Low-Power Optical Circuit for Turbine Blade Clearance Sensing

Ainara Gurtubay

Bachelor Thesis, UPV/EHU

Abstract

This project presents the design, implementation, and validation of a low-power optical circuit for turbine blade clearance sensing, developed in the context of enabling zero-emission aircraft technologies. The work focused on creating a high-speed, noise-optimized electronic system that could measure turbine blade tip clearance with improved accuracy and response time.

The circuit integrates photodiode-based detection, low-noise amplification, and tailored filtering stages. Laboratory testing demonstrated an over 99% reduction in rise time (from 3.6457 µs to 0.0002 µs), confirming the circuit's suitability for real-time blade monitoring. These results contribute to advancing reliable optical sensing solutions for aerospace applications, where both robustness and efficiency are critical.

Introduction

Accurate blade tip clearance measurement is essential for modern aircraft engines. By monitoring the gap between turbine blades and the engine casing (see Figure 1), it is possible to improve engine efficiency by minimizing leakage losses, enhance safety and reliability by detecting abnormal clearance variations caused by thermal expansion or structural wear, and contribute to sustainable aviation by reducing fuel consumption and emissions.

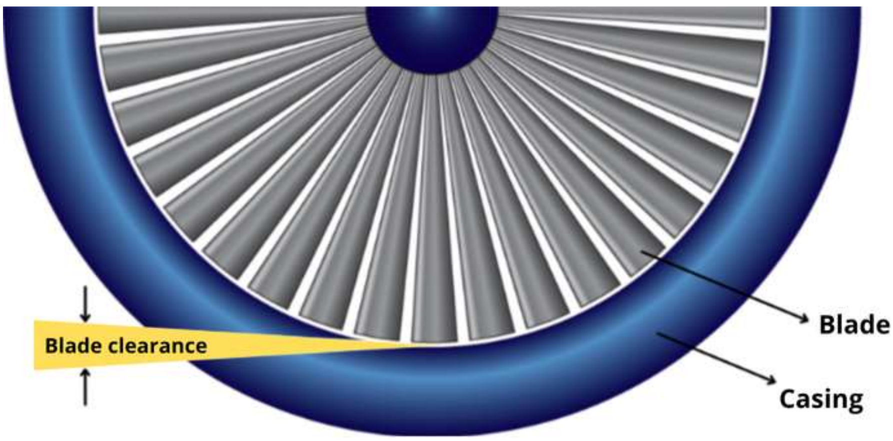

Figure 1. Engine blade clearance.

Traditional sensing techniques, such as capacitive, are effective but often limited by electromagnetic interference or environmental harshness. Optical sensors, on the other hand, are non-contact, fast, and immune to electromagnetic disturbances, which makes them particularly suitable for high-performance turbine environments.

The primary objective of this project was therefore to design an optical front-end circuit capable of processing photodiode signals in real time, with emphasis on low power consumption, low noise, and fast response.

System Design

The circuit was structured around three main functional blocks (see Figure 2).

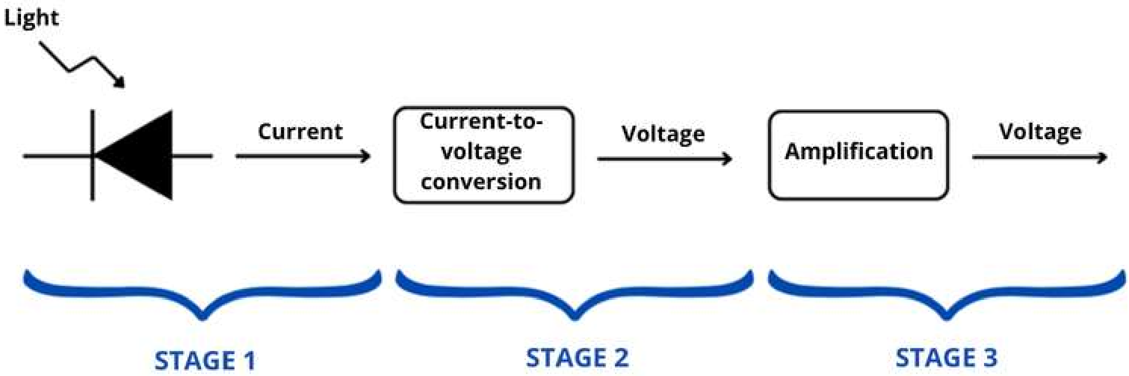

Figure 2. The three stages of the optical detector circuit.

The first stage was the optical detection stage, where a photodiode converted the reflected light from turbine blades into a current signal. The second stage was the current-to-voltage conversion block, which used a transimpedance amplifier to translate the photodiode current into a measurable voltage. Finally, the third stage was the voltage amplification stage, designed to boost the converted signal to levels suitable for further processing while preserving bandwidth and minimizing noise.

