ICT-318247

VECTOR

Versatile Easy installable Connector implementing new Technologies for accelerated fibre Optic network Roll-outs in Europe

Instrument : Small or medium-scale focused research project (STREP)
Thematic Priority : Information and Communication Technologies (ICT)

Deliverable D6.8

Final Report

Due date of deliverable : 30.9.2015
Actual submission date : 4.12.2015

Start date of Project : 1.10.2012 **Duration : 36 months**

Responsible Beneficiary : Tyco Electronics **Revision : 2.0**
Contributing Beneficiaries : All

Contact person : Stephane Berghmans – Tyco Electronics

Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of contents

Abbreviations

CAPEX	Capital expenditure
CEO	Chief Executive Officer
CTO	Chief Technology Officer
DoE	Design of Experiments
EMEA	Europe, Middle East & Africa
EU	European Union
FEA	Finite Element Analysis
FTTH	Fibre-to-the-home
IEC	International Electrotechnical Commission
IL	Insertion Loss
IPA	Isopropyl Alcohol
IPR	Intellectual Property Right
OPEX	Operation expenditure
RL	Return Loss
SC	Subscriber connector
SME	Small and Medium-sized Enterprise
VeC	VECTOR Connector
VeIT	VECTOR Installation Tool
WP	Work package

Document history

Date	Revision	Remarks
10.9.2015	0.1	Table of contents available
24.11.2015	1.0	Draft version available
30.11.2015	1.1	Implementation of final comments
4.12.2015	2.0	Formal approval of Deliverable D6.8 by the Project Steering Committee for submission to the European Commission

1. Executive summary

VECTOR (**V**ersatile **E**asy installable **C**onnector implementing new **T**echnologies for accelerated fiber **O**ptic network **R**oll-outs in Europe) was a European Commission funded research and innovation initiative in which universities and telecom industry teamed up to develop an innovative, low-cost and easy field-installable optical fiber connector technology. It exploits the latest developments in the field of heat-shrinkable materials, nano-materials, high-tech gels, micro-fabrication and micro-mechanical alignment systems to achieve optical connections with superior specifications. Partners from all over Europe have teamed up to achieve the project objectives. The project was coordinated by Tyco Electronics Raychem bvba. VECTOR also relied on important contributions from DEMCON Advanced Mechatronics BV (The Netherlands), Celoplás – Plásticos para a Indústria SA (Portugal), Vrije Universiteit Brussel and Universiteit Gent (Belgium), Telecom Italia S.p.A. (Italy) and Telekom Deutschland GmbH (Germany).

Novel optical fiber connectivity solutions are required to accelerate the deployment of optical fiber communication link-based high speed internet access. In order to distribute signals in fiber optic networks, optical fibers need to be connected with each other, preferably in a reconfigurable manner. Installing connectors on such tiny glass optical fibers in the field, currently requires highly specialized personnel and a multitude of dedicated tools. Dust and dirt made it almost impossible to achieve field connections with a quality level close to the one attainable in a factory or lab environment. The VECTOR project provided a ground-breaking solution to this problem.

The VECTOR solution builds on a ferrule-less connector granting ultra-high optical performance and on a fully automated installation tool allowing for field installation by a general-skill technician. A major result is the optical performance of the ferrule-less VECTOR connector, which meets and exceeds the very severe so-called 'grade B' insertion loss specifications for optical connectors, in accordance with the International Electrotechnical Commission's IEC 61300-3-34 international standard for random mated connectors. The connectors do not require cleaning between mating/unmating cycles: they possess a unique self-cleaning feature that keeps the fibre tip dust free and ensures low connection loss and high repeatability.

Telecom Italia and Telekom Deutschland – two major European telecommunication operators – evaluated the connector in their laboratories. Paolo Pellegrino from Telecom Italia testifies that 'testing VECTOR samples in Telecom Italia has been an amazing lab experience: we measured optical connectors and we obtained results that were only achievable with optical splices so far'. Elmar Pellenz from Telekom Deutschland confirms that 'the optical performance values obtained during extensive laboratory tests on a large set of assembled VECTOR connectors in the facilities of the network operators were very good to excellent. The requirements laid down in Grade B and even better can be met with this technology'.

The VECTOR connector is designed to be field-installable but can also be factory-installed. The process for installing the connector is far easier and less labour intensive than a ferrule-based connector. When compared to other field-installable connectors, the VECTOR connector is the least skill-sensitive.

Stephane Berghmans, project coordinator at Tyco Electronics Raychem is proud of the final result and believes that 'the VECTOR solution is what we needed to bring affordable ultrafast internet connections to all European households'.

The list of beneficiaries of the VECTOR project is provided in the following table.

Beneficiary number	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1	**Tyco Electronics Raychem bvba**	**TEC**	**BE**	**M1**	**M36**
2	**DEMCON Advanced Mechatronics BV**	**DEMCON**	**NL**	**M1**	**M36**
3	**Celoplás – Plásticos para a Indústria SA**	**Celoplás**	**PT**	**M1**	**M36**
4	**Vrije Universiteit Brussel**	**VUB**	**BE**	**M1**	**M36**

5	**Universiteit Gent**	**UGent**	**BE**	**M1**	**M36**
6	**Telekom Deutschland GmbH**	**TDE**	**DE**	**M1**	**M36**
7	**Telecom Italia S.p.A**	**TIT**	**IT**	**M1**	**M36**

The requested **EC contribution** for the VECTOR project is : **3.100.000 €**.

The VECTOR project website address is : www.vectorfp7.eu

The project has been launched on October 1, 2012 for a duration of 36 months.

