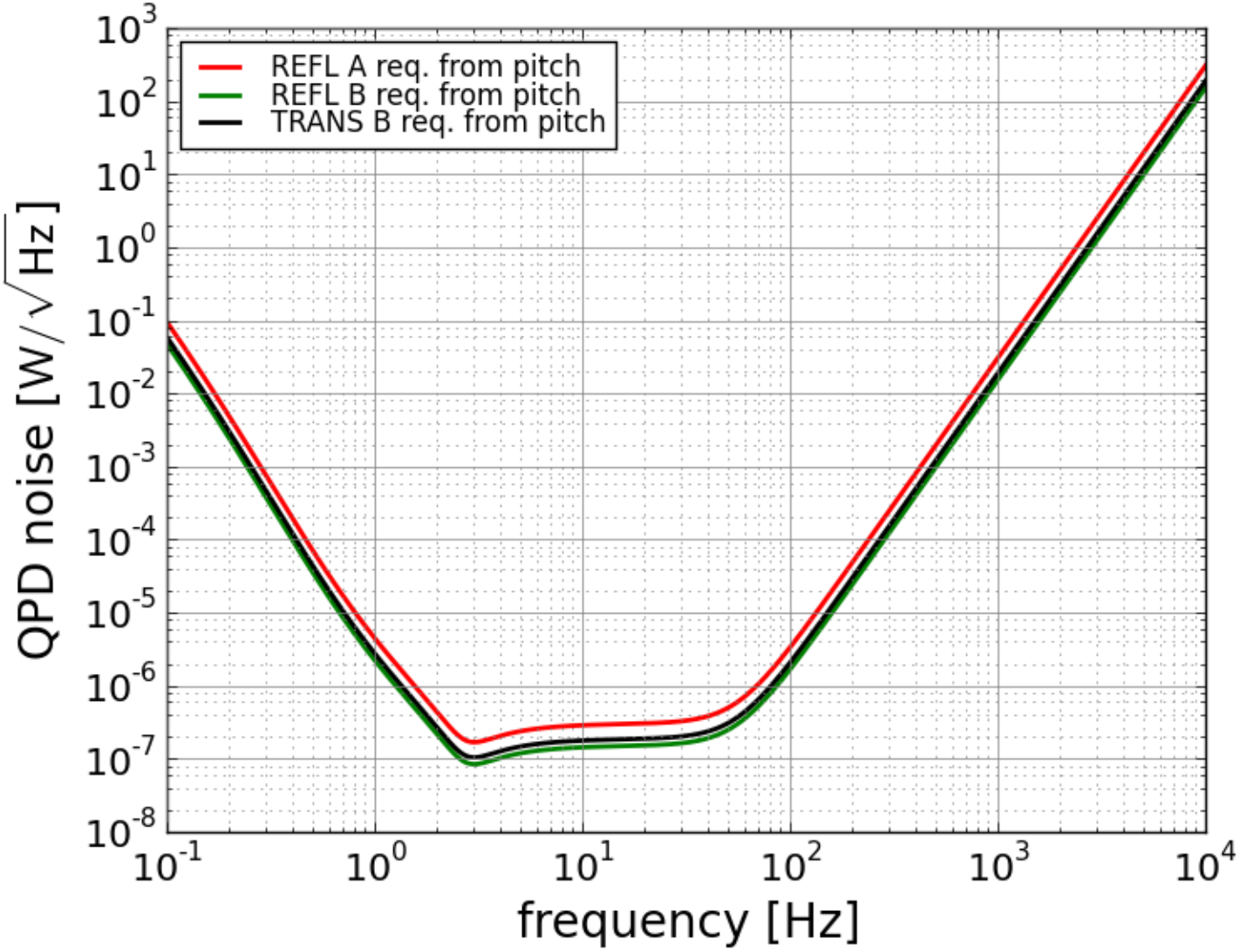
Requirement for Angular Motion

- requirement for yaw $\vec{\theta}_{\mathrm{req}}(f)$



