Improving a fiber optic interferometer for the SAFARI instrument

In Cooperation with Technobis

Finn van Rij, Department: PME , Specialisation: MSD

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Graduate commission:

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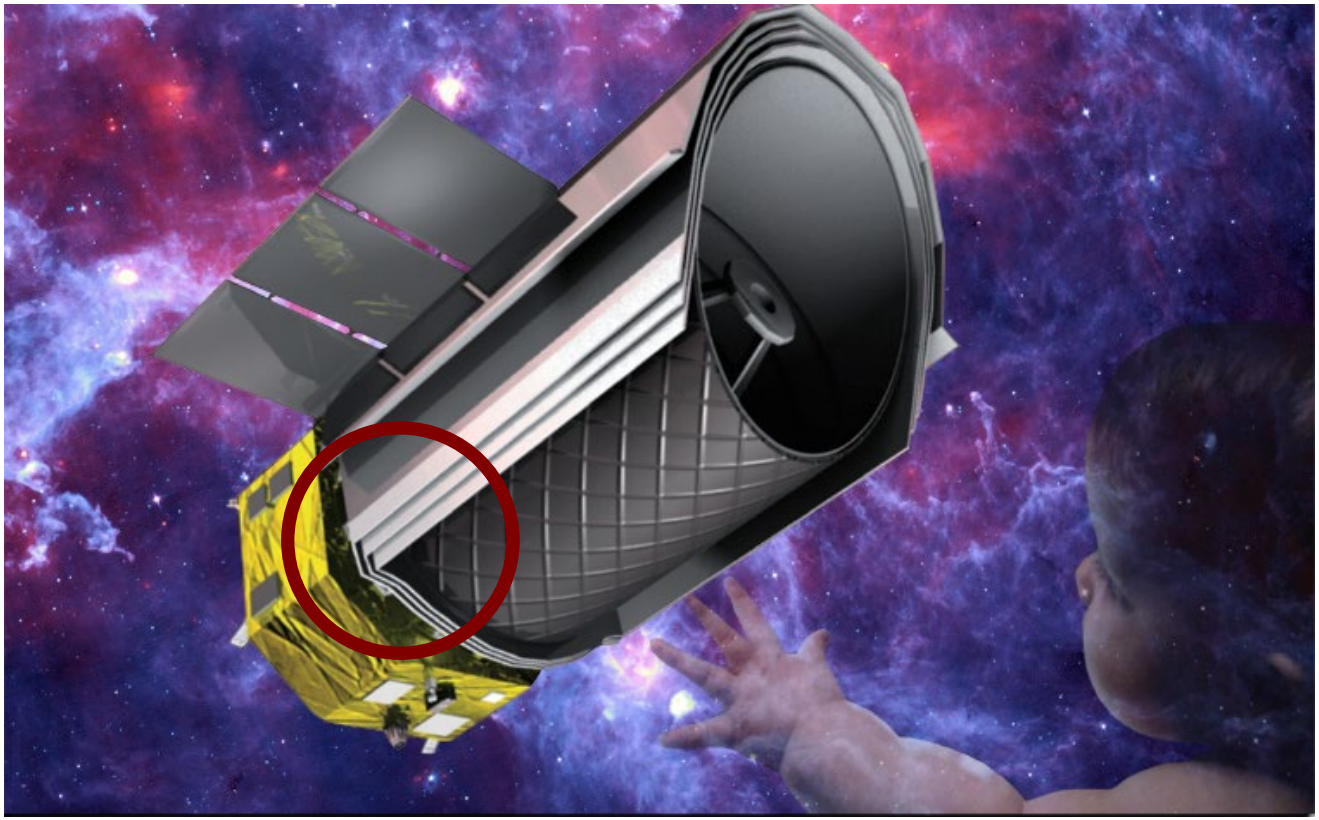
Ing. R. Evenblij
Dr. J.J. van den Dobbelsteen

Please turn of your mobile phones or switch them to silent mode!

Introduction

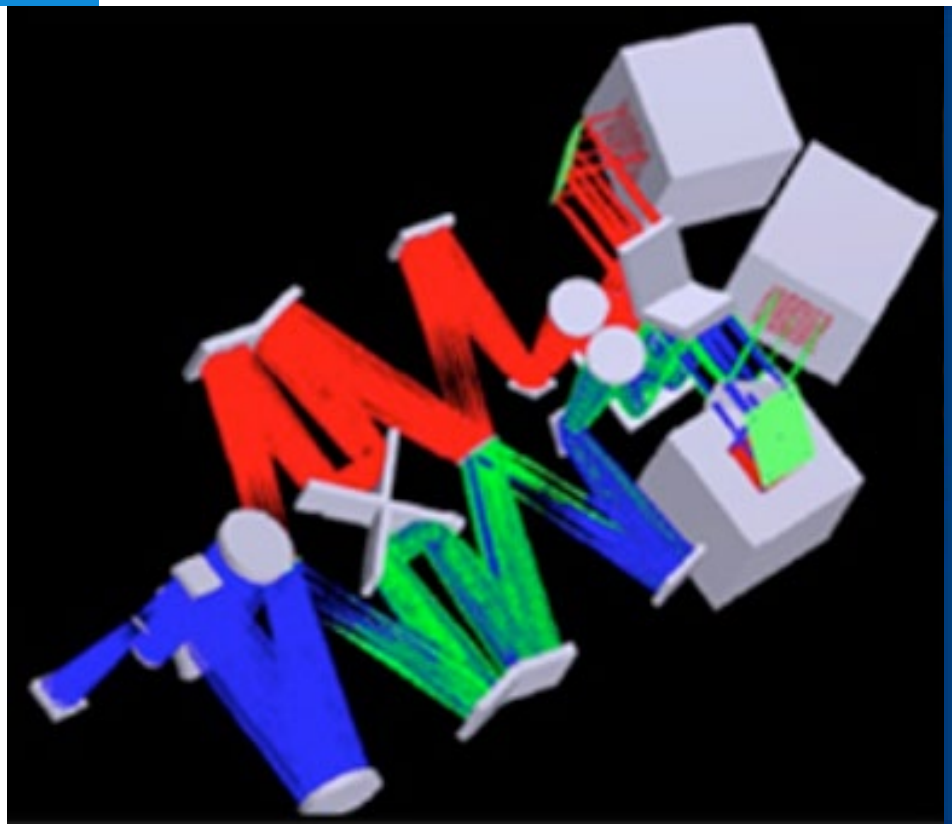
Space telescope: "SPICA"

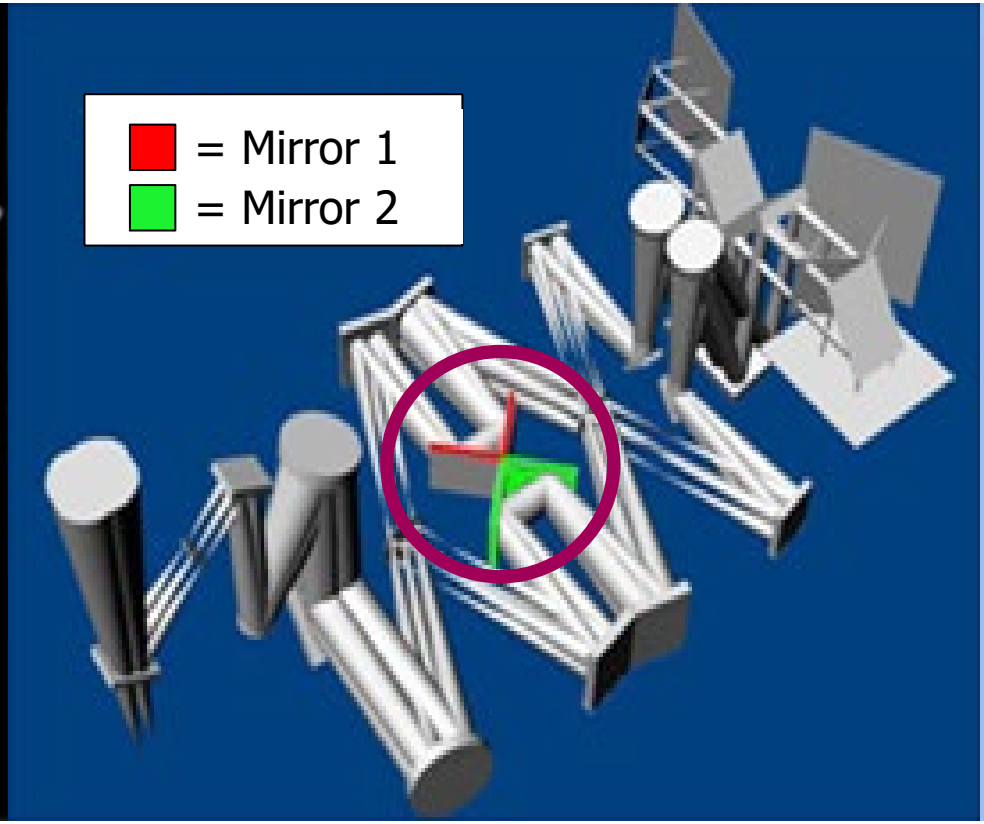


What is the SAFARI instrument?

Introduction

Instrument: "SAFARI"

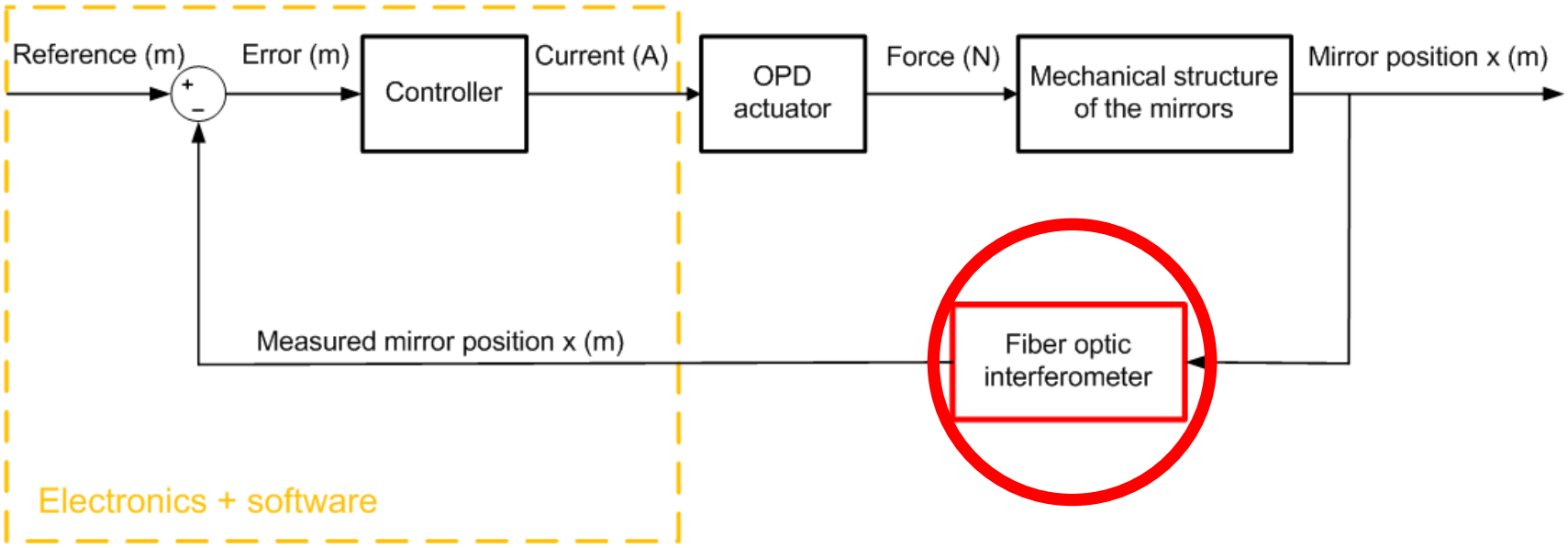




What is the SAFARI instrument?

