MDA UK and the University of Oxford are working on the development of a Compact Scanning LiDAR. The idea is to reduce existing Lidar design mass, volume, and power (MVP) by 70%, using a Spatial Light Modulator (SLM) instead of electromechanical scanning. This would allow the Compact Scanning LiDAR to fit into a 2U CubeSat, as well as improve overall performance and reliability. The University of Oxford (UoO) is working on the development of new Spatial Light Modulators (SLM) based on fast-switching liquid crystal modes. The SLM uses the same physical principles as phased array optics.

The high-level objectives of the de-risk phase of the project have been achieved with a high degree of success. Throughout the de-risk phase, several secondary risks have been identified which should be addressed early in the programme. The immediate next phase of the programme therefore proposes to perform requirements analysis with a specific emphasis on optomechanical design, formulate a concept for the actual LIDAR size, and breadboard the higher risk processor elements that could create a bottleneck in future project phases. This would then be followed by a full phase B1 to carry on and finish requirements analysis and system design to culminate in SRR.

The ultimate aim of the fully-fledged development is to provide a path to flight, design, build, and qualify a Compact Scanning LiDAR with equivalent mass, volume, power (MVP), cost, and reliability to a solid-state solution.

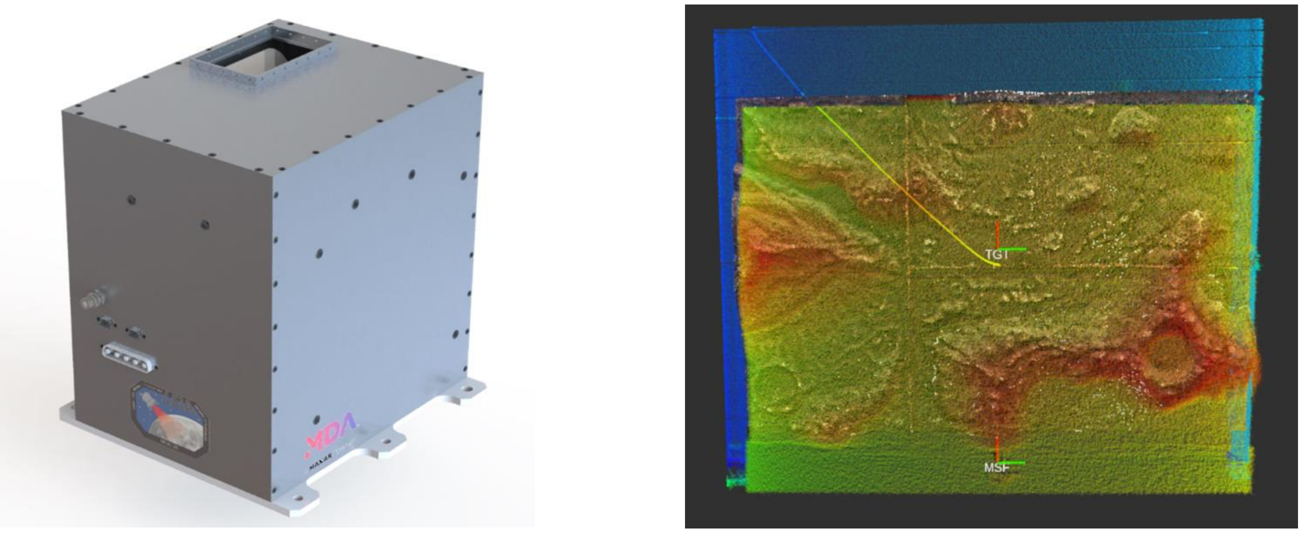


Figure 1-1: MDA UK lidar technology (credit: NGC Aerospatiale)

1. COMMERCIAL APPLICATION OF TECHNOLOGY

Light Detection and Ranging (LiDAR) combines the range finding capabilities of radar with the ability to produce a highly focused 3-D image of a field of view (FOV). Due to the narrow beam width and wavelength of modern lasers, LiDARs can provide very accurate 3-D images of anything that scatters light, including non-metallic objects, atmospheric formations, particle droplets, etc. Laser-focused resolution and the ability to work without background illumination favour the use of LiDAR in space applications such as:

- guidance, navigation and control of rovers and spacecraft
- relative velocity calculations and hazard avoidance
- monitoring spacecraft and payload structural integrity
- formation flying and orbital station keeping
- inter-satellite communications