The **Project Coordinator** and **contact person** for the VECTOR project is :

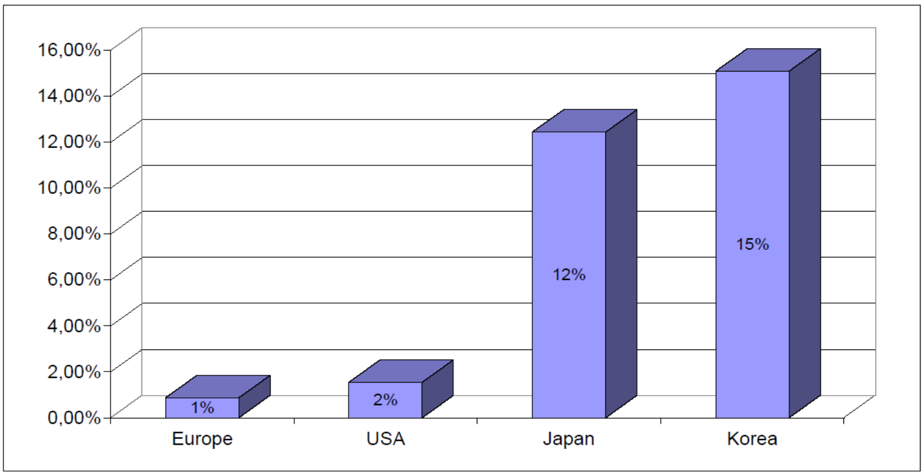
Dr. Stephane Berghmans
TEC – Tyco Electronics Raychem bvba
Diestsesteenweg 692
B-3010 Kessel-Lo
Belgium
Tel : +32-16-35.20.35
E-mail : stephane.berghmans@te.com

2. Overall objectives of VECTOR

The VECTOR project aims to develop an innovative low-cost highly performing field installable **connectivity system** that will impact at a multi-million-euro scale the capital expenditure (CAPEX) and the operation expenditure (OPEX) of telecom fibre broadband networks and that will speed up and harmonize the penetration of fibre-optics in Europe.

We are strongly confident that the ambitious European 2020 objectives for broadband connectivity (namely all households having access to at least 30Mbps connection speed and 50% of households subscribing to at least 100Mbps) can be achieved only by a strong penetration of optical fibre towards the end customer premises and homes. Fibre-to-the-home (FTTH) or fibre-to-the-premises can readily deliver a staggering bandwidth of 1Gigabit/s to the end users and can potentially grow up to 40-100Gigabit/s.

However, the current penetration of fibre-based high speed telecoms network in the EU reaches only 1% (as opposed to 12% in Japan or 15% in South Korea), and Europe will continue to lag behind other major world-economy players if no adequate measures to increase our competitivity are taken (Figure 1).



Source: Point Topic

***Figure 1** : FTTH penetration in the major telecom markets*

The proposing VECTOR consortium has carefully reviewed the reasons behind the apparent delay in fibre penetration among European optical networks and identified **fibre connections** as one of the most crucial issues to be addressed in order to overcome the delay in fibre-optic penetration, irrespective of the network architecture that will be deployed.

State-of-the-art solutions for fibre connections are failing to comply in an economically sound way with the harsh requirements of **connection-density**, **reconfigurability** and **reliability** of FTTH networks. Furthermore, the **wide range of outside plant environments** and the **shortage of specialised labour** at the European level make the installation slow, costly and unreliable and ultimately raise the cost-per-connection to hardly manageable levels. Moreover, from the first FTTH deployments worldwide, a vast majority of the network re-entries could be traced to failures of the connectors. Shortage of specialized field technicians leading to service issues due to bad installations or installations that show early catastrophic failures seem to have an unexpected high impact on the OPEX of the network.

We propose to address and solve all the above issues in an ultimate way by **breaking the current paradigm** of ferrule-based optical connectivity (both factory- or field-installed) requiring extensive pre-engineering and highly specialized manpower for field deployment. The **VECTOR Connectivity System** has the ambition to position itself as a new benchmark for **ferrule-less connectors which can be installed in the field with high yield in an automated way by a general-skill technician.**

In order to succeed in this ambitious goal, we created a consortium comprising the full portfolio of **required technical knowledge, as well as the critical mass necessary to turn our connectivity system into a commercial reality deployed in the optical networks of the whole Europe.**

The VECTOR consortium brings together two major European Telecom operators (Telekom Deutschland and Telecom Italia), a leading global provider of fibre optic connectivity components (Tyco Electronics Raychem), two high-added-value SMEs (Celoplás and DEMCON) as well as 2 leading Universities (VUB and UGent).

The VECTOR Connectivity System comprises two components: the **VECTOR Connector (VeC)** and the **VECTOR Installation Tool (VeIT).**

The VeC will grant the highest grades of insertion and return losses according to the standard IEC61300-3-34 and IEC61300-3-34 without relying on a ceramic or plastic ferrule as an alignment system. The bare optical fibre will be fixed in place by **heat-shrinking technology** and then aligned to the mating fibre by using **novel alignment structures for ferrule less connector fibre coupling**.

The reliability of the VeC will be boosted by its **unprecedented self-cleaning properties** that are implemented by embedding a **cleaning membrane** composed of particle-trapping **electro-spun nanofibres**. The cleaning membrane will remove contaminants from the fibre during matings and protect the unmated connectors from environmental contamination.

The use of ferrule-less technology will lift the requirement for connector polishing to be performed during the installation and will dramatically increase the installation yield in challenging environments.
Full backward compatibility will be ensured with legacy connectors existing in the field.

The **VECTOR Installation Tool will be an innovative mechatronics handheld device that will perform fibre termination at length and connectorisation with VeCs** in the field and will be compatible with the wide majority of optical cables, pigtails and drop cable types (see Figure 2 for a visualization). The VeIT will be operator independent by performing in an automated way all the installation steps (fibre stripping, cleaning, cleaving, fixation) that currently require the work of a skilled technician.

Within VECTOR the consortium aims to develop the **disruptive automated fibre handling techniques** to ensure the **repeatability and reliability of installation** in aggressive outside plant conditions that are barred for today's fusion splicing machines.

High-tech adhesive tapes will be developed by one of the academic partners (UGent) and implemented by one of the SME partners (DEMCON) in order to allow for automated and safe stripping of fibre coatings. We are confident that fibre stripped by the VeIT will be more reliable than mechanically stripped fibres as coating removal by adhesive tapes will not introduce micro-cracks and flaws in the silica cladding as a regular Miller–stripping does.

The high quality stripping process will be complemented by an **automated dry-cleaning** installation step by using **high-tech electro-spun nano-structured textiles** developed by UGent.

The use of nano-structured textiles will allow for removal of any coating debris left on the silica after stripping, therefore completely lifting the need for manually wiping the fibre with solvents such as IPA.

