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Novel Mini-Laserscanner

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Coordinator		Kay Fuerstenberg, SICK AG
Authors		Mika Aikio, VTT Juha Kostamovaara, OULU Axel Jahn, SICK Markus Boehning, SICK Kay Fuerstenberg, SICK
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Executive Summary

This document accompanies the prototype deliverable D6.2 and briefly describes the MiniFaros Laserscanner prototype and the individual deployed components. It has already been mounted to both the passenger car and truck demonstrator and is currently under performance testing.

Due to the reasons discussed, this prototype deviates from either Laserscanner concept included in D4.1 Specification and Architecture [2]. For the coaxial concept, the stray light in the omnilens and challenges in the MEMS mirror production process called for concept adaptation. This lead to the concept of a biaxial Laserscanner with motorised mirror implemented in the MiniFaros Laserscanner prototype described in this document.

List of Authors

Name	Company
Mika Aikio	VTT
Juha Kostamovaara	OULU
Axel Jahn	SICK
Markus Boehning	SICK
Kay Fuerstenberg	SICK

Revision Log

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1 Introduction

The project "Low cost miniature Laserscanner for environmental perception", MiniFaros, is a sensor development project aimed at increasing the penetration of advanced driver assistance systems (ADAS), on the automotive market. The project vision is to have an accident-free traffic environment by the use of effective environment perception systems. Laser scanning is the predominant generic environment sensing technology.

Poor human perception and assessment of traffic situations accounts for the largest amount of traffic accidents with fatal or severe injury outcome. Several safety functions are developed in order to prevent or mitigate many of these accidents. The system costs for these functions are often relatively high, and for this reason vehicles are rarely equipped with these systems, especially small and medium sized cars as well as commercial vehicles.

In order to develop the MiniFaros Laserscanner, the specifications of the Laserscanner itself but also for the demonstrator systems have been derived in D4.1 [2] from the requirements defined within D3.1 [1].

This document accompanies and describes the MiniFaros Laserscanner prototype. This includes a brief summary of different Laserscanner concepts and of all major components deployed in the finally assembled prototype. Details on the individual components can be found in the corresponding deliverables: D5.1 Optics and MEMS mirror [3], D5.2 Measurement and Control Electronics [4], and D5.4 Mechanics [5] as well as in D6.1b Final Component Test Results [7].

A dedicated deliverable, D7.2 Test and Evaluation Results [8], will contain all relevant test results of the assembled Laserscanner prototype.

2 Laserscanner concepts

The specifications of the MiniFaros Laserscanner [2] include two alternative optical concepts, a biaxial and a coaxial concept. These two concepts are schematically shown in Figure 1.

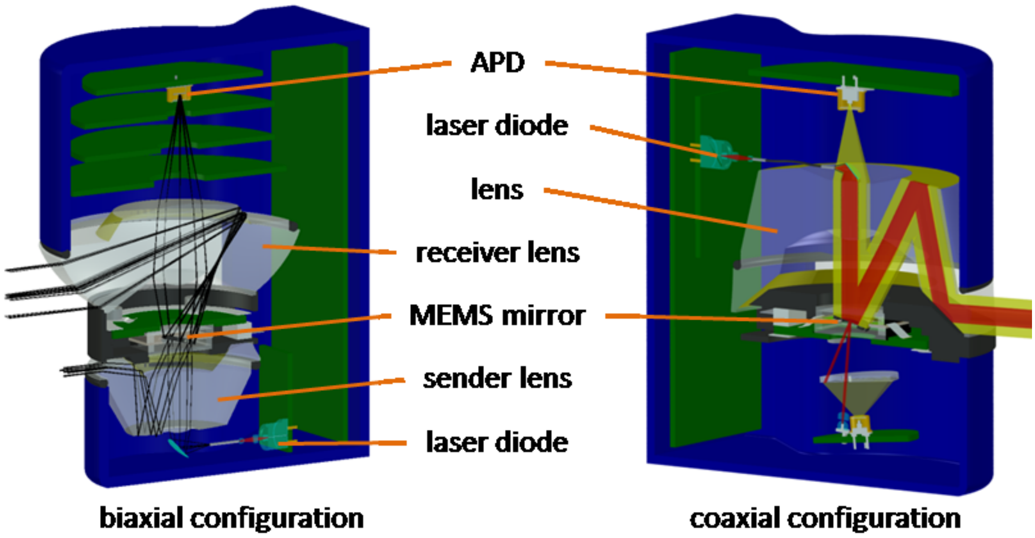

Figure 1: Biaxial and coaxial concept with MEMS mirror.

In addition to these two different Laserscanner concepts with MEMS mirror, a modification of the biaxial concept based on motorised mirrors was conceived and implemented along the way as a parallel backup plan. These three concepts are briefly reviewed in the following sections.

2.1 Coaxial concept with MEMS mirror

In a coaxial Laserscanner concept the transmitter and the receiver basically use the same optical path, as depicted in Figure 2. The grey ferrule marks the laser diode transmitter. A single-sided MEMS mirror deflects both the outgoing laser beam from the transmitter into the omnidirectional lens and the incoming laser beam from the omnidirectional lens into the APD receiver, located at the convergence point above the transmitter.

