LIGO

Status of RF Modulators for Enhanced and Advanced LIGO

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Outline

- eLIGO modulator design
- eLIGO modulator commissioning
- aLIGO modulator prototype
- aLIGO parallel modulation scheme

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eLIGO phase modulator

- LIGO is currently being upgraded to eLIGO
- Laser power is increased to 30 W
- iLIGO electro-optic modulators (EOMs) must be replaced
  - LiNbO3 modulators would suffer from severe thermal lensing or might even break
- eLIGO devices (techniques) serve as testbed for aLIGO

Wedged RTP crystal

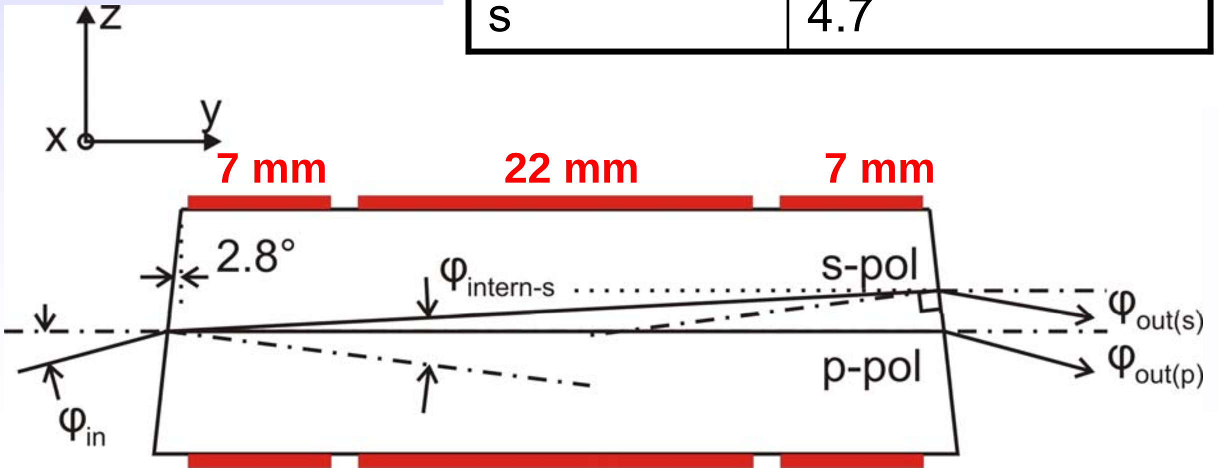
(rubidium titanyl phosphate - RbTiOPO4)

- iLIGO lithium niobate (LiNb03) modulators are not satisfactory
  - Thermal lensing / Damage / Residual absorption.

- Wedged crystal separates the polarizations and acts as a polarizer
  - This avoids cavity effects and reduces amplitude modulation