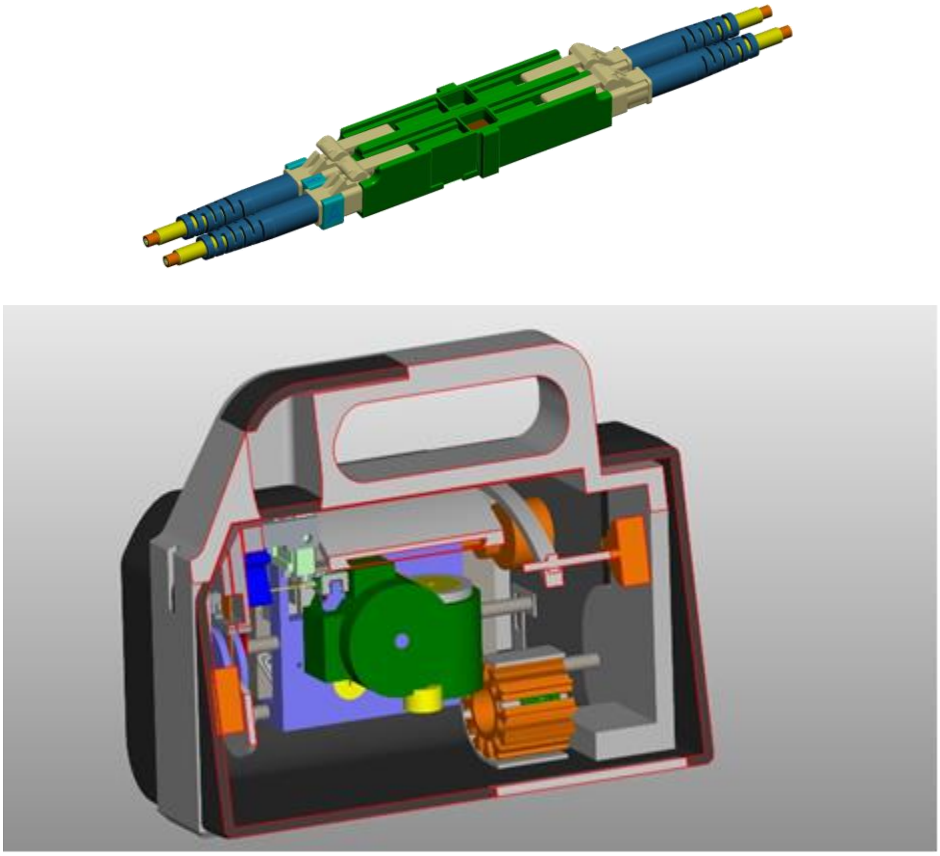


Figure 2 *: VECTOR connector (top) and VECTOR installation tool (below)*

Furthermore, a new-to-the-world process of **plasma discharge shaping** of the cleaved fibre end tip will be developed and implemented in the tool to enhance the connection reliability over repeated cycles of mating and demating. In addition, a **low cost vision system** will ensure proper fibre processing by the VeIT and will substantially increase the installation yield.

Other process steps such as precision cleaving or fibre positioning are already part of the mature technology portfolio of the consortium and **will not require development within the framework of the VECTOR,** and they will be simply implemented in the tool during the integration phase.

We are strongly confident that installations made by the VeIT will outperform those based on current technology developed for core networks. In contrast to fusion splicing equipment, the VeIT will allow performing installations in uncontrolled environmental conditions typical for FTTH, using standard general skilled labour, vastly reducing installation time, eliminating tool maintenance over 20K terminations and acquiring specified termination performance irrespective of the cable and fibre type variations.

The VECTOR program will conclude with **two functional prototypes** of both **VECTOR Connector** and **VECTOR Installation Tool.** Field trials will be performed by Telekom Deutschland and Telecom Italia in their central offices and at the premises of their customers.

During the trials, the performance of the VECTOR deliverables will be assessed in the generic installation environment that is typical of FTTH networks.

3. Overall project assessment

As a technical highlight we succeeded in developing the VECTOR connectivity solution comprising a new ferrule less connector and a mechatronic installation tool. The solution fulfils the expectations of easiness of installation and exceeds the specifications that were originally defined in the project. These two characteristics of the field installable connector solutions were validated by our telecom consortium partners Telecom Italia (TI) and Telekom Deutschland (TD) in a successful field trial:

- TI focused on the universality of the VECTOR Solution and therefore they assessed the performance of the system with a large variety of cables. They measured an average Insertion Loss= 0.08dB and IL<0.25dB for 98% of the connections.
- TD instead focussed on assessing the performance limits and therefore tested only 4 different cables. The measured an average IL=0.07dB IL<0.14dB for 97% of connections.

These results were better than a conventional Grade B connector who must deliver 0.12dB average IL and IL<0.25dB for 97% of connections. Grade A* is not a standard yet; proposed specifications are 0.07dB average IL and IL<0.125dB for 97% of connections.

The highlights of the VECTOR project were:

- It was proven that ferrule-less technology, when successfully implemented in a robust connector design, is able to meet low loss performance, better than grade B in a field situation
- A robust stripping methodology, having little impact to the strength of the fiber after stripping is imperative to make a reliable buckling based field installable connector
- Heat shrink technology for fiber fixation purposes was developed and proven to be a highly performing alternative for crimping methodologies, versatile towards different coating thicknesses
- A self-cleaning intelligent connector was developed, by using gel technology into a shutter
- It was proven that, although very challenging, a mechatronic installation tool can be developed that takes over all the manual preparation steps that an installer with state-of-the-art field installable connectivity solutions has to do. It was proven that this can lead to high yields of installation on a variety of cables.

More generally, the highlight was that by bringing the different players of the value chain together we enabled:

- A better understanding of customer needs
- A forum for customers to exchange their experiences with their peers
- An incubator environment for new and improved concepts
- Shorter time to market of innovative concepts
- Enhanced relationships between suppliers, manufacturers and customers
- Improved visibility and strength of European innovation and industry

At the end of the VECTOR project we evaluated the use of the technologies – that were developed in the VECTOR project – in new applications. This yielded about ten new product ideas that are now being evaluated for starting new projects.

The only lowlight for the project is that the tool still required a larger investment for commercialization than was originally anticipated.