Due to the overlapping measurement channels, this concept allows the detection of targets in close proximity, but obviously there is an increased risk of optical crosstalk.

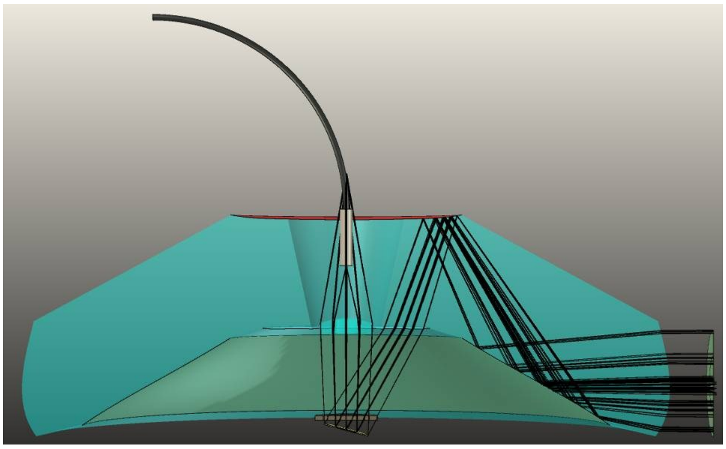

Figure 2: Coaxial concept of the MiniFaros Laserscanner.

2.2 Biaxial concept with MEMS mirror

The biaxial Laserscanner concept uses separate channels for the transmitter and the receiver path, as illustrated in Figure 3. A double-sided, circular rotating MEMS mirror is located between two omnidirectional lenses and deflects the outgoing laser beam from the laser diode into the sender lens and the incoming laser beam from the receiver lens into the avalanche photodiode (APD). This concept requires two different omnidirectional lenses: a beam direction retaining lens for the transmitter path (top) and a beam direction reversing lens for the receiver path (bottom).

Due to the physical separation of the transmitter and receiver channel, there is, at least under ideal conditions, no possibility of channel interference. However, for the same reason, the receiver and transmitter channels can only overlap after a certain minimum measurement distance.

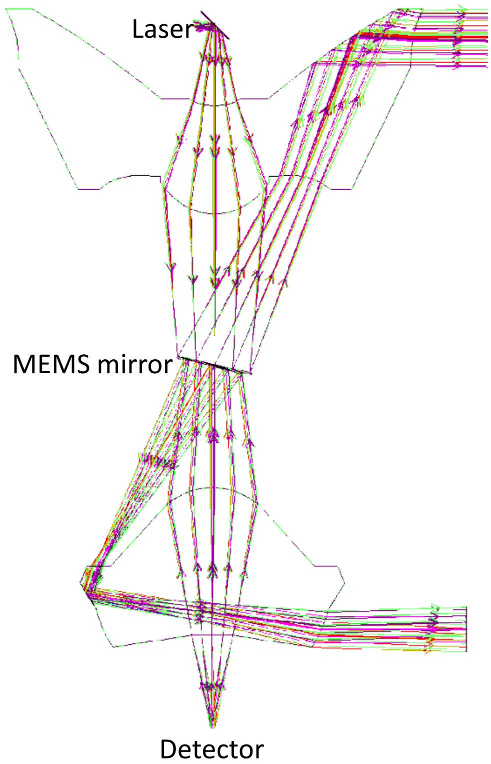

Figure 3: Outgoing and incoming laser beam for the biaxial configuration with MEMS mirror.

2.3 Biaxial concept with motorised mirror

This concept basically combines the advantages of the two aforementioned concepts. This is achieved by substituting the circular oscillating MEMS mirror with two rotating mirrors attached to a single motor, as depicted in Figure 4.

Similar to the biaxial concept with MEMS mirror, the transmitter and receiver channel are physically separated, thus avoiding optical crosstalk. Due to two separate mirrors for the transmitter and the receiver path, both omnidirectional lenses can retain the beam direction and thus are identical to the omnidirectional lens of the coaxial concept with MEMS mirror.