LiDAR has been identified as key enabling technology for safe and precise landing, and rendezvous and docking by NASA and ESA. The technology will, furthermore, be essential for future satellite missions and rover applications where background radiation is hard to observe. The challenge arises from increasing restrictions of mission parameters. The space market collectively prefers more compact solutions that are low cost and high reliability, and LiDAR technology, as it is today, could lose relevance in major applications. Future commercial initiatives from companies such as ONEWeb, Samsung, and SpaceX aim to launch overall more than 10000 satellites, concept demonstration missions in 2019 have already begun, solidifying investment in the ventures. LiDAR technology is well suited for operational mission parameters such as removing space debris, but current LiDAR mass, volume, power (MVP) budget, cost and development time could be a challenge when evaluating proposals for New Space applications. Current scanning LiDARs steer the laser beam using rotating mirrors. Mechanical scanning results in a solution that is bulky, relatively slow, and power hungry. This proposal presents a project to accelerate the development of a modern generation of LiDARs better suited to the growing needs of space applications.

In a collaboration between MDA Space and Robotics Limited (MDA UK) and the University of Oxford (UoO), as well as partners in the UK and German private and public sector, we propose to apply a modern electro-optical technique to build an equivalent to solid-state LiDAR. The idea is to use a state-of-the-art “Spatial Light Modulator” (SLM) to steer the laser beam. SLMs are reflectors subdivided into a dense array of pixels, with each pixel individually addressable to vary the phase of light reflected from that point. By adjusting the phase profile over the 2-dimensional area, the direction of the resultant reflected beam can be altered. The SLM would replace rotating mirrors, and we can expect significant gains in MVP, cost, and reliability.

ESA have been at the forefront of new technology development since its inception, and it has a long tradition in technology transfer to other markets and applications. The Agency currently have several projects where LiDAR technology will be used and have ambitious targets to explore the solar system and establish a Moon Village. ESA has furthermore recently unveiled their Space 2019+ strategy, with particular emphasis on space safety. Space safety in this context aims to protect European assets in Space an on the ground. Compact LIDAR technology could be of particular relevance for orbital debris and planetary protections missions.

These projects will require new navigation technology (for autonomous rover driving, for rendezvous and docking, topographic characterization of celestial bodies, etc.). What is being proposed here is the development of a next generation space qualified LiDAR, using a disruptive technology, and we believe it aligns well with ESA’s roadmap for the next decade.

2. DE-RISK ACTIVITY RESULTS

The De-Risk Phase work breakdown is summarized below:

- **The University of Oxford (UoO): Prove that the Fast SLM is feasible for space deployment and suitable for manufacture on commercial silicon process.** The de-risk activities for UoO cover developing their single pixel SLM prototype into a multi-pixel (6-pixels) prototype, to show high-speed steering capability. The single pixel is able to modulate phase at 1kHz speeds. The multi-pixel device shows the ability to beamform at 1kHz, based on showing that interference from modulated phases can be accurately controlled. This development paves the way for creating a full-scale (thousands of pixels) SLM using commercial silicon processes.
- **MDA UK: Prove that a high-speed SLM beam-steering control system is viable on embedded systems for Space.** The effort on MDA UK work packages is targeted to de-risk the required processing power to control a multi-pixel steering device within an embedded platform. MDA UK de-risking includes development of a full Lidar simulator with particular detail on the control system requirements and optimise the mathematics for embedded processing. Input from UoO work packages are used as the project progresses to mathematically characterise the SLM as a control system block. MDA UK is able to then translate the control system onto a processor with path to flight and benchmark its performance. This ensures an SLM-based Lidar with increased frame-rate can be produced for Space applications.

MDA UK and UoO were able to show the two main risks for the programme to be successfully mitigated. The consortium is confident to report that a Compact Scanning LIDAR based on an SLM as a scanning mechanism is viable for a Space flight programme, from the point of view of 1kHz scanning and available processing power.