Introduction

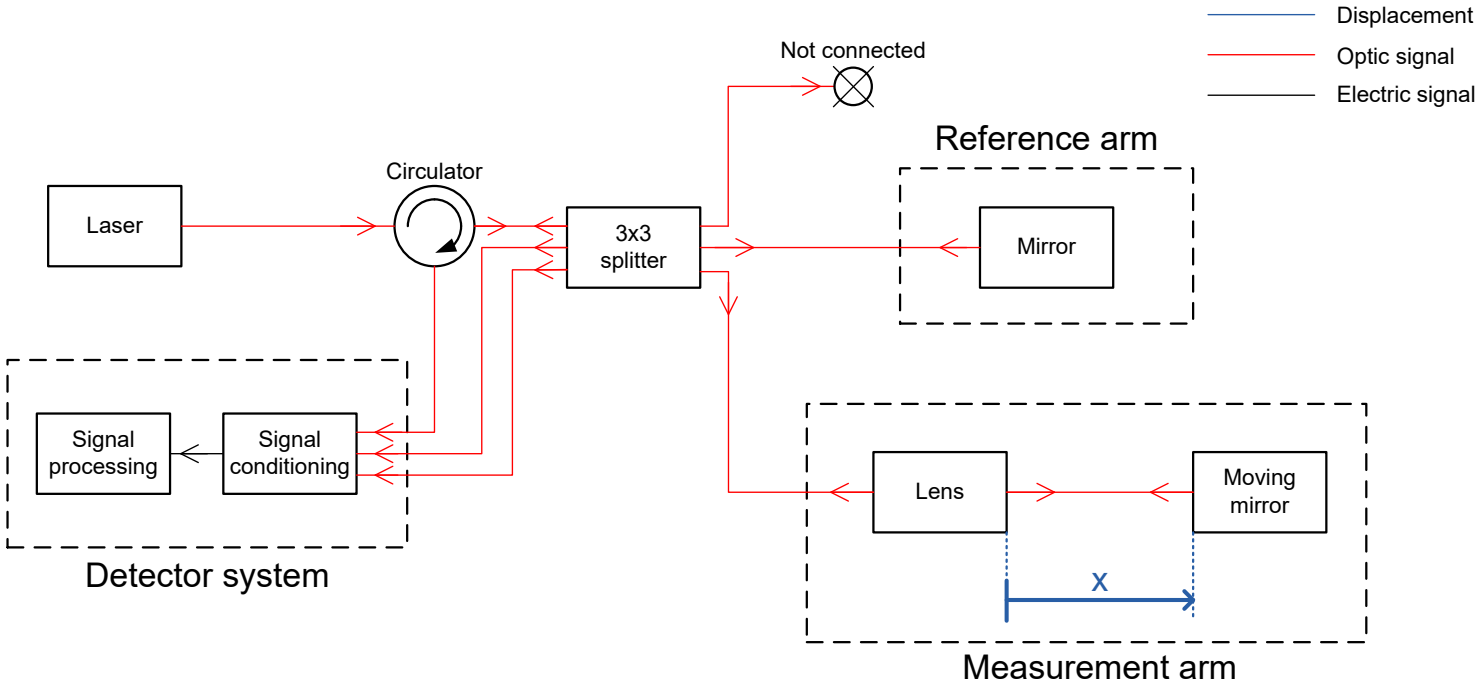
Optical Delay Line: "ODL"



What is the fiber optic interferometer?

Introduction

Fiber optic interferometer: "LUNASYS"



What is the fiber optic interferometer?

Introduction

Full system (Top level)

SPICA (JAXA)

SAFARI

Heat shields + cryo cooling (SRON)

Mach Zehnder interferometer (TNO)

Focal plane arrays (SRON & MECON)

Fourier Transform Spectrometer (FTS) mechanism (TNO)

Optical Delay Line (ODL) (TNO)

Optical Path Difference (OPD) actuator (TNO &magnetic innovations)

Optical Path Difference (OPD) metrology (TNO)

Fiber optic interferometer (Name = LUNASYS) (Technobis)

Electronics + software (SRON)

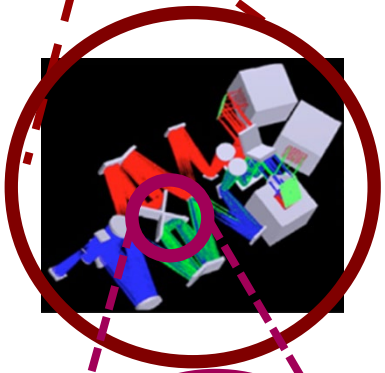
Subsystem (Bottom level)

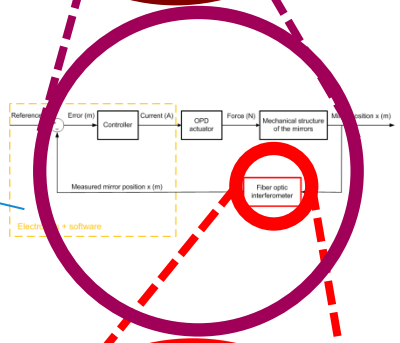
Space telescope name

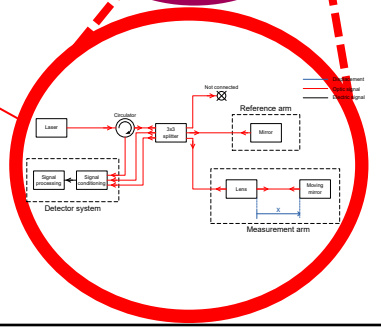
Instrument used to perform measurements in the far infrared spectrum

Mechanism used to position two mirrors

Considered system for this MSc presentation







What is the fiber optic interferometer?

Introduction

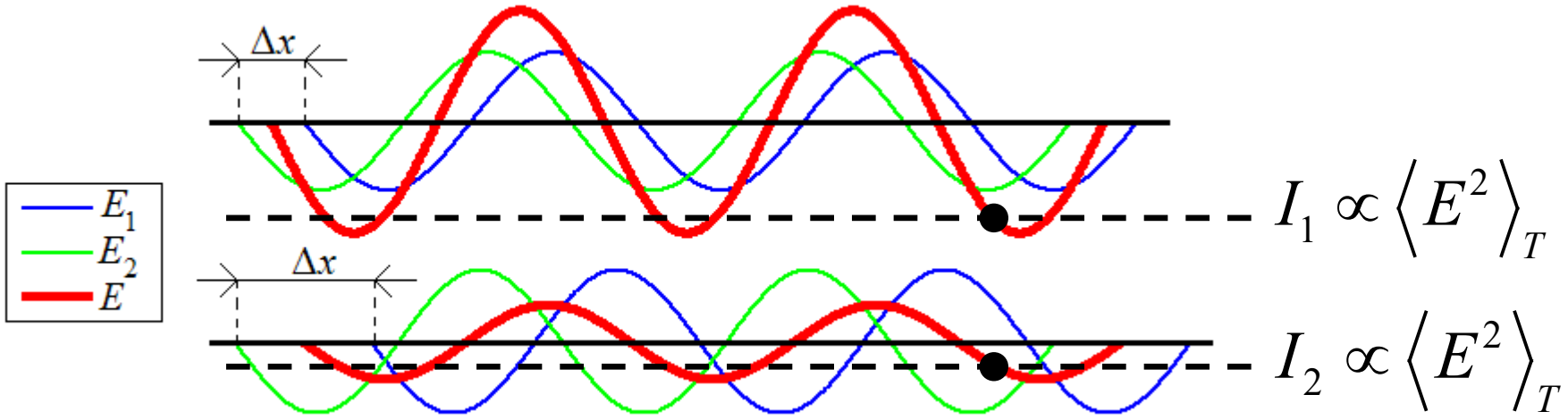
Main goal:

Improve the fiber optic interferometer from Technobis such that it fulfills the requirements for within the SAFARI instrument.

- Resolution = 1 (nm)
- Operate at 4.5 (K) = -269°C
- Accuracy = 10 (nm)
- Heat load < 100 (μW)
- Stray light power < 890 (nW)
- Measurement range = 35 (mm)

What is the main goal of Technobis for the fiber optic interferometer?

Introduction



$$E_1(x,t) = E_{01}\sin(\omega t - k(x+\Delta x))$$

$$E_2(x,t) = E_{01}\sin(\omega t - kx)$$

$$E = 2E_{01}\cos\left(\frac{k\Delta x}{2}\right)\sin\left[\omega t - k\left(x+\frac{\Delta x}{2}\right)\right]$$

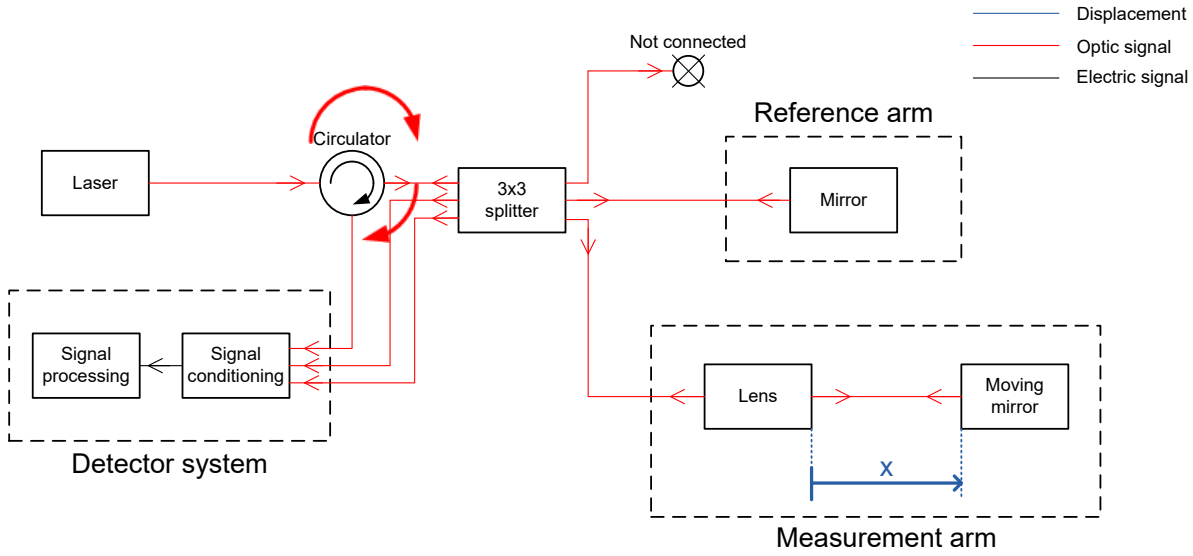
Irradiance:

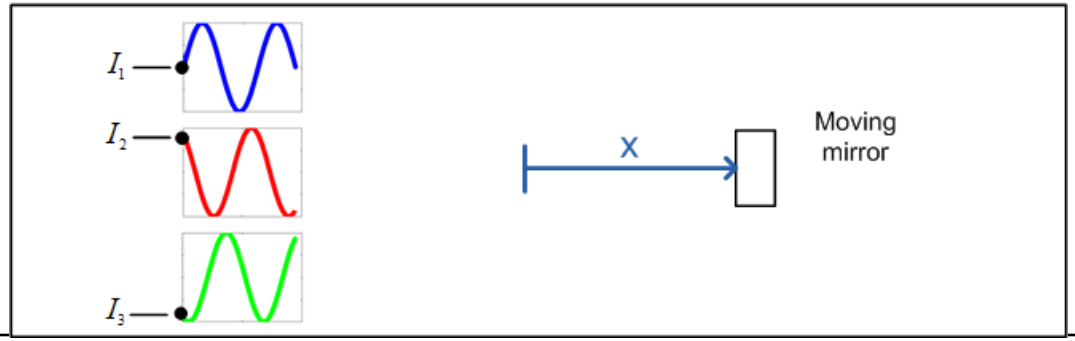
$$\Delta x = OPD$$

$$I = c\varepsilon_0 {E_{01}}^2\left[1+\cos\left(\frac{2\pi}{\lambda}OPD\right)\right]$$

How does a fiber optic interferometer work?

Introduction





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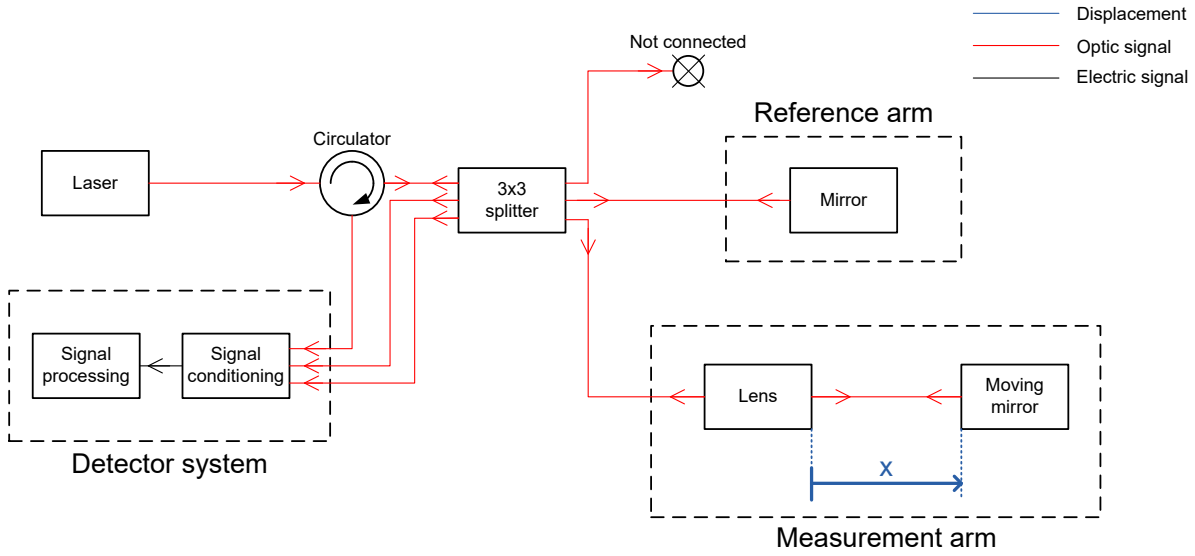

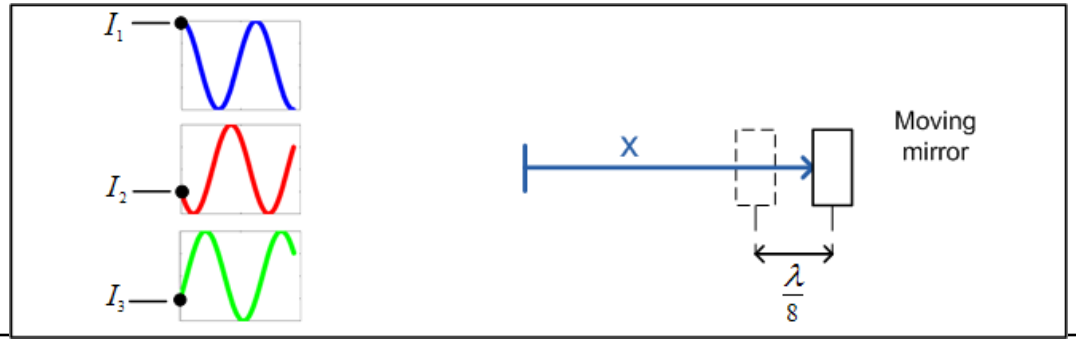

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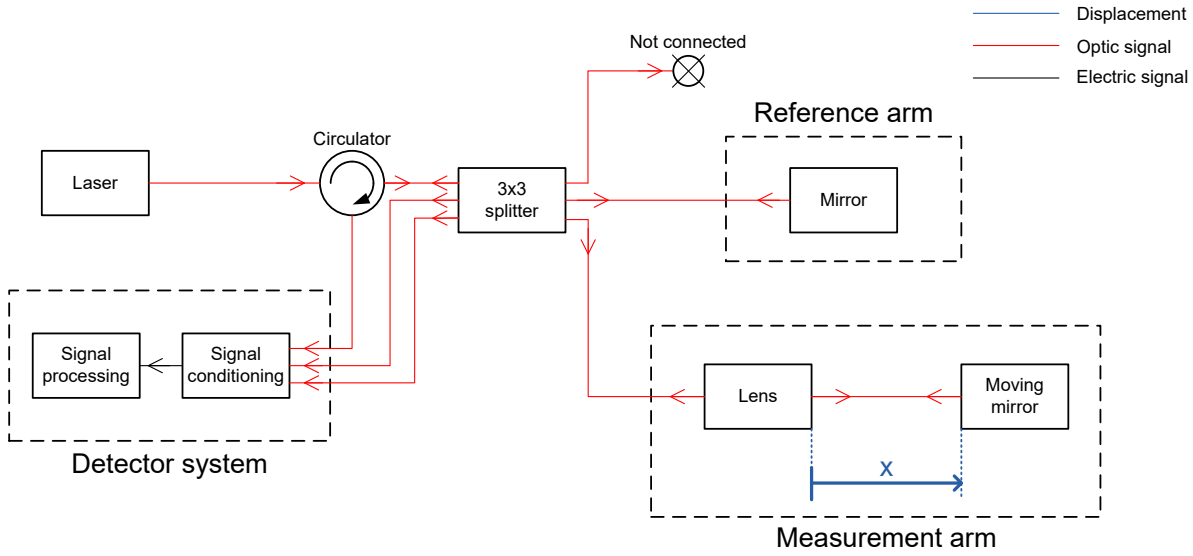
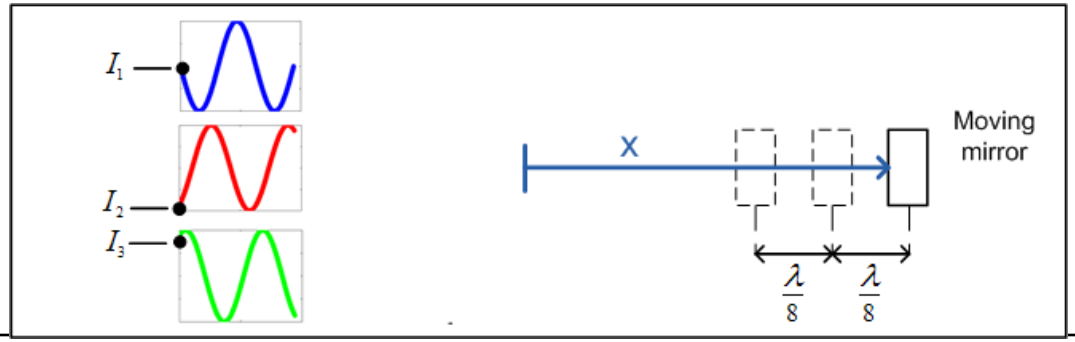




How does a fiber optic interferometer work?

Contents

- Research questions
- Requirements and specifications
- Problem analysis
- New concept
- Conclusions
- Recommendations

Research questions

1) Is the current setup of LUNASYS operational for the SAFARI instrument?

    a) What are the requirements for LUNASYS for the SAFARI application?

    b) What are the specifications of the current setup of LUNASYS?

2) What needs to be improved on the current setup of LUNASYS to make the system operational for the SAFARI application?

    c) Is temperature the dominant factor causing the drift of LUNASYS?

    d) What needs to be improved on the current setup of LUNASYS in order to reach the targeted requirements?

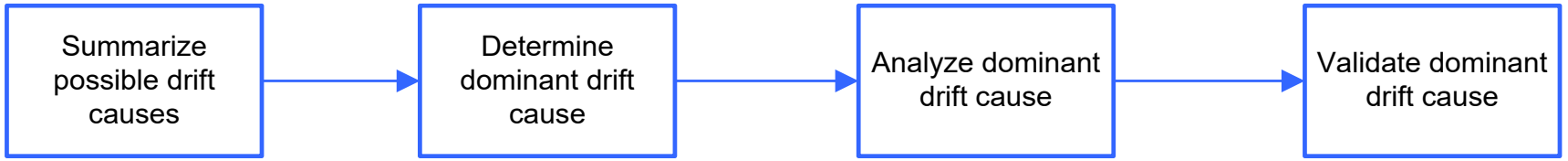
Requirements and specifications

Type of specification	Required value	Specified value
Accuracy	10 (nm) over 200(s)	1100 (nm) over 1 (hr)
Resolution	1 (nm)	0.19 (nm)
Stroke	34.5 (mm)	34.5 (mm)
Sample frequency	439 (Hz)	781 (Hz)
Heat load	100 (µW)	20.9 (µW)
Stray light power	0.89 (µW)	2.4E-12 (µW)
Space qualified	Yes	No
Maximal required electrical power	1.0 (W)	6.67 (W)
Functionality at cryogenic temperature of 4.5 (K)	Yes	No
Relative displacement measurement	Yes	Yes
Laser + electronics placed in room of 253 (K)	Yes	Yes
Sensor head placed near the ODL	Yes	Yes

a) + b) What are the requirements and specifications for the fiber optic interferometer?