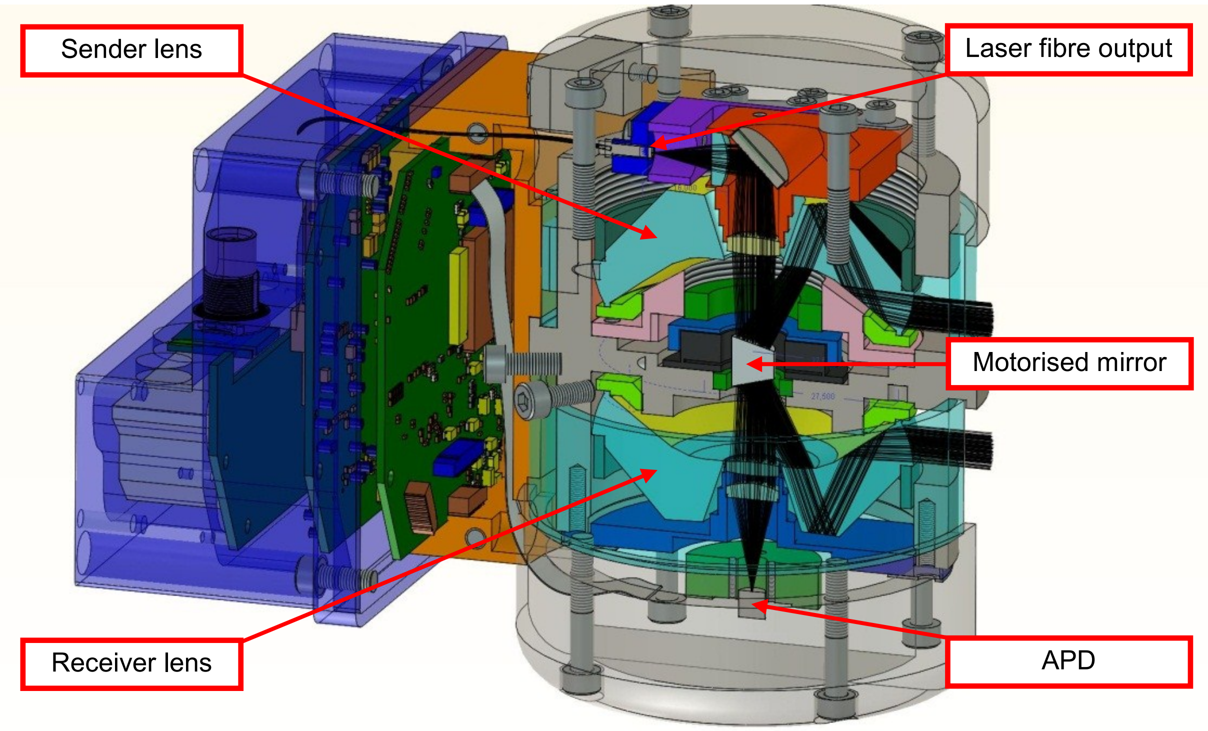

Figure 4: Biaxial concept with motorised mirror.

2.4 Discussion

A detailed discussion on the individual advantages and disadvantages of the two MEMS mirror concepts can be found in D5.1 Optics and MEMS mirror [3], so this section only constitutes a summary.

During the detailed inspection of the biaxial concept it turned out that, in comparison to the coaxial concept, it has good performance even with stray light in the omnilenses, but more challenging mechanics that are likely not able to provide the required adjustment accuracy and long-term stability over the required parameter range under all conditions expected in automobile applications.

Due to the latter, the coaxial concept was selected to be demonstrated as it constituted a lower overall risk for the project not meeting its objectives. However, during the analysis and realisation of the coaxial concept, it became evident that the optical crosstalk in the omnilens shared by the transmitter and receiver path was uncontrollable. In addition to the stray light, the MEMS mirror production process faced several major challenges, requiring several time-consuming redesigns and production cycles.

In order to proceed with the original schedule and to be able to demonstrate the functionality and the high performance of all other components such as the omnilens, the receiver channel and time-to-digital conversion, as well as of the assembled Laserscanner in general and its suitability in the automotive context in particular, the biaxial concept with motorised mirror was conceived, followed and implemented.

In conclusion, this document describes the biaxial motorised mirror prototype as it is the Laserscanner concept actually deployed in the demonstrator vehicles as well as for the intersection surveillance.

3 MiniFaros Laserscanner prototype (Biaxial concept with motorised mirror)

This chapter briefly describes the individual components deployed in the MiniFaros Laserscanner prototype. Figure 5 shows a photograph of one of the assembled prototypes without weather sealing.

Figure 5: Assembled MiniFaros Laserscanner prototype without weather sealing.

3.1 Optics

The two main optical components of the MiniFaros Laserscanner prototype are the omnidirectional lens and the fibre coupler. These are described in the following.

3.1.1 Omnidirectional lens

The main optical component of the MiniFaros Laserscanner prototype is the omnidirectional lens. This lens has the capability of rotating the laser beam 360° (hence omnidirectional) without rotating or moving itself and is used for both the sender and the receiver path. A photograph of this omnidirectional lens is shown in Figure 6.

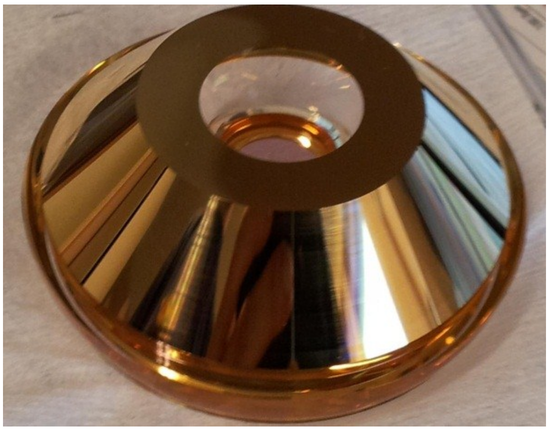

Figure 6: Omnidirectional lens manufactured by diamond turning.

For a detailed description of this component, please refer to D5.1 Optics and MEMS Mirror [3] and D6.1 Final Component Test Results [7].

3.1.2 Fibre coupling

Due to the additional damping in the omnidirectional lens, a fibre coupler was developed to produce a smaller spot from a 50 µm fibre, leading to a higher energy density on a distant target and thus increasing the realised measurement range. It was necessary to design the coupler to fit inside the designed MiniFaros PCB Laser, which lead to some volume restrictions which could not be exceeded. Figure 7 shows a schematic of the fibre coupler on the PCB Laser.

