LASERS AND INPUT OPTICS

INTRODUCTION

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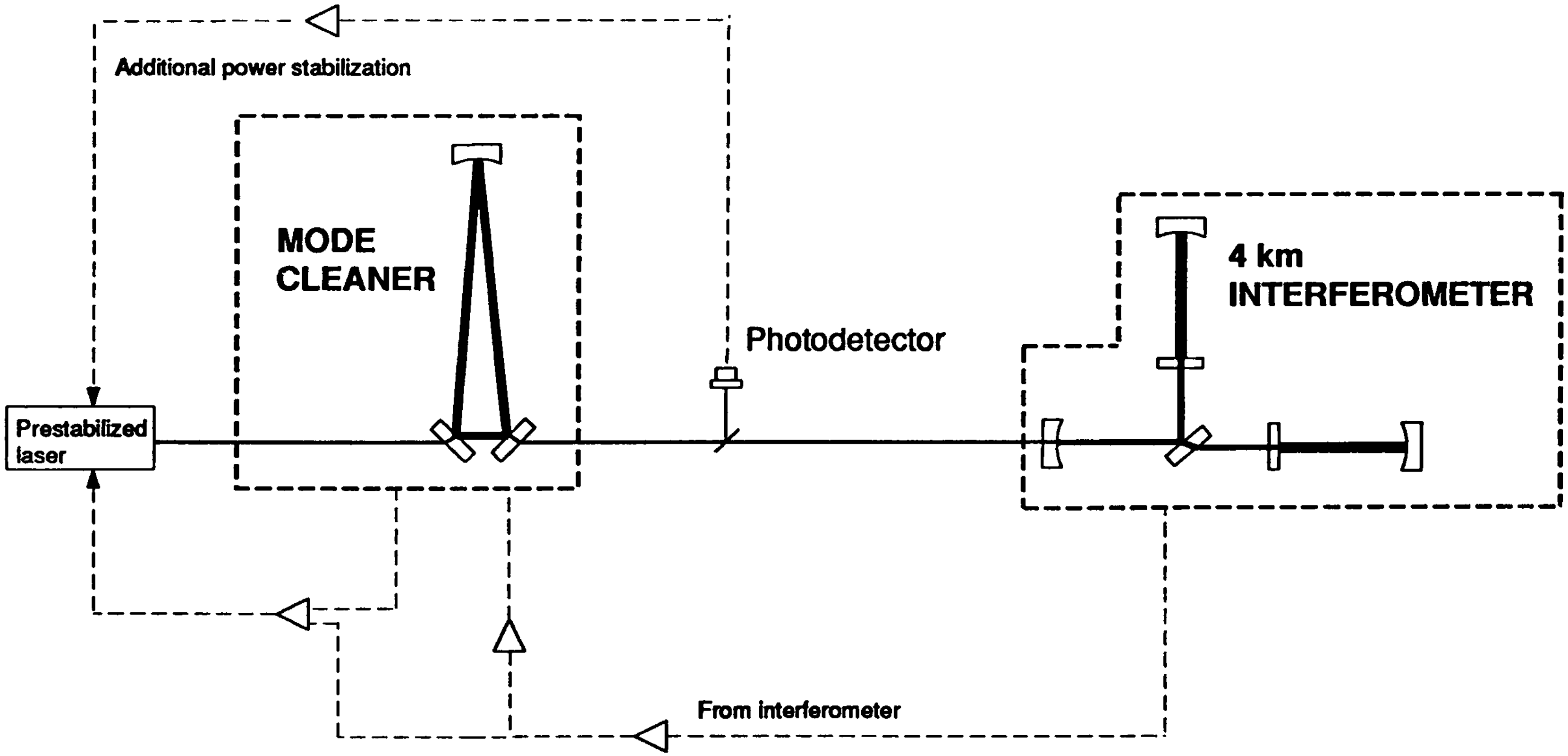
June 9, 1993

