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RocketChip
D6.3 Final Public Report

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Contents

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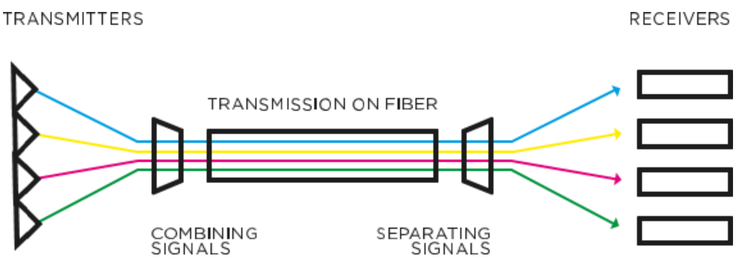
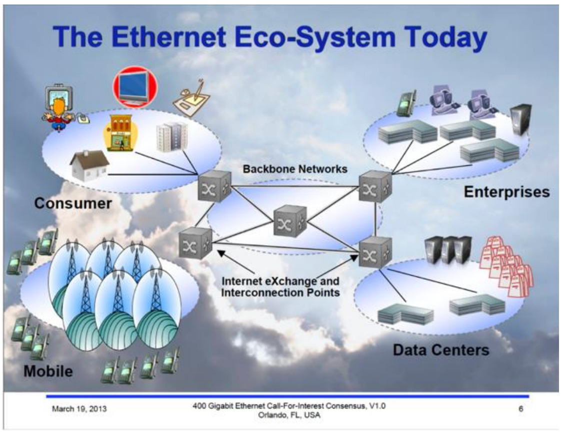
1. Introduction

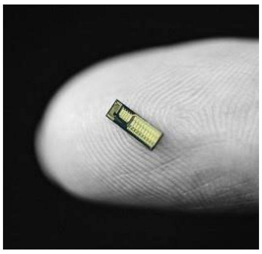
Technological advances in communication and data transfer are increasingly visible all around us, in our homes, our workplaces and also in the organisations that we depend on. In the 21st century, our lives have become fully immersed in internet data through our use of smartphones, tablets, Internet-enabled Televisions, social media, online gaming, video calling, and cloud storage. New internet applications such as mobile video, Virtual Reality, and Internet of Things are emerging all the time. With our rapidly increasing use of Internet technology, ever-faster data networks are being rolled out, each wave driving even more data through optical fibre networks.



To boost network capacity, without having to install more fibres, planners are moving to deploy as many as 40 streams of different coloured light through each fibre, each colour is a channel carrying its own data: a technology known as Wavelength Division Multiplexing (WDM).

Wavelength Division Multiplexing (WDM) has already been proven as the solution for increasing capacity at the core of the networks. However, there is an urgent need for a cost-effective solution at the edges of the network, (where the connections between cloud-computing data centres and mobile phone towers are). There is great potential to implement this complex manipulation of light at the edges of the network. However, before this can be realised low cost/high volume requirements need to be met.





Our company, EFFECT Photonics, has developed the solution to this problem. Our unique Optical System-on-Chip technology allows the complete integration of multiple complex light functions into a single tiny chip. This tiny chip is known as a Photonic Integrated Circuit (PIC). Our developed chips are capable of sending many coloured streams of light-data.

The PIC chips (and the associated control electronics) can be assembled and packaged using our non-hermetic packaging technology, into a very compact module (see picture on page 4).

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This module is used to transmit and receive data along optical fibres and is known as a transceiver module. Our unique technology allows EFFECT Photonics to deliver the lowest cost and highest performance optical transceiver modules available today.

These compact transceiver modules are industry standard size and can be plugged directly into the equipment within data centres, connecting those data centres to other data centres and the rest of the telecommunications network. This directly pluggable module is sold to system integrators and Web2.0 companies.

2. Project RocketChip Summary

The main objective of Project "RocketChip" was to develop and produce **high-speed, tuneable, cost-efficient DWDM integrated optics**, packaged in very compact modules to meet customer needs in several potential telecom applications. As we transition from 4G (4th generation of telecoms infrastructure) to 5G, we have observed a clear trend towards densification (i.e increasing the amount of available capacity) and cloudification (moving services to the internet) in the telecoms market.

As capacity demand increases with the transition to 5G, digital optics need to move out towards the edges of the network. This is driven by the need to centralize compute power. As a result, optical transceivers that were previously targeting communication between datacentres, will now also be used to feed the edges of the (telecoms)-network. The convergence between data- and telecoms-networks is an excellent example of how technology from one domain can be successfully applied in another. However, this is only feasible if technological solutions meet the cost expectations for the application.

