The A+ Low-Loss Faraday Isolators

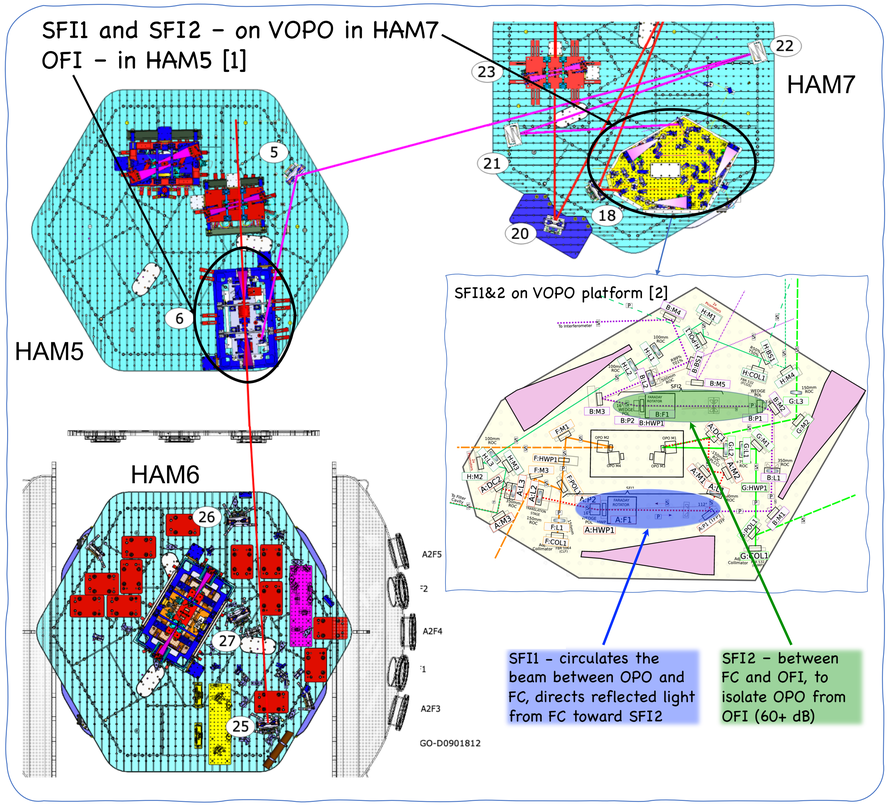
R.M. Martin, J. Notte, J. Reyes, *Montclair State University, Montclair, NJ, USA*
P. Fulda, R. Goetz, D.B. Tanner, *University of Florida, Gainesville, FL, USA*

Abstract

Advanced gravitational-wave detectors require low-loss Faraday isolators in the squeezer path, in order to maximize the benefits of the squeezed light injection. The University of Florida and Montclair State University have developed and are currently building two designs of low-loss Faraday isolators for the A+ upgrade, one output Faraday isolator (20 mm clear aperture) and two squeezer Faraday isolators (5 mm aperture). Both designs also serve as circulators. The required losses are <1% single pass, while maintaining an isolation ratio higher than 30 dB. The designs use TGG as the magneto-optical material placed inside a vacuum-compatible magnet, with temperature tunability of the Verdet constant via a thermo-electric Peltier device. A single quartz rotator cut at 45 deg restores the initial polarization. The input polarizer is a wedged KTP prism, while a thin film polarizer at the output allows for the injection of s-polarized light from the squeezer or the optical parametric oscillator. The output Faraday isolator design also includes a fused-silica wedge to compensate for the beam's angular displacement from the signal recycling mirror. All optics are super-polished and coated with high- performance IBS dielectric coatings. The Faraday devices assembled so far show single-pass losses as low as 0.45%, with better than 30 dB isolation.