LIGO-G930035-00-D

LIGO Input Optics

- Role is to Generate and Condition Laser Light for Injection into Interferometer
- Well-Defined Interface to Interferometer
  - Light from Input Optics to Interferometer
  - Control Signals From Interferometer to Input Optics
  - Input Optics Subsystem Consists of Units with Independently Testable Performance
- Performance Specifications Depend on Interferometer Characteristics, Primarily Asymmetries in the Interferometer
  - Example: Frequency Noise Couples to Mismatches in the Storage Time of the Arm Cavities to Produce Noise in Interferometer Output

LIGO INPUT OPTICS



Input Optics Design Approach

- Reduce Frequency and Intensity Noise as Much as Possible, by Prestabilizing the Laser
- Suppress Beam Jitter by Passing the Light Through a Resonant Cavity with Suspended Mirrors, Called a "Mode Cleaner"
- Achieve Additional Frequency Noise Suppression by Locking the Light to the Mode Cleaner, and by Passive Filtering of Mode Cleaner
- Achieve Additional Intensity Noise Suppression by Sensing the Intensity Downstream From the Mode Cleaner and Correcting at the Prestabilized Laser

Initial vs. Advanced Interferometers

Initial Interferometers

- Shot Noise Specification Based on 2 W Effective Power into Interferometer
- Secondary Specifications on Input Light Based on Experience with Laboratory Interferometers
    - Frequency Noise
    - Intensity Noise
    - Beam Jitter