Problem analysis

Method:



Problem analysis

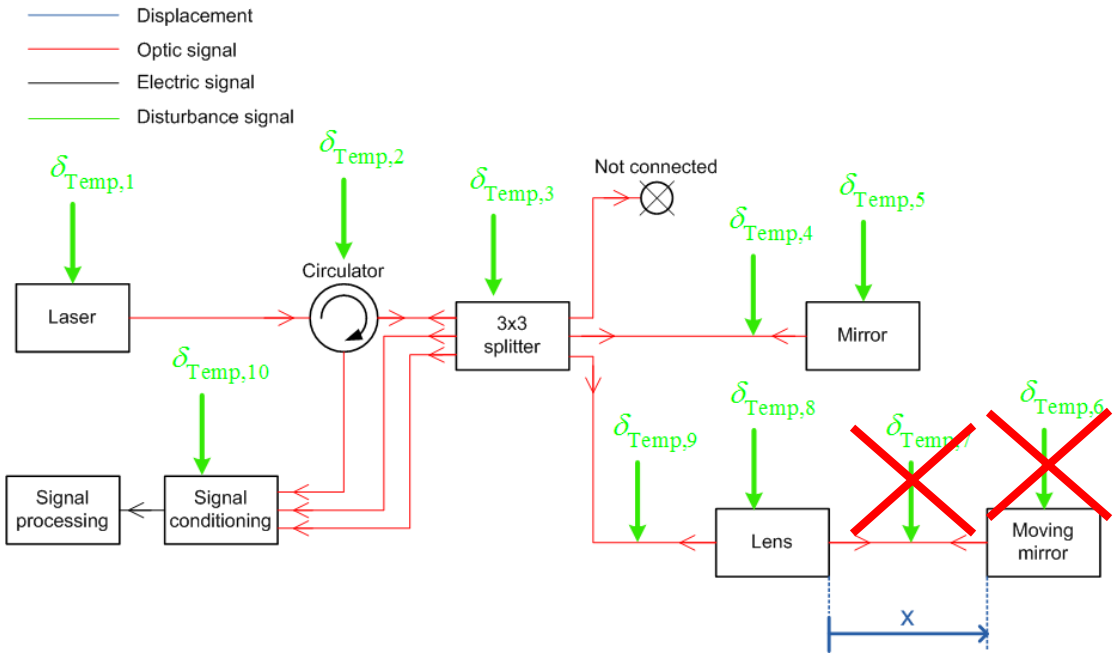
Summarize possible drift causes

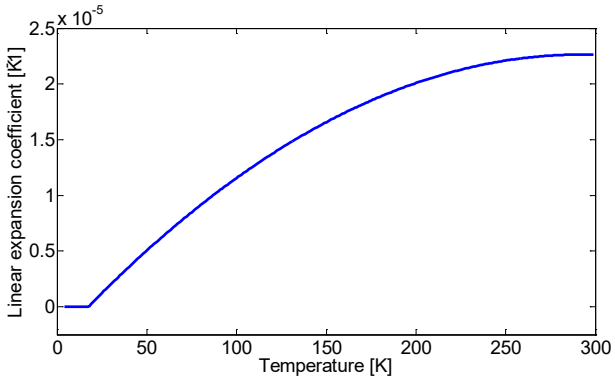
• Laser wavelength stability	1(nm)
• Mechanical vibrations	12 (nm)
• Refractive index changes of air	94 (nm)
• Phase and gain changes of the 3x3 splitter	???
• Temperature disturbances acting on the measurement and the reference arm	750 (nm)

c) Is temperature the dominant factor causing the drift of the fiber optic interferometer?

Problem analysis

Determine dominant drift cause





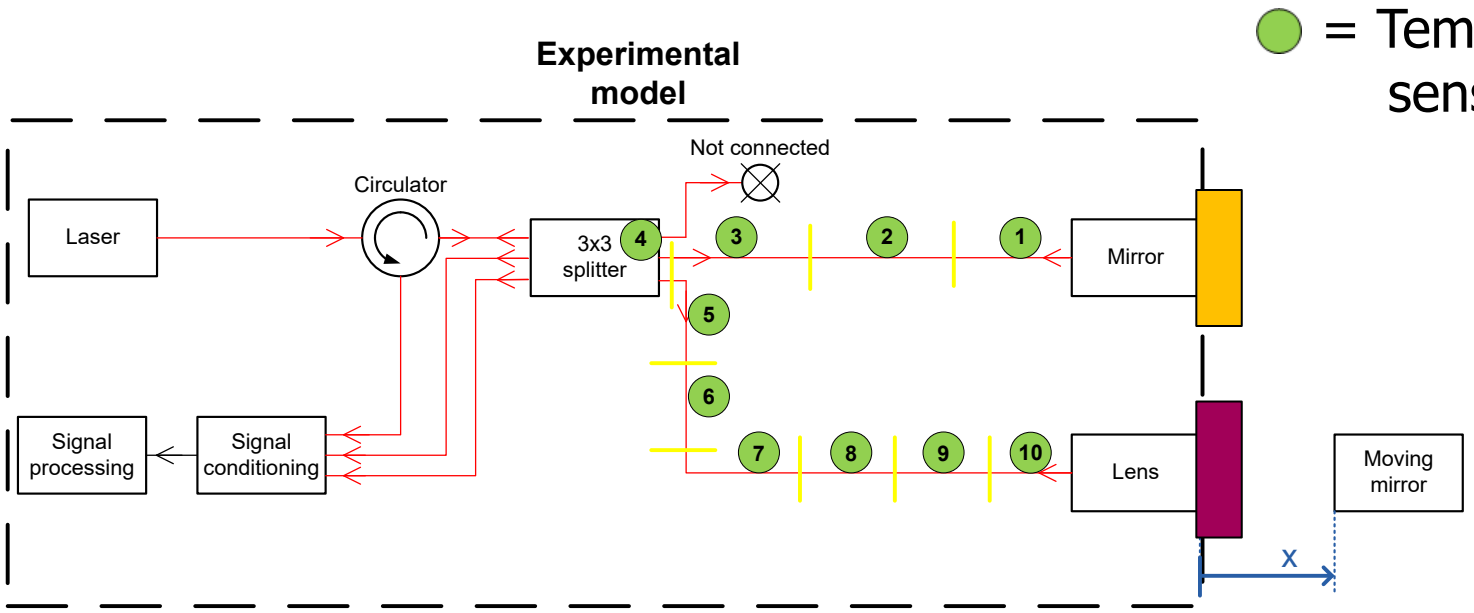
In vacuum: n = constant

@ 4.5 (K): $\alpha_{Al} = 0$

c) Is temperature the dominant factor causing the drift of the fiber optic interferometer?

Problem analysis

Analyze dominant drift cause



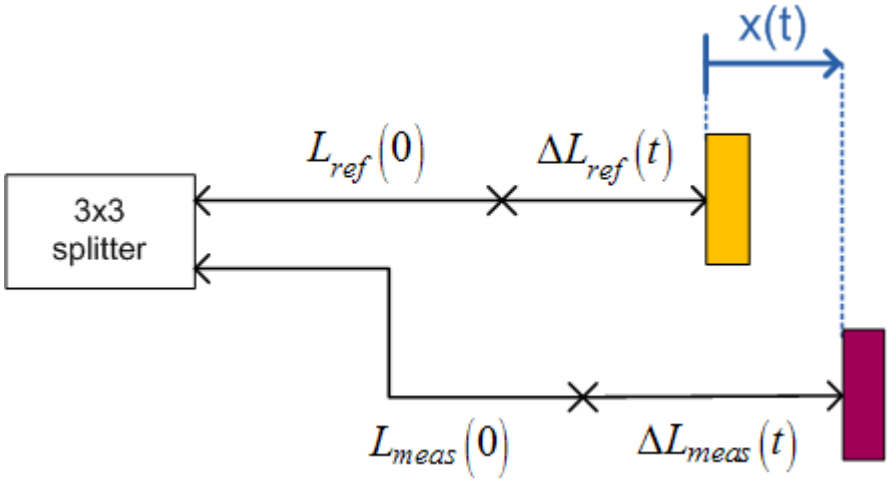
Calculate position drift with the measured temperature changes in the fibers!

$$\Delta l = l_0 \alpha \Delta T$$

c) Is temperature the dominant factor causing the drift of the fiber optic interferometer?

Problem analysis

Analyze dominant drift cause



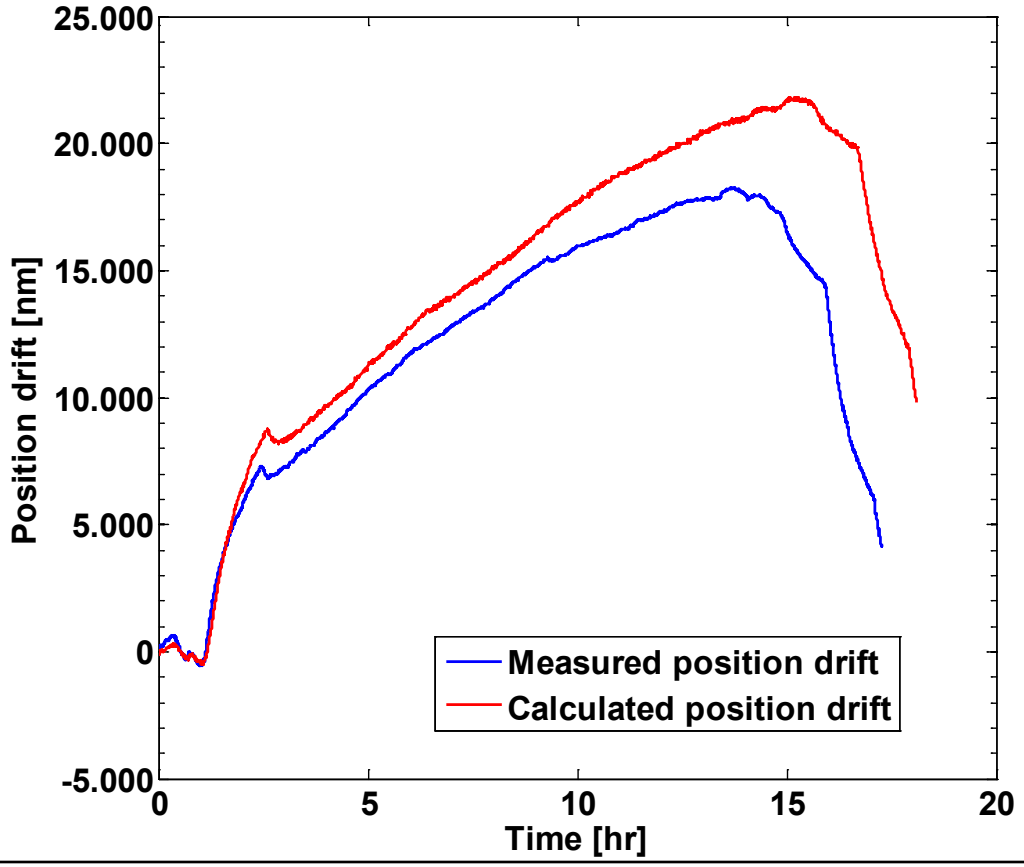
$$x_{drift}(t) = \left(L_{meas}(0) + \Delta L_{meas}(t)\right) - \left(L_{ref}(0) + \Delta L_{ref}(t)\right)$$

$$x_{drift}(t) = \sum_{m=1}^{3} L_{0m}\left(1 + \alpha_{eff}\left(T_m(t) - T_m(0)\right)\right) - \sum_{m=5}^{10} L_{0m}\left(1 + \alpha_{eff}\left(T_m(t) - T_m(0)\right)\right)$$

c) Is temperature the dominant factor causing the drift of the fiber optic interferometer?