A full lidar simulator using an SLM mathematical description was developed in MATLAB, and the results were used to determine a preliminary design and associated set of requirements for the SLM-based LIDAR. The preliminary FPGA codebase was developed for a full SLM lidar using an FPGA with extensive flight-heritage and benchmarked to show processing power is ample. An upgrade FPGA has furthermore been identified and initial testing begun to further future-proof the design. In parallel, the emerging technology of an SLM using the flexo-electro-optic effect of chiral-nematic liquid crystals has been de-risked from the fundamental physical principles observed (TRL1) to an experimental proof of concept (TRL3). MDA UKs current LIDAR technology (TRL6, with TRL9 heritage) has been leveraged to ensure the resulting overall concept is viable.

The next phase of the COLD project is proposed to be an advancement of activities of critical importance to phase B1, with emphasis on mitigating the next level of identified risks. Of particular importance is optical design to enhance FOV and minimize range loss. Requirements analysis flowing down from potential missions to the LIDAR, and to the SLM are proposed, as well as a solid optical and processing solution baseline for the COLD project going forward. Preparation for SLM manufacturing is envisioned with partnership from German SLM manufacturers and academia, as well as the current UK consortium.

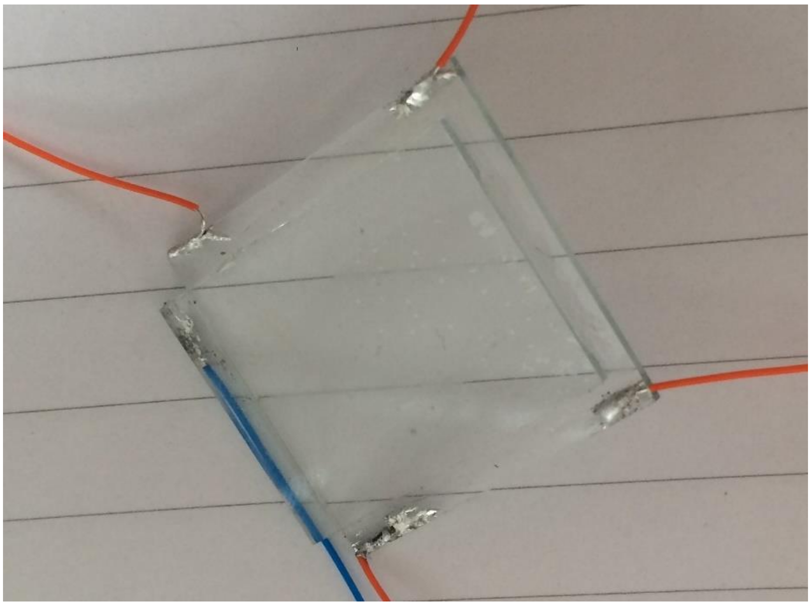
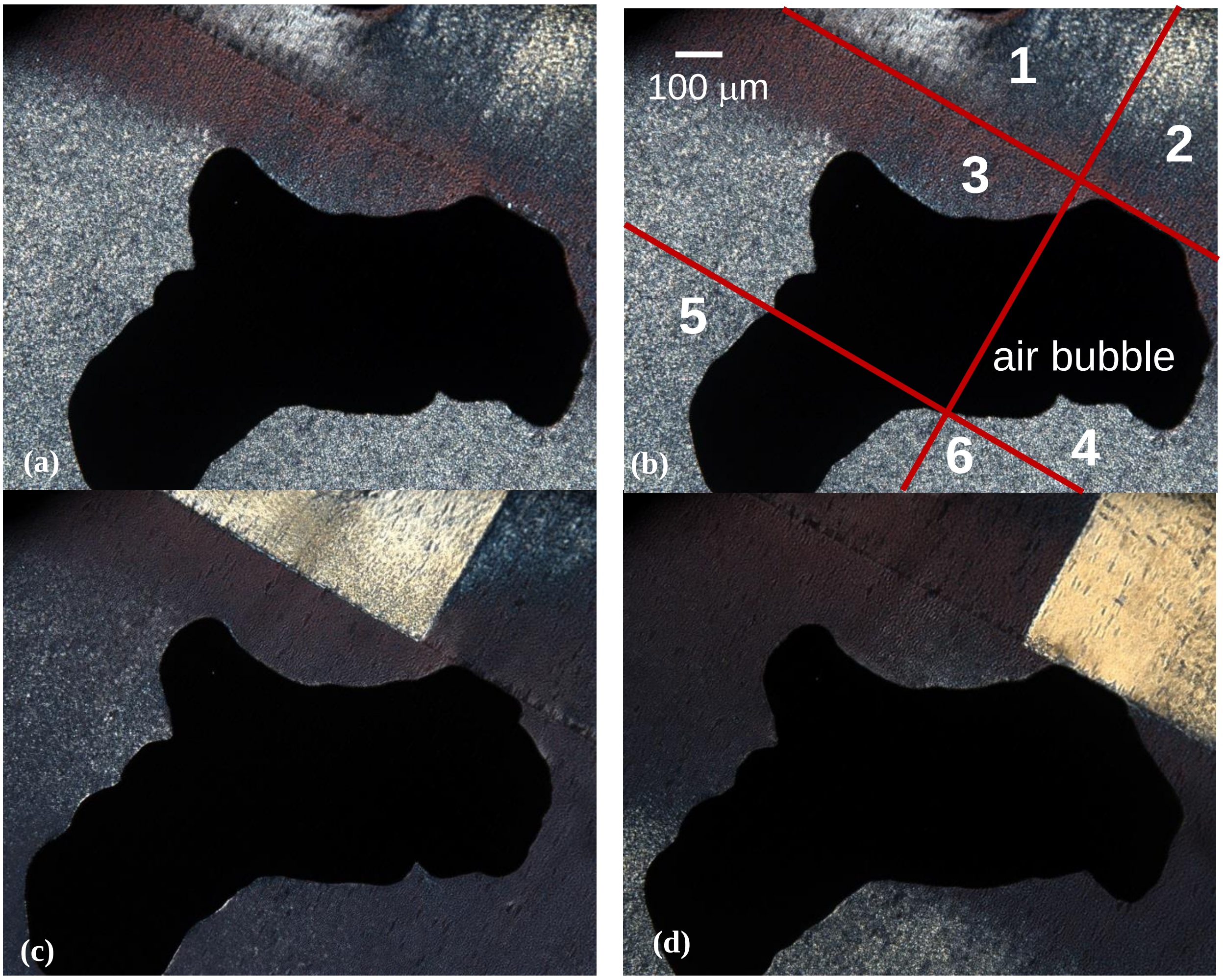