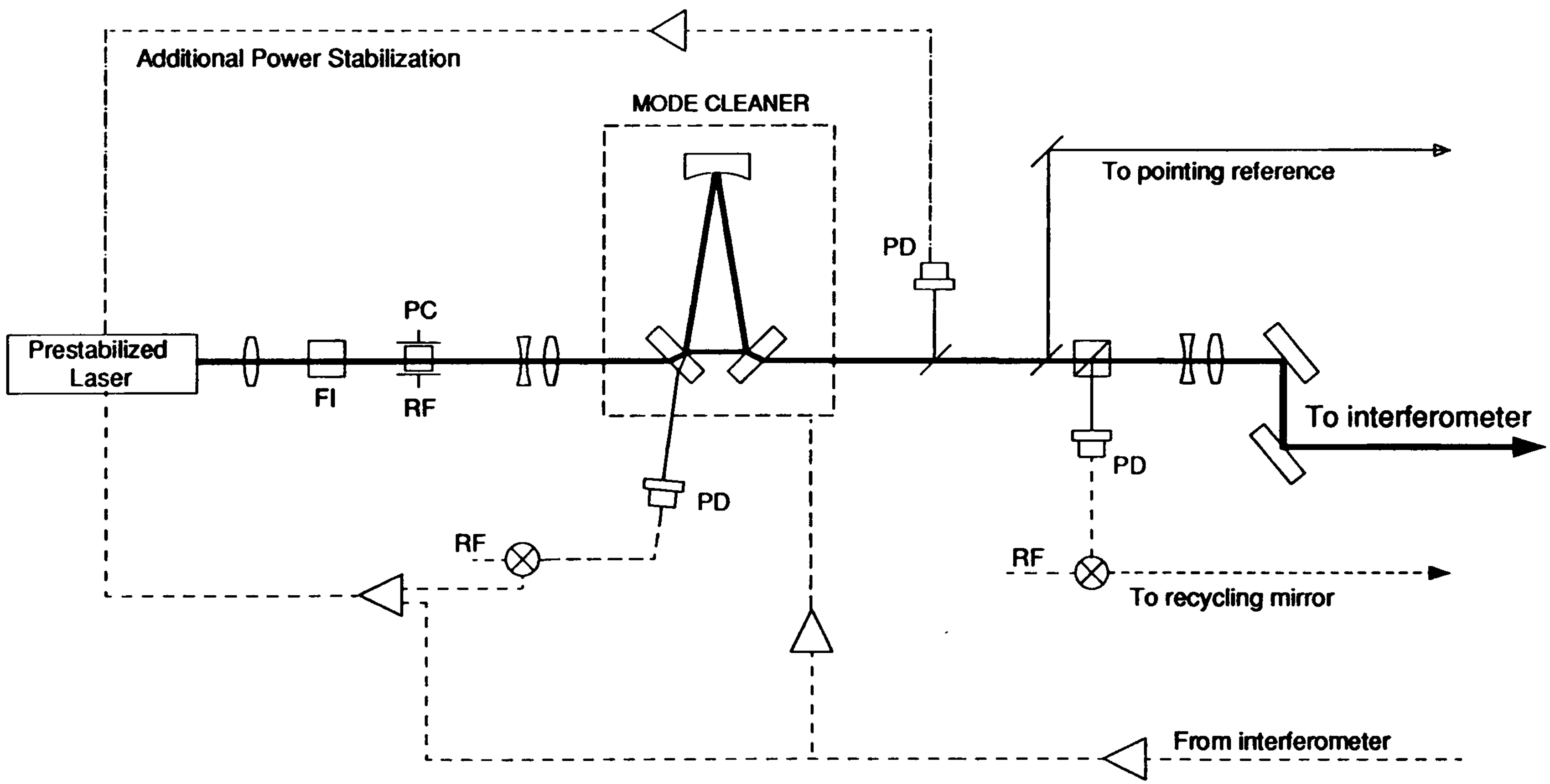
Advanced Interferometers

- Shot Noise Projection Based on 60 W Effective Power into Interferometer
- Basis for Setting Secondary Specifications Less Secure
    - Only Preliminary Estimates for Sensitivity of Alternative Optical Configurations to Laser Noise
    - Experience with Initial Interferometers Will Give Better information on Input Light Requirements for Advanced Interferometers

In-house Effort Emphasizes Development of Argon Ion Lasers and Supporting Input Optics for Initial Interferometers

Collaboration with R. Byer and Co-workers at Stanford for Development of Solid State Lasers for Subsequent Interferometers

