Recent developments in the LIGO Input Optics

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Outline

- IOO overview
- Mode Cleaner
- Mode Matching measurement
- Faraday Isolator
- Summary

Requirements

	requirement	measurement
polarization	100:1	170:1
power loss by Faraday isolator*	5%	3%
RFAM at EOM** (intensity)	1×10^{-3}	$\sim 10^{-4}$

*coupling loss caused by thermal wavefront distortion.

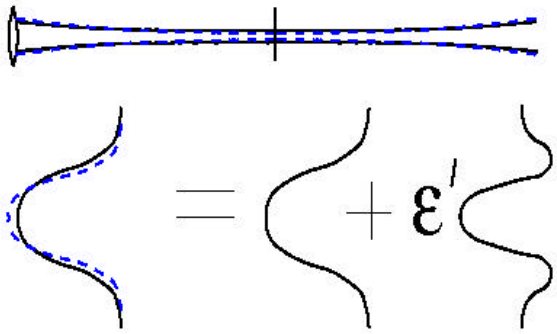
** static RFAM

Mode cleaner

	2 km	**4 km**
Plane mirror transmittance	0.002	0.002
Curved mirror transmittance	1×10^{-5}	1×10^{-5}
Finess	1550	1550
Free spectral range	9.829 (MHz)	12.246 (MHz)
Cavity full width half max	6.26 (kHz)	7.83 (kHz)
Cavity optical half length	15.240 (m)	12.24 (m)
Curved mirror radius of curvature	21.5 (m)	17.25 (m)
g = 1 – L/R factor	0.291	0.290
Waist size	1.818 (mm)	1.629 (mm)
Beam divergence	186 (μrad)	208 (μrad)

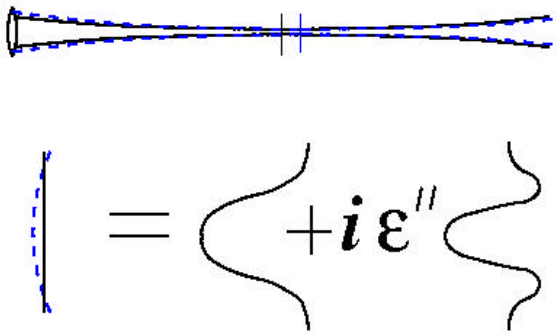
MODE MISMATCH

Wrong Beam Size:



$$\hat{U}_{00} = U_{00} + \frac{\delta w}{\hat{w}} U_{10}$$

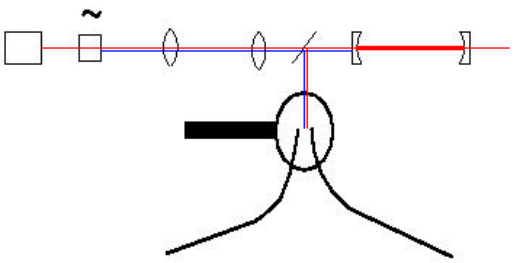
Wrong Waist Position:

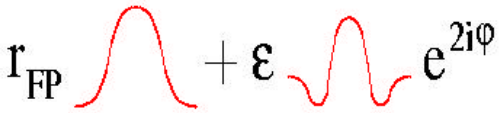


$$\hat{U}_{00} = U_{00} + i\frac{\delta z}{2\hat{z}_R} U_{10}$$

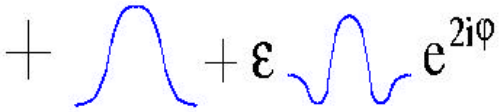
compare Y. Hefetz et.al. J. Opt. Soc. Am. B 14, 1597 (1997)

SPATIAL PM-SPECTROSCOPY





carrier



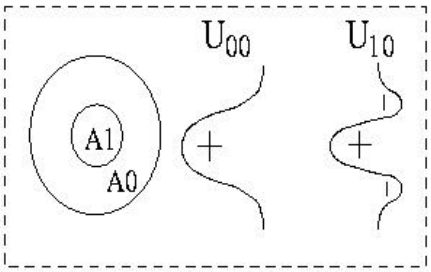
sideband

$$\varepsilon = \varepsilon' + i\varepsilon''$$

φ : Gouy-phase between Cavity and Detector

$$I_{AC}(x,y) = \sin(\Omega t) * \Big(\overbrace{\Im\{r_{FP}\} * |U_{00}(x,y)|^2}^{\text{length control}} + \underbrace{\Im\{(1-r_{FP}) * U_{00}(x,y) * U_{10}^*(x,y) * \varepsilon * e^{2i\varphi}\}}_{\text{mode matching}} \Big)$$