Overview of A+ LLFI in the output path

SFI1 and SFI2 – on VOPO in HAM7
OFI – in HAM5 [1]



SFI1&2 on VOPO platform [2]

SFI1 – circulates the beam between OPO and FC, directs reflected light from FC toward SFI2

SFI2 – between FC and OFI, to isolate OPO from OFI (60+ dB)

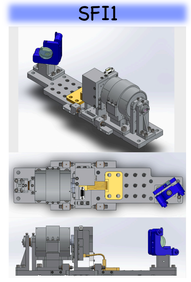
Mechanical and Optical Design

A+ SFI

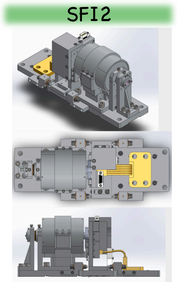
Design Requirements:
>99% transmission
>30 dB isolation

KTP: 8x8x3 mm, 18 deg wedge
TGG: 6 mm diameter, 18 mm long
QR: 12.7 mm diameter
Pol. Rotation 45 deg
Accuracy <5 arcmin
TFP: 25.4 mm diameter, 6.35 mm thick
AOI = 56 deg
T_p > 99.5% (some AOI 54-58 deg)
Extinction >40 dB (for 54-58 deg)

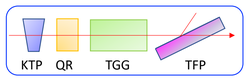
All optics are superpolished and IBS coated.



12" x 3.5" footprint, ~2.2 kg



8.75" x 3.5" footprint, ~1.9 kg



(off platform)

A+ OFI

Design Requirements:
20 mm aperture (limited by MOE)
>99% transmission
>30 dB isolation

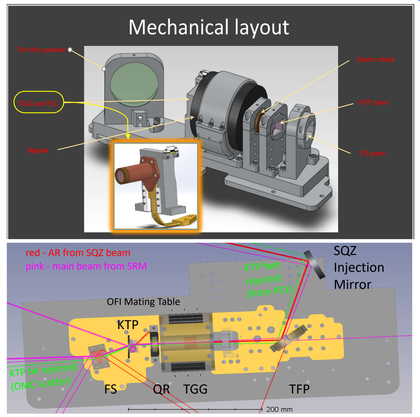
Optical Components:

MOE: TGG – 45 deg rot in ~1.2T field
Polarizers: KTP – wedge polarizers, TFP to pickoff the SQZ beam
Quartz Rotator: 45deg rotation (in place of a ½ waveplate)
Fused Silica: FS compensation prism – specific to OFI

Vacuum compatible magnet

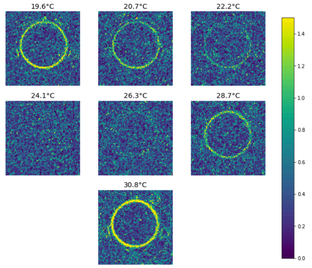
DLC coated mounts & dumps

Temperature tuned MOE via TEC (tuning range of ~2 deg polarization rotation)



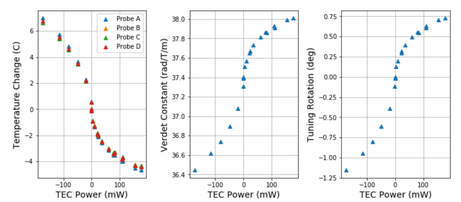
MOE thermal tuning (TEC testing prototype)

Temperature Gradients (°C/pixel)
(central value subtracted)



No obvious gradients beyond background noise in crystal bulk [4]

Temperature Tuning of the Verdet Constant [4]



Roughly 2 deg rotation tuning range can be achieved with +/-200 mW TEC power (>10°C temperature range).

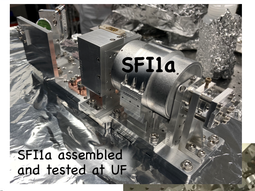
LIGO-G2101056

First Item Device Performance

SFI 1&2 (LHO)

SFI1a: [5]
34.9 dB isolation
(from OPO side)
0.63% single pass loss
Confirmed at site [8]
32 dB (from OPO side)
43 dB (from SFI2 side)

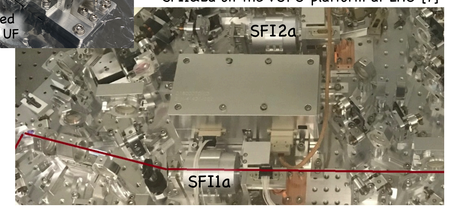
Performance was still limited by the testing method, e.g. scattering or beam size.