LIGO INPUT OPTICS LAYOUT



FI Faraday Isolator
PC Pockels Cell
PD Photodetector

LASERS AND INPUT OPTICS

OVERVIEW OF INPUT LIGHT SPECIFICATIONS

A. Abramovici

June 9, 1993

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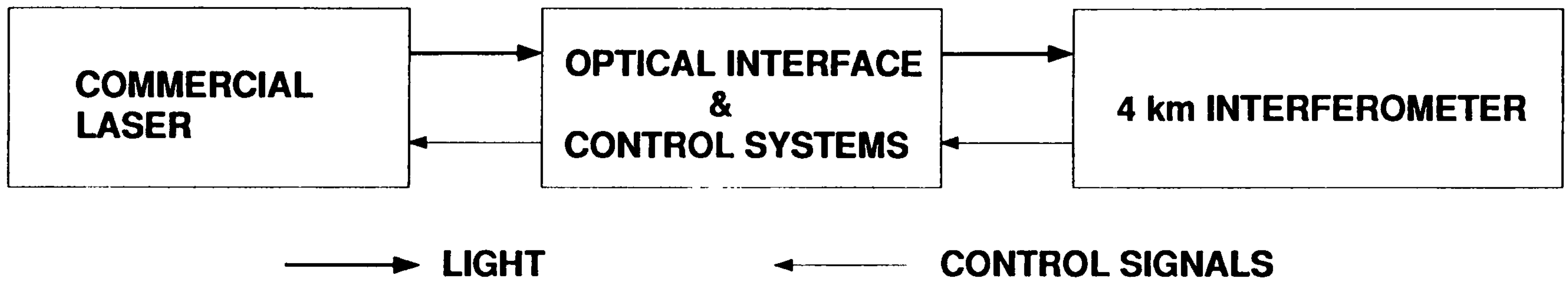
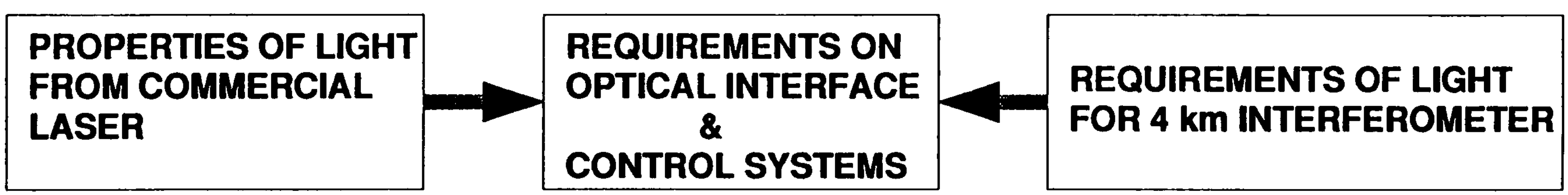
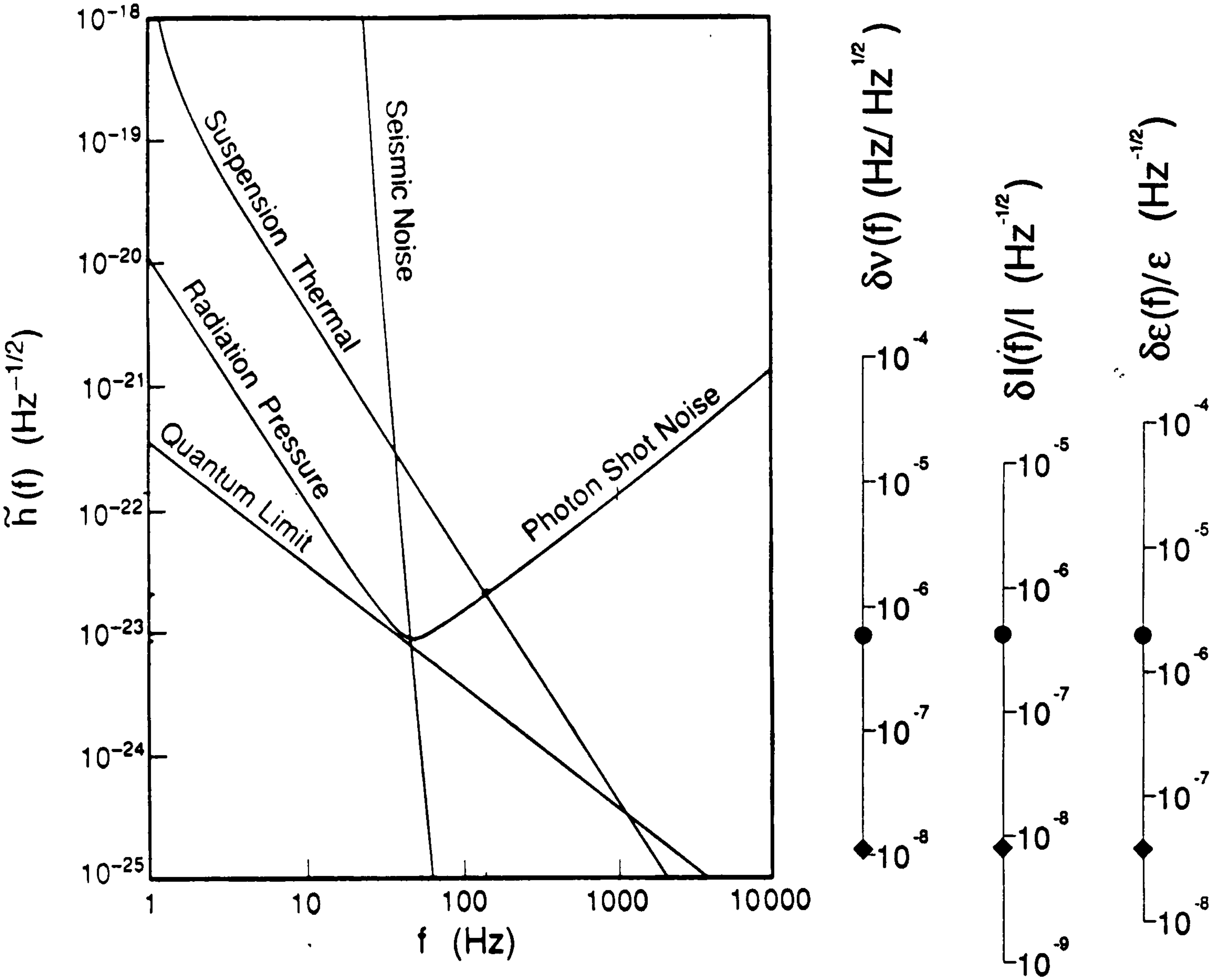