BULLSEYE DETECTOR



$$\int_{A1\text{-}A0} |U_{00}|^2 = 0$$

$$\int_{A1\text{-}A0} U_{00} U_{10}^* \simeq 0.33$$

Distance of Bullseyes:

$$\varphi_1 = \frac{3}{4}\pi \Leftrightarrow e^{2i\varphi_2} = -i$$

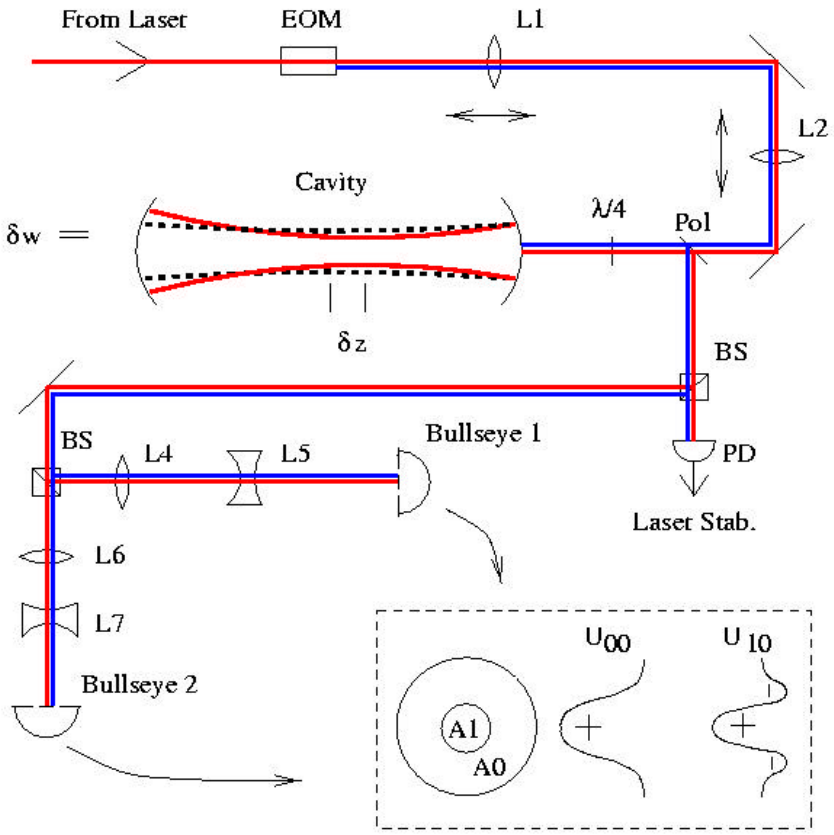
$$\varphi_2 = \pi \Leftrightarrow e^{2i\varphi_1} = 1$$

Demodulated signals:

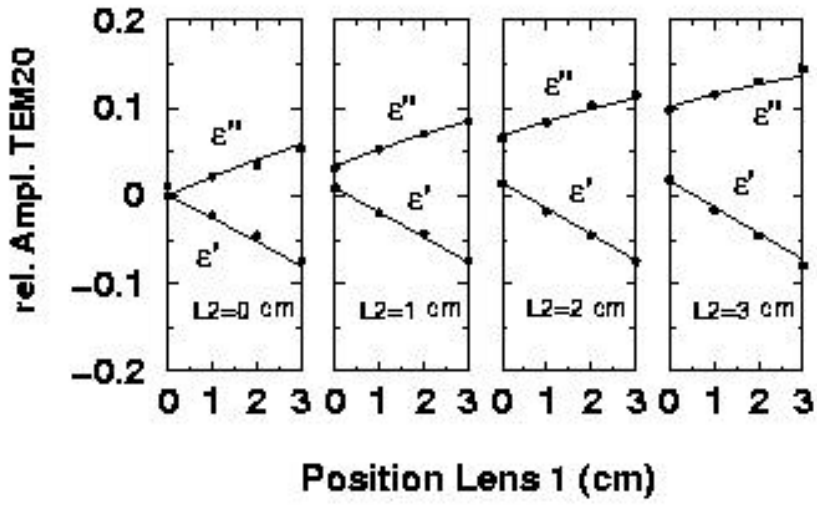
$$D_1 \propto \varepsilon' \propto \frac{\delta w}{\hat{w}}$$

