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Study of Photoreceivers for Space-Based Interferometry

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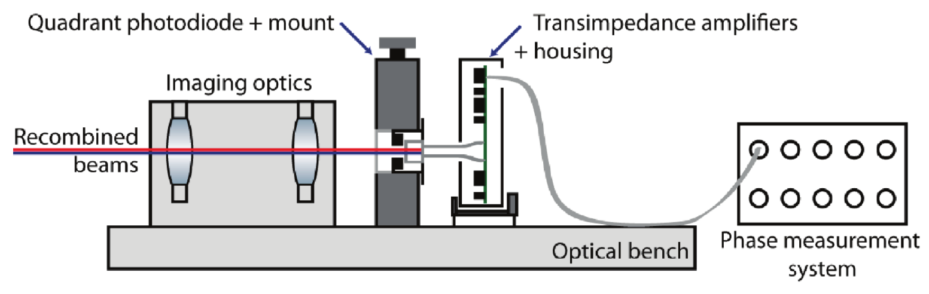
Introduction

What do we need photoreceivers for?



Laser interferometry is used in space missions such as eLISA LPF and GFO to measure distance variations with pm/√Hz (eLISA, LPF) or nm/√Hz (GFO) accuracy.

- A precise phase measurement of the laser signal is essential to obtain the required distance information. Prior to the phasemeter, a photoreceiver is needed for the opto-electrical conversion.

- Any problem in the photoreceiver significantly affects the phasemeter accuracy.

Limited speed in silicon photodiodes

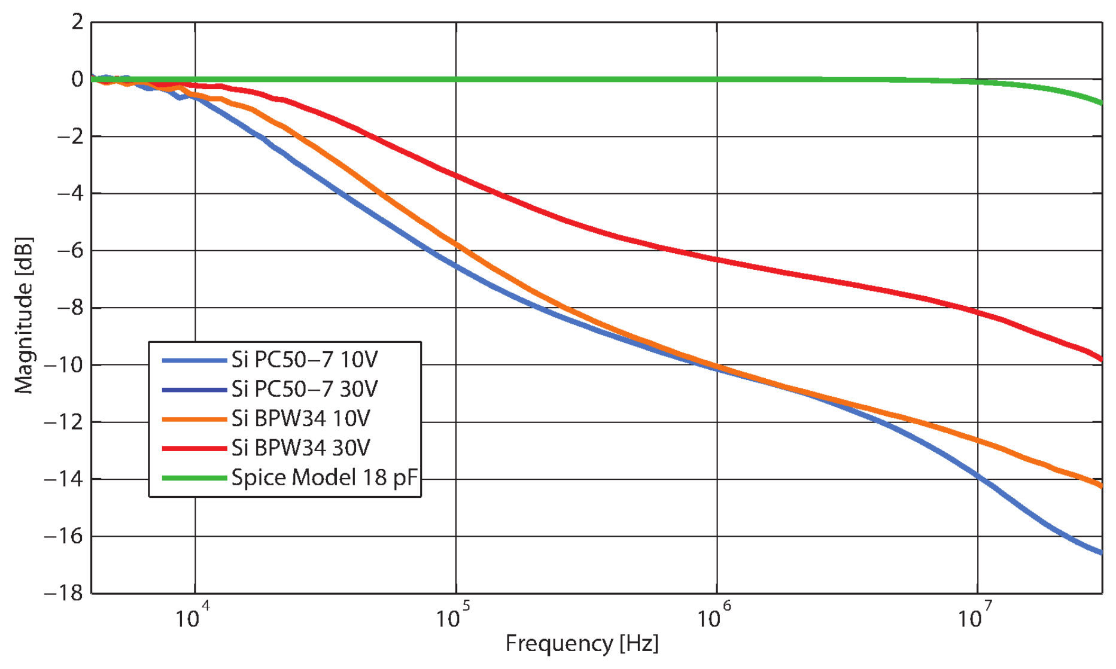
Transit-time dependancy on bias voltage

Silicon photodiodes could represent a good alternative to InGaAs devices in low noise photoreceivers due to their lower junction capacitance, which directly affects the noise budget at high frequencies. But at the same time they show drawbacks which make them unsuitable for our photodetection chain.