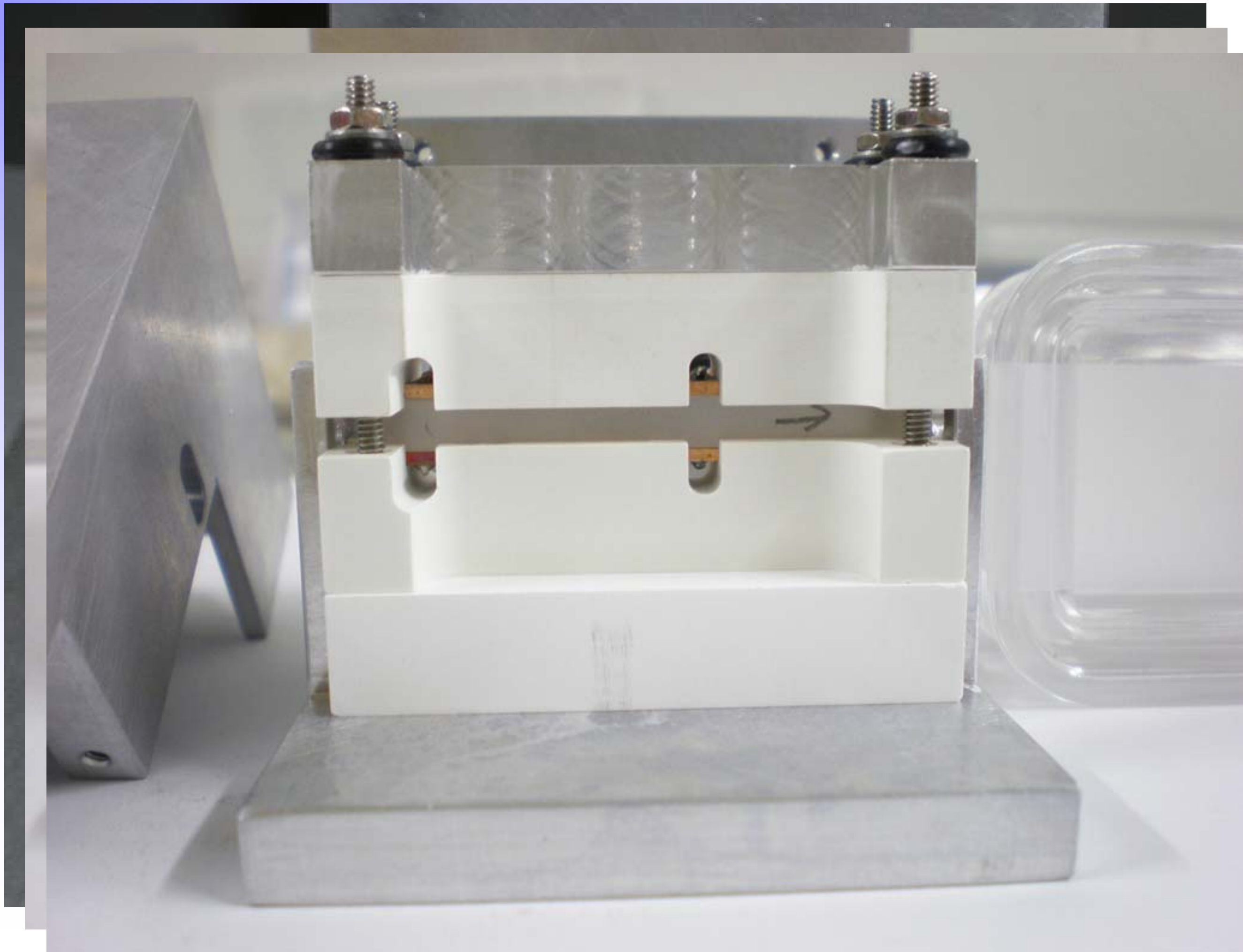
Polarization	Angle [degrees]
p	5.2
s	4.7

- AR coatings (< 0.1%)



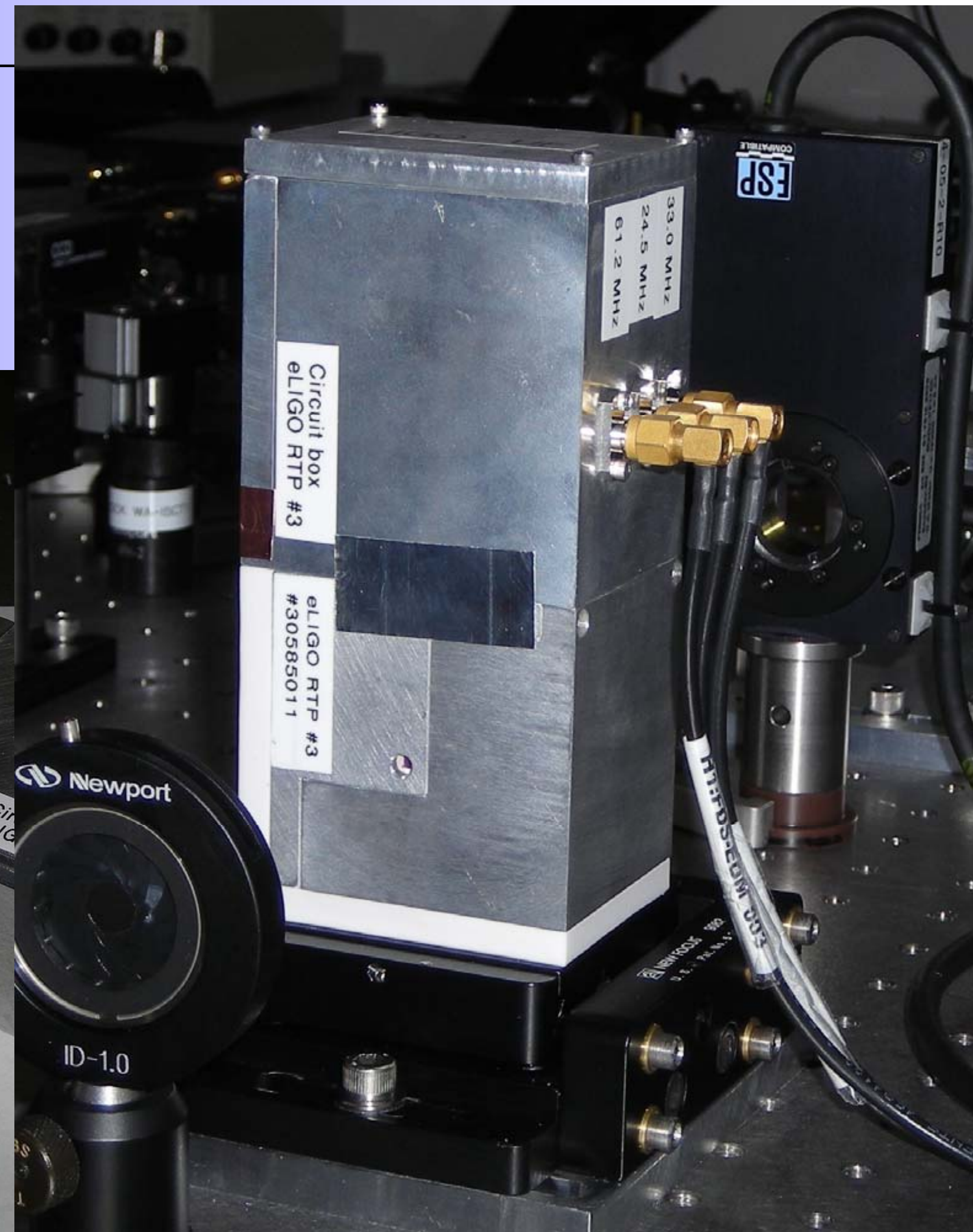
Three Modulations / Single Crystal design