SFI1a assembled and tested at UF

SFI2a: [6]
51.5 dB isolation ratio
0.62% single-pass losses

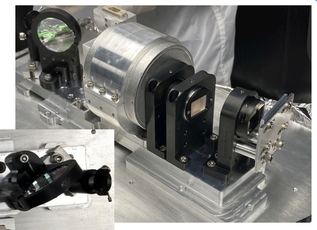
SFI1&2a on the VOPO platform at LHO [7]

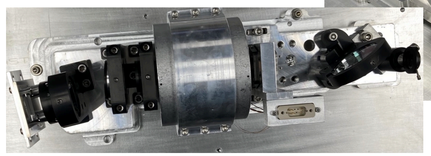


OFI-a (LLO)

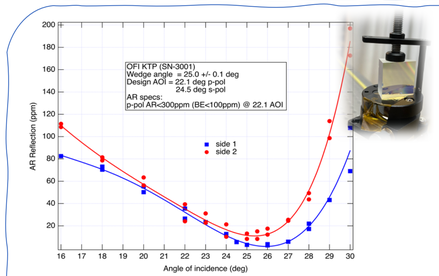
OFI-a: [9]
38.5 dB isolation ratio
0.45% single pass loss

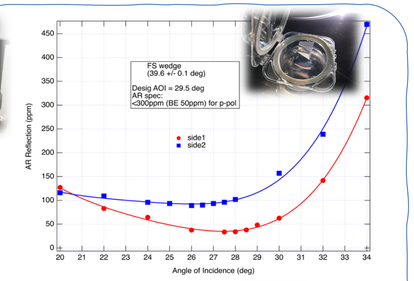
Specs were confirmed at site [10]





Component Characterization [11]

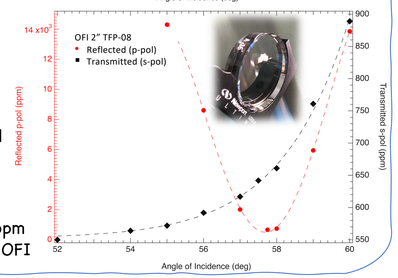




AR performance:
FS: 60-160 ppm/side (side 1, 2 variations)
KTP: < 40 ppm/side (p-pol)
QR: <100 ppm (two sides)
TGG: < 55 ppm (two sides)

TFP performance:
Extinction: Ts/Tp = 40+ dB; Rp/Inc = [31.7dB best, 27.1dB worst]
(polarization contamination; accounted for in transmission by sending the beam through a second CWP)
- 99.7% transmission Tp
- AR at min p-pol reflection: 610-930 ppm

[(60+160)+2*40+100+55+(1-0.997)*10⁶](ppm)=3455 ppm
Expect ~3500ppm single-pass component losses in OFI



References:
[1] Top Level Conceptual Layout of A+, LIGO-D1800027
[2] Frequency Dependent Squeezing Final Optical Layout, LIGO-T1900649
[3] A+ Squeezer Faraday Isolators Mechanical and Optical Design Review, LIGO-G2001099
[4] A+ Low-Loss Isolator MOE Thermal Tuning Prototype Test Update, LIGO-G2000665
[5] SFI1a test report, LIGO-T2100094
[6] SFI2a test report, LIGO-T2100116
[7] alog LHO 58126, alog-58126
[8] alog LHO 58135, alog-58135
[9] A+ OFIa (L1) test report, LIGO-Q2100013
[10] alog LLO 55716, alog-55716
[11] Component Characterization of an A+ Low-Loss Faraday Isolator, LIGO-G2100421

Acknowledgments:
This work was supported by National Science Foundation Awards PHY-1806839, PHY-2012021, CIT 75-S434395, and CIT 75-S434499.