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<td>Christoph Helmrath</td>
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1 INTRODUCTION AND PROJECT SUMMARY

This document comprises the final project presentation (deliverable D0.4) of the project HECTO, which is also the publishable final activity report. The purpose of this deliverable is to present the project and its end results to the public and to explain the purpose and the impact of the project.

In recent years efforts have been made to achieve higher data rates in optical communication systems. In the IST projects FASHION and TOPRATE it has been shown that datarates of 160Gbit/s can be transmitted using Optical Time Division Multiplexing. The focus of these projects has been in the optical domain rather than in realization of cost-efficient components.

Further IST-projects address IP-based optical networks and develop concepts for optical packet-switched networks, e.g. IST-LASAGNE and IST-IP NOBEL. In packet switching networks, the next logical step after 10 Gigabit Ethernet (GbE) is 100GbE.

The objective of HECTO has been the development of photonic components, transmitter and receiver, for high-performance and high-speed but cost-efficient communication systems. Applications are Time Division Multiplexed (TDM) optical systems with up to 160Gbit/s as well as optical packet-switching networks based on serial 100GbE signals requiring 112Gbit/s including forward-error correction. The bitrate 112Gb/s was chosen during the project by the HECTO partners as a result of interaction with ongoing international standardization.

Transmitters have been developed with Travelling-Wave Electro-Absorption Modulators (TWEAM) with bandwidths of 100GHz or more, integrated with continuous-wave lasers. Electronic driver amplifiers and multiplexers have been developed for the connection between the modulators and external electronics at lower speeds.

Receivers with bandwidths on the order of 100GHz have been developed with waveguide pin photodetectors integrated with electronic amplifiers, and the required high-speed electronics for electrical clock recovery and demultiplexing to lower speeds were also developed.

The components have been tested in systems experiments. To ensure that they will meet the demands of the future market, technology application assessment accompanied the technical investigation and development.

The HECTO project will allow European companies to gain share in the increasingly competitive photonic component and packet switching market. HECTO will form a basis for a cost-efficient extension of European networks, and the introduction of end-to-end broadband services for all European citizens.

Information regarding HECTO may also be found at the project web site:

www.hecto.eu
2 MOTIVATION

By the end of the 20th century and the beginning of the 21st century, telecommunication and information technology started to strongly influence society. Today, all areas of society, politics, and economics make use of the possibilities offered by these technologies and as an example, the influence on economic processes is enormous. Also private users take more and more advantage of mobile communication and Internet. As the new techniques have come to play a key role in all social areas and in the lives of people, the requirements on the telecommunication technologies have changed dramatically.

In today’s metro and core networks 10Gbit/s transmission systems with a total number of 80 wavelengths channels in the core (dense wavelength multiplexing systems, DWDM) and 16 channels in the metro area (coarse WDM) are established. Until the year 2001 the speed of development of optical SDH/SONET, transmission systems was enormous, from below 1Gbit/s to 2.5Gbit/s and today’s 10Gbit/s (SDH=Synchronous Digital Hierarchy is the international standard published by the International Telecommunications Union, ITU; SONET= Synchronous Optical NETwork is the United States version of the standard published by the American National Standards Institute, ANSI). At that time, all major system vendors promised to provide systems with a data rate of 40Gbit/s per channel soon. To be prepared for the next steps, many research projects envisaging 160Gbit/s transmission were started, among them the very successful IST projects FASHION and TOPRATE, but with the downturn of the communication industry the innovation nearly stopped. Suddenly, the best performing system with over a hundred wavelengths bridging a distance of several thousand of kilometers was of no interest, but a cheap system just satisfying short-term requirements. Recently the situation has become more relaxed again. Some operators now ask for the option to deploy 40Gbit/s systems, although no larger installation of this bit rate has been performed so far. Another topic from the past is also under strong discussion and has high chances of becoming realized in the next years: Automatically Switched Optical Network (ASON) in combination with Generalized Multi Protocol Label Switching (GMPLS) seems to be a very promising solution to reduce network costs, capital expenditure (CAPEX) as well as operational expenditures (OPEX).

At the same time the Ethernet technology has expanded from local area networks (LAN) into the metro area networks where it won the race against the ATM-technology (ATM=Asynchronous Transfer Mode). Today, Ethernet is the definite standard in the local and metro area offering the best cost-benefit relation. Its evolution is an impressive success story up to now, with bitrates of 10Mbit/s in year 1990, 100Mbit/s in 1994, 1Gbit/s in 1998, and 10Gbit/s in 2002.

It is now visible that technological advances in the area of high bandwidth optical transmission and high-speed electronics will allow climbing to the next Ethernet speed level of 100Gbit/s within the next few years. It may also be expected that the Ethernet will utilize these technological advances and enter the core networks. Especially the fact that the share of packet based data transport is rapidly growing and that voice traffic is already possible in packet networks as “Voice-over-IP” (VoIP) paves the ground for the Ethernet also in the central area of the data network. The figure below shows the intrusion of Ethernet into the Metro and Core parts of the network.
The packet data connection and IP is still a purely electrical technology, especially the switching, but to transport these packets at data rates of 10Gbit/s today or even 100Gbit/s in the future, there is no alternative to the optical domain. The optical single mode fiber provides the unique solution to transport such high data rates over long distances. Transmission experiments have been demonstrated in which for example 160Gbit/s signals were submitted error-free over several hundred kilometers of deployed fiber. However, to convert these high data rates between the electrical and the optical domain, sophisticated optical multiplexing and demultiplexing technologies have been applied.