Problem analysis

Validate dominant drift cause

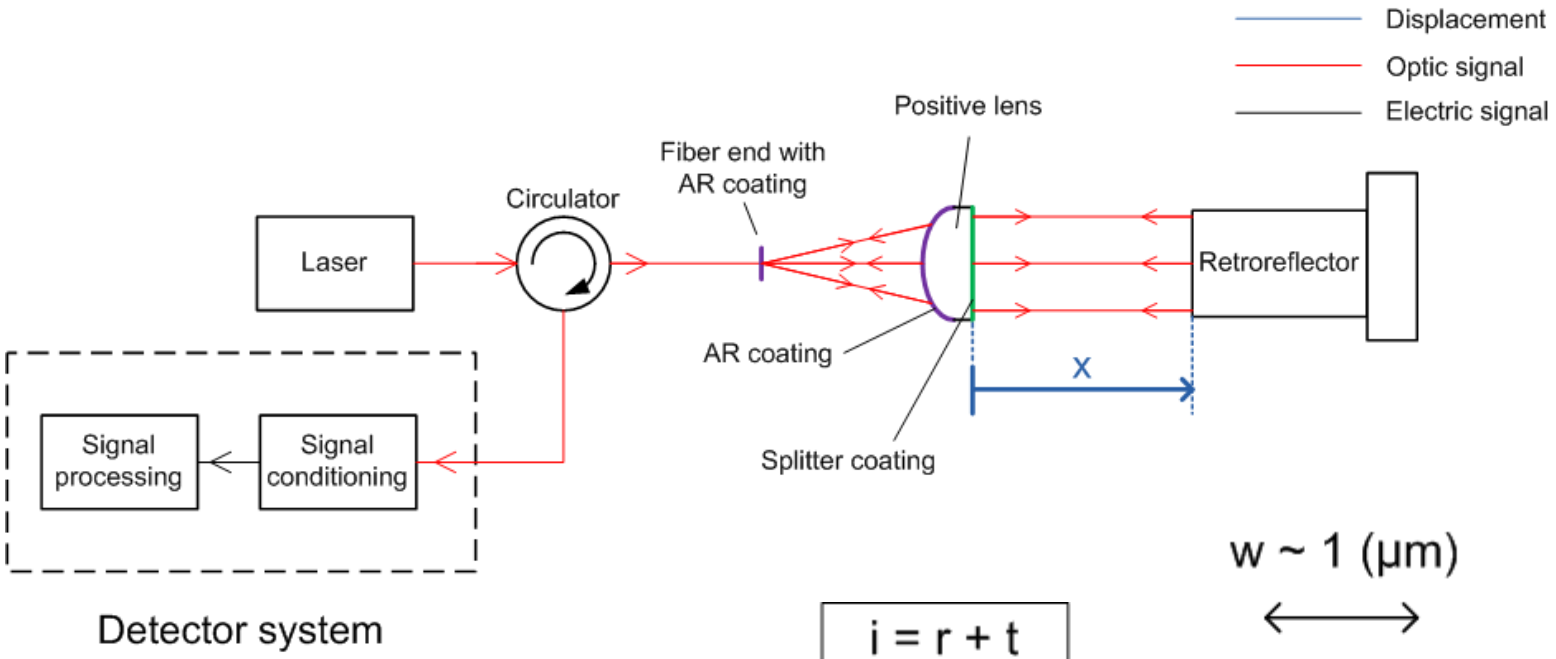


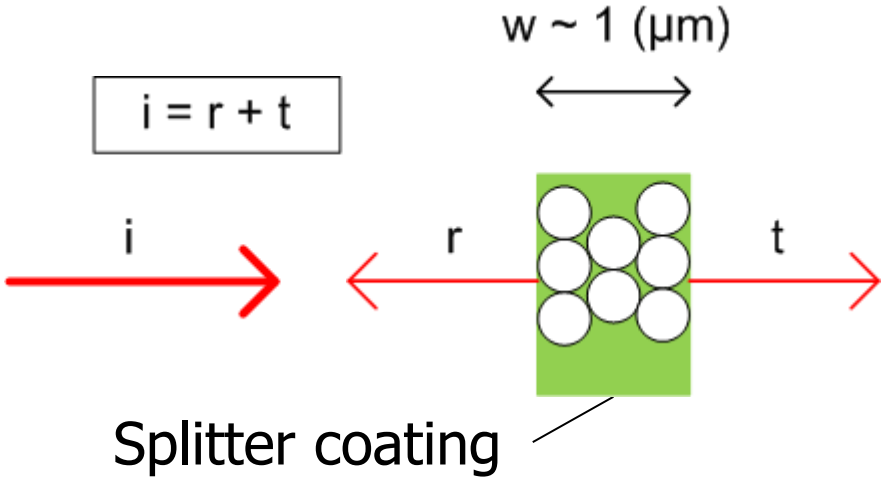
Temperature disturbances acting on the measurement and the reference arm are the dominant factor causing the drift!

c) Is temperature the dominant factor causing the drift of the fiber optic interferometer?

New concept

Tekst afmaken!!





$$I = c\varepsilon_0 {E_{01}}^2 \left[1 + \cos\left(\frac{2\pi}{\lambda} OPD\right)\right]$$

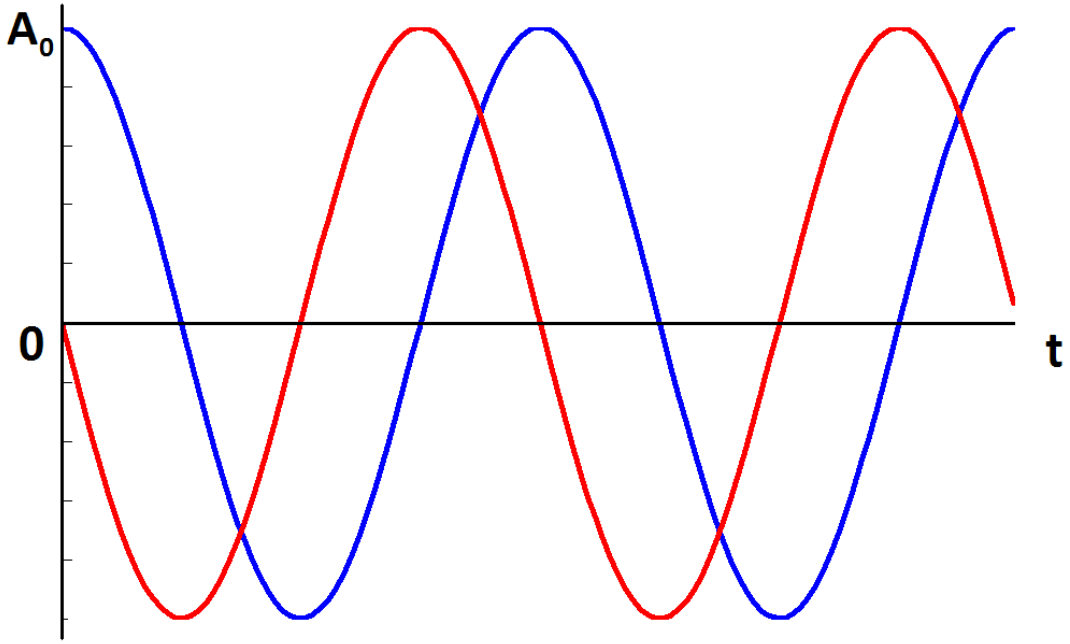
d) What needs to be improved on the fiber optic interferometer to meet the requirements?

New concept

Quadrature phase relation:

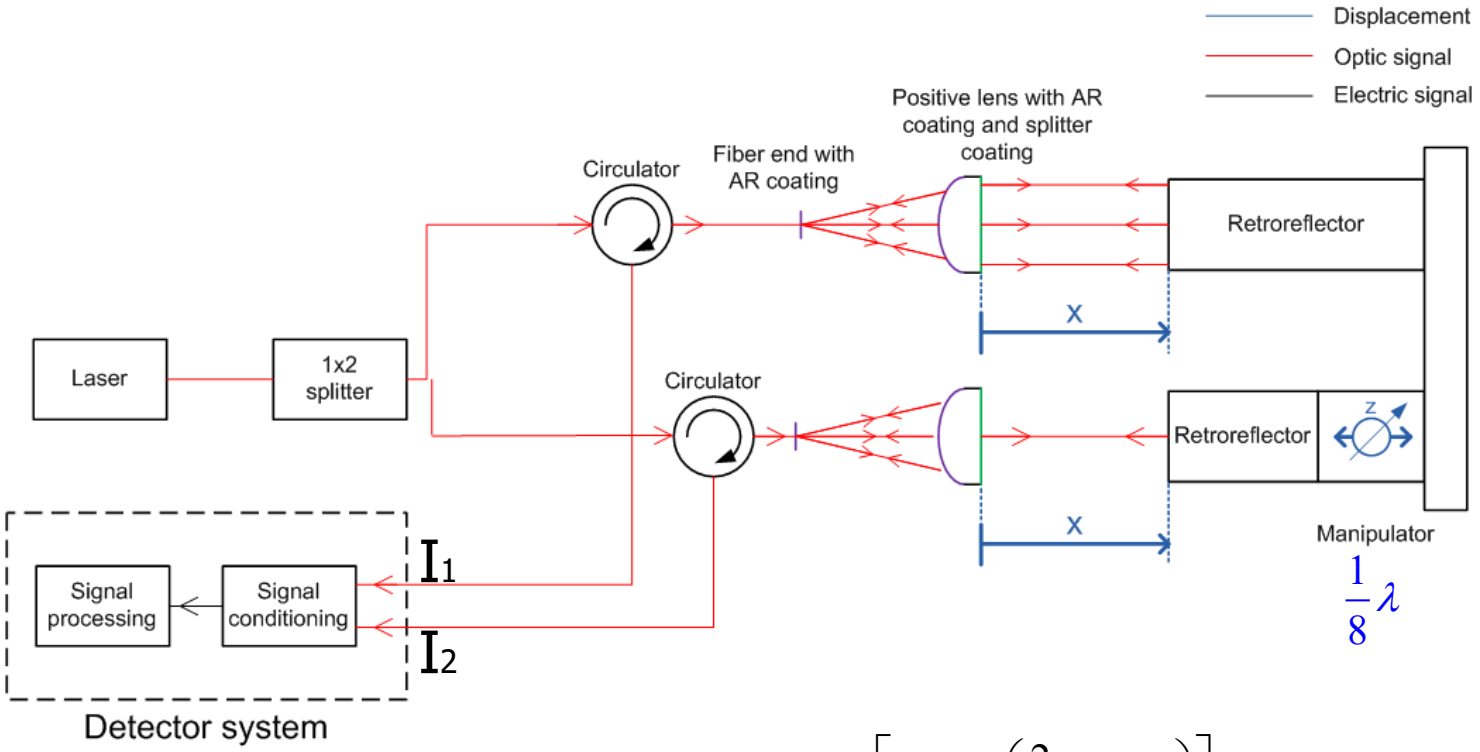
$$S_1 = A_0 \cos(ft)$$

$$S_2 = A_0 \cos\left(ft + \frac{\pi}{2}\right)$$



d) What needs to be improved on the fiber optic interferometer to meet the requirements?