The data communications market is split into several subsections:

1. Very short distance computer to computer interconnect (Electrical <10m)
2. Short distance computer LAN connections (Electrical <100m)
3. Long-distance computer LAN connections & Data Centre intra-connect (connections between racks of computers within a Data Centre) (Multimode Optical < 2km)
4. Data Centre Interconnect (connections between Data Centres, or Data Centres to telecommunications networks) (Single-Mode Optical <40km)
5. Mobile Phone Mast "Front-Haul" and "Back-Haul" connections to telecommunications network (Single-Mode Optical <40km)

The continual and rapid evolvement of the data communications market has been carefully monitored throughout the duration of Project RocketChip. Core technology development has been driven to meet market demand, aiming to maximise exploitation opportunities.

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RocketChip explored exploitation opportunities for single-mode optical fibre transmission of less than 40km, by pushing the limits of direct detect technology, and exploiting high-bit rate 4-level pulse amplitude modulation (PAM4) at 1550nm. Our extensive market research and customer interactions throughout the project revealed that mobile front-haul applications would benefit the most from the project results.

RocketChip integrated optics solutions have been developed to be compatible with physically small, and compact (small form factor) modules. The squeeze in volume and increase in speed per channel associated with small form factors bring important engineering challenges in the transceiver design. For example, more advanced assembly techniques are required and the hardware performance at higher speed needs to be guaranteed. These challenges were successfully addressed in project RocketChip.

Project RocketChip, built on our existing knowledge and exploited our proprietary IP. The project enabled EFFECT Photonics to develop a leadership position in the next generation of PICs and hence develop a strong, profitable and growing business in Europe.

3. Overview of project results

The technology trend for next-generation high-speed transceivers (e.g. 100G/400G) implementation is to exploit a fewer number of channels (e.g. one/four) while maximising the speed per channel (e.g. 100Gb/s per channel). The solutions should fit in an industry-standard, small form factor. This high-density approach is driven by the critical power consumption and cost requirements of short-range (e.g. mobile fronthaul) applications.

The figure below shows an overview of different 100G and 400G transceiver form factors. The dimensions in millimetres are indicated, and the different power classes handled per form factor are listed.

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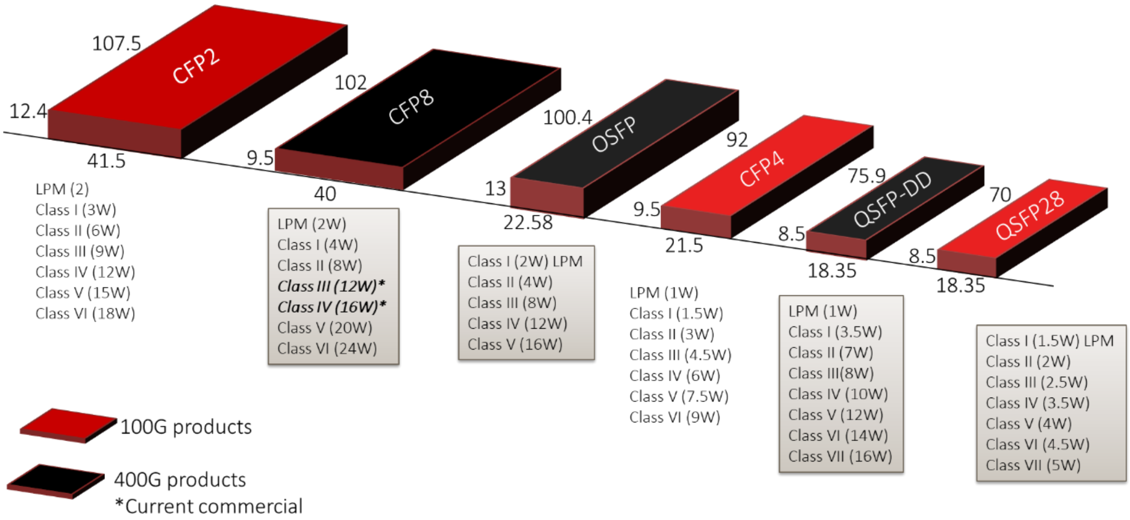

Overview of different 100G and 400G transceiver form factors.

The core technical activity in Project RocketChip was the development of high-speed small form factor transceiver (up to 100Gb/s per channel). The project results mainly fall into the categories addressed in the following subsections.

3.1 High-speed photonic integrated circuit design

Tunability and bandwidth transceiver requirements (>25GHz) were addressed through the optimisation of the photonic building blocks and their integration into a single photonic integrated circuit featuring an integrated frequency locker structure.

The two main building blocks which were optimised were the Mach-Zehnder modulator and the tuneable laser source. The modulator has a 3-dB electro-optical bandwidth of ~ 25GHz with excellent phase linearity up to 50GHz. The laser tunes over 7 channels with a 150GHz channel spacing.