In order to make 100Gbit/s Ethernet or also higher data rate TDM technologies economically interesting, cost efficient electro-optical and opto-electrical components have to be provided. Within the project HECTO high-speed components for both directions have been developed: electrical to optical as well as optical to electrical signal converters. In order to achieve not only high-performance devices but also cost-efficient technologies, these converters were developed as integrated devices. In the transmitter and the receiver, the converters were accompanied by high-speed integrated electronic circuits, which also were developed within this project.

Finally, the goal of the project has been not only to provide individual converters in both directions, but to develop both components in tight cooperation. Therefore, dedicated system experiments were performed to investigate the proper interaction between the transmitter component (electro-optical converter) and the receiver component (opto-electrical converter).
This enabled the consortium to demonstrate that these components can be integrated into a high-speed transmission system. Finally, field experiments were successfully conducted to verify the applicability under reality conditions.

3 THE HECTO CONSORTIUM

The consortium consists of 9 principal contractors (P1-9) from the EU Member states Denmark, Germany, Sweden and Greece. Three principal contractors are academic institutions (P1, P5, P9), three are industrial laboratories (P3, P7, P8), two are SMEs (P3, P7), and three are non-profit research institutes (P2, P4, P6).

P1: Royal Institute of Technology (Kungliga Tekniska Högskolan, KTH), Laboratory of Photonics and Microwave Engineering (FMI), Kista, Sweden
P2: Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., Heinrich-Hertz-Institut (FhG/HHI), Berlin, Germany
P3: Syntune AB, Kista, Sweden
P4: Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., Institut für Angewandte Festkörperphysik (FhG/IAF), Freiburg, Germany
P5: DTU Fotonik, Lyngby, Denmark
P6: Acreo AB, Kista, Sweden
P7: U2T Photonics AG, Berlin, Germany
P8: Nokia Siemens Networks (NSN) GmbH & Co. KG, Munich, Germany
P9: University of Peloponnese (UoP), Tripolis, Greece

The project has been managed by P1 who has handled the administrative functions. P1 has also been responsible for the design and characterization of the TWEAM, as well as process coordination in close collaboration with P3. P3 has developed epitaxy and the fabrication process of the TWEAM and the monolithically integrated laser-TWEAM, and fabricated these devices. The TWEAM chips were packaged by P7 and connected to the driver IC designed and fabricated by P4 who also designed and fabricated an electronic multiplexer. The role of P2 was to design, fabricate, and characterize receivers with detectors and amplifiers, which were connected to clock recovery circuits and electronic demultiplexers designed and fabricated by P4 and packaged by P7. P5 contributed to the modulator evaluation using equipment only available at this partner. Field tests were performed using the test-bed operated by P6. Techno-economic evaluation of systems working at bitrates up to 112Gbit/s and above were performed by P8 and P9 to ensure that the components will meet the demands of the future market.

Coordinator contact details

The project has been coordinated by Associate Professor Urban Westergren, Laboratory of Photonics and Microwave Engineering, School of Information and Communication Technology, Royal Institute of Technology (Kungliga Tekniska Högskolan, KTH).
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E-mail: urban@kth.se, Telephone: +46 8 790 60 00

Project web site: www.hecto.eu
4 PROJECT OBJECTIVES

HECTO has been a 40 month project. The main objectives of the project are summarized as:

- To develop fully packaged transmitters and receivers suitable for optical systems based on serial 100GbE signals requiring about 110Gbit/s.
- To determine specifications for all interfaces of the photonic components taking into account emerging relevant standards, and to determine application areas for the components and their impact on the specifications.
- To test the fully packaged transmitters and receivers in laboratory systems test-beds and to perform test in field trials.
- To disseminate the results of the project, including field trials.
- To exploit the results of the project, including plans for commercial exploitation by the SME component vendors of the consortium.

Figure 2. Schematic summary of development of transmitter and receiver components
5 PROJECT RESULTS

Work performed in the 1st and 2nd years

In the first year of the project the work performed included:

- All internal interfaces were identified.
- Specifications of the components and interfaces for the first fabrication run were determined.
- Relevant standardization bodies were identified and a plan of standardization activities was made.
- Designs were finished for the first of two planned technology runs of optical modulator, electrical multiplexer and driver amplifier in the transmitter.
- Designs were finished for the first of two planned technology runs of photoreceiver, clock-and-data recovery and demultiplexer.
- The technology runs for both the transmitter and the receiver were started.

