Photodiodes for Initial LIGO

Nickel and Dime Gravity Meeting

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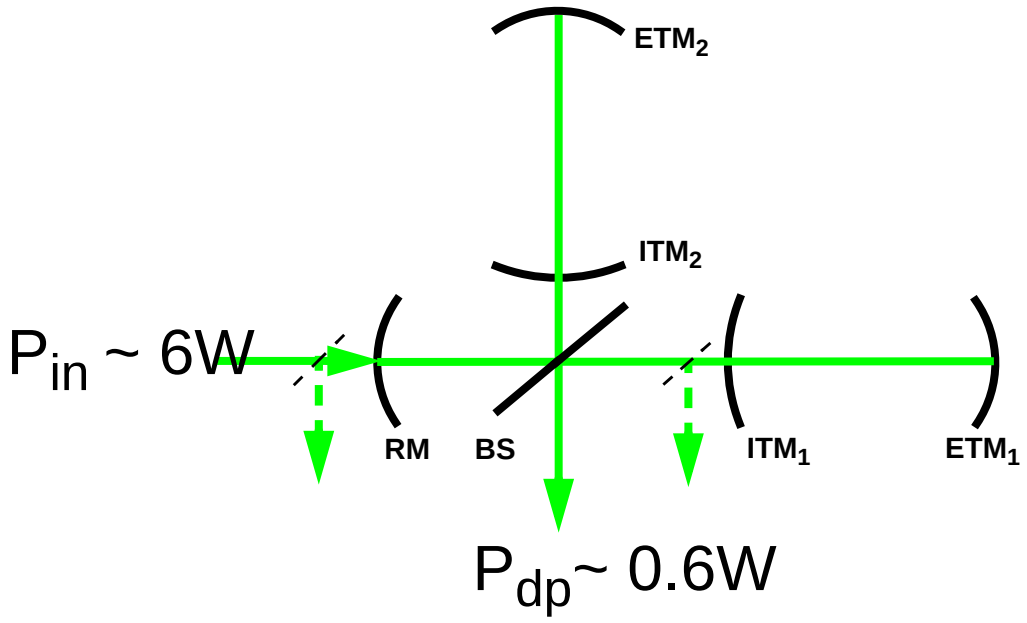
Outline

- Introduction
- General Requirements
- Some Measurement Results
- Conclusions

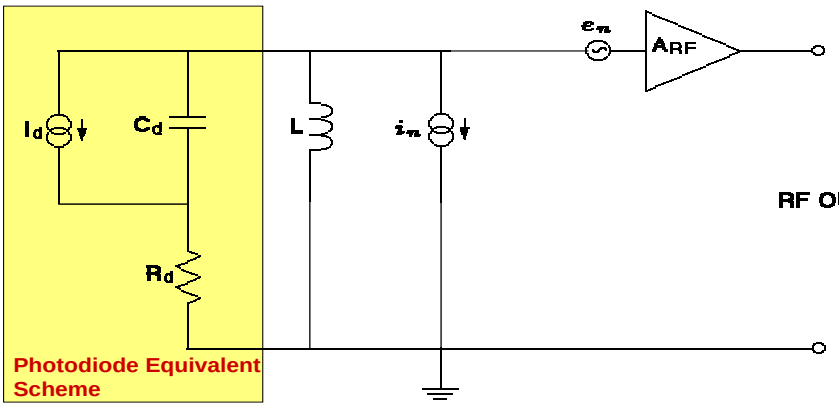
Introduction
InGaAs Photodiodes in LIGO



- Detection of RF modulated light
  - ››Length Control Signals (Alignment uses other devices)
  - ››Gravitational Wave Signals
- For LIGO I, tested commercial diodes
  - –EG&G, Hamamatsu, GPD (2mm and 3mm diameter)
  - –Choice: EG&G 2mm (omit discussion of others here)