- One crystal with three separate pairs of electrodes. Crystal and electrodes are held by Boron-Nitride spacer (2nd generation, replaced Teflon).
- Electrode lengths:
  - 7 mm
  - 22 mm
  - 7 mm



Separate optic and electronic cases

- The crystal housing is separated from the resonant circuits to maintain maximum flexibility while the crystal remains in the optical setup.



Resonant circuit

- Impedance matching circuit in separate housing.
- Pi-network resonant circuit with 50 Ω input impedance.
- Matched to eLIGO Frequencies:
  - 24.5 / 33.0 / 61.2 MHz

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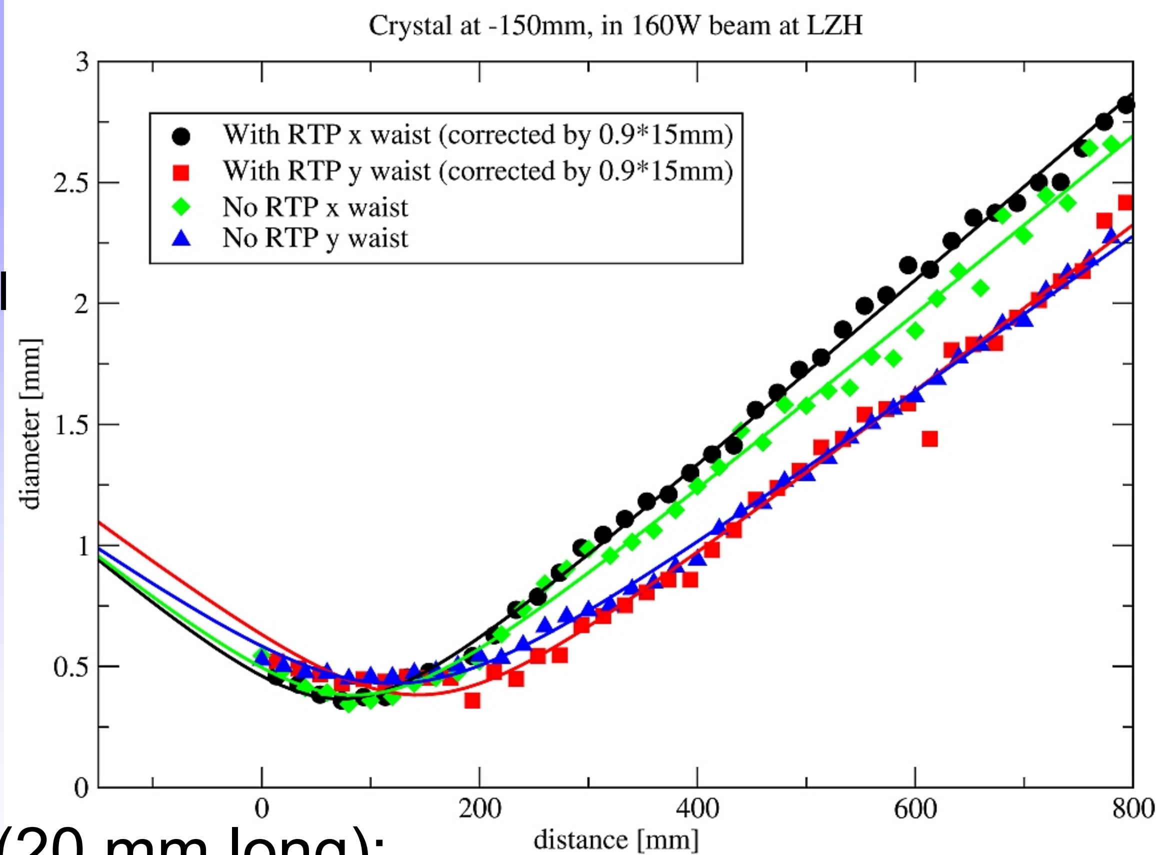
Thermal properties