The results in the second year of the project included the first technology run where chips were fabricated and packaged in all semiconductor technologies in the project. The results during the second year were reported to the European Commission in the following 4 deliverables:

- A list of specification of all components, modules, and interfaces for the second production run taking into account results from the techno-economic evaluations.
- A report on the characterization of the optical modulator, the electrical multiplexer, and the driver amplifier from the first technology run.
- A report on the characterization of the photoreceiver and the CDR/DEMUX from the first fabrication run.
- An intermediate report on Standardization and Exploitation.

Work performed in the 3rd reporting period

Since a large part of HECTO has involved hardware development (semiconductor chips) in two consecutive technology runs, the main results have been produced during the last reporting period of the project. The results during the 3rd reporting period, the last 16 months of the project, were reported to the European Commission in the following 5 deliverables:

- Report on the characterization of the optical modulator, the electrical multiplexer, and the driver amplifier from the second technology run.
- Report on the characterization of the photoreceiver and the CDR/DEMUX from the second technology run.
- Report on the final system laboratory and field experiments of 2nd run of transmitter and receiver.
- Report on possible application fields for the technologies developed within the project including Standardization and Exploitation and an update of the recommendation of the specifications.
- Final Project Presentation: Publishable final activity report (this report).
End results of the HECTO project

The bitrate 112Gb/s was chosen during the project by the HECTO partners as a result of interaction with ongoing international standardization regarding 100GbE signals.

Transmitters have been developed with Travelling-Wave Electro-Absorption Modulators (TWEAM) with bandwidths of 100GHz or more, integrated with continuous-wave lasers. Electronic driver amplifiers and multiplexers have been developed for the connection between the modulators and external electronics at lower speeds.

![Image of a 2:1 MUX module](image)

*Figure 3. Typical appearance of the 112 Gbit/s 2:1 MUX modules developed by P4 FhG/IAF.*

![Image of a modulator driver module](image)

*Figure 4. Modulator driver module developed by P4 FhG/IAF (RF input is on the bottom, output on the top; module size is 30 × 21 × 15mm³).*
Figure 5: Finished DFB-TWEAM transmitter module, with chips developed by P1 KTH and P3 Syntune, packaging by P7 U2T, photo taken in the systems measurement setup at P6 Acreo.

Receivers with bandwidths on the order of 100GHz have been developed with waveguide pin diodes integrated with electronic amplifiers (pin-TWA), and the required high-speed electronic circuits for electrical clock recovery and demultiplexing to lower speeds were also developed.

Figure 6: Fabricated wafer from maskset WARP100ADV with various pin-TWAs developed by P2 FhG/HHI, comprising among others a pinTWA in cascode design, containing 10 HEMTs within the TWA.
Figure 7. Typical appearance of the 107-112 Gbit/s CDR/1:2 DEMUX modules developed by P4 FhG/IAF (based on 0.7µm DHBTs) with 1mm input connector.

Figure 8. Summary of the HECTO project with all developed components and an example of measured eyediagram at 112Gbit/s
To ensure that the produced modules will meet the demands of the future market, technology application assessment accompanied the technical investigation and development. The components were successfully tested in systems experiments up to 112Gb/s. Successful field trials over more than 40km of field-installed fibre were conducted.

**Intentions for use and impact**

Aiming at components for high-speed conversion of electrical to optical signals and vice versa, the STREP HECTO contributes to the IST-2005-2.5.1 strategic objective "Photonic Components". HECTO has intended to design cost-efficient component solutions for the next generation of Ethernet.

Especially for the future of packet switched networks, components developed within HECTO will enable an evolution of today's 10Gbit/s Metro Ethernet to 100Gbit/s Metro or even core Ethernet. The fact that the Ethernet technology comes at a cheaper price, compared with the expensive WDM equipment, will lead to significant cost reductions that will contribute to make the broadband access affordable. HECTO thus contributes to the availability of low-cost access and edge network equipment by providing integrated photonic components for the realization of 100Gbit/s Ethernet network elements. HECTO provides possibilities of developing necessary technologies to meet future demands on higher communication capacity and thus reinforces European strengths in areas where it has already established industrial and technological leadership.

Developed integrated transmitters and receivers have been tested in fibre-optical systems to investigate advantages and disadvantages of different solutions to determine which types of photonic components are optimal in various systems, depending on communications distance etc. This has provided the possibility of studying the achievable performance at extremely high speeds, and the results will also aid in the determination of specifications for these photonic components. The feedback of this information in the project will also provide information that may be helpful in future standardization work, such as possible standards for Ethernet at higher rates than 10Gbit/s. HECTO has included participation of experts in standardization work for 10Gbit/s Ethernet who have provided experience and guidelines for a realistic determination of the demands of future communications networks at higher speeds.