In the first place, a reduced absorption at 1064 nm requires special photodiode topologies to improve the responsivity, including additional layers and a thicker intrisic region.

Secondly, a high bias voltage (~100 V) is needed in order to obtain a flat frequency response.

Measurements indicate that this limitation in the magnitude of the transfer function is caused by a long transit time of carriers and it is not an effect of the junction capacitance. Carriers' velocity becomes higher by increasing the bias voltage. This compensates the lower mobility of electrons and holes compared to InGaAs and the presence of a thicker transit region.



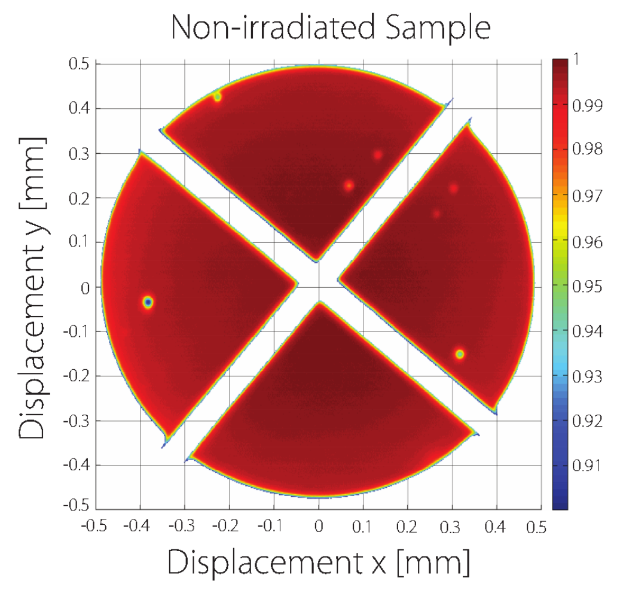
Radiation test in InGaAs photodiodes

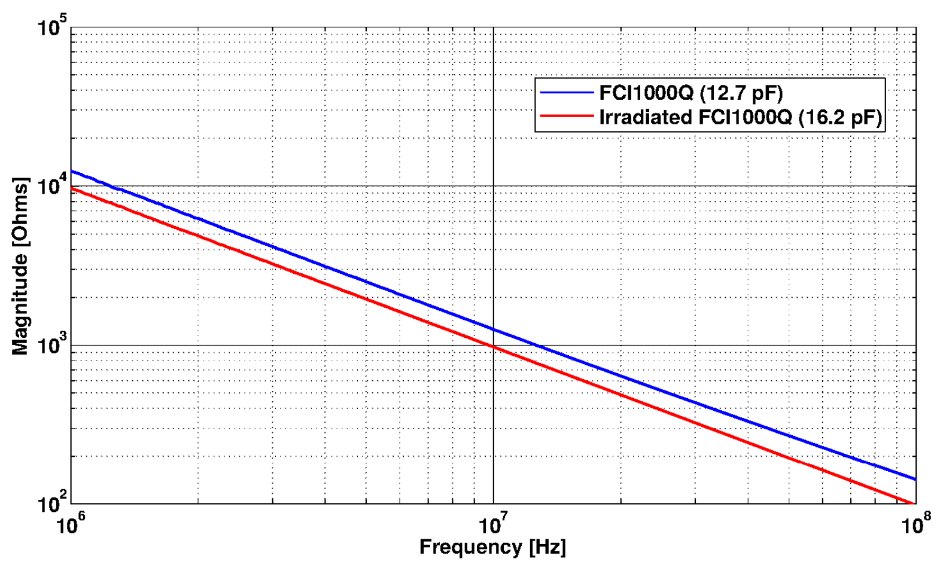
Observing effects of an equivalent 5 years in-flight exposure