4. Work package overview

4.1 Work package 1 : VECTOR geometrical constraints

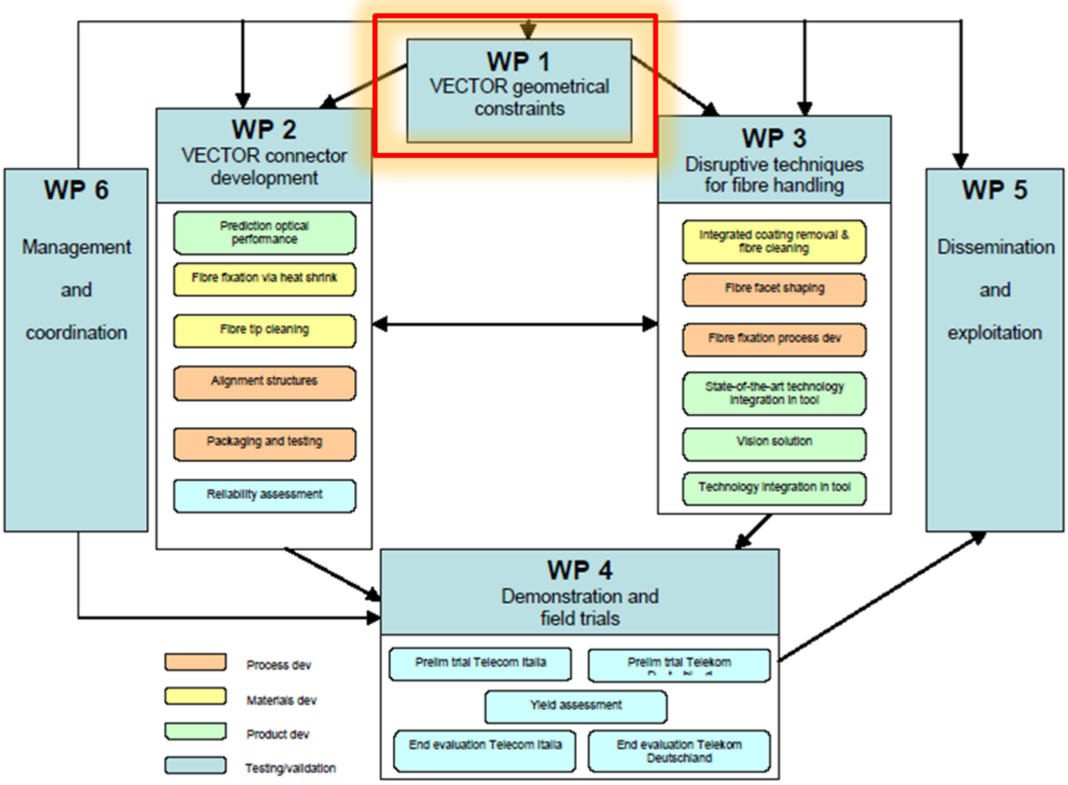


***Figure 3** : Work package structure of VECTOR.*

The work package structure of VECTOR is illustrated in Figure 3.

VECTOR is structured in such a way that the technology development work is spread between two main work packages:

- WP2 (VECTOR connector development) focussing on the development of the Vector Connector (VeC),
- WP3 (Disruptive techniques for fibre handling) focussing on the development of the Vector Installation Tool (VeIT).

WP1 enables the activities of WP2 and WP3 to run in parallel by issuing a set of geometrical constraints for the footprint of Vector Connector and Vector Installation Tool. A consortium-wide effort insured that constraints were available at Month 6. Compliance with the constraints insured compatibility and performance of the whole system.

The consortium identified multiple classes of constraints that apply to the connector-tool system, namely :

- **Technology constraints**, i.e. the required physical footprint to implement a certain technology in the Vector Connector
- **Vector Installation tool constraints** i.e. footprint adjustments that are aiming to mitigate/accommodate tolerances on fiber handling performed by the installation tool

- **Connector-Tool interface constraints** i.e. design elements to be included in the connector housing in order to allow automated handling of the connector in the installation tool
- **Network element compatibility constraints** i.e. the required footprint to remain compatible with legacy network elements existing in the field

A cross section of the Vector connectors in shown in Figure 4.

The use of **bare-fibre connectivity** allows for Vector Connector (VeC)'s lateral dimensions of **6.1±0.05 mm** (width) by **8.85±0.05 mm** (height). This allows for **double connection density** on panels and trays compared to SC connectors.

The technologies implemented within the connector impose the following requirements on the length of the VeC:

- Shutter technology: No impact
- Buckling cavity technology: 20 mm
- Heat shrink technology: 13 mm
- Cable fixation: 18 mm (on a 2mm patchcord)
  10 mm (on a 900µm buffer)
- Alignment system: 3 mm
- Cleaning intelligence: No impact

These constraints result into a (single side) connection length of **71.5 ± 2.5 mm** when terminating a 3 mm patch-cord with a 40mm boot and **50 ± 2.5 mm** when terminating a 900µm buffer with a 20mm boot. These dimensions are shorter than typical field installable SC connectors and slightly longer than factory installed SC connectors.

Installations are possible for the majority of network elements in both central office and FTTH networks.