HECTO has involved the participation of two SMEs that are candidates for the commercial dissemination of the results of the project in future products. It is likely that commercial implementations will occur in a few years since these solutions will offer potential economic advantages by making it possible to increase the capacity of a communications network without requiring additional space such as a parallel systems increase would (parallel links/fibres or several wavelengths in one fibre). The techno-economic aspects of choices between different technical solutions have been investigated in the HECTO project to ensure that the technical work is relevant to the emerging future communications market. Initial exploitation of the results of HECTO in the measurement equipment market will be explored in direct contact with manufacturers of this type of equipment.
Components developed by the HECTO consortium represent a step further on the extension of Ethernet to the core and metro area networks, and may be expected to strongly impact the telecommunication's industry as well as the network-user community in general. High-speed TDM networks, which today only can be realized with optical switching technologies, may become economically interesting with the ability of direct opto-electronic conversion of the signal at the maximum transmission speed.

6 PUBLICATIONS


25. M. Chacinski, R. Schatz, U. Westergren, A. Djupsjöbacka: "Extension of a 40 Gbps link with a directly detected 2.5 Gbps subcarrier channel", 11th International Conference on Transparent Optical Networks (ICTON), Session (and paper) Mo.C5.4, June 2009


30. R. Driad, R.E. Makon, V. Hurm, F. Benkhelifa, R. Lösch, J. Rosenzweig, M. Schlechtweg "InP-based DHBT technology for high-speed mixed signal and digital applications" (INVITED), 21st Int. Conf. on InP and Related Materials, Newport Beach (USA), May 10-14, 2009


7 PUBLISHABLE DISSEMINATION AND USE PLAN
FINAL PLAN FOR USING AND DISSEMINATING THE KNOWLEDGE

Identifier: Plan for using and disseminating the knowledge
Class: Report
Period: From 01/11/2006 to 31/05/2010
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PLAN FOR USING AND DISSEMINATING THE KNOWLEDGE

Section 1 - Exploitable knowledge and its Use

Plans for exploitation are part of the following deliverables:

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<th>Lead participant</th>
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<td>Intermediate report on Standardization and Exploitation</td>
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The last of these reports was finalised and submitted together with the 3rd periodic activity report. The main points regarding exploitation by the SMEs of HECTO were:

- **P3 Syntune** plans commercialization of the modulator chip developed together with **P1 KTH** when a market appears.
- **P3 Syntune** plans prototype sampling to key potential customers shortly after the completion of HECTO.
- **P7 U2T** plans to develop all packaging technologies developed in the project in order to make them usable in future commercial applications and to ensure that it will be possible to reach the right price targets.
- **P7 U2T** plans to explore initial exploitation of the results of HECTO in the test and measurement equipment market in direct contact with manufacturers of this type of equipment.

The SMEs **P3 Syntune** and **P7 U2T** have continuously during the project provided information for the exploitation plan regarding the development of the market situation for the components developed in HECTO. This information has been entered into the public reports on exploitation in the table above (D1.4 and D1.5).
For the initial exploitation of the results of HECTO, it is reasonable to assume that the measurement equipment market will have an immediate interest in the exploitation, and that it will precede the telecommunications market. Three major manufacturing companies of relevant measurement equipment were invited to evaluate the HECTO modules when these are available later in the project. These companies have also been invited to supply their opinions and advice regarding specifications to ensure that the transmitter and receiver modules are suitable as extensions of electrical measurement equipment to be used in optoelectrical measurements.

The remaining partners of the project plan to exploit the results of the project as follows:

- **P1 KTH** plans to continue its research on high-speed and high-efficiency modulators. In the short term, **P1 KTH** will start at least one more MSc thesis project continuing the development work on TWEAM in HECTO.
- **P2 FhG/HHI** regarding long term exploitation, the results of **P2 FhG/HHI** form the basis for the development of arrayed 4x100 Gbit/s pinTWA-photoreceivers, planed to be co-packaged with dedicated DEMUX circuits from partners within the European Union funded FP7 project POLYSYS, scheduled to be started on Oct. 1st 2010 (3 years). This 400 Gbit/s receiver is a subcomponent within an ultra-high-capacity optical cable transmission application, applying advanced ETDM technology. This will enable maturing InP technology into a higher yield OEIC fabrication technique and pushes the commercialization of pinTWA receiver OEICs as a key component to save costly EDFAs in high data capacity short range interconnections together with industry partners.
- **P4 FhG/IAF** has been in contact with among others measurement instrument manufacturers and intends to explore future exploitation possibilities of the electronics modules with them.
- **P5 DTU** does not plan any specific exploitation of project results.
- **P6 Acreo**, as an independent research institute, has through the participation in this project enhanced the knowledge and competence in the field of serial high-speed optical transmission systems, including the upgrade of the lab system testing facility to the signal baud rate up to 60 Gbaud, and the setting up and demonstration of a complete HECTO system working at the signal baud rate up to 112 Gbaud. The enhanced knowledge and competence obtained through the project will be exploited and used for applying for and participating in new projects, both in the academic (national and European) and industry world, especially when the interest for high baud rate serial transmission systems bounces back. In the case that the commercialization of the modules developed in HECTO happens, **P6 Acreo** is also willing to test these modules, to compare the performance with the modules developed during the project.
- **P8 NSN** there are three areas where **P8 NSN** intends to use the results of the project:
  1. **100GbE**: HECTO has set the stage for a 100GbE serial standard. When in a few years this will be included in the standardisation of 100GbE and such 100GbE modules will be available for a reasonable price, **P8 NSN** will use these modules.
2. **BBA:** As pointed out in D1.5, due to increasing traffic in general, traffic in the Terabit/s range has to be aggregated and cost-effectively processed at the interface between the access domain and the metro or core network. This requires components, which operate with speeds as high as possible, 100 Gbit/s at least. Already the broadband-access business of **P8 NSN** stated its interest in such high-speed processing components and will use these in its broadband-access solutions, when they will be available on the market.