REQUIREMENT FLOW CHART



REQUIREMENTS ON LIGHT FOR LIGO INTERFEROMETERS



● Initial interferometers

◆ Subsequent, advanced interferometers

FREQUENCY NOISE SPECIFICATION

$$\Delta\nu = \frac{\Delta L}{L} \cdot \nu \cdot \frac{\tau}{\Delta\tau} \cdot F(f)$$

- ΔL: **displacement noise.**
- L: **interferometer arm length.**
- ν: **frequency of light.**
- τ: **interferometer arm storage time.**
- $\Delta\tau/\tau$: **Degree of matching between interferometer arms.**

  A. $\Delta\tau/\tau = 0.01$ **assumed. Should be easily achieved using mirrors from same batch.**

  B. **Frequency noise suppression equivalent to** $\Delta\tau/\tau = 0.001$ **achieved at 40m lab, using signal processing techniques.**

- $F(f) = [1 + (\frac{f}{1.5\ Hz})^2]^{1/2}$ **: Suppression factor due to filtering by recycling cavity.**

in freq. interval [2 Hz, 90 Hz]

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POWER STABILITY SPECIFICATION

$$\Delta I = I \cdot \frac{\Delta L}{x_0} \cdot F(f)$$

- I: **optical power.**
- x_0: **interferometer arm detuning from resonance, expressed in length units.** $x_0 = 10^{-13}$ **m was measured at the 40 m lab.**
- $F(f) = [1 + (\frac{f}{1.5\ Hz})^2]^{1/2}$: **Suppression factor due to filtering by recycling cavity.**

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FREQUENCY NOISE CAUSED BY BEAM JITTER