3.2 High-speed sub-assembly design and implementation

The photonic integrated circuit needs to be built into an optical sub-assembly for a proper interconnection with the supporting electronics. To ensure high-speed, low-loss, electro-optical signal conversion, the interconnect technology was carefully designed, implemented and verified. The sub-assembly was designed to cope with the continuously evolving surrounding technology. This allowed us to establish a solid baseline which we can build upon, employing the most appropriate technology choices as they emerge. The optical sub-assembly displayed our company's core strengths.

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Through the development of the optical sub-assembly, we proved the integration of multiple functions into a single chip with tunability features. Furthermore, we demonstrated our chip can be coupled with a high-speed interconnect technology and our non-hermetic packaging, designed to meet the challenging size constraints of very small form factors.

3.3 Advanced assembly techniques

The squeeze in volume and the increase in speed per channel associated with the small form factors brings important engineering challenges in the transceiver design. The more compact box also requires more advanced assembly techniques to address the new challenges that come with the miniaturization. For example, the connection of the optical fibre to the chip. Hence as part of the project, a new assembly process was developed to enable the small form factor transceivers. This included the design, build and automation of a fibre alignment station and the development of other sophisticated tools. The automation of our processes is typically considered towards facilitating a scale-up volume production.

3.4 Test execution

Diverse tools and stations were developed and automated to support the testing of the produced hardware. Our test execution strategy, which was devised to reach the test objectives, was based on the so-called V-model (see for reference https://en.wikipedia.org/wiki/V-Model). The V-model was adapted to the optical module development. This set the foundations and provided the framework for (in-house and external) test planning. Furthermore, portability and compatibility were aspects carefully considered during the design and creation of demonstrators. Compatibility and ease of set up were recognised as key requirements for external site testing, so we developed a simplified setup with a minimum of necessary equipment.

4. Exploitation of results

Exploitation of project results at different levels is addressed in the following subsections.

4.1 Advanced product development and new product introduction

RocketChip project aims to exploit its results to deliver the next-generation optical transceiver modules in an industry-standard (pluggable) form factor. Two key aspects of the project are being actively exploited. On one hand, we are making full use of the key technologies developed in RocketChip to accelerate the delivery of a next-generation high-speed direct detect product, and on the other, we are using the know-how and experience generated to accelerate our entry to the multi-billion dollar coherent global market.

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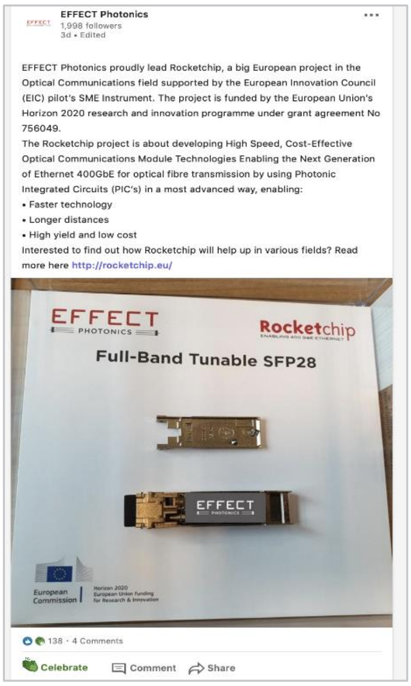
In brief, our New Product Integration (NPI) process involves 3 key steps - Feasibility, Prototyping and Product Development. Our RocketChip enabled technologies will allow us to move straight to Product development, enabling us to significantly reduce the time to market for our new commercial products in our direct detect portfolio and towards our coherent portfolio introduction.

4.2 Visibility and dissemination

The technical progress achieved during RocketChip has been continuously shared with customers, through teleconferencing, visiting customer sites, attending major industry events and international conferences. Furthermore, at the most advanced stages of the project, organisation of demonstrators and pilots have taken place along with intense customer interaction. All these activities have helped to build a certain level of 'presence' in the market/industry. This is a key part in the development of a product or solution within a business-to-business environment. Moreover, our communication and dissemination activities have contributed to building an ecosystem of users and suppliers in the value chain. We will continue the promotion of our technology and innovations to the market, through the diverse channels that we established during Project RocketChip (e.g. industry events, customer visits, discussion fora, etc.).

Furthermore, the RocketChip project active website http://rocketchip.eu, and the social media tools such as the LindkedIn and Twitter company accounts are continuously maintained and exploited to share interesting news in the field, project-related news (e.g. the selection of our project for publication in the "Results in Brief" section of the European Commission's CORDIS website), our project-related publications (both for specialised and non-specialised audiences), photographs and event announcements.