3. **Upcoming projects:** In upcoming projects **P8 NSN** will build on the results of the project HECTO and the knowledge gained therein. This especially holds for research projects on ways towards advanced Tera-bit/s transmission systems. In this way the results of HECTO have already been used for the project proposal "Photonic Components Paving the Way for Advanced Terabit/s Transmission Systems for Power Efficient Data Centres of the Future" for the EU FP 7, call 5.

- The planned exploitation of project results by **P9 UoP** is broadly divided into two categories:
  1. The analytical modelling techniques developed during the project will be also used in other research areas, including the wavelength routing system that takes physical layer effects into account that we have developed. Moreover they will form the basis for the development of even more advanced modelling techniques.
  2. The simulation parameters extracted from the developed components as well as the relevant know-how will be used for the analysis of further systems and subsystems that are central to our research interests including wavelength converters and multi-granular cross connects.

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### Overview table

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<th>Exploitable Knowledge (description)</th>
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<th>Patents or other IPR protection</th>
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<td>1. EO converter design (electrical to modulated optical signal)</td>
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<td>Test &amp; Measurement market</td>
<td>Shortly after the project</td>
<td>According to descriptions in the DoW and the CA, no patents or other IPR protection at this time</td>
<td>P1 KTH, P3 Syntune, P7 U2T, ownership and rights according to the CA</td>
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<td>2. Transmitter components design</td>
<td>Packaged 100Gb/s transmitters</td>
<td>Communication market</td>
<td>After a product development and qualifications phase (1-2 years after the project)</td>
<td>According to descriptions in the DoW and the CA, no patents or other IPR protection at this time</td>
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<td>Communication and Test &amp; After improvement</td>
<td>According to descriptions</td>
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Exploitable Knowledge (description) | Exploitable product(s) or measure(s) | Sector(s) of application | Timetable for commercial use | Patents or other IPR protection | Owner & Other Partner(s) involved |
--- | --- | --- | --- | --- | --- |
Design | Receivers (pin-TWA) | Measurement market | Of the performance (Conversion Gain) | In the DoW and the CA, no patents or other IPR protection at this time | Ownership and rights according to the CA |
4. Improvement of photodiode components design | Packaged 100GHz photodiode modules | Test & Measurement market | Shortly after the project | According to descriptions in the DoW and the CA, no patents or other IPR protection at this time | P7 U2T, ownership and rights according to the CA |
5. Advances in rf-design and simulation | All u2t products | Communication market | Shortly after the project | According to descriptions in the DoW and the CA, no patents or other IPR protection at this time | P7 U2T, ownership and rights according to the CA |

Short texts per exploitable result:

1. EO converter design (electrical to modulated optical signal)
The exploitable result is a packaged 100Gb/s EO converter. Partners involved: P1 KTH has developed DFB-TWEAM chip design methods, P3 Syntune has developed methods to fabricate DFB-TWEAM, P7 U2T has developed packaging methods. P3 Syntune plans commercialization of the modulator chip developed together with P1 KTH when a market appears. P3 Syntune plans prototype sampling to key potential customers shortly after the completion of HECTO. P7 U2T plans to develop the transmitter packaging technology in order to make it usable in future commercial applications and to ensure that it will be possible to reach the right price targets. Ownership and rights will be agreed according to the terms of the CA. P7 U2T plans to explore initial exploitation of the results of HECTO in the test and measurement equipment market in direct contact with manufacturers of this type of equipment. Competing technologies that have been demonstrated in field trials to be suitable for On-Off Keying at up to 112Gbit/s are not known today. No third party rights are known. Standards have not yet been established for 100GbE with serial signal. Some further additional research and development work is needed before products are ready, but the additional effort is limited. The partners believe they can carry out this additional work among the HECTO partners. No patents have been filed to date, but design details and know-how not described in publications may still be protected in the future.
2. Transmitter components design
The exploitable result is a packaged 100Gb/s transmitter. Partners involved: P1 KTH has developed DFB-TWEAM chip design methods, P3 Syntune has developed methods to fabricate DFB-TWEAM, P7 U2T has developed packaging methods. P7 U2T and P3 Syntune, with support from P1 KTH, plan exploitation of the packaged transmitter after a product development and qualifications phase (1-2 years after the project). Ownership and rights will be agreed according to the terms of the CA. Exploitation is planned in the communication market. Competing technologies that have been demonstrated in field trials to be suitable for On-Off Keying at up to 112Gbit/s are not known today. No third party rights are known. Standards have not yet been established for 100GbE with serial signal. Some further additional research and development work is needed before products are ready, but the additional effort is limited. The partners believe they can carry out this additional work among the HECTO partners. No patents have been filed to date, but design details and know-how not described in publications may still be protected in the future.