- The aLIGO laser prototype was used to measure the thermal lensing.
  - Full Power = 160 W
  - Beam Waist = 950 µm diameter at crystal
  - 4x4x15 mm RTP crystal
  - Thermal lenses:
    $f_X > 4$ m
    f_Y = much longer



- compare with LiNbO3 (20 mm long):
  $f_{thermal} \sim 3.3$ m @ 10 W

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RFAM

- Wedged geometry suppresses amplitude modulation. (No polarization rotation possible)

- Piezo effects in can lead to standing waves (AOM) and pointing (RF-pointing) at the modulation frequency

- Measured AM:
  $\Delta I/I <\ 10^{-6}$ at $\Omega_{mod} = 24.5$ MHz / m = 0.5

  This requires very precise alignment of the beam on the PD, RF pointing is present!

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eLIGO modulator commissioning

- Installed at LHO
  - drive electronics changed to output 24dBm
  - installed after PMC, before power control. EOM always sees maximum power (~28W)
  - Modulation indices
    - 24.5MHz: m=0.50 @ 12.0Vpp
    - 33.3MHz: m=0.094 @ 5.0Vpp
    - 61.2MHz: m=0.146 @ 8.6Vpp
  - MC visibility 98%
- Installation at LLO is scheduled for the week of 10/20/2008.