Figure 2-1: Photograph of fabricated multi-pixel cell. The patterned substrate is below, with 4 (orange) leads contacting the electrodes for the 4 individual pixels. The unpatterned substrate is on top with a single (blue) lead contacting a common electrode



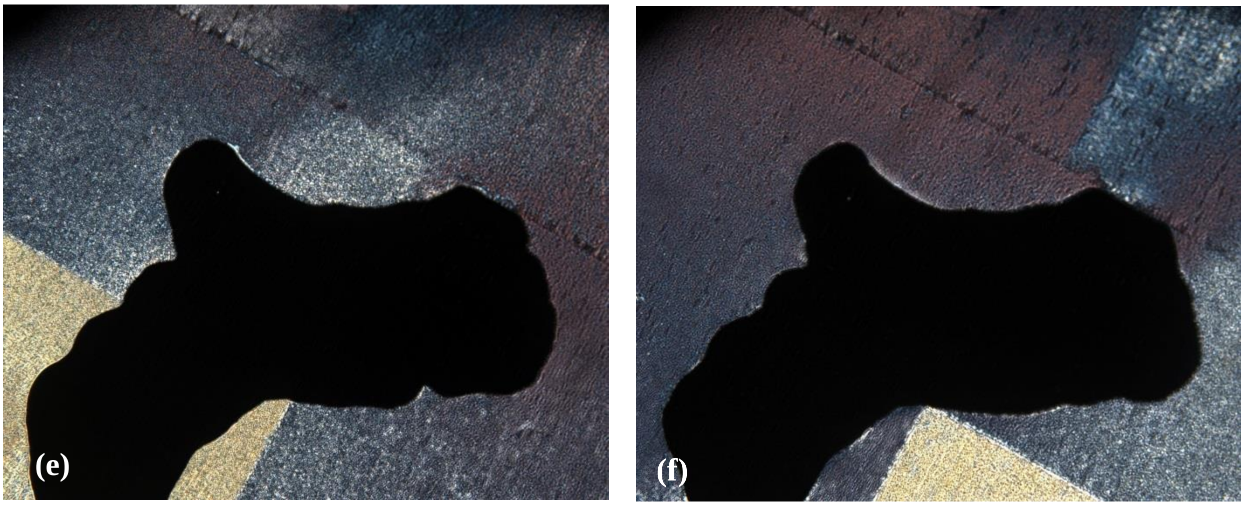


Figure 2-2: Microscope images of 4 pixel device, (a) no applied electric field. (b) showing pixel regions 1-6: Regions 1,2,5 and 6 are active contacted region, whilst regions 3 and 4 are not contacted. (c) electric field applied to region 1. (d) electric field applied to region 2. (e) electric field applied to region 5. (f) electric field applied to region 6. In each of images (c)-(f) the applied electric field was a 1 kHz square wave of approximately 2.1V/µm.