3. Receiver components design
The exploitable result is a packaged 100Gb/s receiver (pin-TWA). Partners involved: P2 HHI has developed pin-TWA chip design methods, P7 U2T has developed packaging methods. P7 U2T and P2 HHI plan exploitation of the packaged receiver after improvement of the performance (Conversion Gain). Ownership and rights will be agreed according to the terms of the CA. Exploitation is planned in the communication and test&measurement market. Competing technologies that have been demonstrated in field trials to be suitable for On-Off Keying at up to 112Gbit/s are not known today. No third party rights are known. Standards have not yet been established for 100GbE with serial signal. Some further additional research and development work is needed before products are ready, but the additional effort is limited. The partners believe they can carry out this additional work among the HECTO partners. No patents have been filed to date, but design details and know-how not described in publications may still be protected in the future.

4. Improvement of photodiode components design
The exploitable result is Improvement of photodiode components design. Partner involved: P7 U2T has developed packaging photodiodes. P7 U2T plans exploitation of the knowledge in all its products. Exploitation is planned in the test&measurement market shortly after the project. Some further additional research and development work is needed before products are ready, but the additional effort is limited. The partner believes they can carry out this additional work. No patents have been filed to date, but design details and know-how not described in publications may still be protected in the future.

5. Advances in rf-design and simulation
The exploitable result is advances in rf-design and simulation. Partner involved: P7 U2T has developed packaging photodiodes. P7 U2T plans exploitation of the knowledge in all its products. Exploitation is planned in the communication market shortly after the project. Some further additional research and development work is needed before products are ready, but the additional effort is limited. The partner believes they can carry out this additional work. No patents have been filed to date, but design details and know-how not described in publications may still be protected in the future.
Section 2 – Dissemination of knowledge

Dissemination in the 3rd reporting period

Dissemination of work in and results of the project during the 3rd reporting period has been conducted in the following ways:

P1 KTH has maintained a project web site, www.hecto.eu.

P1 KTH has included public information about technologies used in HECTO, and mention of HECTO as a project, in lectures to MSc students in the KTH course “Photonics”. Over 30 students took part in the course, and most of these were international MSc students and European exchange students (through Erasmus) at MSc level.

P1 KTH has included public information about technologies used in HECTO, and detailed description of HECTO as a project, in lectures to PhD students at both KTH and Chalmers Institute of Technology in the course “Photonic Devices and Circuits” November 2009 to February 2010.

P7 U2T has presented the work on 100G components to its customers and potential customers in the test and measurement and systems market.

P8 Nokia Siemens Networks has provided dissemination through:

- work in standardization bodies, IEEE Higher-Speed Study Group, IEEE 802.3ba Task Force and ITU-T
- contribution to the improvement of the HECTO web pages by clarifying copyright issues with respect to publication of HECTO-related publications on the HECTO web pages.
- establishing a description of HECTO on the web pages of Nokia Siemens Networks with a link to the HECTO-home page.
- updating of a Wikipedia page on 100GbE with link to the HECTO web site

P9 UoP together with P1 KTH prepared a poster for presenting the project. The poster is shown in the following figure. P1 KTH also prepared a leaflet based on the poster. The poster has been printed and displayed at the conference ECOC2009 in Vienna by P9 UoP as well as locally by partners (for example at P1 KTH and P8 NSN).
Figure 1: The HECTO poster

P9 UoP: ECOC 2008
Like in the previous reporting periods, HECTO was presented in an ECOC 2009 exhibition stand in Vienna between 20 and 24 September 2008. This year the stand was organised by the BONE network of excellence and was visited by many exhibition visitors. The HECTO poster was presented at the stand, and it attracted considerable interest among the visitors. Several other projects were represented including PHOSPHORUS, FUTON, ISIS, TRIUMPH, NOBEL2, POF-PLUS, and EUROFOS.
Several of the partners have produced a number of publications related to and referring to HECTO, to a large extent as results of the hardware development in WP2 and WP3. Relevant submitted, accepted, or published publications are:

Publications by partners regarding technologies used and developed in HECTO


76. M. Chacinski, R. Schatz, U. Westergren, A. Djupsjöbacka: "Extension of a 40 Gbps link with a directly detected 2.5 Gbps subcarrier channel", 11th International Conference on Transparent Optical Networks (ICTON), Session (and paper) Mo.C5.4, June 2009


81. R. Driad, R.E. Makon, V. Hurm, F. Benkhelfa, R. Lösch, J. Rosenzweig, M. Schlechtweg "InP-based DHBT technology for high-speed mixed signal and digital applications" (INVITED), 21st Int. Conf. on InP and Related Materials, Newport Beach (USA), May 10-14, 2009


Popular presentations (some in domestic media in Sweden and Germany)