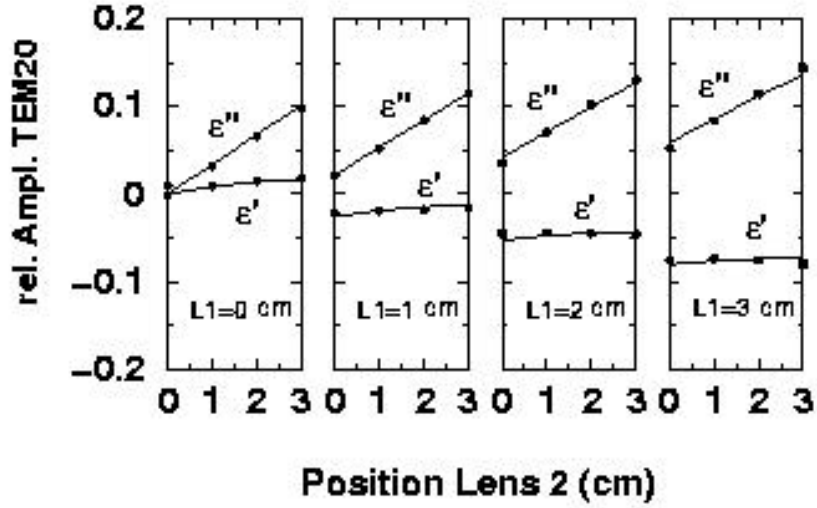
$$D_2 \propto \varepsilon'' \propto \frac{\delta z}{2\hat{z}_R}$$

EXPERIMENT

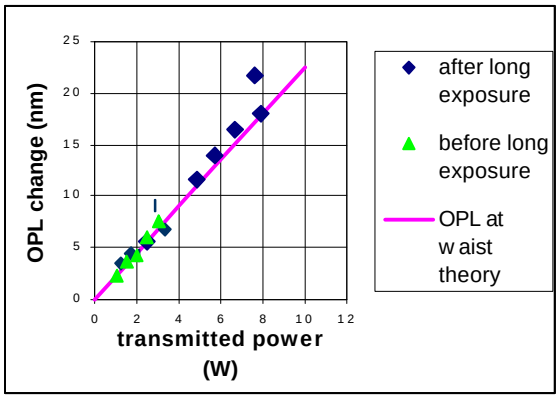

From Laser
EOM
L1
L2
Cavity
δw =
λ/4
Pol
δz
BS
BS
L4
L5
Bullseye 1
PD
Laser Stab.
L6
L7
Bullseye 2
U00
U10
A1
A0

RESULTS


rel. Ampl. TEM20
0.2
0.1
0
−0.1
−0.2
ε''
ε'
L2=0 cm
L2=1 cm
L2=2 cm
L2=3 cm
0 1 2 3
Position Lens 1 (cm)


rel. Ampl. TEM20
0.2
0.1
0
−0.1
−0.2
ε''
ε'
L1=0 cm
L1=1 cm
L1=2 cm
L1=3 cm
0 1 2 3
Position Lens 2 (cm)

Thermal wavefront distortion in EOM

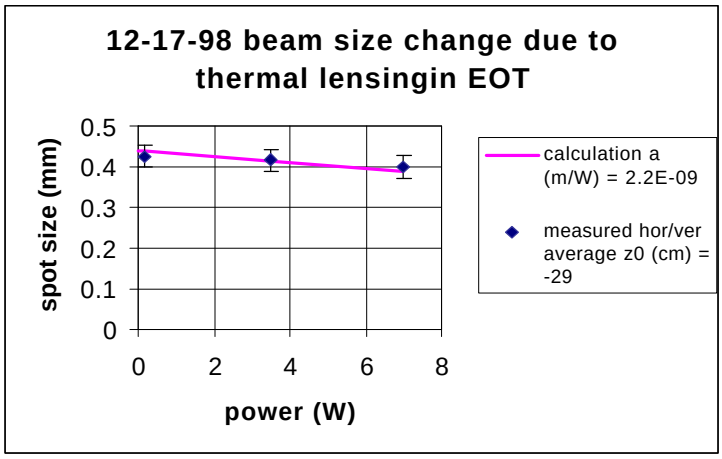


Thermal lens before and after long exposure

$$\Delta OPL(r) \approx 0.07741 \frac{P_{abs} L}{k_{th}} \left(\frac{dn}{dT} + an \right) \left(\frac{r^2}{w^2} + 0.4 \frac{r}{w} \right)$$ 1)