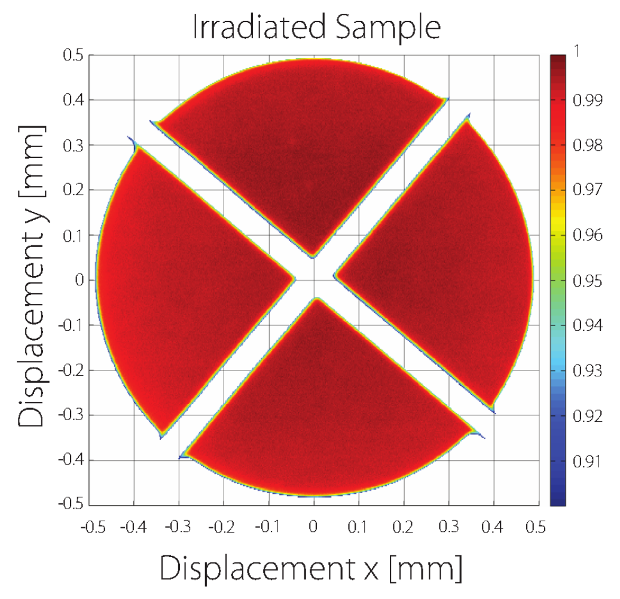
Components for space-based missions must keep an optimal operation in extreme conditions. A radiation test was performed to detect variations in critical parameters of photodiode candidates for space-based interferometry.

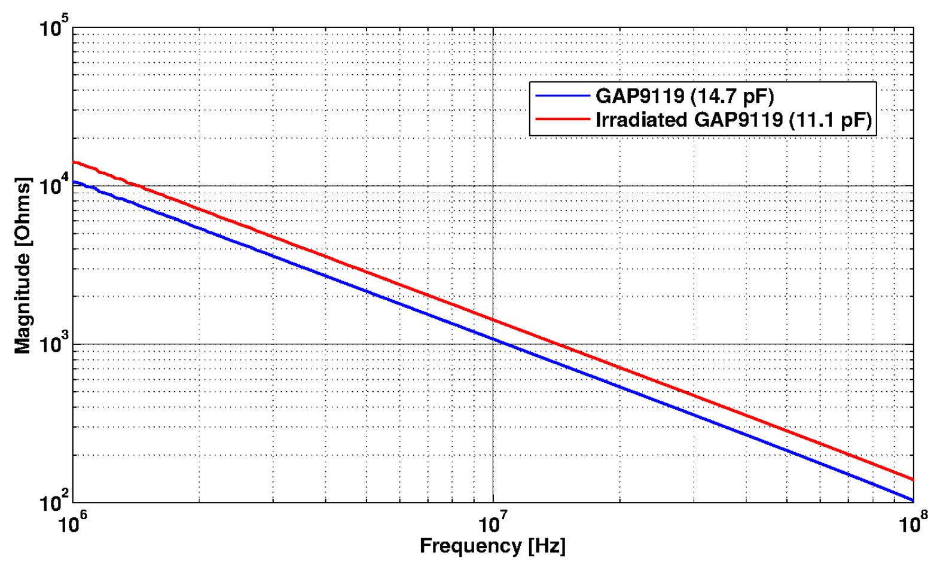
The samples were exposed to gamma radiation in two steps, recreating in-flight conditions and including a safety margin. First a Cobalt60 source (1.17 MeV and 1.33 MeV) was used to obtain a total ionization dose equal to 3 krad. A second test was performed using a cyclotron to generate a 35 MeV proton beam with a flux of $2 \cdot 10^{10}$ protons/cm^2.

Post-radiation measurements were divided into two, a spatial characterization of the photodiode response and an impedance measurement. Figures on the left show the normalized spatial response for the FCI1000Q. Irradiated samples do not show any significant change in their homogeneity. On the other hand, the equivalent capacitance of the irradiated photodiodes seems to be altered. FCI1000Q presents a higher capacitance, while GAP9119's is lower. Further measurements using photodiode samples of the same lot could verify these results, since the variation might be within the tolerance of the manufacturing process.