New concept



$$I_1 = c\varepsilon_0 {E_{01}}^2 \left[1+\cos\left(\frac{2\pi}{\lambda}OPD\right)\right]$$

$$I_2 = c\varepsilon_0 {E_{01}}^2 \left[1+\cos\left(\frac{2\pi}{\lambda}\left(OPD-\frac{\lambda}{4}\right)\right)\right]$$

d) What needs to be improved on the fiber optic interferometer to meet the requirements?

Conclusion

- The current setup of LUNASYS is not yet operational for the SAFARI application
- Temperature disturbances acting on the reference and the measurement arm are the dominant factor causing the drift in the current setup of LUNASYS
- The new fiber optic interferometer concept is much less sensitive to temperature disturbances (a factor of 1,000,000) and less strict demands regarding cryogenic functionality
- Stray light has been reduced to a acceptable level
- The calculated heat load meets the requirements

Verbeteren!!

Recommendations

- Work out the promising new fiber optic interferometer concept
- Custom design the lens for 4.5 (K) in order to obtain functionality at cryogenic temperature
- Reduce the required electrical power for the laser, by choosing another laser or improve the current laser
- Space qualification in corporation with SRON.

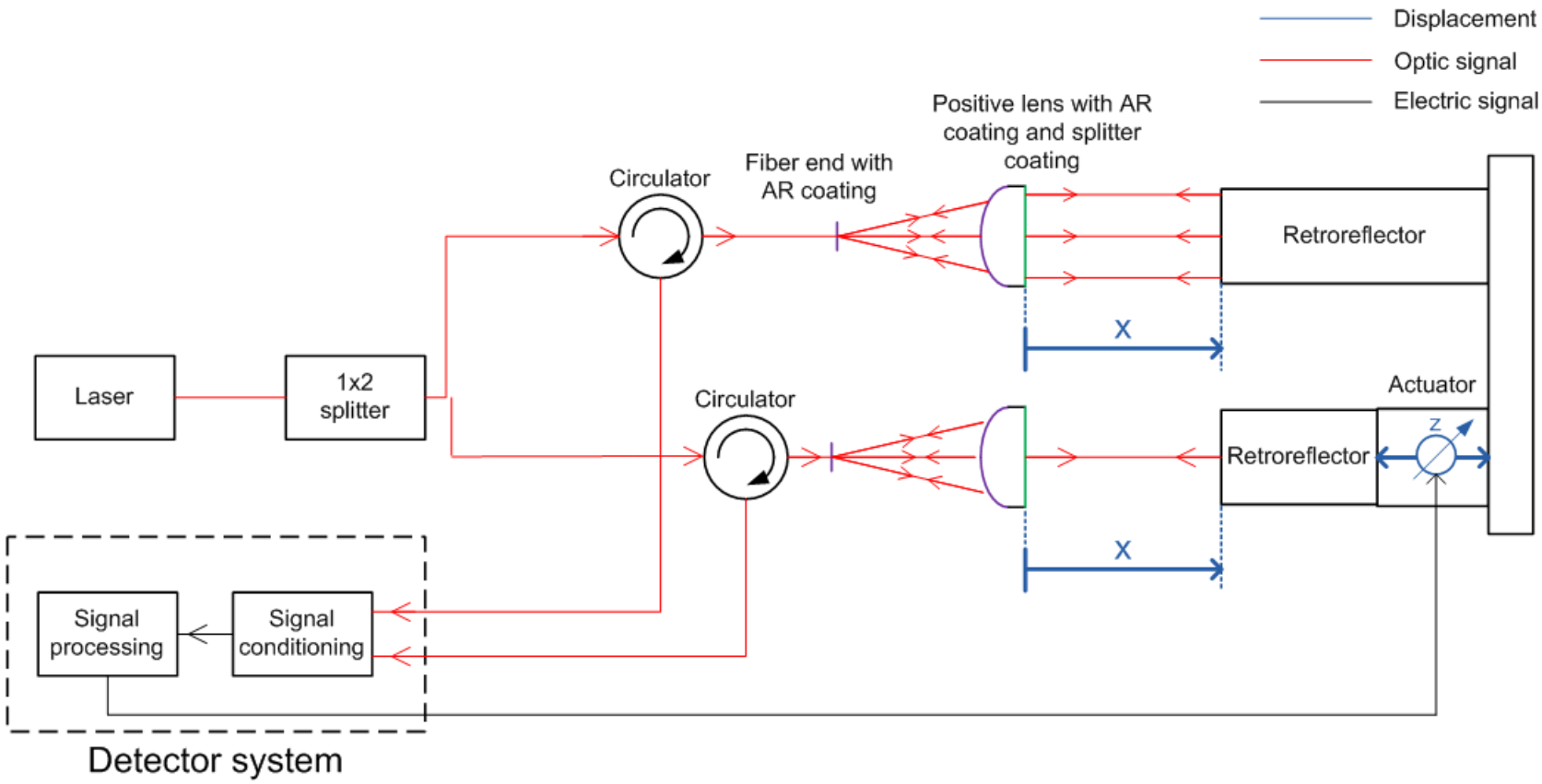
Positiever maken!!

Questions

Questions or compliments?