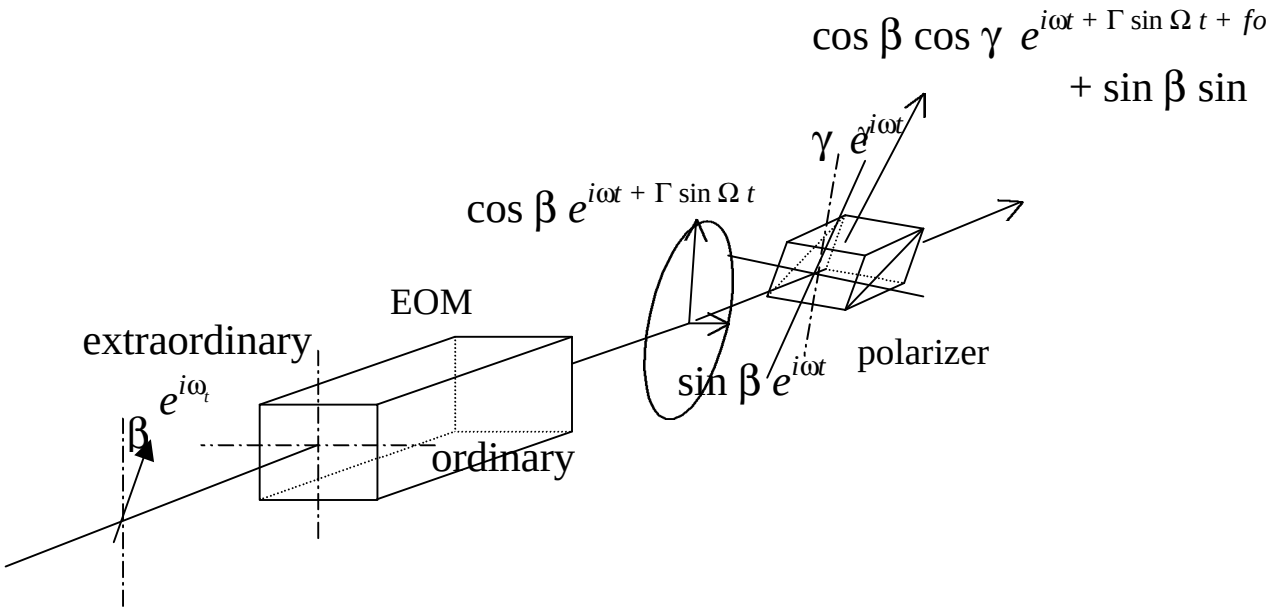
1) Justin Mansell, private communication (1997)

PSL beam size measurement



Measured and calculated spot size of a cw, Nd:YAG beam transmitted through EOM

RF amplitude modulation (intensity)



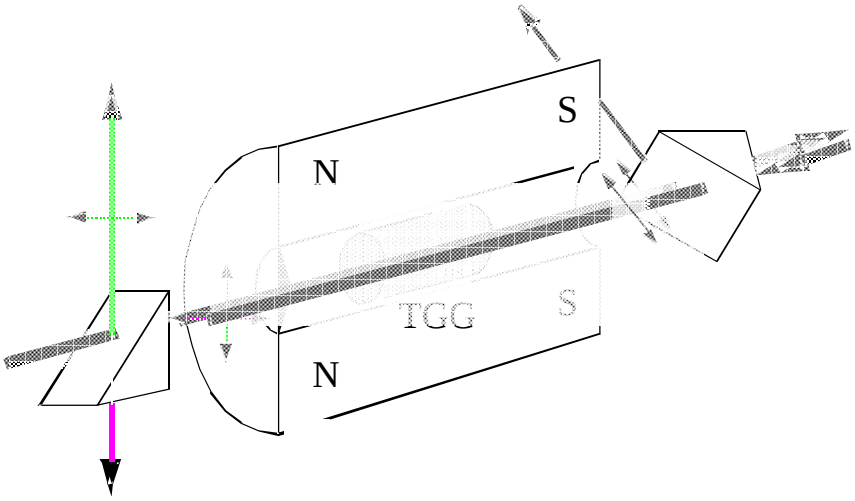
Residual intensity modulation caused by angular misalignment.