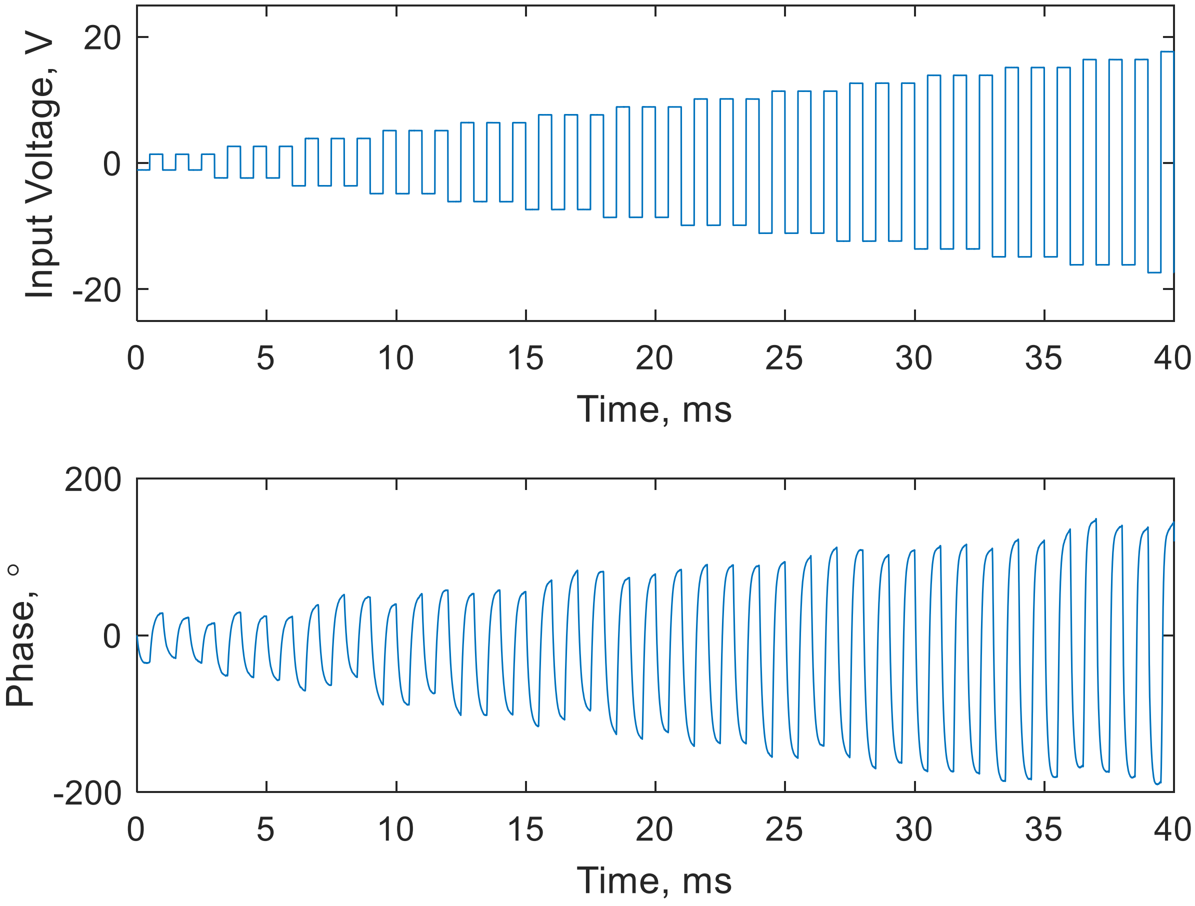
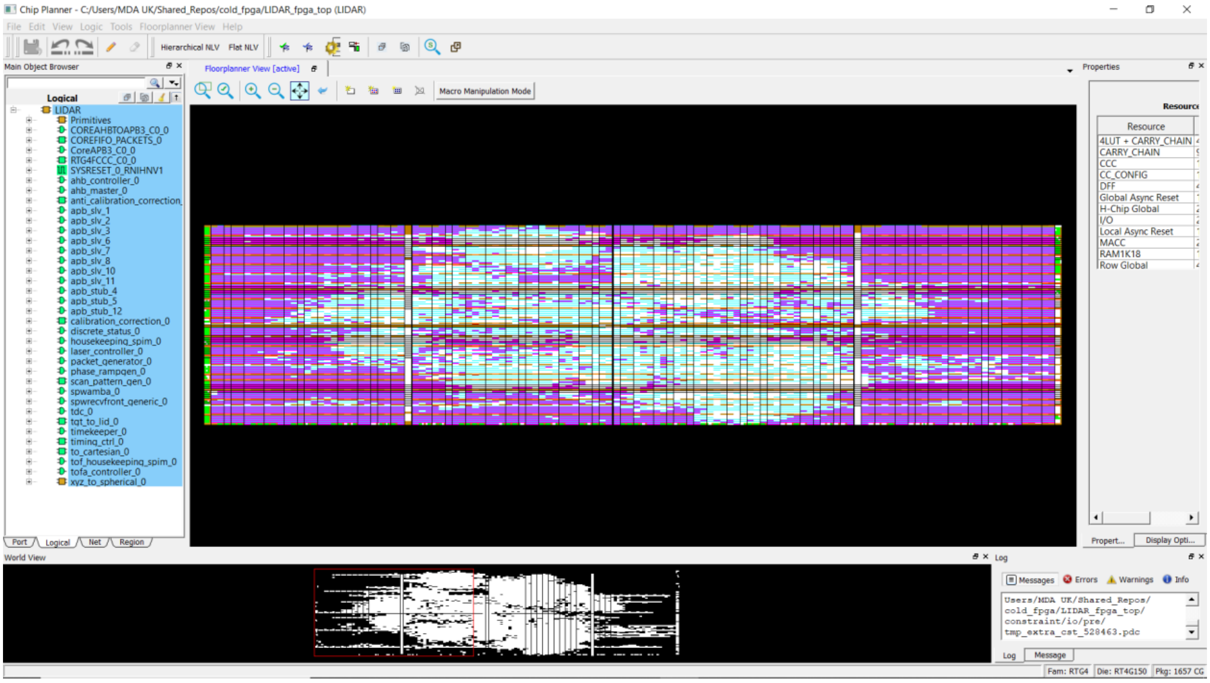