ON AXIS BEAM

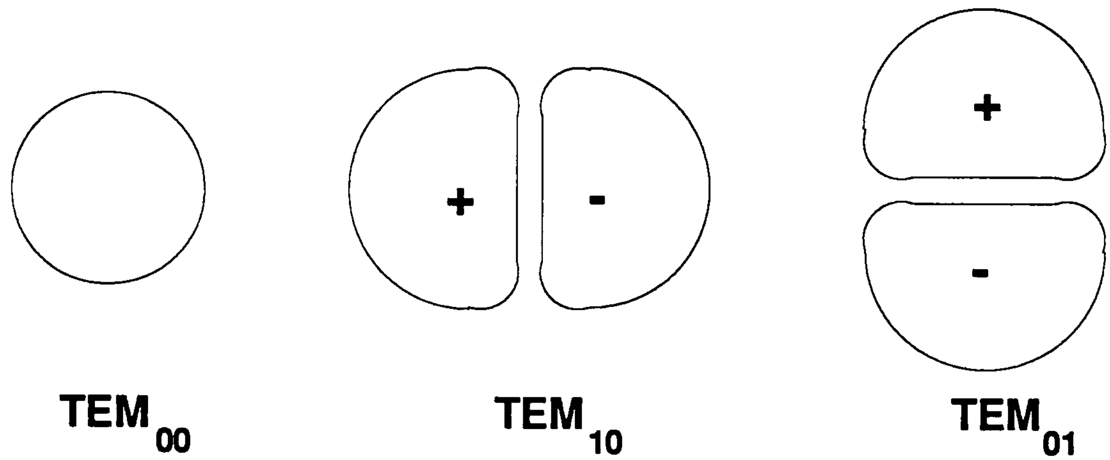
L

OFF AXIS BEAM

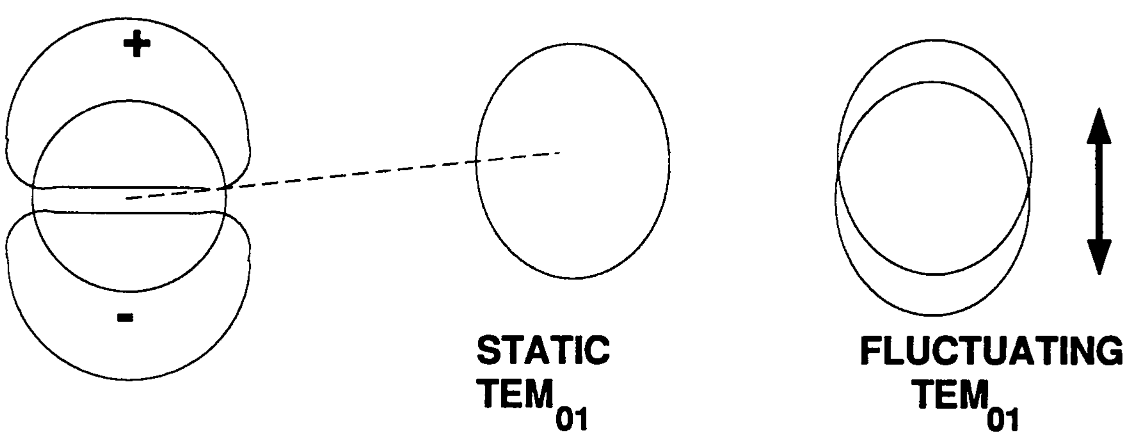
L + ΔL

$$\Delta\nu = \nu \frac{\Delta L}{L}$$

ELECTROMAGNETIC FIELD MODES IN LASER RADIATION



EFFECT OF PRESENCE OF HIGHER MODE



UPPER LIMIT ON BEAM JITTER

$$\Delta\nu = \frac{\pi c}{2L\mathcal{F}^2} \cdot \frac{|\,\epsilon_0 \Delta\epsilon\,| \sin\phi_N}{1 + R_1 R_2 - 2\sqrt{R_1 R_2}\cos\phi_N}$$

- $\Delta\epsilon$: amplitude of fluctuating higher transverse mode, responsible for beam jitter. Examples:

  A.

  $$\Delta\epsilon = \frac{\pi w_0}{\lambda} \cdot \Delta\theta$$

  for angular beam jitter by $\Delta\theta$. w_0: beam waist parameter, λ: wavelength.

  B.

  $$\Delta\epsilon = \frac{\Delta y}{w_0}$$

  for lateral beam displacement by Δy.

- ϵ_0: amplitude of higher transverse mode, corresponding to static misalignment. $\epsilon_0 = 0.3$ is assumed.
- $\mathcal{F}$: resonator finesse.
- $R_{1,2}$: mirror reflectivities (power).
- ϕ_N: phase depending on resonator geometry and transverse mode index.

NEEDED NOISE SUPPRESSION FACTORS

(at 100 Hz)

Noise type	Initial interferometer	Subsequent, advanced interferometers
Frequency noise	$5 \cdot 10^{10}$	$2.7 \cdot 10^{12}$
Intensity noise	50	2500
Beam jitter	75	3750

INPUT OPTICS DESIGN APPROACH

- Reduce frequency and intensity noise as much as possible, by prestabilizing the laser.
- Suppress beam jitter by passing the light through a resonant cavity with suspended mirrors, called "mode cleaner".
- Achieve additional frequency noise suppression by locking the light to the mode cleaner, and by passive filtering by the mode cleaner.
- Achieve additional intensity noise suppression by sensing intensity downstream from mode cleaner, and additional correction at prestabilized laser.