Measurement

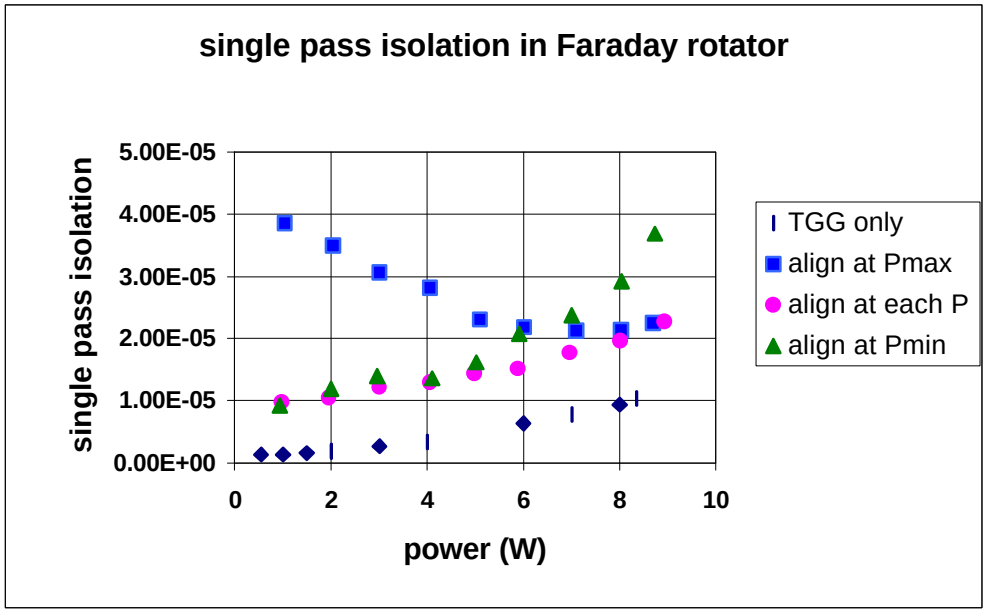
f (MHz)	@ 6 W	note
26.7	5.94×10^{-5}	Mode Cleaner align (Γ=0.1)
29.4	9.25×10^{-5}	Core optics align (Γ=0.5)
68.8	1.75×10^{-4}	Recycling mirror align (Γ=0.05)
35.5	1.38×10^{-5}	PSL pre-MC side band
40	1.55×10^{-4}	PSL AOM

( ): required modulation depth. Measurement was made at Γ=0.5 for 29.4 MHz and 68.8 MHz EOM, and at Γ=0.1 for 26.7 MHz EOM.