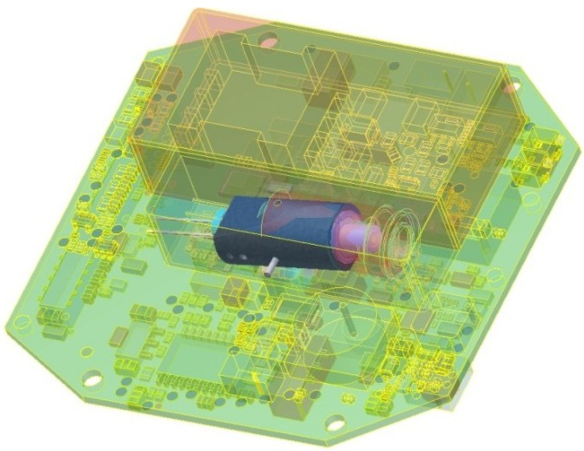

Figure 7: Fibre coupler mounted inside the MiniFaros PCB Laser.

For a detailed description of this component, please refer to D6.1 Final Component Test Results [7].

3.2 Mechanics

The mechanics of the biaxial Laserscanner are shown in Figure 8. The individual parts of the Laserscanner are shown in the exploded view presented in Figure 9.

Figure 8: The finalized biaxial Laserscanner with omnidirectional lenses and a single rotating mirror.

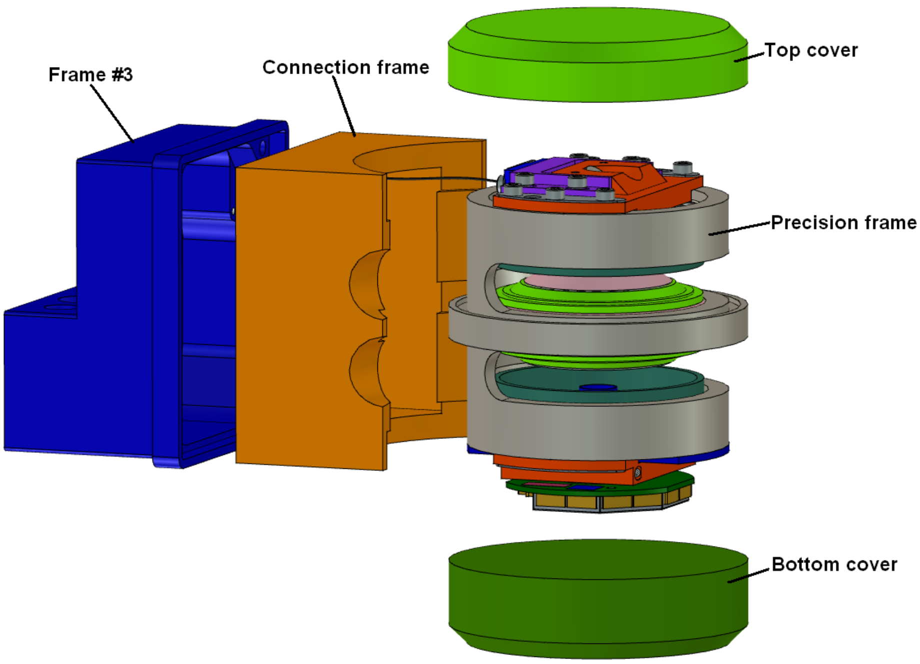

Figure 9: Exploded view of the biaxial Laserscanner.

For the biaxial Laserscanner, it is very important to keep the transmitter and receiver channels very close to the nominal scan plane, a deviation in either of them renders the Laserscanner inoperable. This was achieved by a newly designed and developed monolithic block, to which all the high precision components are adjusted, as illustrated in Figure 9.

After all the adjustments are done, the Precision frame is sealed by adding top and bottom covers on it and then adding the connection frame to it. The connection is responsible for weather sealing the rest of the Laserscanner and connecting the rest to Frame #3, which houses the electronics. The idea behind this construct is to have all the important optical components directly in the single part which can be adjusted separately, and later adding the connection frame to it. This design allows for relatively easy adding of the weather sealing, which can be done later, after the other components are adjusted.

In the centre of the biaxial Laserscanner, a two sided mirror is used. This mirror provides the beam steering, and is assembled inside a hollow motor (Figure 10). This type of a motor achieves rotation frequencies in excess of 80 Hz, well above the specified 25 Hz scanning frequency.

The precision frame is manufactured with very strict tolerances, leading to a fundamental 0.07° uncertainty between the transmitter and receiver beams after all the adjustments are done. This is acceptable, as the receiver beam has a divergence of 1.7°, while the divergence from a 50 µm transmitter fibre is within 0.45°. In this case, the transmitter beam will always be within the receiver field of view. If a 200 µm diameter fibre is used in the transmitter channel, both the receiver and the transmitter have the same divergence, and an offset between the channels affects the received power on the avalanche photo diode.