**P1 KTH**: U. Westergren interviewed in:
- Compound Semiconductor Magazine, ”Miniaturised monolithic transceivers promise to boost Ethernet capacity”, pp 29-31, July 2009
- Elektroniktidningen, “KTH-försök ger hopp om 100 Gbit Ethernet”, 20 April 2010
- Affärsvärlden, ”Superbredbandet är här”, 21 April 2010
- Computer Sweden, ”Rekordsnabb dataöverföring”, 22 April 2010
- PC för alla, ”112 gigabit i sekunden när KTH trimmar fibernät”, 22 April 2010
- Datormagizin, ”Forskare fixar rekordsnabbt nätverk”, 23 April 2010
- Ingenjören, ”KTH testade fetaste nätverket”, 24 April 2010

**P8 NSN**: Several popular articles following the press release: ”EU funded collaboration results in simpler 100 Gigabit Ethernet networks” (a Google search gave about 300 hits in mid-June 2010)
Planned dissemination

**P1 KTH** will maintain the project web site, [www.hecto.eu](http://www.hecto.eu) including lists of titles and abstracts of all publications related to the project.

**P1 KTH** will continue to include updated public information about technologies used in HECTO in lectures to MSc and PhD students in the course “Photonics” at KTH and in the PhD student course “Photonic Devices and Circuits” offered approximately bi-annually together with CTH.

**P2 FhG/HHI** plans short term dissemination of the HECTO results by publications, in lectures to PhD students and through its own web site.

**P6 Acreo** will maintain the already working complete HECTO system as a live demo showpiece for marketing activities of **P6 Acreo**. Furthermore, the already developed HECTO system and the separate Tx & Rx modules can also be used for educational activities within Acreo (in cooperation with, e.g., **P1 KTH**), both on the master level and for the PhD students. One example of this is that a live demo of HECTO system already had been carried out for the master students in the Photonics program of **P1 KTH** in April 2010, and will most likely be repeated even for the next few years. In addition, separate HECTO modules can also be used for other research purposes, e.g., the DFB-TWEAM module can be used both for data modulation and as a light carver to generate high repetition-rate optical pulse trains for the research in OTDM systems and optical signal processing. The generated optical pulse train can also be used as a pulsed local oscillator for high-speed OTDM coherent receivers.

**Several partners** plan further publication of results also after the end date of the project, especially regarding the successful systems tests and field trial.
## Overview table

<table>
<thead>
<tr>
<th>Planned/actual Dates</th>
<th>Type</th>
<th>Type of audience</th>
<th>Countries addressed</th>
<th>Size of audience</th>
<th>Partner responsible /involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2007</td>
<td>Short lecture series and computer exercise</td>
<td>MSc and PhD students at KTH</td>
<td>Sweden</td>
<td>40</td>
<td>P1 KTH</td>
</tr>
<tr>
<td>June 2007</td>
<td>Short lecture series and computer exercise</td>
<td>PhD students at KTH and CTH</td>
<td>Sweden</td>
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<td>P1 KTH</td>
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<td>2007 and continuing</td>
<td>Participation in the IEEE Higher Speed Study Group Meetings*</td>
<td>International companies involved in 100Gbps standardization</td>
<td>Int**</td>
<td>Large***</td>
<td>P8 NSN</td>
</tr>
<tr>
<td>March 2007</td>
<td>Participation in the conference OFC2007, Anaheim, California, USA</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P8 NSN, P2 FhG/HHI</td>
</tr>
<tr>
<td>May 2007</td>
<td>Presentation at ITG-Fachbericht 201</td>
<td>Engineers and researchers</td>
<td>Germany</td>
<td></td>
<td>P8 NSN</td>
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<tr>
<td>May 2007</td>
<td>Participation in the conference IPRM2007, Matsue, Japan</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P2 FhG/HHI</td>
</tr>
<tr>
<td>September 2007</td>
<td>Presentation of HECTO at the IST ECOC booth, Berlin, Germany</td>
<td>European companies and universities</td>
<td>Europe (and int**)</td>
<td>Large***</td>
<td>P9 UoP</td>
</tr>
<tr>
<td>October 2007</td>
<td>Participation in the conference CSICS 2007, Portland, Oregon, USA</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P4 FhG/IAF, P8 NSN</td>
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<tr>
<td>February 2008</td>
<td>Participation in the conference OFC2007, San Diego, USA</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P1 KTH</td>
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<tr>
<td>May 2008</td>
<td>Participation in the conference IPRM 2008*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P4 FhG/IAF</td>
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<tr>
<td>May 2008</td>
<td>Short lecture series and computer exercise</td>
<td>MSc and PhD students at KTH</td>
<td>Sweden</td>
<td>30</td>
<td>P1 KTH</td>
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<tr>
<td>April 2008</td>
<td>Participation in the conference CS MANTECH 2008*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P4 FhG/IAF</td>
</tr>
<tr>
<td>2008-2009</td>
<td>Press releases to be sent to appropriate specialized press such as Fibre Systems Europe, Optics and Lasers in Europe, etc, when results are available</td>
<td>Both experts and a more general audience</td>
<td>Int**</td>
<td>Large***</td>
<td>P8 NSN after input from the other partners</td>
</tr>
<tr>
<td>2008-2009</td>
<td>Translated or identical press releases to be distributed to technical publications at a national level or even national mass media to increase the public awareness of HECTO results</td>
<td>Both experts and a more general audience</td>
<td>National and Int**</td>
<td>Large***</td>
<td>P8 NSN after input from the other partners</td>
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<td>September 2008</td>
<td>Presentation of HECTO at the exhibition at ECOC2008, Brussels, Belgium</td>
<td>European companies and universities</td>
<td>Europe (and int**)</td>
<td>Large***</td>
<td>P9 UoP</td>
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<tr>
<td>2008</td>
<td>Posters and leaflets to be used for presentation of HECTO by partners</td>
<td>Both experts and a more general audience</td>
<td>Int**</td>
<td>Large***</td>
<td>P1 KTH and other partners</td>
</tr>
<tr>
<td>October 2008</td>
<td>Participation in the conference CSICS 2008*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P4 FhG/IAF</td>
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</table>
## Planned/actual Dates