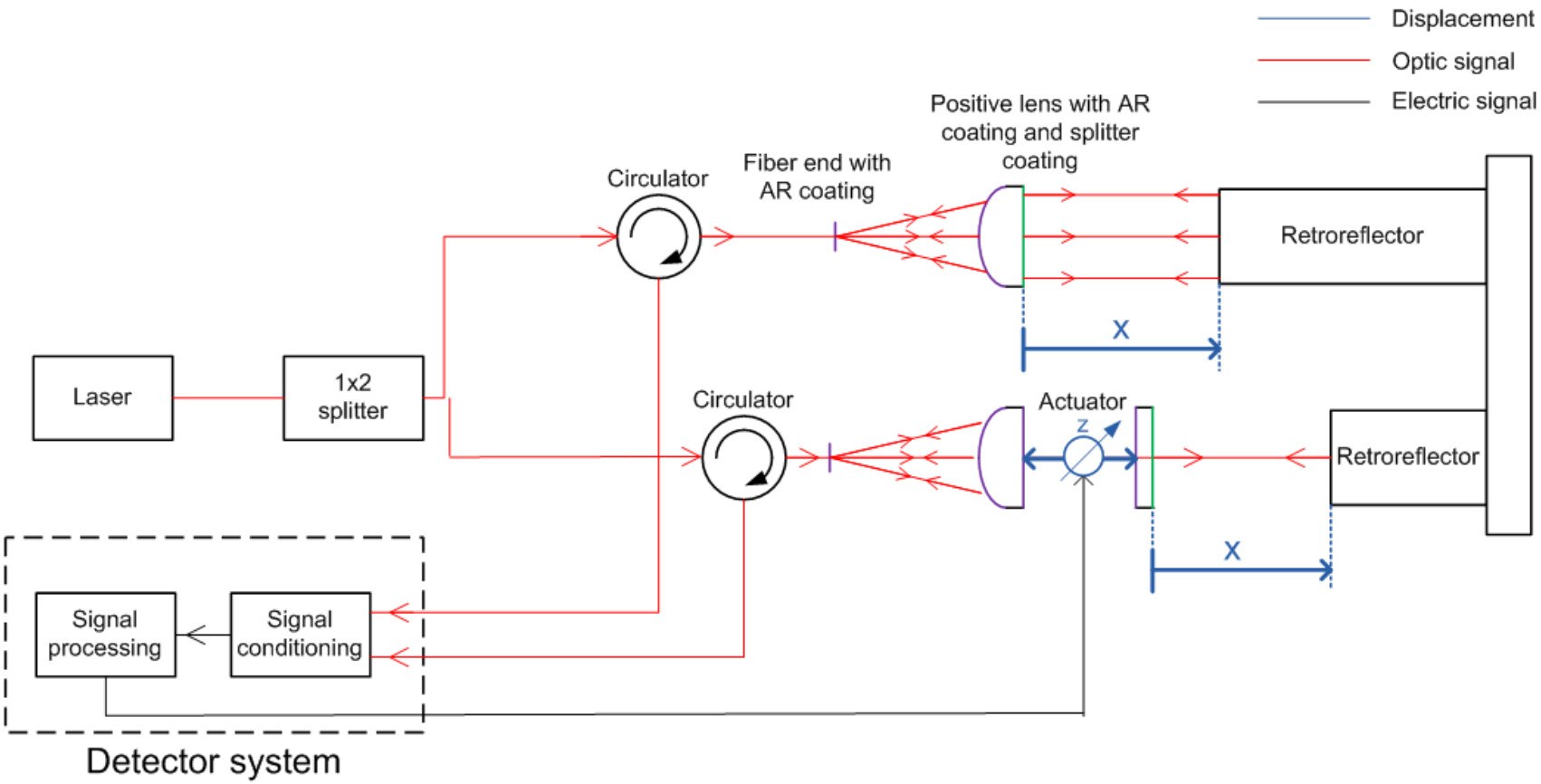
Extra slides 1

Extra interferometer concept 2

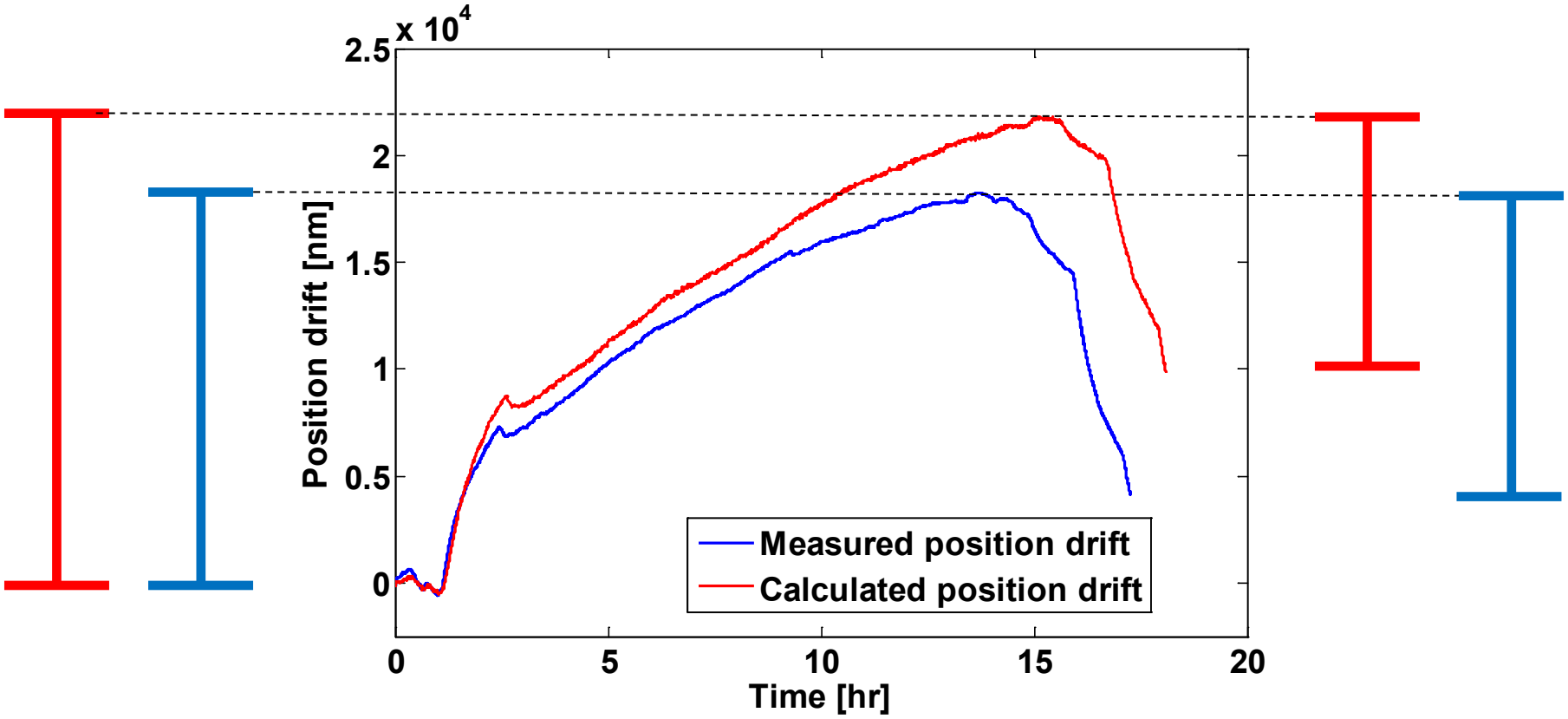


Extra slides 2

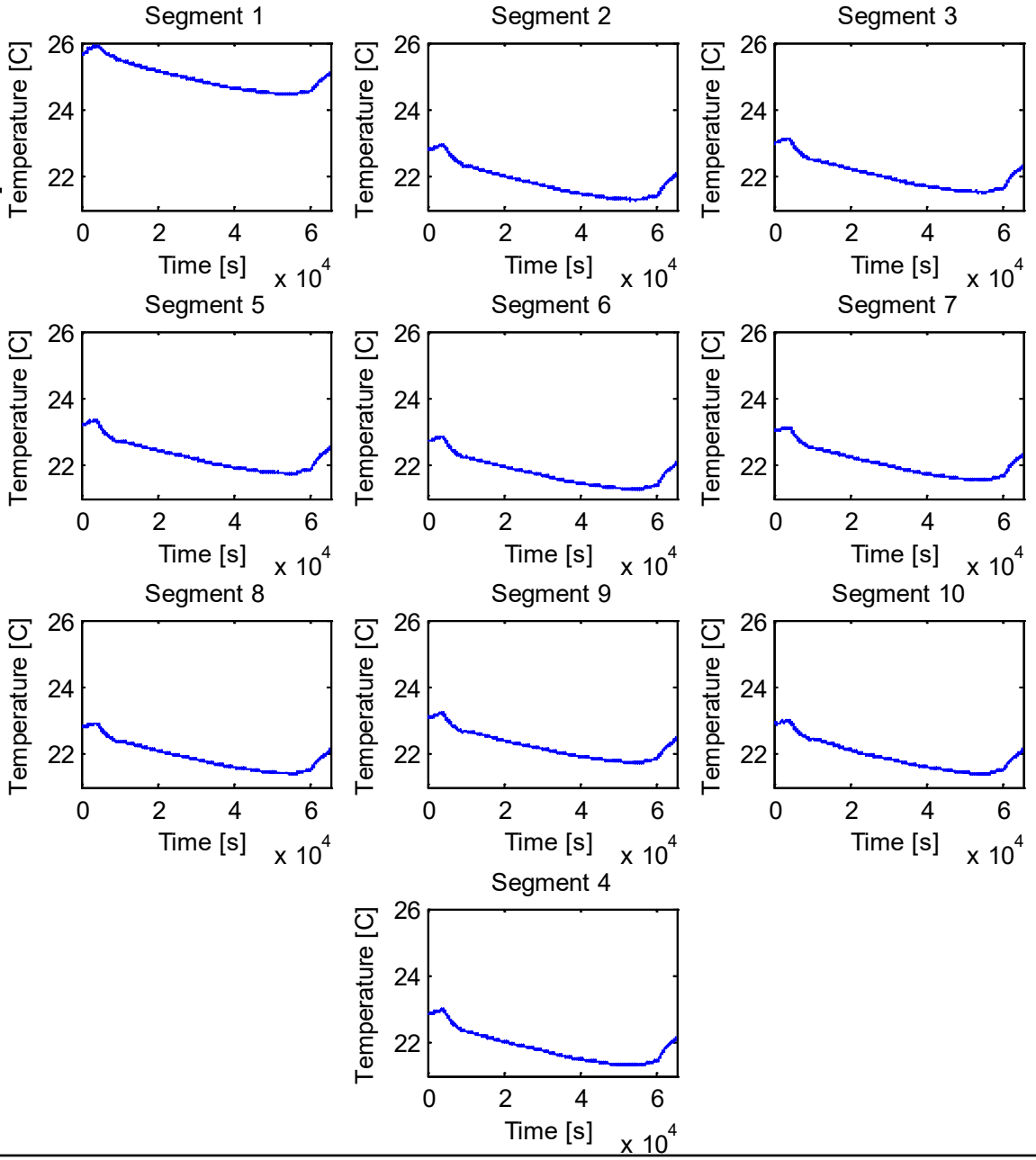
Extra interferometer concept 3



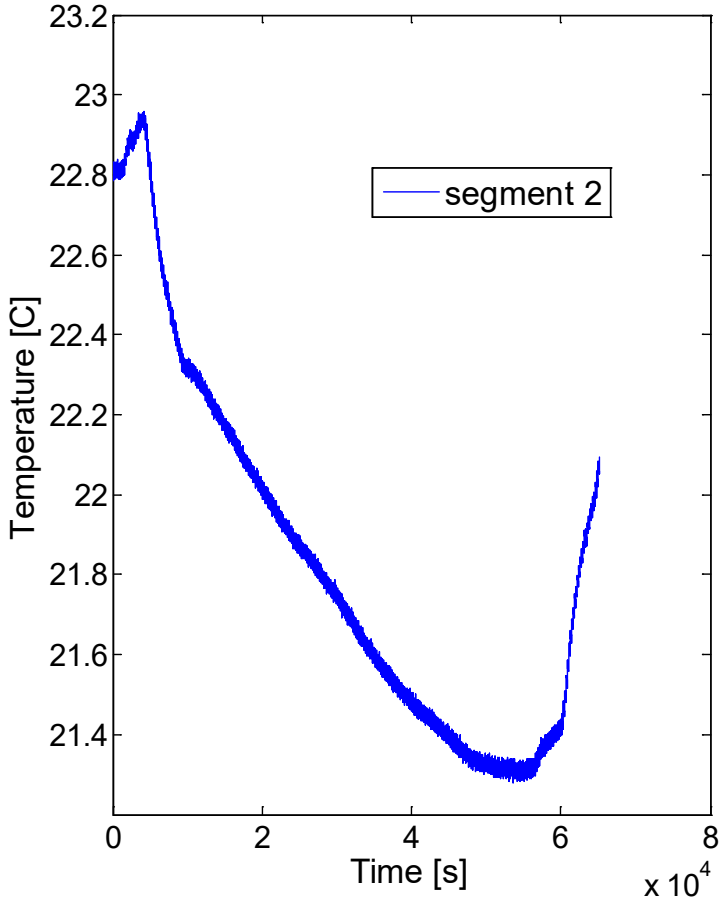
Extra slides 3

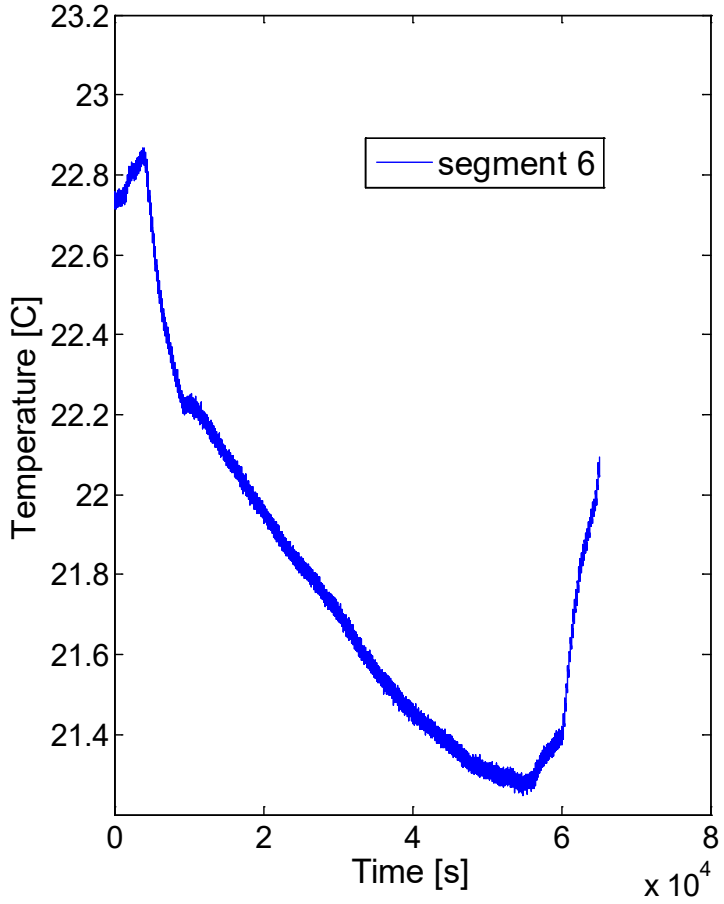


Extra slides 4

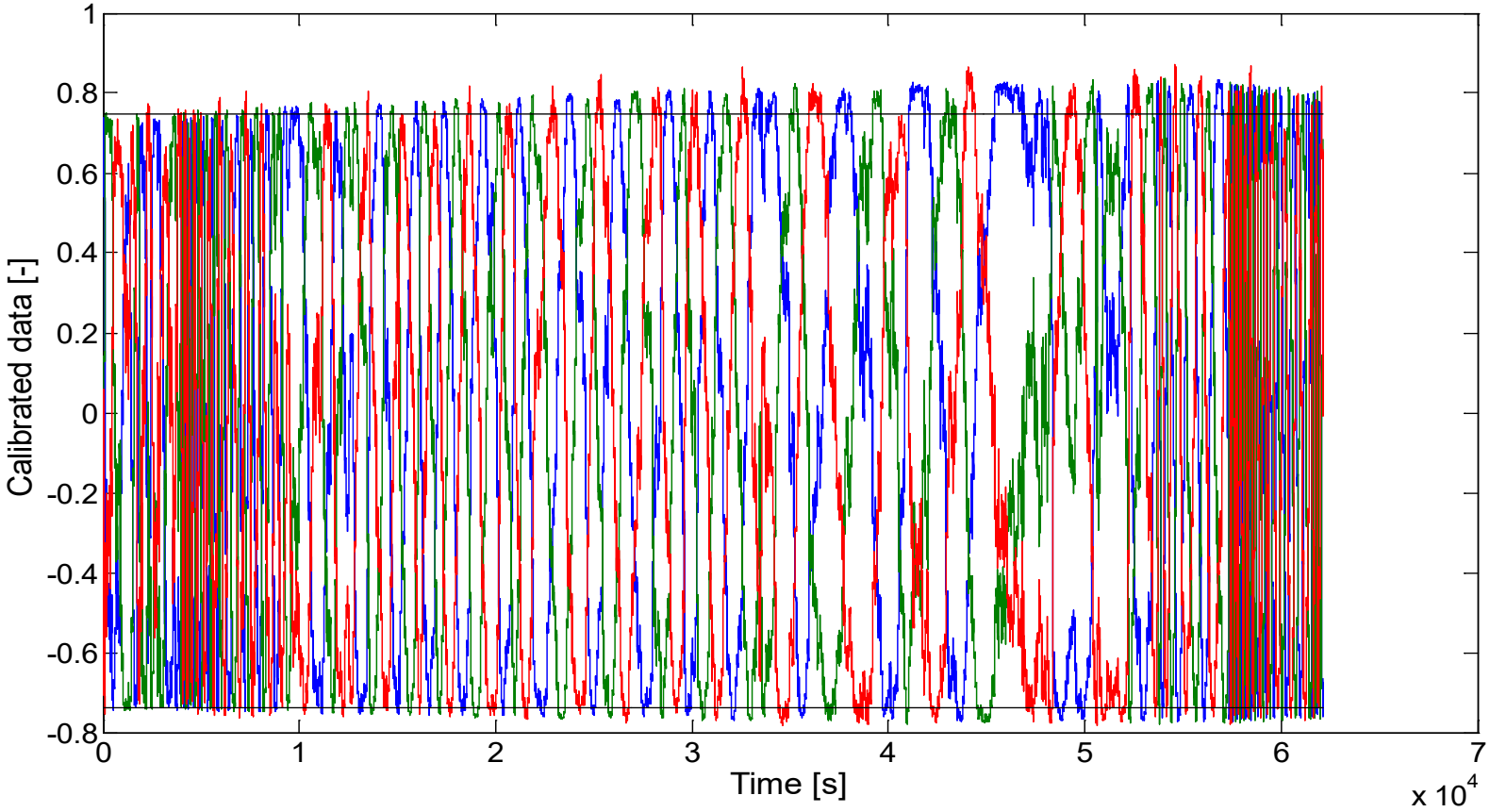


Extra slides 5