Due to the required precision and the motor inside, the biaxial Laserscanner prototype becomes slightly larger than the coaxial Laserscanner. This is also reflected in the Laserscanner height, the only possibility of decreasing its height would be to place the avalanche photo diode inside Frame #3 and using fibre instead on the Precision frame. However, the same considerations in the miniaturisation possibilities of Frame #3 still hold, and the total Laserscanner volume should be considered less.

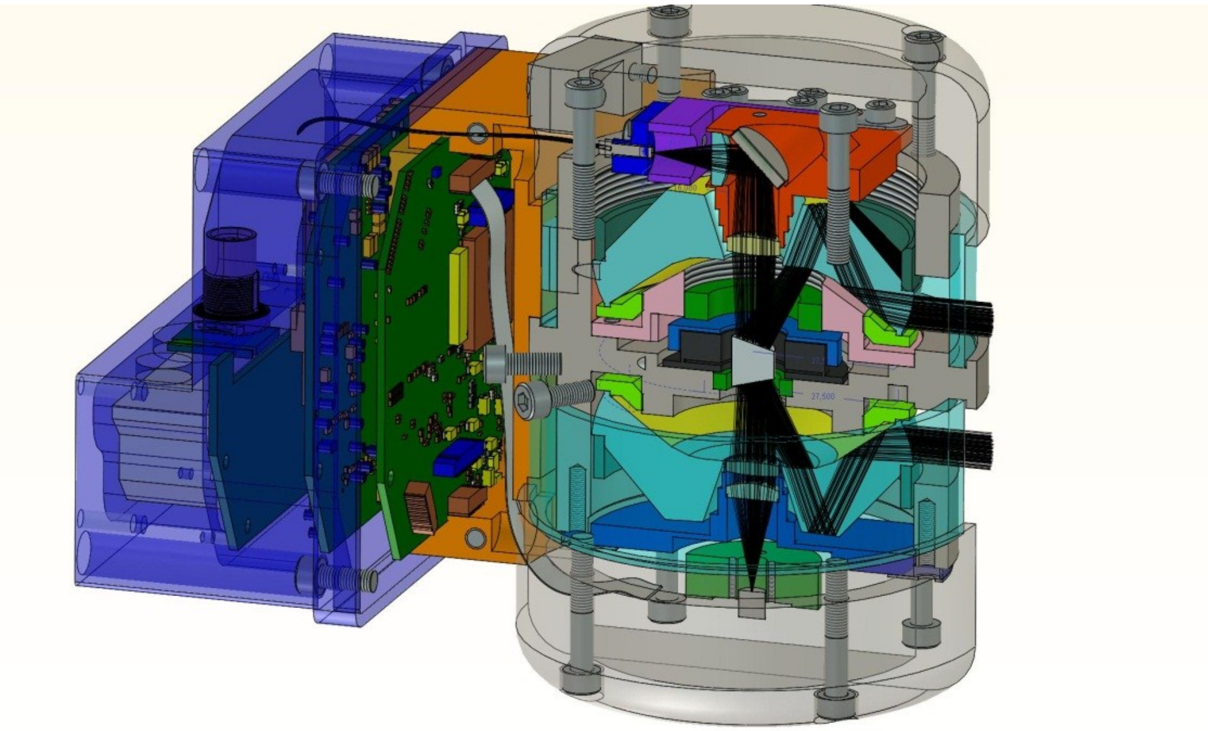

Figure 10: Cross-section of the biaxial Laserscanner. The minimum height is determined by the height of the motor inside the precision frame.

3.3 Control electronics

3.3.1 PCB System Control

The PCB System Control is the digital heart of the MiniFaros Laserscanner. A photograph of both the top and bottom side is shown in Figure 11. Here the scans of the MiniFaros Laserscanner are subdivided into segments and all details of the measurement sequence are defined. During the scan, the measured distance and pulse width values are continuously collected, corrected, sorted and finally transferred via Ethernet to the external ECU.