Detector SNR Requirements

- LIGO I: f_{mod} = 25 - 32 MHz

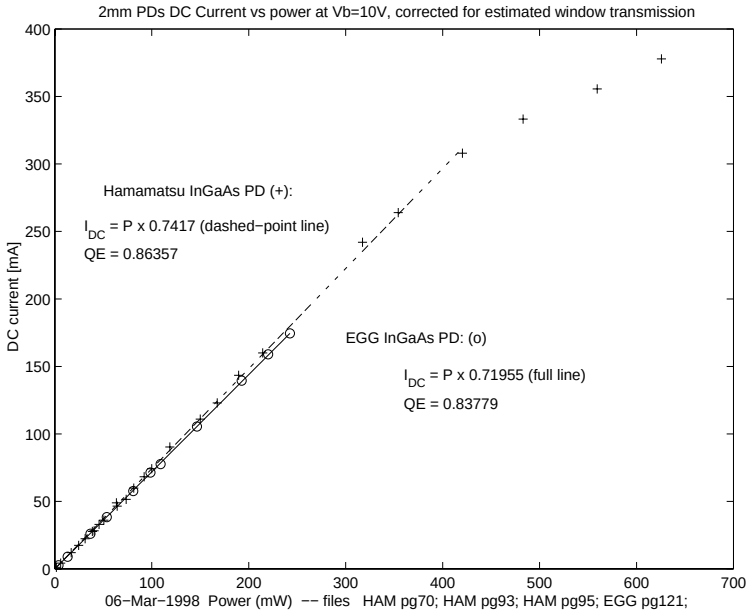


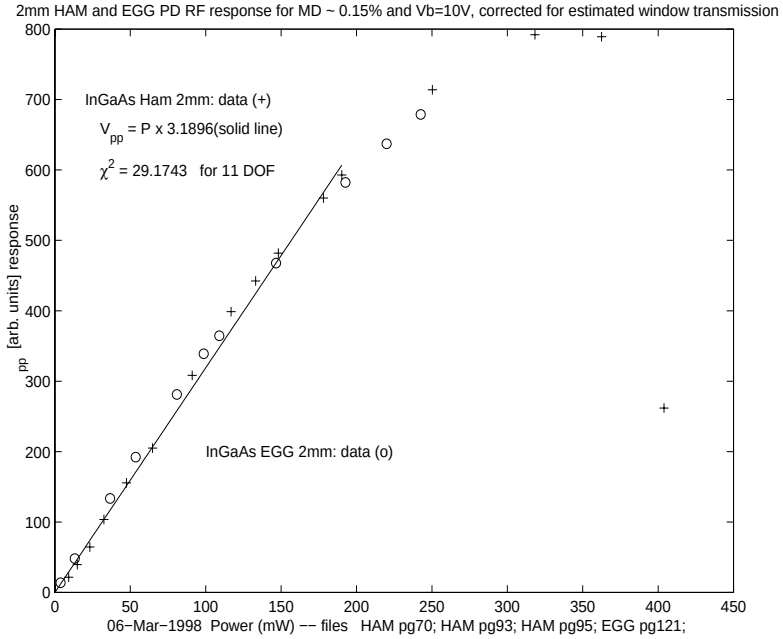
- $10 < \frac{S_{shot}}{S_{elec}} \propto \frac{Z_D\sqrt{2eI_{DC}}}{e_n}$
- $Z_D = \frac{1}{R_D(\omega_0 C_D)^2}$

›› need low diode resistance and capacitance

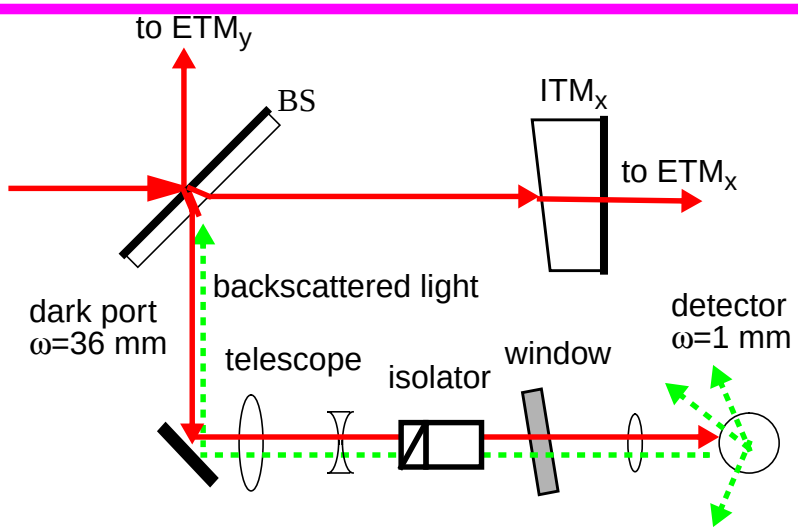
– Ex: EG&G 2mm at 10V Reverse bias 72 pF, 9 Ω