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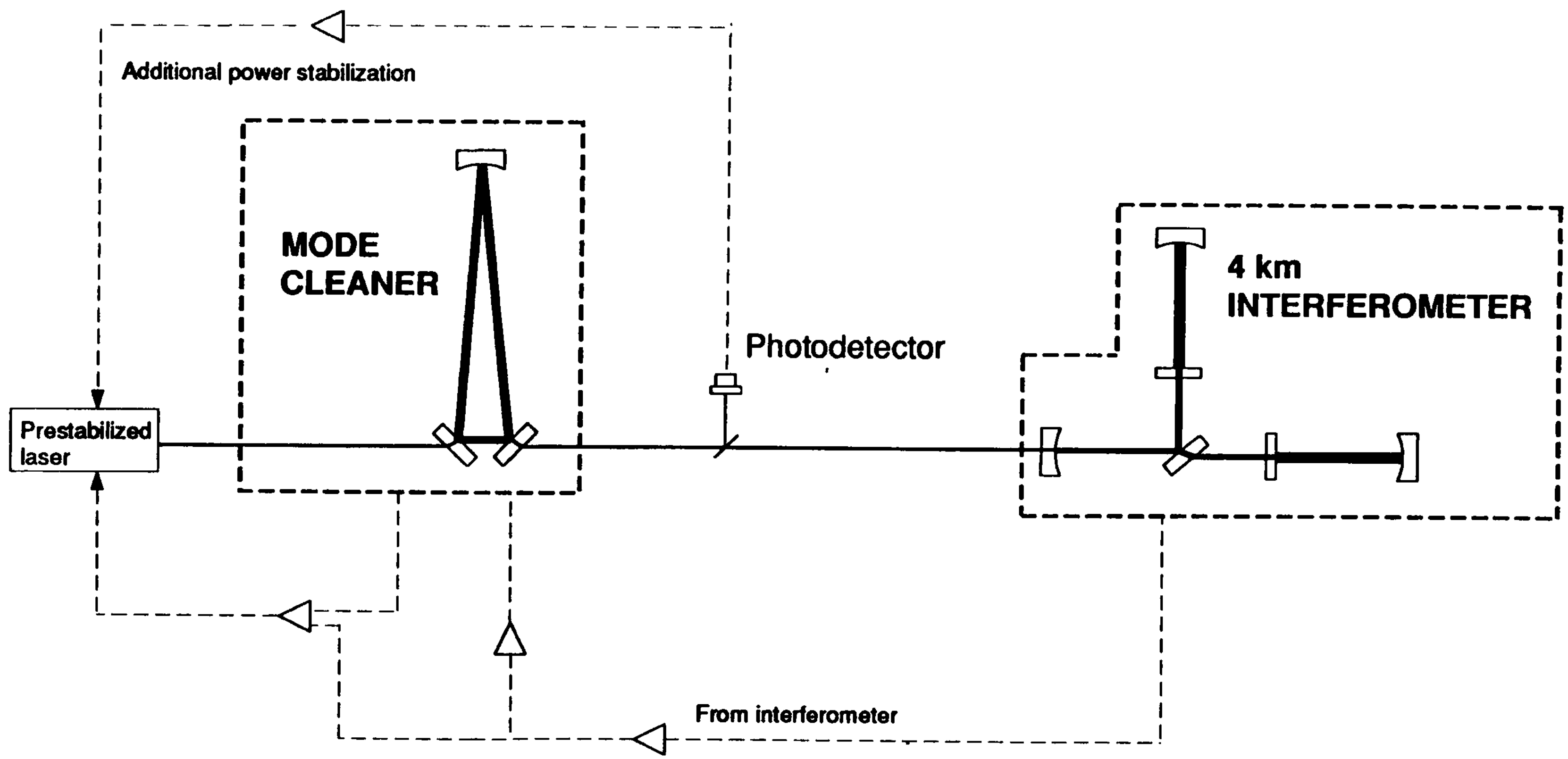

Comparison between Interferometer Requirements and Commercial Laser Performance

Parameter	Laser performance (current commercial Argon laser)		Initial interferometer requirement (at interferometer input)		Advanced interferometer requirement (at interferometer input)	
Laser power at $\lambda \sim$500 nm (W)	5		3		60	
	@100 Hz	@1 kHz	@100 Hz	@1 kHz	@100 Hz	@1 kHz
Strain sensitivity $(1/Hz^{1/2})$			10^{-23}	10^{-22}	$2 \cdot 10^{-25}$	$2 \cdot 10^{-25}$
Frequency noise $(Hz/Hz^{1/2})$	$3 \cdot 10^4$	10^3	$6 \cdot 10^{-7}$	$6 \cdot 10^{-6}$	$1.1 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$
Relative intensity noise $(1/Hz^{1/2})$	$2 \cdot 10^{-5}$	$6 \cdot 10^{-6}$	$4 \cdot 10^{-7}$	$4 \cdot 10^{-6}$	$8 \cdot 10^{-9}$	$8 \cdot 10^{-9}$
Relative amplitude of higher transverse mode $(1/Hz^{1/2})$	$1.5 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-5}$	$4 \cdot 10^{-8}$	$4 \cdot 10^{-8}$
Relative amplitude of "wrong" polarization $(1/Hz^{1/2})$	10^{-6}	10^{-7}	(10^{-6})	(10^{-5})	$(2 \cdot 10^{-8})$	$(2 \cdot 10^{-8})$