LIGO-T880019

#10

List of 3/1/89

MEMO

From: Alex
To: Robbie
Subject: LIGO interferometer light budget (2nd draft)
Date: August 3rd 1988

1 Introduction

An estimate of Θ, the overall transmission of the optical chain[1] in a sample LIGO interferometer[2] is presented in what follows.

This light budget exercise is interesting since it gives an indication on how efficiently one can use the limited amount of light coming from a small number of argon-ion lasers (adding the outputs from more than four lasers is considered impractical). The importance of the issue is highlighted by the fact that the sensitivity of the 40 *m* prototype is limited at present by the low power level at the input of the main cavities, due to the fact that $\Theta_{40m} = 1\%$.

Section 2 presents an analysis of the throughput Θ_{40m} of the 40 *m* prototype under the assumption that, except for losses in the fiber and in the mode cleaner (and some polarization effects), light is lost solely due to improper antireflection (AR) coatings on optical surfaces. This is shown to account for the measured value of Θ_{40m} within a factor of 3. Section 3 then proceeds and gives an estimate of maximum throughput for the optics in the Sample LIGO interferometer, with the conclusion that it might be possible to bring about two thirds of the laser output to the 4 *km* cavities. Section 4 is a summary.

An issue which has not been addressed in this memo is whether the components and coatings can withstand the light intensities that will prevail at various points in the LIGO optical chain.

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[1] i. e. the optical power at the main cavities input couplers versus the power at the output of the laser light source

[2] see Ron's sketch of a LIGO interferometer design

2 40 m Prototype Optics Throughput

2.1 Assumptions

1. Transmissive elements have wide band coatings. This refers to lenses, windows, Faraday rotators and the acousto-optic device. A reflection loss of 2% per surface will be assumed for $\lambda = 514.5\ nm$, based on a single measurement on one coated surface. This is probably the single most important source of uncertainty for the analysis in this section.
2. The uncoated corner cube is made of BK-7 glass. Then, a 4% loss occurs each time the light beam crosses an air/glass interface. This element would then have a transmission of 0.92.
3. Steering mirror loss is 1%. The steering mirrors we now use are not laser mirrors and have a nominal reflection coefficient of 0.995. The assumption here is that their performance has degraded to some extent, due to exposure to a dirty lab environment and/or use at an improper incidence angle or with the wrong polarization.
4. There is a 10% loss due to polarization effects. Both the fiber and the corner cube are mildly birefringent elements. A 5% loss due to fiber birefringence has been measured. It is assumed that a similar loss occurs at the corner cube.

2.2 Individual Component Losses and System Transmission

The following table shows the losses occuring at various optical components in the 40 m prototype. An asterisk marks actually measured values. The estimated throughput and the measured one are listed at the bottom of the list.

Component	Loss (%)
4 polarizers	* 34.4
2 polarizing beam splitters	* 19.0
10 beam steering mirrors	9.5
7 lenses	25.0
2 Faraday rotators	7.8
1 v. good Faraday Isolator	* 15.0
Corner cube	8.0
Fiber input coupler	* 9.0
Fiber output coupler	* 18.0
Fiber	* 41.0
Mode cleaner	* 55.0
Mode cleaner tank	8.0
2 $\lambda/4$ plates	8.0
3 $\lambda/2$ plates	11.5
Output port	4.0
Acousto-optic device	4.0
4 Pockels cells	4.0
Polarization losses	10.0
Estimated throughput	3.1%
Measured throughput Θ_{40m}	1.0%

3 LIGO Optics Throughput

3.1 Assumptions

1. All faces of optical components are either cut at the Brewster angle or AR coated

It is assumed that the reflection loss at a Brewster surface is 0.1%.

Narrow band AR coatings with reflection loss of 0.1% – 0.2% are commercially available, e. g. from Optics for Research. 0.2% will be assumed.

2. All Pockels cells are in vacuum

For the Pockels cell design currently in use in the 40 m prototype there are 4 Brewster surfaces for each cell, thus a loss of 0.4% per device will be assumed.

3. Losses at each polarizing beam splitter are 2%. This kind of spec is commercially available.

4. Mode cleaner cavity loss is 10%. This is based on a throughput estimate for a mode cleaner thought to be adequate for LIGO, on one hand, and on the assumption that a mode matching level of 96 – 97% can be achieved (92% has been demonstrated in our lab).

5. Steering mirror loss is 0.2%. This is true for cheap, off the shelf laser beam steering mirrors.

6. Faraday isolator loss is 6%. This is the best spec we could obtain, from Optics for Research. According to our own experience, we think this is a realistic spec.

7. Loss at the recycling mirror (variable transmission mirror) is 1%. This is the result of a variable transmission mirror design exercise targeted at maximizing the recycling factor.

3.2 Individual Component Losses and System Transmission

The following is a listing of individual optical component losses. The list of components is drawn from Ron's sketch of a Fabry-Perot interferometer for LIGO. A copy of his sketch of the optics is provided, which also shows the designation of components. The bottom line is the transmission (throughput) of the whole optical chain.

Component	Loss (%)
Pick-off for ref. cavity	1.0
P_0	0.4
$\lambda/4$	0.4
C_0	10.0
$\lambda/4$	0.4
P_2	0.4
B_1	2.0
B_2	2.0
FR	6.0
R	1.0
Main cavity mirror back	0.2
B_3	2.0
$\lambda/4$	0.4
C_3	10.0
6 pairs of mode match. lenses	2.4
2 beam steering mirrors for C_0	0.4
5 more steering mirrors	1.0
Injection window	0.4
System throughput Θ	65.9%

4 Summary

The above analysis indicates that, within a factor of 3, losses in the optical chain of the 40 *m* prototype can be understood in terms of inappropriate AR coatings, losses in the mode cleaner and in the fiber and losses due to polarization effects.