Non-irradiated Sample

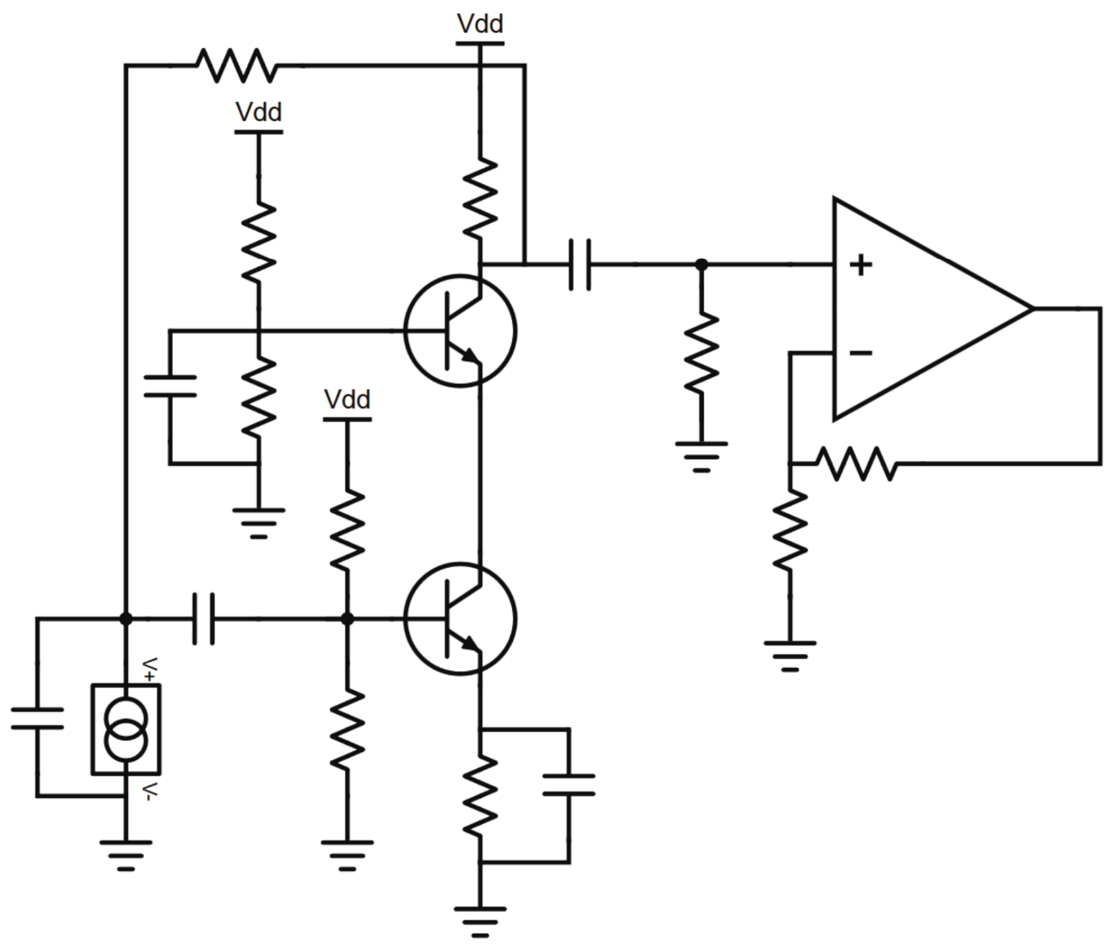



Irradiated Sample



Hybrid topology for the photoreceiver front-end

Improving noise performance while mantaining stability



Front-end electronics for the photoreceiver amplifier must provide a flat frequency response in the range of interest (10 MHz to 30 MHz) and a low contribution to the noise budget in order to ensure a shot-noise limited operation.

Transistor-based designs have the advantage of being less noisy, but at the same time they are very problematic in terms of stability. Fast OpAmps have been used so far to build stable transimpedance amplifiers, with the drawback of having excees noise at high frequencies.

The topology presented here combines both elements. Low noise performance is obtained thanks to the transistor-based input stage. Stability is achieved through the use of an OpAmp for the intermediate gain.

Additionally, more transistors could be used in parallel with the input emitter follower to reduce the noise by a factor of √2 per device.

Outlook

What's next?

Development of optimized, flight-compatible photoreceivers is on progress. The radiation test shows the strength of InGaAs QPDs in a space-like scenario, with minor changes in their parameters.

Concerning the front-end electronics, efforts will be focused on the development of a stable hybrid photoreceiver prototype to improve the noise performance.

Characterization of the temperature dependancy of the photoreceiver is also fundamental to ensure low thermally-induced phase variations during operation.

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