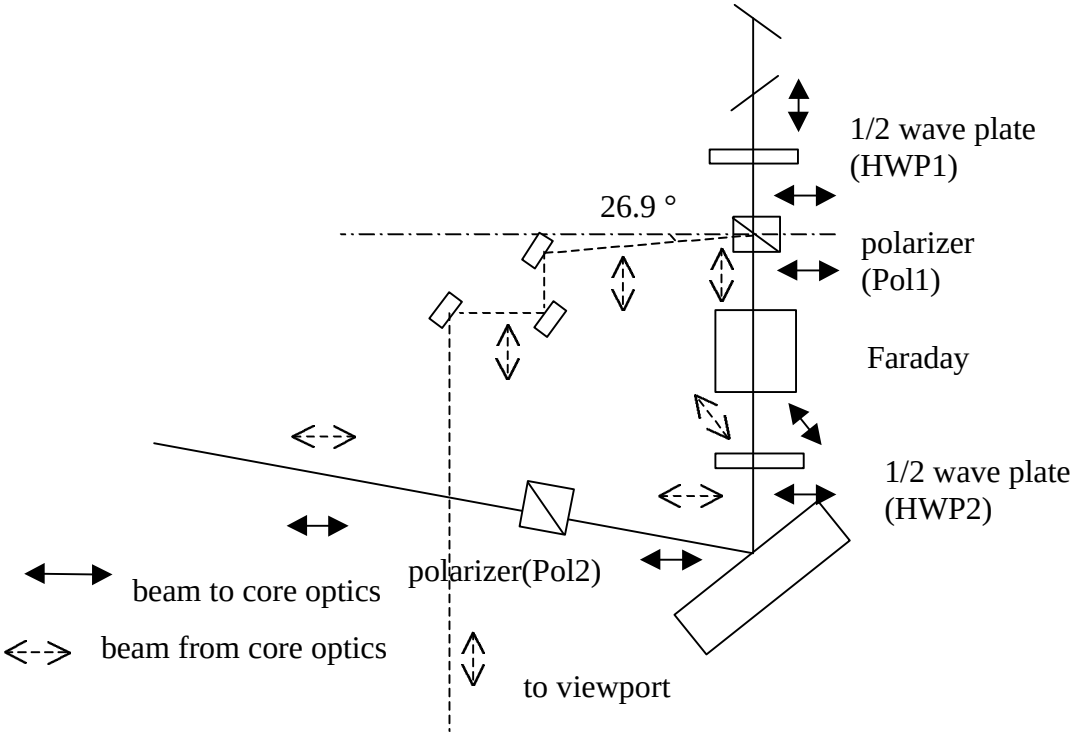
Faraday isolator



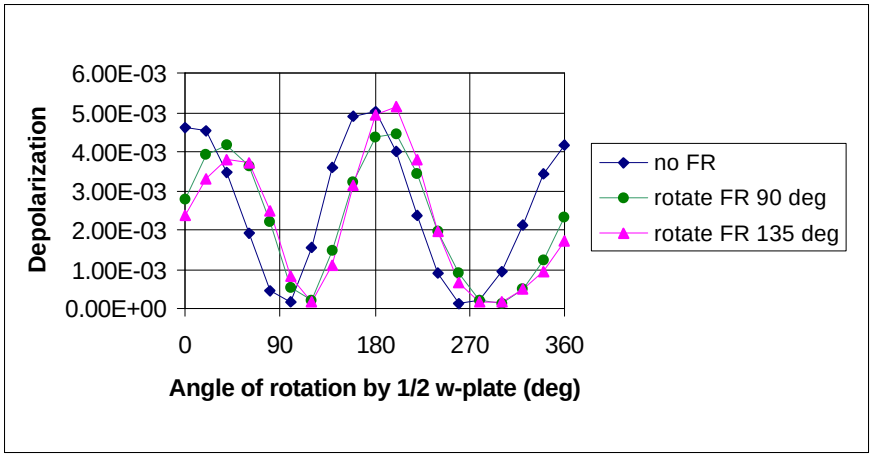
Thermal depolarization (single pass isolation)



Faraday isolator with ½ wave plate



Angle dependence



Birefringence in ½ w plate and TGG

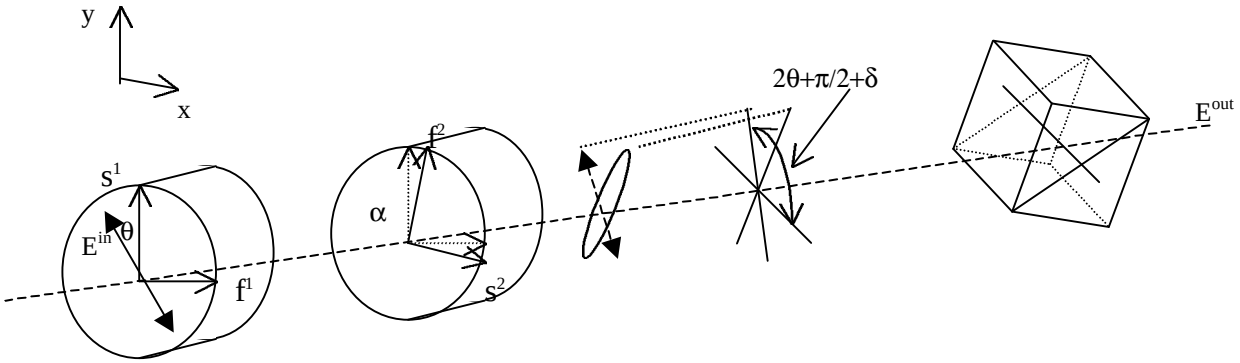


Fig.1 zero-order HWP and an analyzer cross-polarized to slightly elliptical output polarization.