Furthermore, it is assumed that all losses in the LIGO optical chain occur in the mode cleaner, in the recycling mirror and by reflection at various optical surfaces. It is then shown that, at least in principle, laser light can be used quite efficiently if 0.2% antireflective coatings are used throughout the optical chain in a sample LIGO interferometer. Such coatings are current technology, but are usually not available off the shelf due to the fact that the 514.5 *nm* wave length is not in widespread use. State of the art coatings (100 *ppm* reflection loss) as made by the laser-gyro industry are not likely to improve system transmission much and are probably too hard to get in terms of money and delivery times to represent a worthwhile option.

Since it is likely that the new interferometer set-up associated with the 6 foot tank will prove power hungry already at an early stage, it seems desirable to freeze the design of that set-up and order appropriately coated optical components as soon as possible. This will give a feeling of the costs and of the delays involved.

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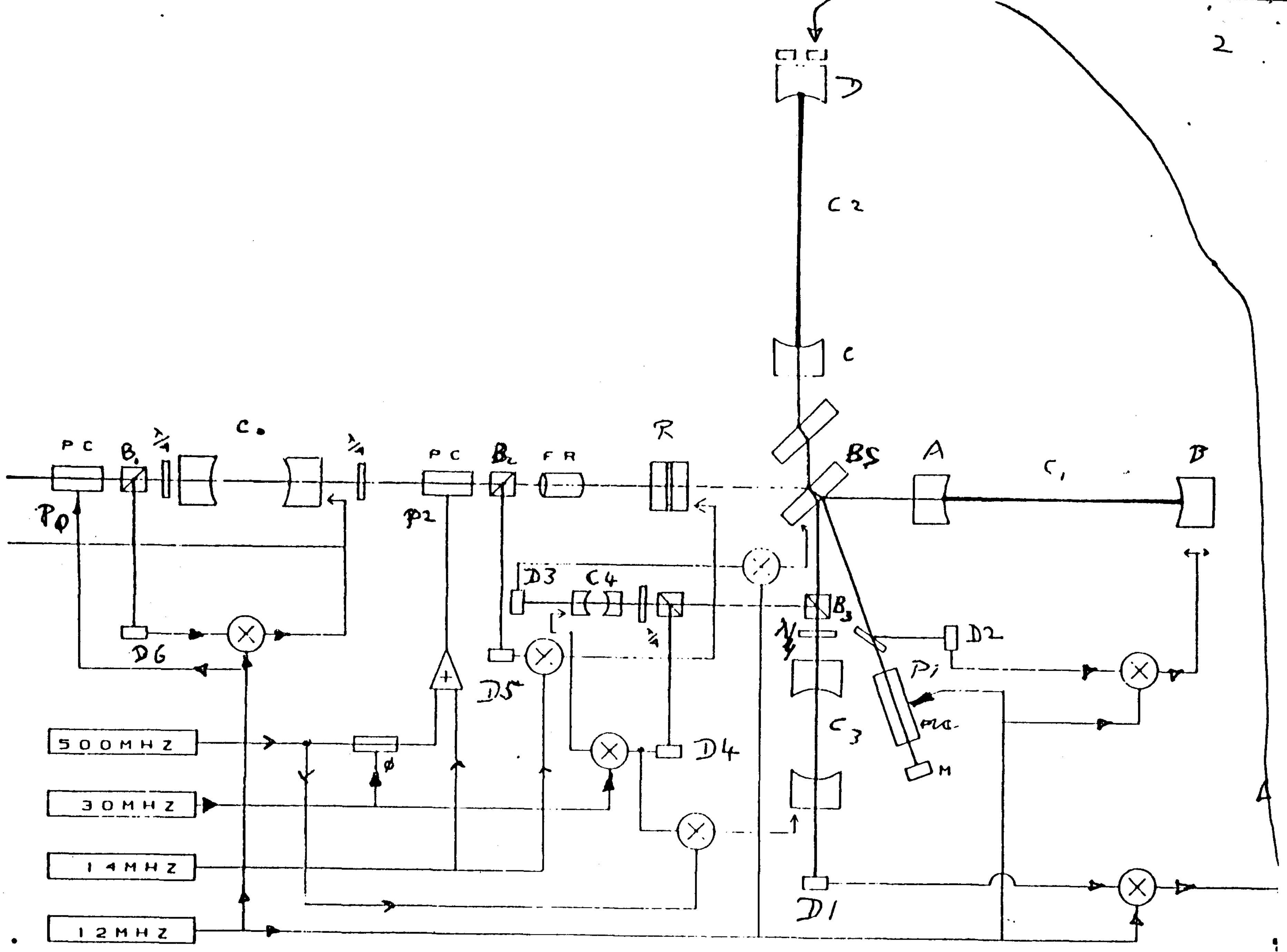

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C2
C
BS
A
C1
B
PC
B1
λ/4
C0
λ/4
PC
B2
FR
R
P0
P2
D3
C4
λ/4
B3
D2
λ/4
Pi
PZC
M
DG
D5
C3
D4
φ
D1
+
500MHZ
30MHZ
14MHZ
12MHZ