All design decisions were supported by SPICE simulations and analytical modeling, guaranteeing a balance between speed, gain, and power efficiency.

Implementation & Results

The prototype circuit (see Figure 3) was implemented on a laboratory PCB, as shown in Figure 4 and 5, and tested using high-speed instrumentation.

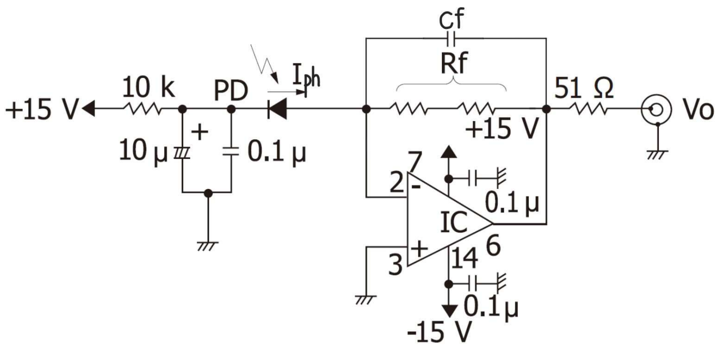

Figure 3. Final circuit schematic.

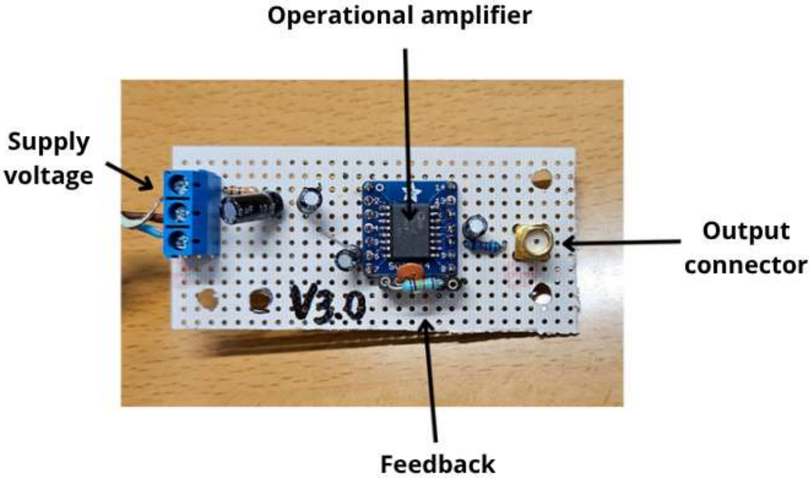

Figure 4. Prototype, front view.

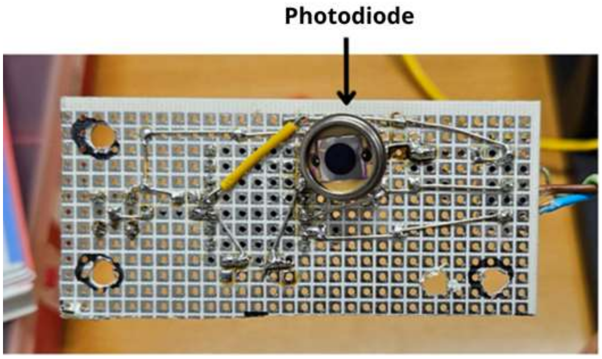

Figure 5. Prototype, back view.

Experimental results confirmed the effectiveness of the design. The rise time of the circuit was reduced from 3.6457 µs to 0.0002 µs (see Table 1), representing an improvement of more than 99% and enabling accurate detection of rapid blade events.

Table 1. Rise times of the signals.

	Signal generator	**Designed photodetector**	**Commercial photodetector**
Rise time (us)	0	0.0002	3.6457

Noise levels were significantly reduced through the optimized filtering stages, which increased the signal-to-noise ratio and provided stable, repeatable measurements (see Figures 6, 7, and 8).