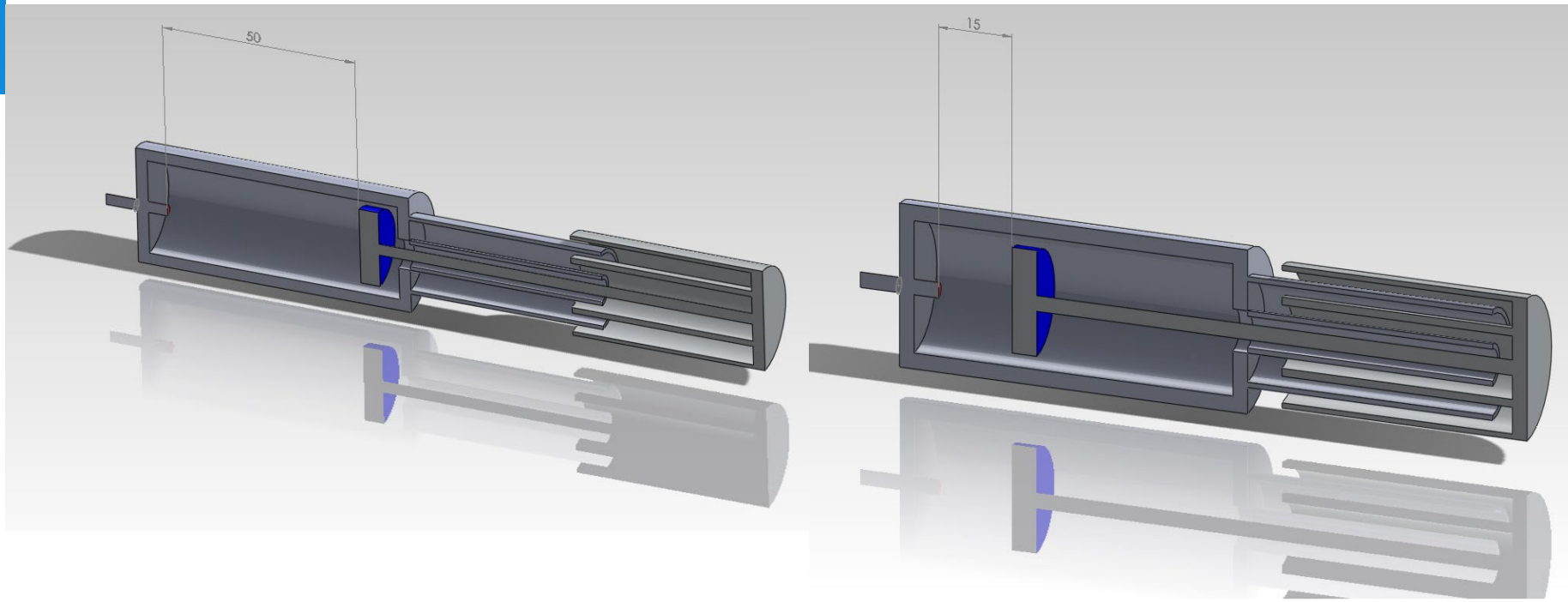




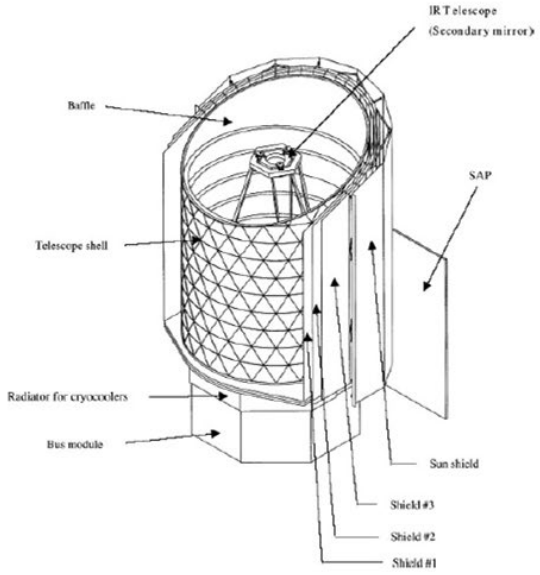
Extra slides 6



Extra slides 7



Extra slides 8



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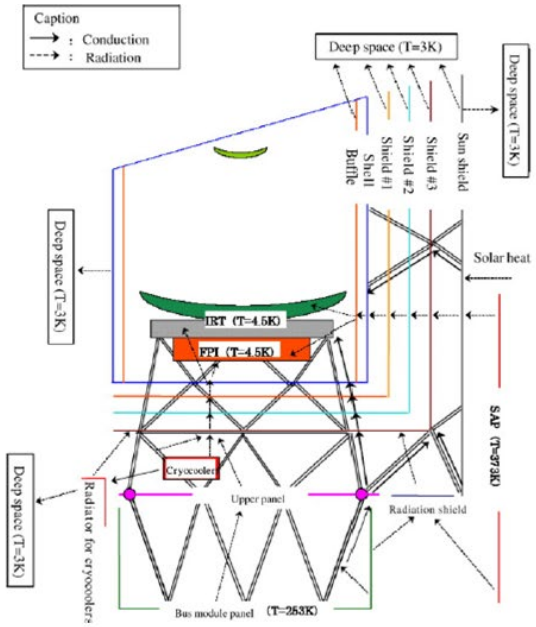
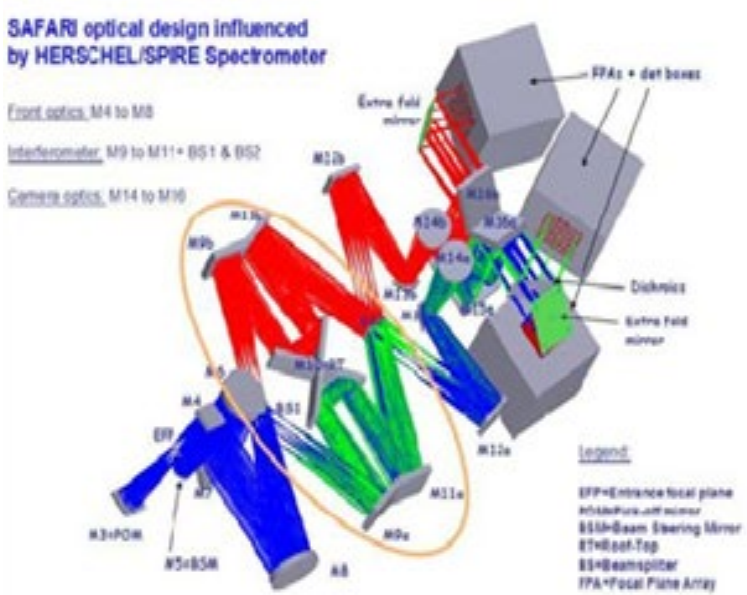


(b)

Extra slides 9



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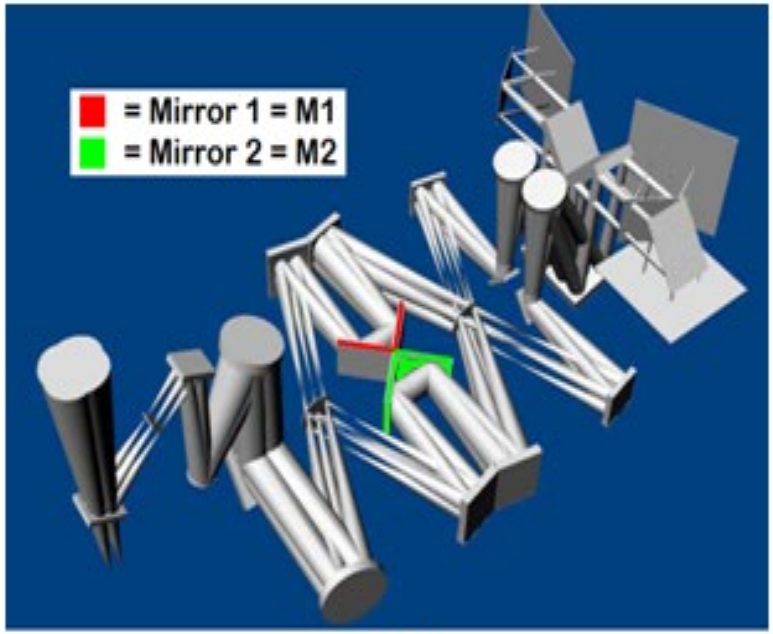

(b)