Measured Linearity





Backscatter

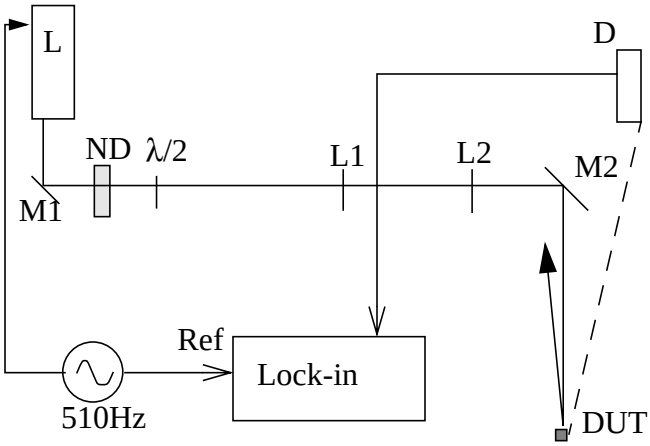


- Photodiode Surface Backscatter

$$h_n^2 \sim P_{dp} \cdot BRDF \cdot \Delta\Omega \cdot \frac{\omega_0^2}{\omega_{pd}^2} \cdot \delta x_{pd}$$

  - BRDF: “Bidirectional Reflectance Distribution Function”
  - optical isolation (costs efficiency)
  - seismic /acoustic isolation (costs $)
  - improved BRDF
  - larger detector area

Backscatter Measurement



L - Laser (1.064μm)

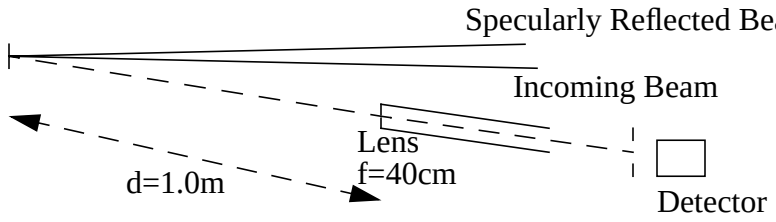
L1, L2 - Lenses

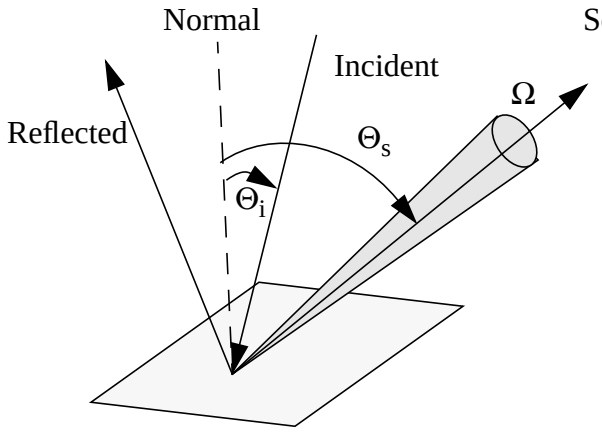
ND - Neutral Density Filter

λ/2 - Halfwave plate

DUT - Diode under test

D - Detector





$$BRDF \equiv \frac{P_{out}}{P_{in}\Omega}$$

BRDF Measurement Results

Table 1: 2mm Diode Backscatter

Diode	BSDF (BRDF) at 6.5° (10^{-4}/ster)
Hamamatsu (G5832-2)	1.1
EG&G (C30642G)	0.37
GPD (GAP2000)	0.11

- Requrements: 10^{-4}/ster

Power Handling

- Steady State (600mW at DP for LIGO I)
  - ›› $N_{pd} \geq P_{dp} / P_{MAX} \approx 4$
    the fewer, the better (SNR, $, scatter,...)
  - ››tradeoff against linearity
- Transient
  - ››Sudden loss of lock releases stored energy U~3J through dark port
  - ››P_{refl} rises briefly to 4 P_{in}
  - ››Damage likely due to thermal effects (bias has automatic safety switch)
    - –EO shutter may be required (costs efficiency)
    - –Thermal properties of diode & package

Other Issues

- High Quantum efficiency
  - Greater than 80% at ND:YAG wavelengths
    - InGaAs necessary (Si is roughly 20%)
    - Tests: all about 85%, but different Anti-Reflection coatings
- Spatial uniformity
  - Defeats modal orthogonality, enhancing effect of beam tube scattering recombination
  - Requirement of ~ 1% uniformity for LIGO I is met

Conclusions

- InGaAs Photoiodes will be used in LIGO I
- We have extensively tested commercial items
- Baseline design will require 4 diodes at DP

- Specs Summary

Parameter	*LIGO I*	*Current design*
Steady-state power	0.6 W	0.75 W
Transient damage	3 J / 10 ms	3 J / 10 ms
Signal/Noise	1.4×10^{10} $Hz^{1/2}$	1.5×10^{10} $Hz^{1/2}$
Quantum efficiency	80%	83%
Spatial uniformity	1% RMS	1% RMS
Surface backscatter	10^{-4} /sr	$< 10^{-4}$/sr