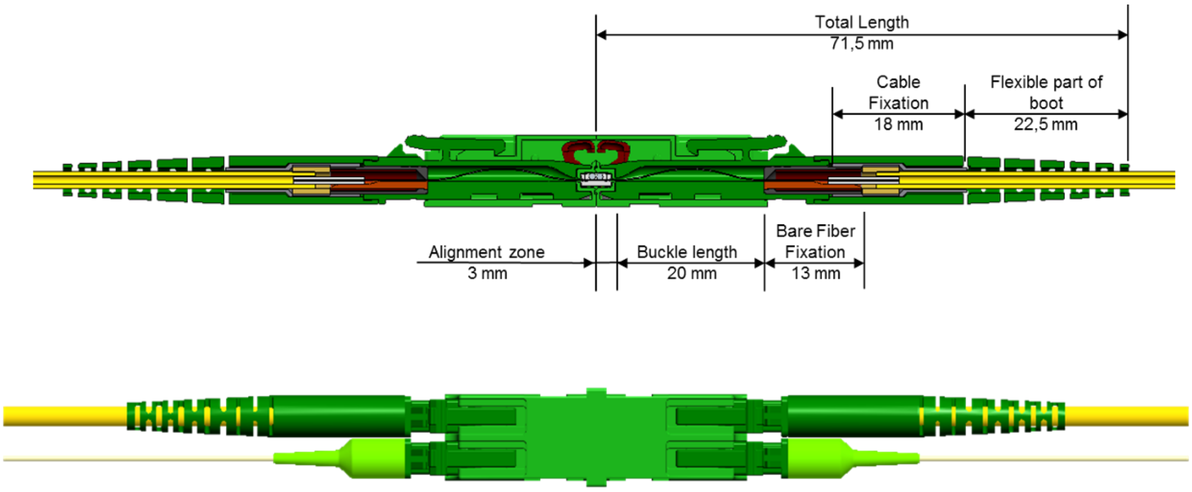


***Figure 4** : Vector connector and its footpring.*

4.2 Work package 2 : VECTOR connector development

1. Fibre-tip cleaning of the ferrule-less connector

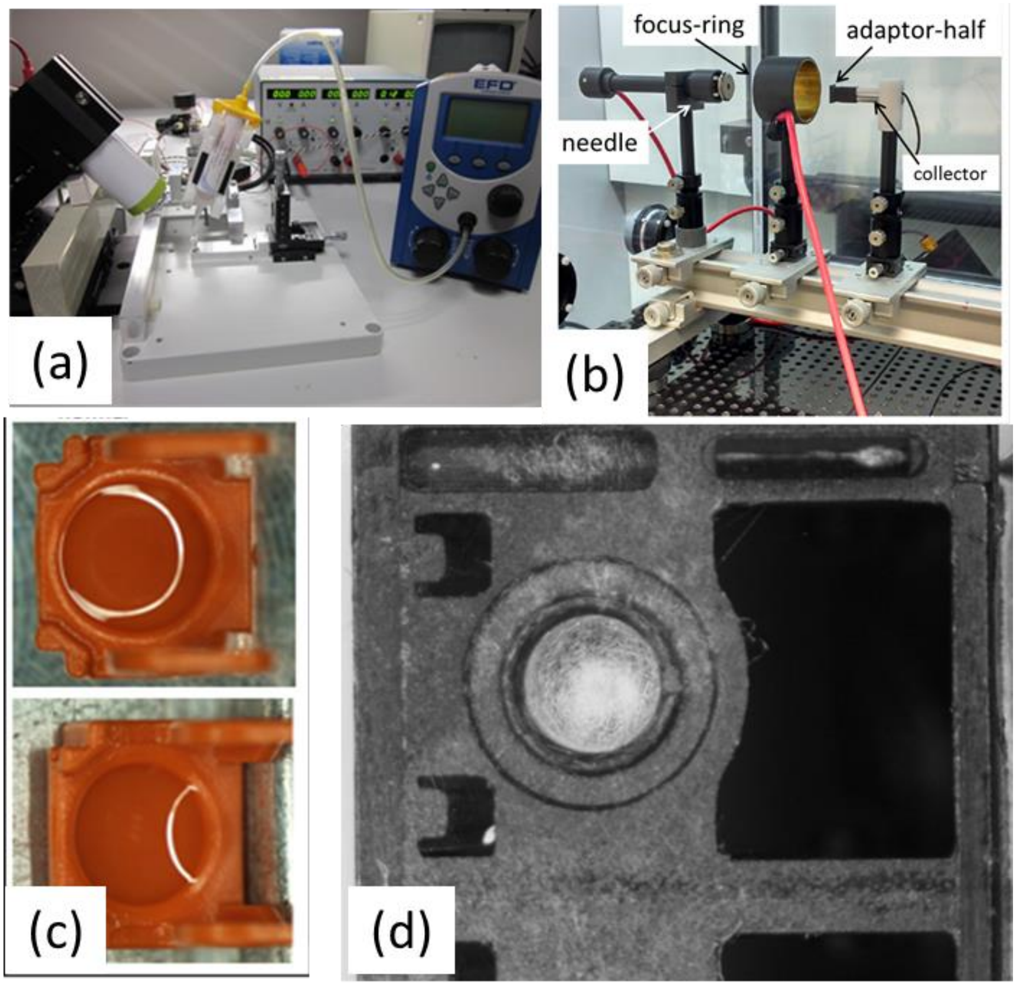


Figure 5 *: (a) Dispensing setup for the cleaning gel to apply into the shutter (b) Electrospinning equipment for confined electrospinning into the adapter (c) Shutter filled with cleaning medium (d) Electrospun scaffold in the VeCo adapter*

Dust is identified by the VECTOR consortium as one of the main causes for network reentrance and thus one of the main contributors to network OPEX.

In order to tackle this critical issue, the VECTOR consortium committed to implement self-cleaning intelligence in the Vector Connector and Adapter.

A **connector shutter** was designed such that the optical fibre is permanently protected when the connector is in the unmated state. Upon insertion in the Vector Adaptor the shutter is mechanically actuated by pivot points in the adaptor and opens up. The fibre is inserted in the alignment system at this stage and therefore is dust protected.

In order to increase the protection of the shutter, a **cleaning gel** is dispensed in the shutter cap in such a way that any stray contaminant on the optical fibre will be removed and trapped in the gel upon opening and closing action of the shutter.

A **mixture DoE** design study has been executed to find the most appropriate gel formulation that can be punctured by the fiber and still can protect the gel in outside plant conditions. The quantity of gel injected in the shutter was included as a DoE variable. The dispense system for the gel is shown in Figure 5(a); the filled shutter in Figure 5(c).

A second self-cleaning intelligence was incorporated in the Vector adapter. A **cleaning membrane** is deposited in the inner part of the adaptor which must be crossed by the fibre upon connection. As the fibre moves across the membrane, cleaning of stray contaminants takes place.

Several membrane materials were evaluated. A **micro-electrospinning technique** was developed allowing to deposit a fibrous material around the alignment system. With this technique micro- and nano-fibres are spun from a solution under a voltage of 30000V. The elasitc nature of the fibres allow the membrane to recover after the fibre is withdrawn, thus allowing the membrane to retain its cleaning capability for multiple connections.

The setup used to micro-spin the membrane is shown in Figure 5(b), whereas the membrane is shown in Figure 5(d).

2. Development of a microstructured alignment system

State-of-the-art alignment systems based on ceramic split-sleeves or glass capillaries are challenged by the activities which aim to develop a fully alternative concept that can be mass-manufactured by either **micro-injection molding** or **hot embossing** techniques.