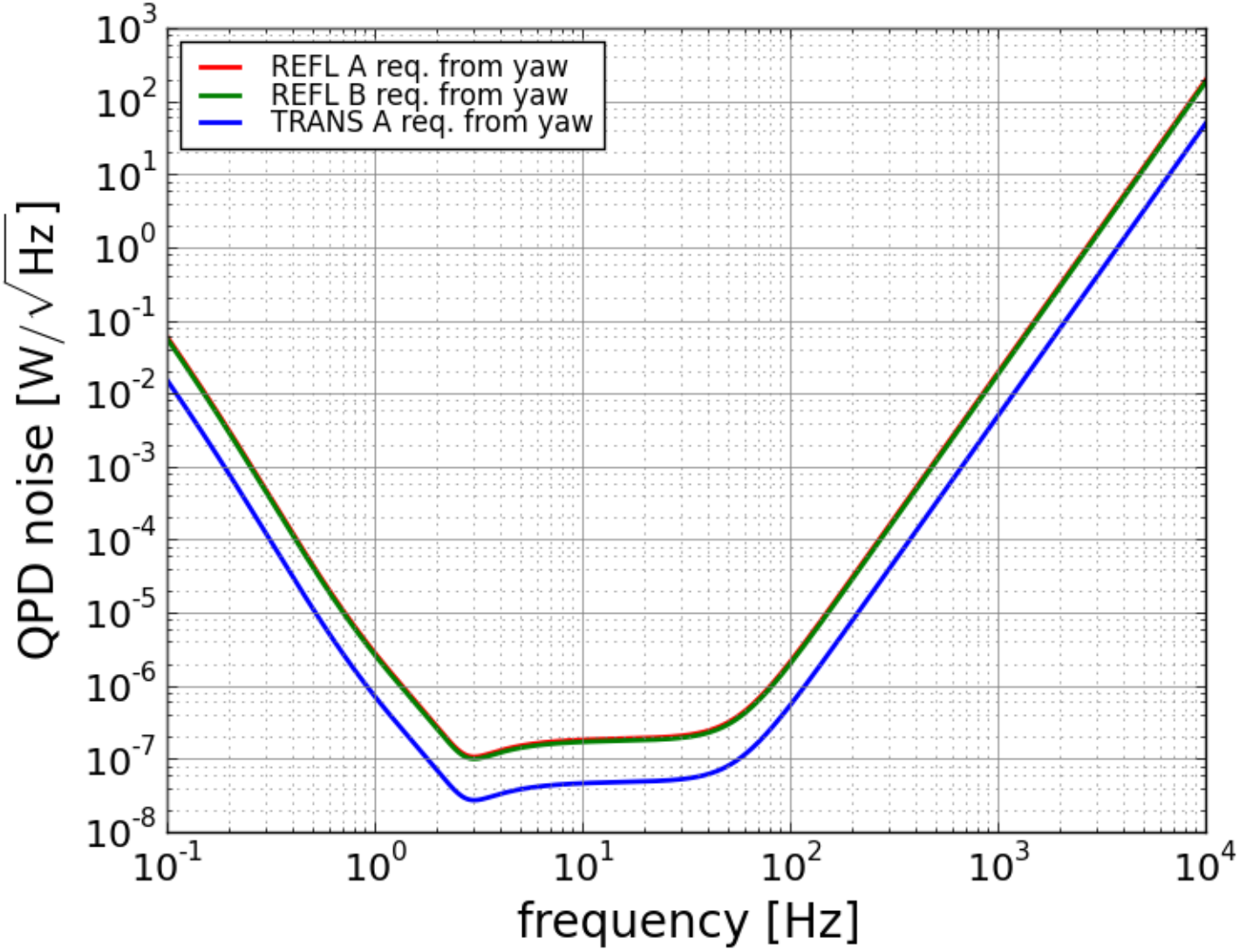
QPD Noise Requirement (pitch)

- 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