Figure 2-3: Time-resolved phase measurement for one pixel of the SLM.



```
Users/MDA UK/Shared_Repos/
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constraint/io/pre/
tmp_extra_cst_528463.pdc
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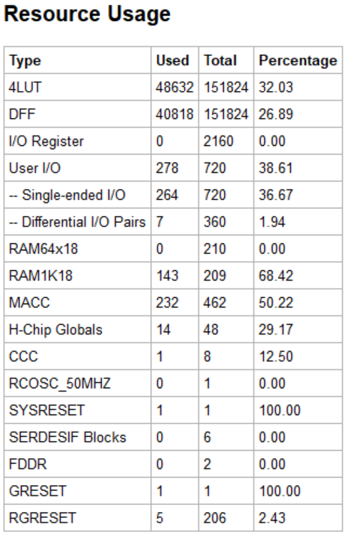
Figure 2-4: FPGA layout chip-planner view



Resource Usage

Type	Used	Total	Percentage
4LUT	48632	151824	32.03
DFF	40818	151824	26.89
I/O Register	0	2160	0.00
User I/O	278	720	38.61
-- Single-ended I/O	264	720	36.67
-- Differential I/O Pairs	7	360	1.94
RAM64x18	0	210	0.00
RAM1K18	143	209	68.42
MACC	232	462	50.22
H-Chip Globals	14	48	29.17
CCC	1	8	12.50
RCOSC_50MHZ	0	1	0.00
SYSRESET	1	1	100.00
SERDESIF Blocks	0	6	0.00
FDDR	0	2	0.00
GRESET	1	1	100.00
RGRESET	5	206	2.43

Figure 2-5: Resource usage