Social media is an inexpensive but effective way to reach a significant amount of people. During key industry exhibition events, social media was used to attract callers to EFFECT's Trade Show Booth to actively demonstrate new product innovations. In the picture, a recent RocketChip LinkedIn post showing a project result showcased during the large, global European Conference on Optical Communications (ECOC) which took place in Dublin, Ireland in September 2019. Our social media campaigns will continue beyond the project.

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Overall, the diverse communication and dissemination activities carried out throughout the project have helped to extend our network and raise the profile of SME EFFECT Photonics within the Photonics Sector and the awareness of Project RocketChip.

5. Socio-economic impact of action

The need for high-bandwidth, low-cost optics (particularly in densely populated areas), has been highlighted by next year's planned 5G roll-outs across Europe, Asia and the US. In big cities, long link lengths (>20km) are not required, but bandwidth demands are enormous. For example, New York State (with ~20 million inhabitants) has an average state-wide bandwidth of 70Mbps (https://broadbandnow.com/New-York). This means that on average 1400Tbps interconnection is needed. Although not all this requirement is optical, the figures clearly demonstrate the extent of the demand.

The high-bandwidth optical elements developed in the RocketChip project enable the delivery of a low-cost Direct Detect solution for mobile front-haul and hence contribute positively to the 5G roll-outs needed to keep-up with our connectivity needs. Furthermore, the automation of the packaging and assembly process developed in project RocketChip ensures that the final product is less dependent on manual labour. This means that there is no need to transfer these processes to low-salary countries to make them cost effective.

A number of social-economic impacts can be directly attributed to Project RocketChip. These are summarised in the following table.

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CATEGORY	**STAKEHOLDER**	**IMPACT**
Enhancing profitability and growth performance of industry (and SMEs) in EU	EFFECT PHOTONICS	Production in EU leading to Revenue opportunity: grow towards >€100M Euros/year within the next 3 years Employment growth: +86 employees
	Supply chain e.g. Materials and Wafer Fabrication Supplier	Employment growth: Some of our supply chain partners, such as SMART Photonics, have doubled in size over the last few years. Companies like EFFECT Photonics play a trailblazing role in the development of the photonic integration eco-system in Europe
	Systems customers (mainly European)	The products of EFFECT Photonics will allow our European customers to develop new high capacity systems and stay competitive towards the US and Asian based competition.
Increase of private investment in R&D	Venture capitalists seek innovative, high growth investments	EFFECT Photonics raised >25M€ of expansion capital for global market growth. Aligned with EU's aim to increase levels of research investment to provide a stimulus to the EU's competitiveness
Enabling Technology for 5G roll out		Economic: Following 5G roll-out, we expect to see an increase in GDP. This is based on Ericsson's simulation results showing that doubling broadband speeds for an economy can add 0.3 % to GDP growth (https://www.ericsson.com/49e75a/assets/local/about-ericsson/sustainability-and-corporate-responsibility/documents/download/socioeconomic-effect-of-broadband-speed.pdf).

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		Social: Provide faster, improved access to online services. This facilitates flexible working for parents (work from home).
Environmental	Global Regions	Creating higher speed optical fibre connections allows more data to be handled in efficient datacenters, rather than in local server rooms. The next step is to distribute these datacenters so that they are close to renewable energy sources. This step is also enabled by low cost, high-speed optical transceivers. Once this transition is complete, the optical network can then be used to cleverly balance the computing and storage capacity so that fluctuations in renewable energy production can be smoothened out. Therefore optical technology can accelerate the energy transition. Non-hermetic box-less packaging technology does not use rare, precious gold. In 2011 UK publication Telegraph reported only 20 years' worth of accessible gold left in the world. Enabling silica glass optical fibre links also reduces copper cabling. Silica is an abundant global resource, whose conversion into fibre has a significantly lower environmental impact than the production of copper.

6. Conclusion

The main objective of the RocketChip project has been to develop the next-generation high-speed optical transceiver module technologies for short reach direct detect transmission. RocketChip's core technology development has been driven to maximise the exploitation of the project results in view of the ever-evolving data communications market as revealed by our continuous and intense market research and customer engagement. We will continue to leverage our differentiators such as our tunability and DWDM capabilities to gain a place in the mobile fronthaul market, where our project outcomes have proved to be more attractive. The project outcomes contribute to the technologies needed for the upcoming 5G roll-outs needed to keep-up with our connectivity needs. The project has helped EFFECT Photonics become a strong driving force in the European integrated photonics ecosystem. The follow-up investments raised by EFFECT Photonics allows the company to grow and continue to develop successful products that will sustain the world-wide growth of data demand, without increasing the load on our fragile environment.