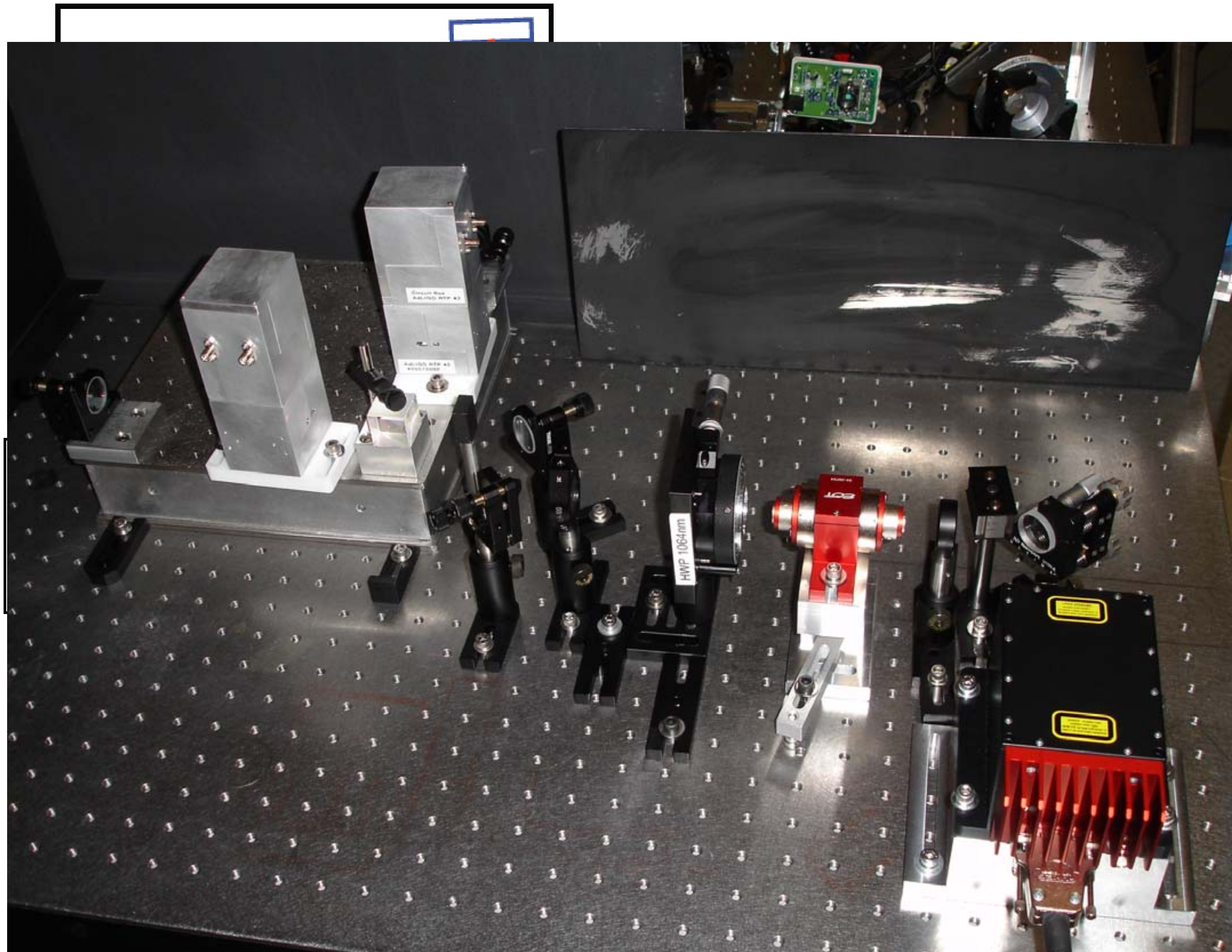
Status of aLIGO modulator

- Prototypes are ready.
- Same internal setup as eLIGO modulators, but only two electrode pairs:
  31 mm / 7 mm
- High power testing at LZH is pending
- aLIGO modulator can be used for parallel modulation setup.

Parallel Modulation setup

Not required by latest LSC document, but kept as a fall-back solution

- Symmetric setup on invar breadboard
- Fast phase control with phase correcting EOM
- Modulation at 9 MHz and 45 MHz
- UGF > 50 kHz previously realized, higher is possible
- High dynamic range length control thermal/PZT (investigation pending)



Summary

- eLIGO modulators:
  ready and installed (or will be soon)

- aLIGO modulators
  prototypes are ready and about to be tested

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Supplementary material

RTP Thermal properties

Properties	Units	RTP	RTA	KTP	$LiNb0_3$
dn_x/dT	$10^{-6}/K$	-	-	11	5.4
dn_y/dT	$10^{-6}/K$	2.79	5.66	13	5.4
dn_z/dT	$10^{-6}/K$	9.24	11.0	16	37.9
κ_x	W/Km	3		2	5.6
κ_y	W/Km	3		3	5.6
κ_z	W/Km	3		3	5.6
α	cm^{-1}	< 0.0005	< 0.005	< 0.005	< 0.05
Q_x	1/W	-	-	2.2	4.8
Q_y	1/W	0.047	0.94	2.2	4.8
Q_z	1/W	0.15	1.83	2.7	34

Optical and electrical properties

Properties	Units/conditions	RTP	RTA	$LiNbO_3$
Damage Threshold	MW/cm^2,	>600	400	280
n_x	1064nm	1.742	1.811	2.23
n_y	1064nm	1.751	1.815	2.23
n_z	1064nm	1.820	1.890	2.16
Absorption coeff. α	cm^{-1} (1064 nm)	< 0.0005	< 0.005	< 0.005
r_{33}	pm/V	39.6	40.5	30.8
r_{23}	pm/V	17.1	17.5	8.6
r_{13}	pm/V	12.5	13.5	8.6
r_{42}	pm/V	?	?	28
r_{51}	pm/V	?	?	28
r_{22}	pm/V			3.4
$n_z^3\, r_{33}$	pm/V	239	273	306
Dielectric const., ε_z	500 kHz, 22 ^oC	30	19	
Conductivity, σ_z	$\Omega^{-1}cm^{-1}$, 10 MHz	$\sim 10^{-9}$	$3x10^{-7}$	
Loss Tangent, d_z	500 kHz, 22 ^oC	1.18	-	