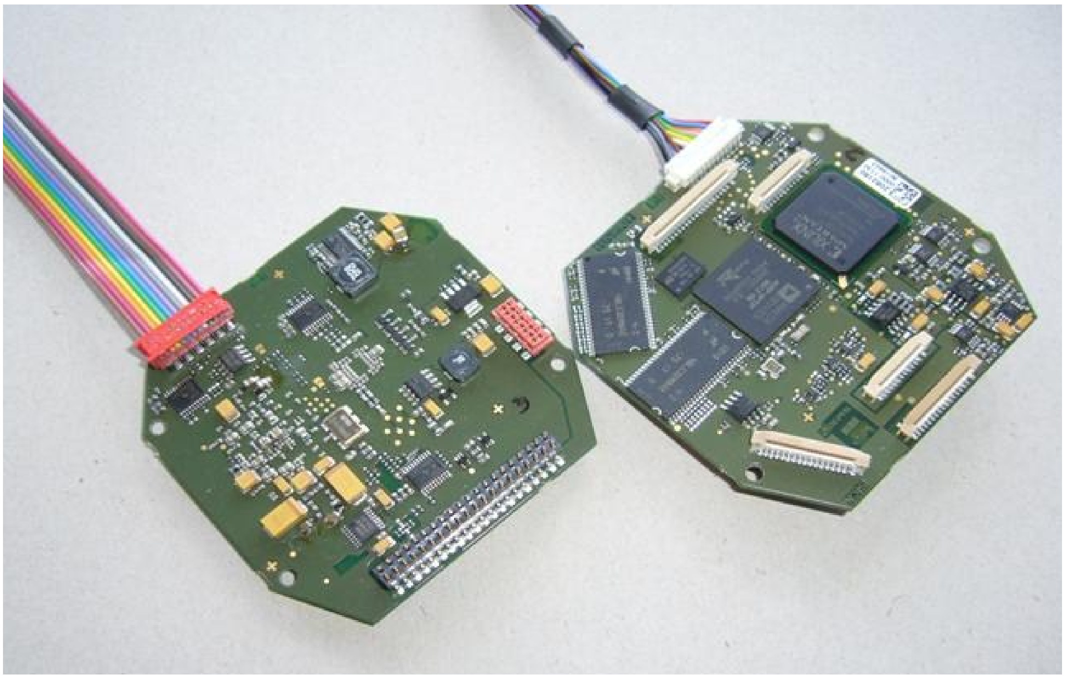

Figure 11: Bottom side (left) and top side (right) of the PCB System.

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

3.3.2 PCB Interface

The interface to the outside world is the place where most of the relevant protective elements must be placed to suppress interferences like burst, surge, ESD or electromagnetic emission from the outside into the Laserscanner and vice versa. Figure 12 shows the top and the bottom side of this PCB.

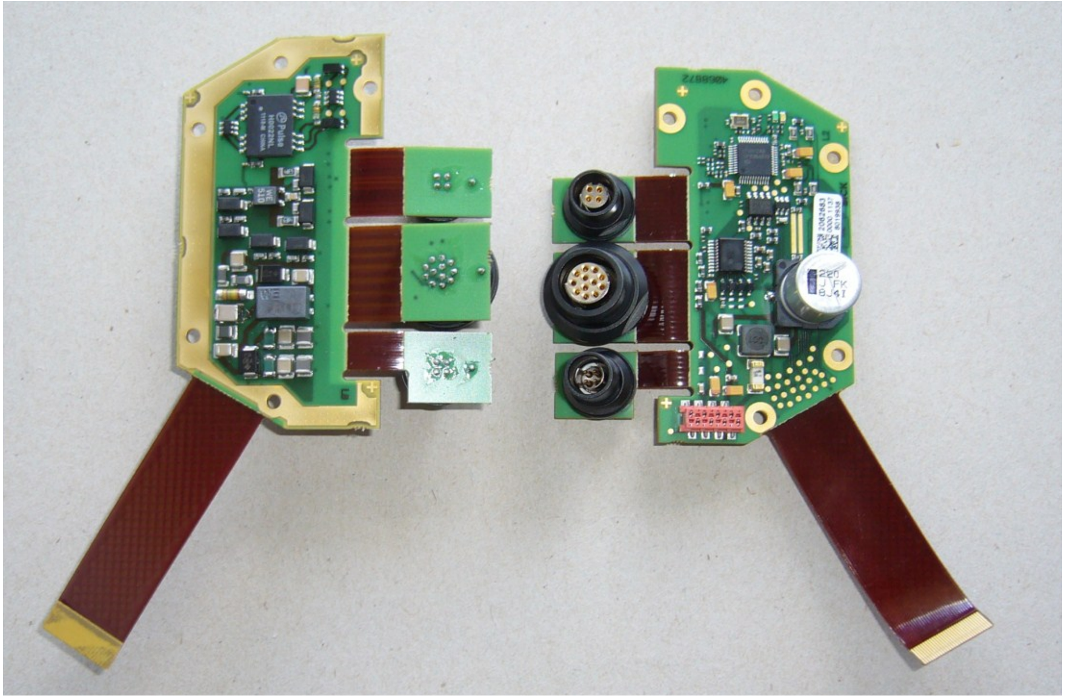

Figure 12: Bottom side (left) and top side (right) of the PCB Interface.

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

3.3.3 PCB Laser

The PCB Laser contains two very different functional blocks. The first functional block is the laser driver including the high power laser diode and the coupled fibre. The other one is the high efficiency power supply, which generates almost all supply voltages needed in the MiniFaros system. Figure 13 shows the top side of this PCB including the fibre coupling. The bottom side of the PCB carries several DC/DC-converters, the laser driver and the interface circuitry.