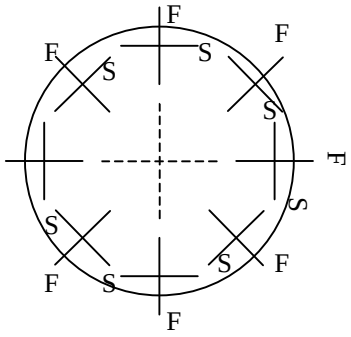
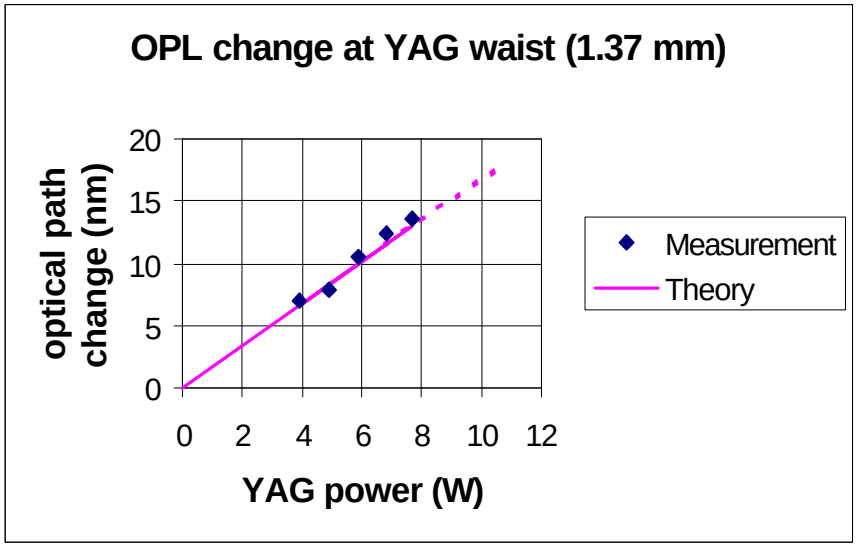
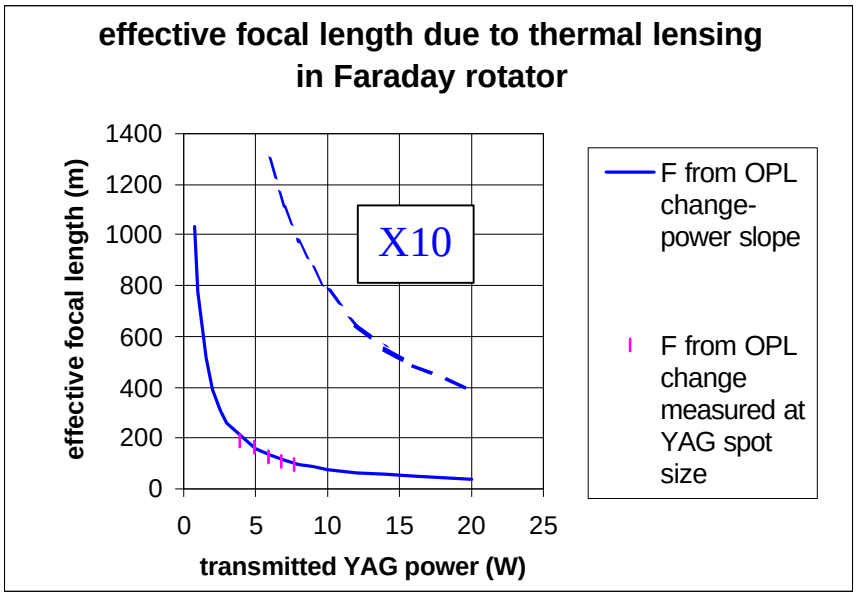


Fig.2 Thermally induced birefringence in TGG

Thermal lens in Faraday rotator



Effective focal length



Current status

- UF
  - Bullseye detector tested on tabletop

- LHO 2-km interferometer

  - All IOO components installed, aligned

  - Mode Cleaner locked

Visibility (reflection)	97%
Length adjustment	15.2396 (m) (0.4 mm short)

  - Faraday Isolator and Mode Matching telescope aligned

- LLO

  - Mechanical installation underway