The design effort is supported by Finite Element Analysis (FEA). Via FEA the behaviour of plastic parts in contact with an optical fibre is simulated. This allowed us to identify a set of **design rules** that could insure sufficiently low force to allow for fibre insertion and sufficiently high force to correctly align the mating fibres. Examples of FEA simulation of microstructured alignent systems are shown in Figure 6.

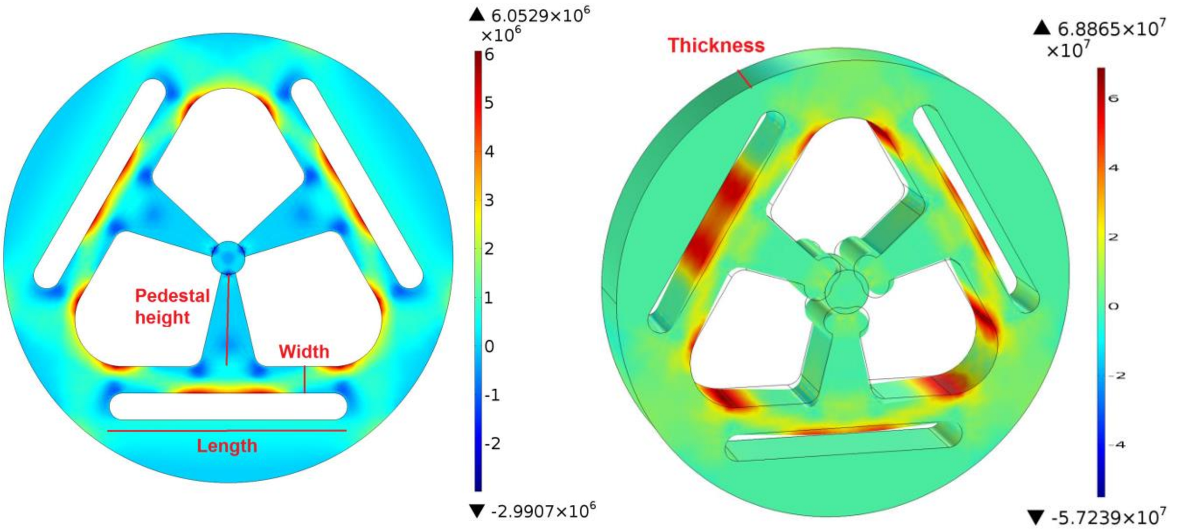


***Figure 6** : Examples of FEA simulation of microstructured alignent systems*

Two techniques were used to mould the final designs.

The injection moulding was performed using a **Battenfeld Microsystem 50** (see Figure 7(a)), whereas hot embossing was performed with a **Jenoptik HEX04** machine (see Figure 7(b)). These two machines are to be considered the state-on-the-art worldwide.

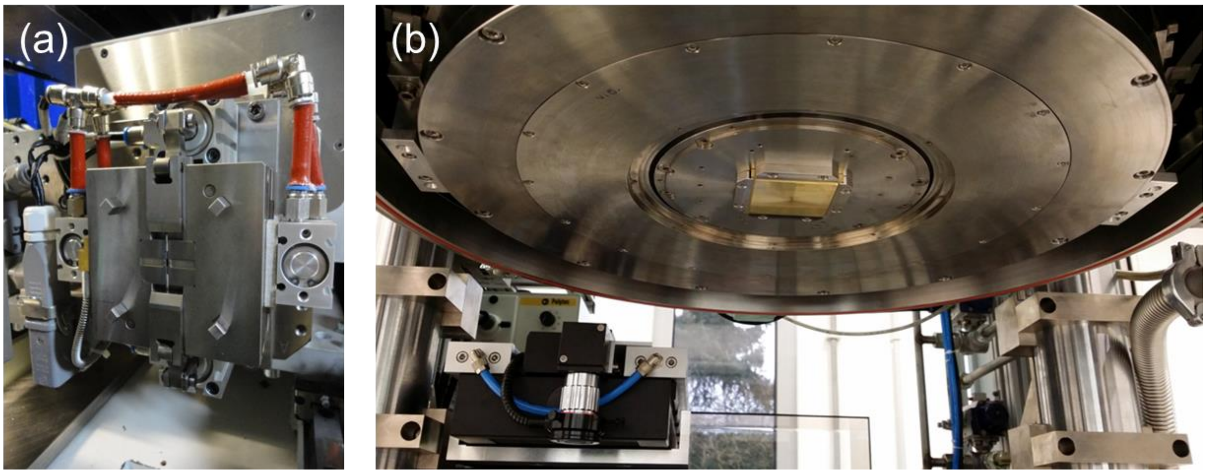


Figure 7 *: (a) Battenfeld Microsystem 50 available at Celoplás; (b) Jenoptik HEX04 machine available at Vrije Universiteit Brussel.*

The replicated parts were assembled and completed by injection of index matching material. Their optical performance was measured by TEC yielding the insertion loss distribution shown in Figure 8.