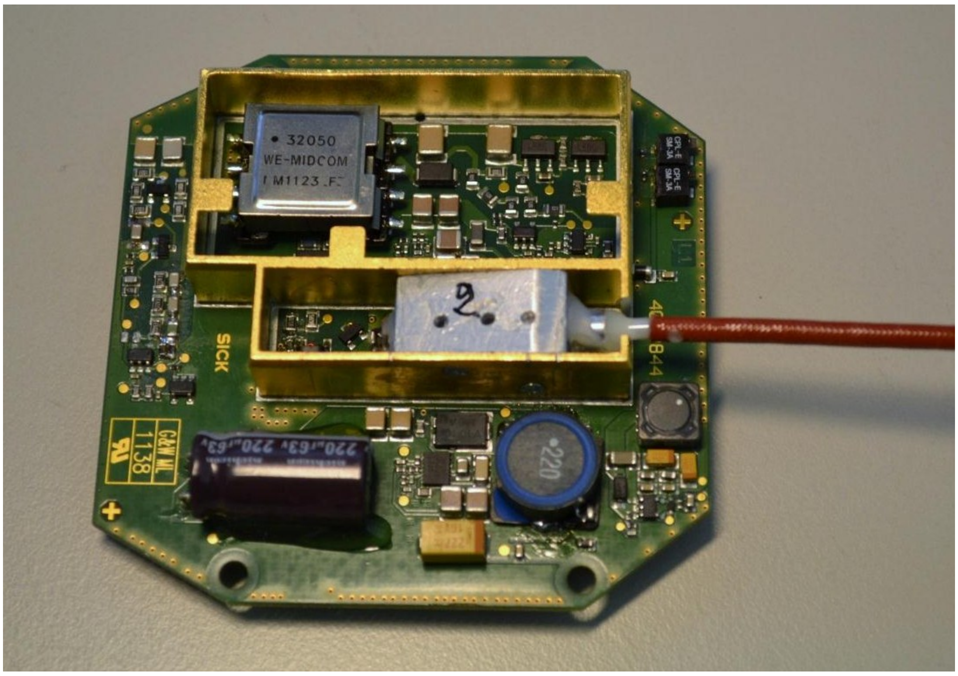

Figure 13: Top side of the PCB Laser. The housing contains the HV power supply, parts of the laser driver and the laser diode with the optical fibre.

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

3.3.4 PCB APD Receiver

This PCB carries the measurement heart of the Laserscanner. At the same time, it is the most sensitive circuit of the whole system. That is why it is shielded with metal covers to protect it against electro-magnetic interferences. Figure 14 shows a photograph of the top and bottom side of this PCB.

The APD detects the incoming laser pulse, which was transmitted by the laser and reflected by the target. It converts the signal to an equivalent photo current and feeds it to the differential input of the receiver channel. The integrated trans-impedance amplifier generates an equivalent voltage pulse out of it. A subsequent comparator compares the signal with a predefined adjustable reference voltage level. As soon as the signal over- or undershoots the reference level, it generates a comparable stop signal for the TDC.

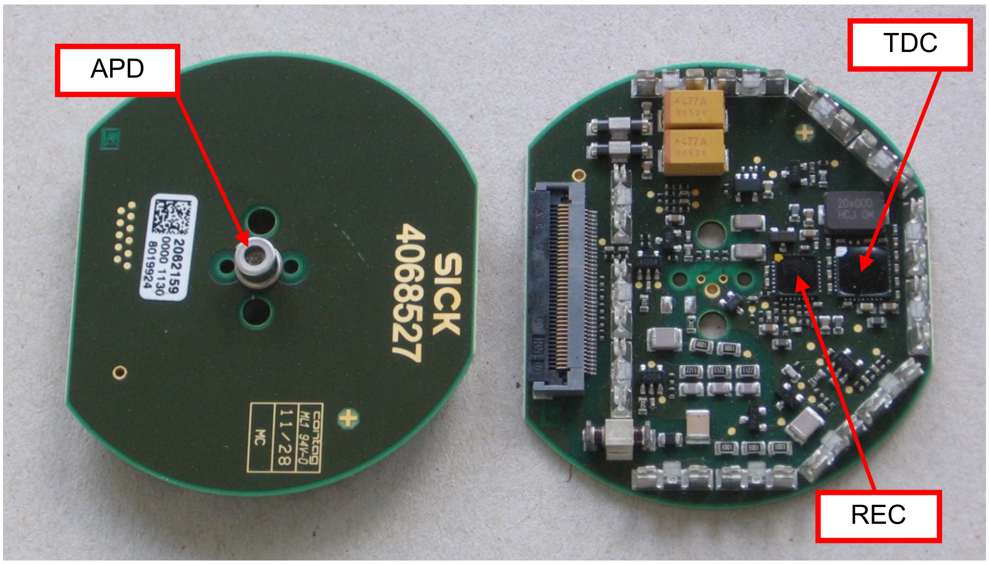

Figure 14: The avalanche photo diode (APD) is arranged on the bottom side of the PCB APD Receiver. All other components are placed on the top side. They are protected by a metal shielding cover (removed here). The PCB carries the receiver channel (REC) and the time-to-digital converter (TDC).

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

3.4 Measurement electronics

3.4.1 Receiver Channel

The receiver channel (REC) includes a pre-amplifier, a post-amplifier, a timing comparator and bias generators. An analogue output buffer is used for measuring noise, bandwidth and trans-impedance of the receiver channel. Figure 15 shows a photograph of the 1.6 mm x 1.6 mm receiver channel IC.