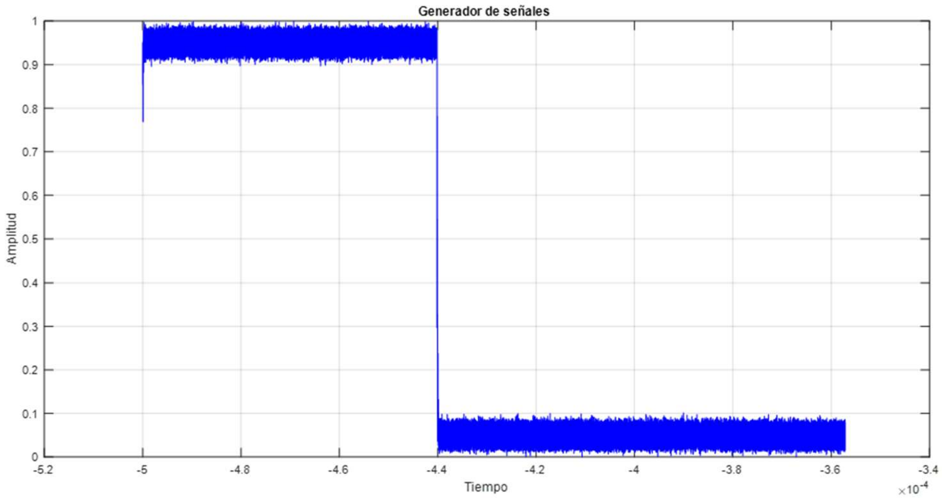

Figure 6. Normalization of the signal generator data.

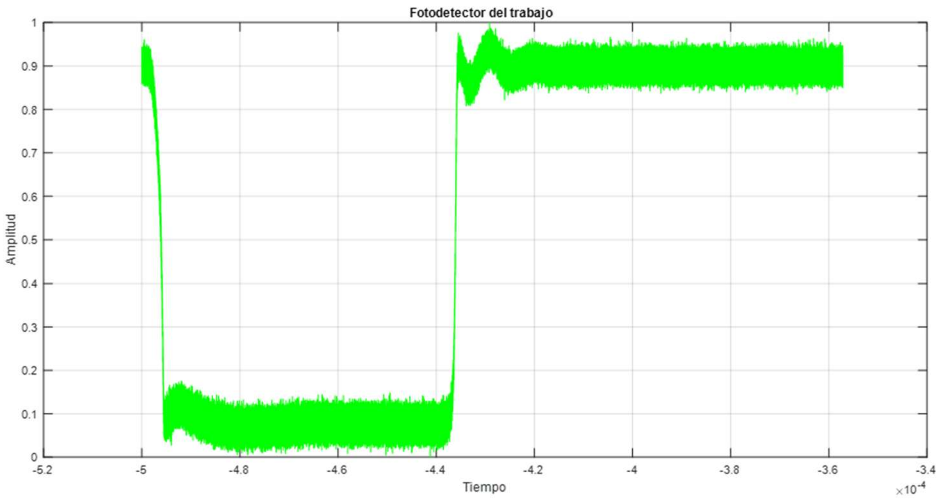

Figure 7. Normalization of the designed photodetector data.

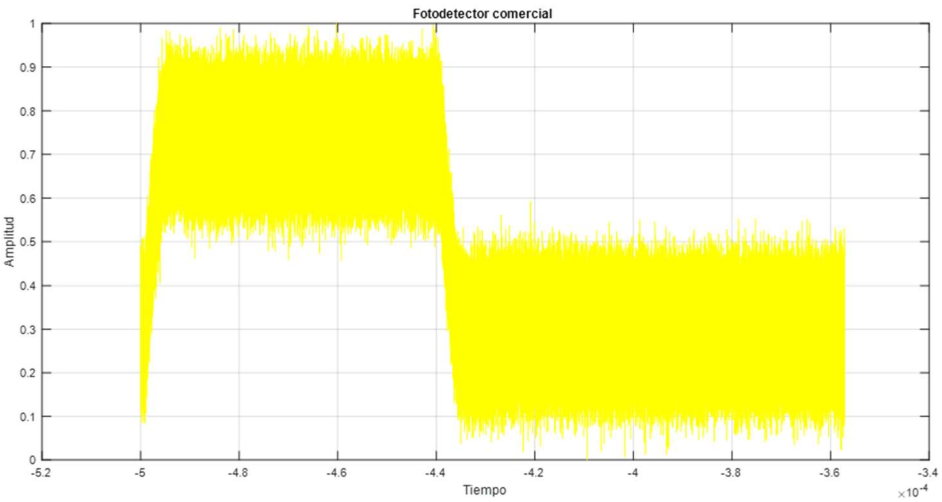

Figure 8. Normalization of the commercial photodetector data.

The system also demonstrated very low power consumption, aligning with the constraints of embedded aerospace environments, where energy efficiency is critical.

Overall, the validation process confirmed that the circuit meets the stringent requirements of real-time, safety-critical turbine monitoring applications.

Conclusion

The project successfully achieved its objective of developing a fast and low-power optical circuit for turbine blade clearance sensing. The drastic improvement in response time highlights the potential of optical sensing systems in next-generation aerospace engines. Beyond its technical contributions, the project also reinforced key skills, including analog design and photodiode interfacing, noise analysis and EMI/EMC considerations, signal conditioning and filtering, and experimental validation with precision instrumentation.

This work contributes directly to the broader vision of zero-emission aviation, where efficient and reliable monitoring systems are essential for sustainable propulsion technologies.