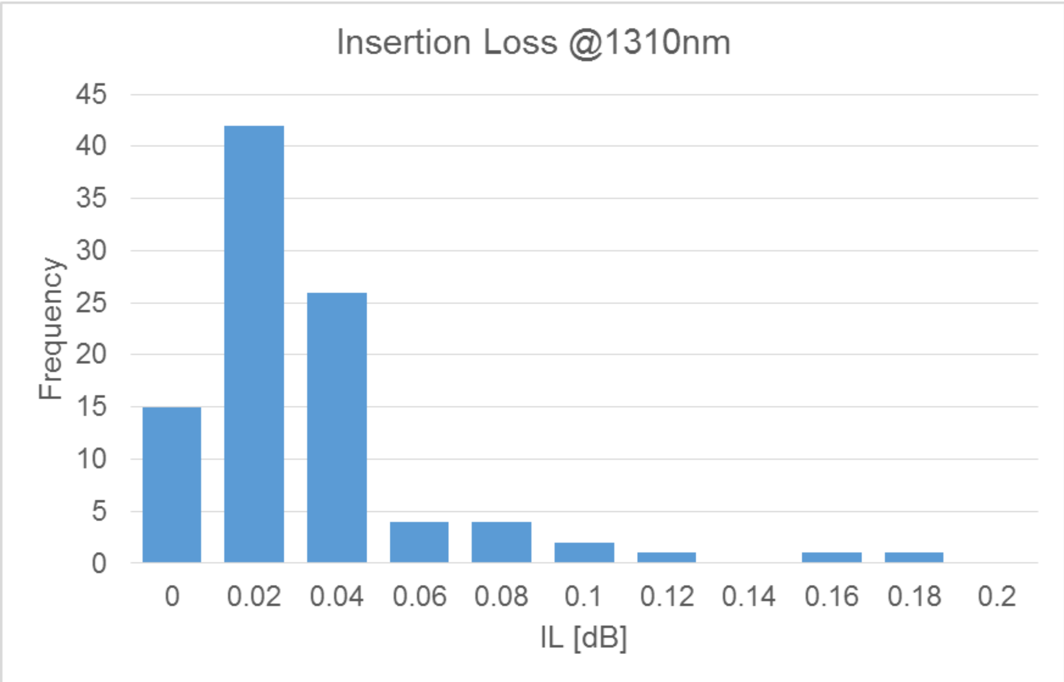


Figure 8 *: Distribution of insertion loss measured with the micro-structured alignment system. Loss figures meet and exceed grade B and are in line with achieving Grade A*.*

From the data in Figure 8 we conclude that the microstructured alignment system **meets and exceed the specification for a grade B connection**.

Environmental stability of the microstructured alignment system was tested by performing an IEC 61300-2-22 temperature cycling in air. Here samples are inserted in a climatic chamber together which oscillates between -40ºC and +70ºC with a dwell time of 2 hrs in the extreme temperatures. Insertion and return loss of the samples are continuously monitored during the test.

Results of the cycling are shown in Figure 9. We see from Figure 9 that insertion loss and return loss are **stable** during IEC 61300-2-22 temperature cycling.

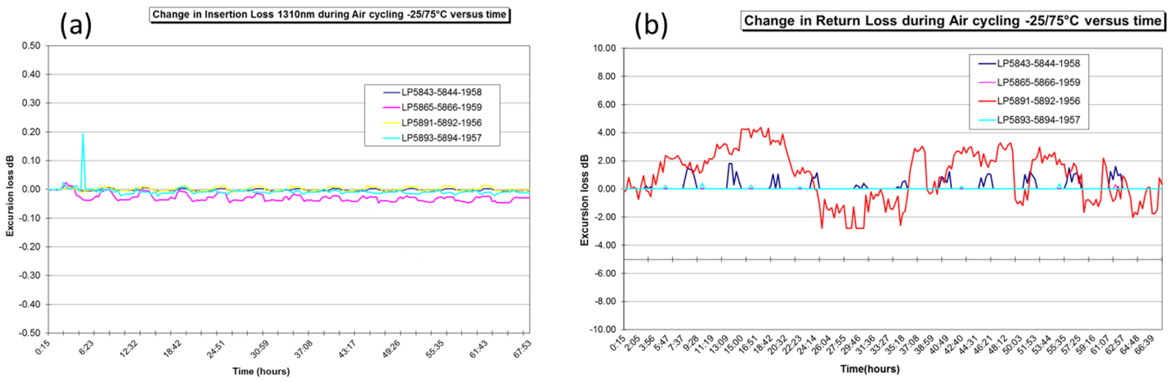


Figure 9 *: (a) Change of insertion loss at 1310nm during IEC 61300-2-22 temperature cycling. Specifications of ΔIL<0.2dB are met. (b) Change of return loss at 1310nm during IEC 61300-2-22 temperature cycling. Specifications of RL>60dB are met.*

3. Connector packaging

All VECTOR technologies are finally packaged in a connector that is compliant with the user's footprint requirements. All subassembly components as well as the final assembly ready for fire termination are shown in Figure 10.

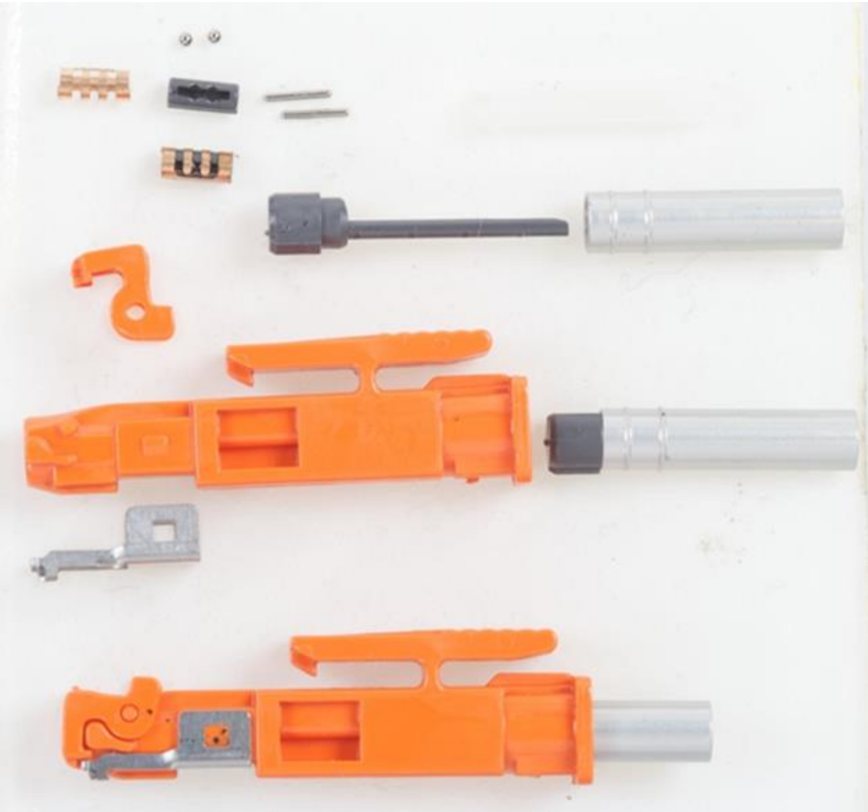


Figure 10 *: Final subassembly components and final assembled connector ready for fibre termination.*

4.3 Work package 3 : Disruptive techniques for fibre handling

Objectives

Within VECTOR we strived to develop an innovative highly performing field-installable connectivity system, consisting of two major developments.

- The development of a ferrule-less connector granting very high optical performance
- The development of a fully automated installation tool allowing for field installation by a general-skill technician.

An impression of both is given in the Figure 11 below.