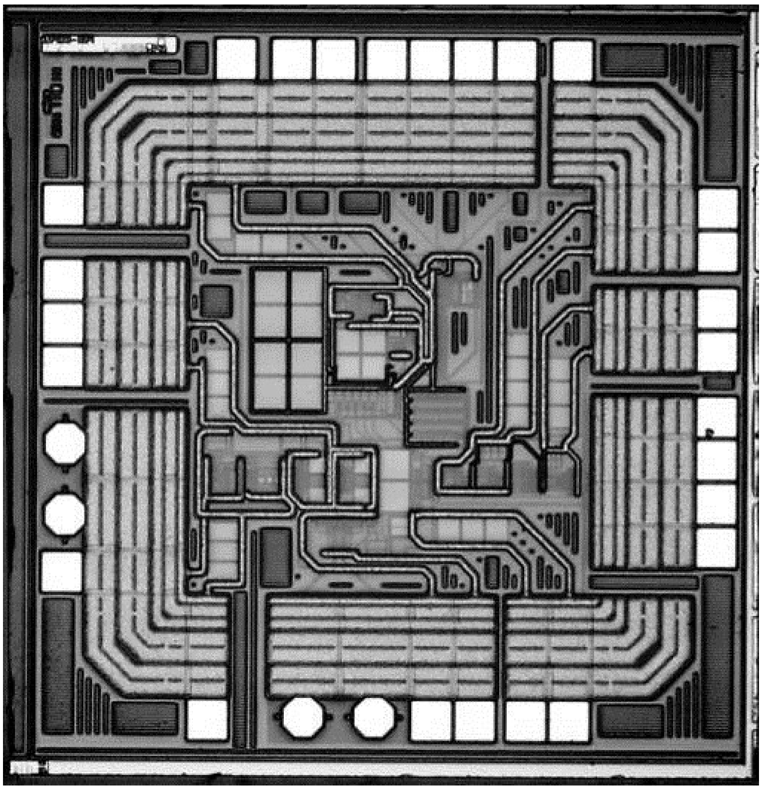

Figure 15: Photograph of the receiver channel.

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

3.4.2 Time-to-Digital Converter

The time-to-digital converter (TDC) measures the time intervals between electrical timing pulses and converts the results to digital words. The TDC has two timing signal input channels (start and stop) and 7 measurement channels and thus can measure the time intervals from a start timing signal to 3 succeeding stop signals. Additionally, it also measures the pulse widths of the stop signals. At the system level, the stop signal measurements correspond to the distances from the Laserscanner to the targets and the stop signal pulse width information can be used in timing walk error compensation. The layout of the TDC circuit is shown in Figure 16, the dimensions are 2.4 mm × 3.7 mm.

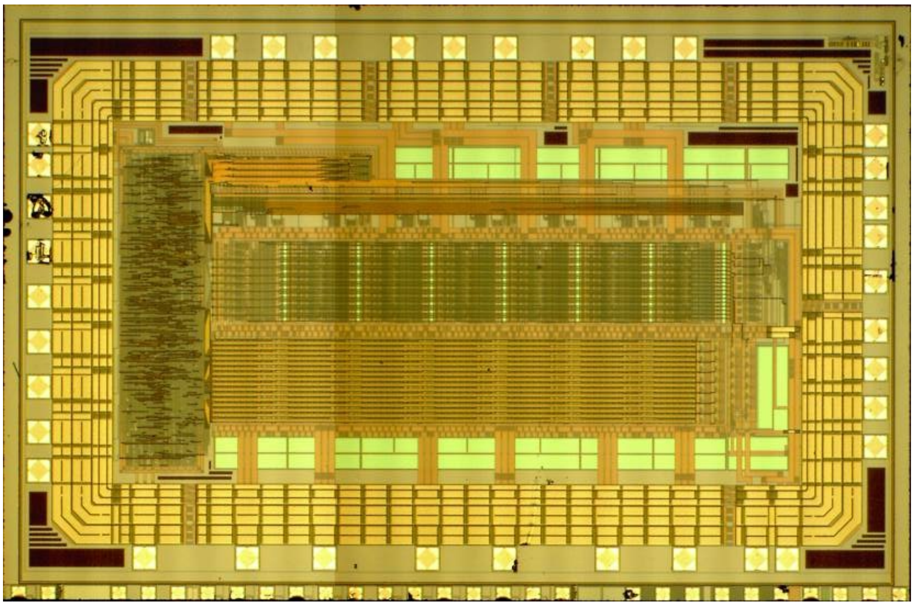

Figure 16: Photograph of the TDC circuit.

For a detailed description of this component, please refer to D5.2 Measurement and Control Electronics [4].

4 Summary and Conclusions

This document describes the MiniFaros Laserscanner prototype and its main components and modules. After thorough testing of the final components, it has been assembled and delivered and is currently under performance testing.

The test results will be documented in D7.2 Test and Evaluation Results [8].

5 Acknowledgements

The MiniFaros research project is part of the 7th Framework Programme, funded by the European Commission. The partners of the consortium thank the European Commission for supporting the work of this project.

List of Abbreviations

APD	avalanche photo diode
ADAS	advanced driver assistance system
DC	direct current
ECU	electronic control unit
ESD	electrostatic discharge
IC	integrated circuit
MEMS	micro-electro-mechanical system
PCB	printed circuit board
REC	receiver channel
TDC	time-to-digital converter

List of Figures

References

[1] MiniFaros: D3.1 – User needs and operational requirements for MiniFaros assistance system, 2010
[2] MiniFaros: D4.1 – Specification and architecture, 2010
[3] MiniFaros: D5.1 – Optics and MEMS mirror, 2011
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