<table>
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<tr>
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<tbody>
<tr>
<td>November 2008</td>
<td>Participation in the workshop High Speed Interconnects, Stuttgart, Germany</td>
<td>International companies and universities</td>
<td>National and Int**</td>
<td>Small</td>
<td>P4 FhG/IAF</td>
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<tr>
<td>May 2009</td>
<td>Participation in the conference IPRM 2009*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P4 FhG/IAF</td>
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<tr>
<td>September 2009</td>
<td>Participation in the conference ECOC2009*</td>
<td>European companies and universities</td>
<td>Europe (and int**)</td>
<td>Large***</td>
<td>All partners with relevant results</td>
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<tr>
<td>March 2009</td>
<td>Participation in the conference OFC2009, San Diego, USA*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P2 FhG/HHI</td>
</tr>
<tr>
<td>March 2010</td>
<td>Participation in the conference OFC2010, San Diego, USA*</td>
<td>International companies and universities</td>
<td>Int**</td>
<td>Large***</td>
<td>P1 KTH, P6 Acreo</td>
</tr>
<tr>
<td>2010</td>
<td>Field trial demonstration with prototype transmitter and receiver*</td>
<td>Both experts and a more general audience</td>
<td>Int**</td>
<td>Large***</td>
<td>P6 Acreo</td>
</tr>
<tr>
<td>2010</td>
<td>Template data sheets</td>
<td>Potential future customers among network operators</td>
<td>Int**</td>
<td>Large***</td>
<td>P8 NSN</td>
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<tr>
<td>2010</td>
<td>Press releases*</td>
<td>General public</td>
<td>Int**</td>
<td>Large***</td>
<td>P8 NSN</td>
</tr>
<tr>
<td>2010</td>
<td>Press releases*</td>
<td>General public</td>
<td>Int**</td>
<td>Large***</td>
<td>P1 KTH</td>
</tr>
</tbody>
</table>

*) For more details, see the list of publications above  
**) International  
***) “Large” refers to audiences primarily consisting of for example conference participants but information also being made available to a wider range of people due to distribution of proceedings, printed versions of presentations etc
Section 3 – Publishable results

Transmitters have been developed with Travelling-Wave Electro-Absorption Modulators (TWEAM) with bandwidths of 100GHz or more, integrated with continuous-wave lasers. Electronic driver amplifiers and multiplexers have been developed for the connection between the modulators and external electronics at lower speeds.

Figure 3. Typical appearance of the 112 Gbit/s 2:1 MUX modules developed by P4 FhG/IAF.

Figure 4. Modulator driver module developed by P4 FhG/IAF (RF input is on the bottom, output on the top; module size is 30 × 21 × 15mm³).
Figure 5: Finished DFB-TWEAM transmitter module, with chips developed by P1 KTH and P3 Syntune, packaging by P7 U2T, photo taken in the systems measurement setup at P6 Acreo.

Receivers with bandwidths on the order of 100GHz have been developed with waveguide pin diodes integrated with electronic amplifiers (pin-TWA), and the required high-speed electronic circuits for electrical clock recovery and demultiplexing to lower speeds were also developed.

Figure 6: Fabricated wafer from maskset WARP100ADV with various pin-TWAs developed by P2 FhG/HHI, comprising among others a pinTWA in cascode design, containing 10 HEMTs within the TWA.
Figure 7. Typical appearance of the 107-112 Gbit/s CDR/1:2 DEMUX modules developed by P4 FhG/IAF (based on 0.7µm DHBTs) with 1mm input connector.

Figure 8. Summary of the HECTO project with all developed components and an example of measured eyediagram at 112Gbit/s
To ensure that the produced modules will meet the demands of the future market, technology application assessment accompanied the technical investigation and development. The components were successfully tested in systems experiments up to 112Gb/s. Successful field trials over more than 40km of field-installed fibre were conducted.

END OF DOCUMENT