(a) (b)

Figure 11 *: (a) A ferrule-less connector with adaptor, (b) a fully automated installation tool.*

The development of a ferrule-less connector is described in Work package 2. Within Work package 3 we focused on the tool and the processes required to terminate the glass fiber with a VECTOR Connector.

Fiber processes

Current glass fibers consist of a silica core which transmits the data, surrounded by a silica cladding of different refractive index which enables total internal reflection. Several protective outer layers can surround the glass fiber, such as an acrylate coating, a buffer jacket, additional strength members and a polyurethane outer jacket, see also Figure 12a.

Removing the outer layers up to the buffer jacket is relatively straightforward. However, to strip and process the fiber from buffer jacket to the glass fiber requires additional skills and is prone to variability when performed by a general-skill technician. The automated tool is therefore intended to handle all necessary process steps from 1000µm down to 125µm.

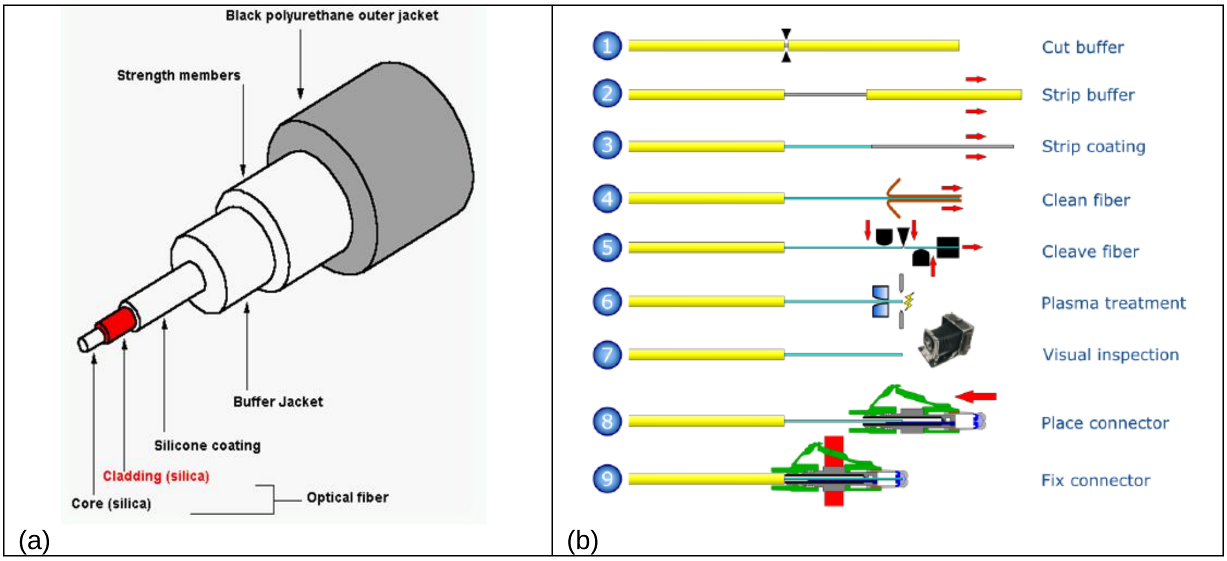


Figure 12 *: (a) Structure of a glass fiber (b) processes required to terminate the fiber with a connector*

An overview of the process steps executed by the tool is shown in Figure 12b. First, the buffer and coating are cut and stripped from the glass fiber. An additional cleaning step is integrated to remove any remaining coating particles. A cleave process then creates a flat facet on the tip of the 125 µm fiber. After cleaving, the fiber tip is plasma treated. In this process a surface treatment of the bare glass fiber is performed that reduces surface roughness and removes any artifacts from the cleaving process. Next, an optical inspection is performed to verify correct execution of the above steps. Finally, the connector is placed and fixed to the fiber using heat shrink fixation.

At the start of the VECTOR program some partners already possessed solutions to some of the process steps (like cleaving by Commscope for instance), others were not yet available. Within VECTOR the development focus was centered around the following steps which will be briefly discussed in the next paragraphs:

- Cleaning
- Plasma treatment
- Visual inspection
- Connector placement

1. <u>Cleaning</u>

In the VECTOR tool, stripping is performed by means of heat assisted mechanical stripping. To avoid damage to the fiber in this process (as well as contamination of the tool), the fiber is enclosed by tissue as depicted in Figure 13.

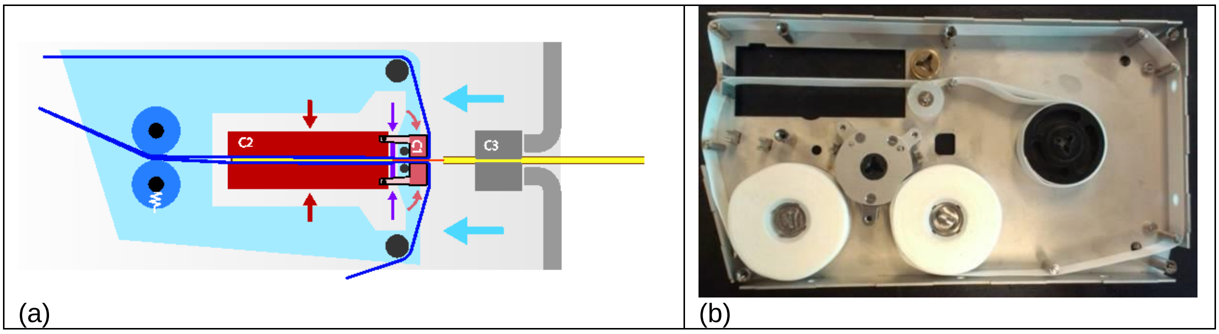


Figure 13 *: (a) schematic representation of fiber (yellow) in strip & clean unit. The red and purple arrows point to the the actuators with which the strip action is performed, blue is the tissue that surrounds the fiber during this process, (b) tissue cartridge as implemented in the tool.*

Within VECTOR, a development was started to find a chemical formulation such that the stripping action could be combined with a cleaning movement. During this cleaning movement the tissue is pressed on the bare glass by the clamps C1 (Figure 13a), however the result of this cleaning swipe with dry tissue alone was unsatisfactory. UGent identified an oil and made an emulsion with which the tape could be impregnated (see also Figure 14).

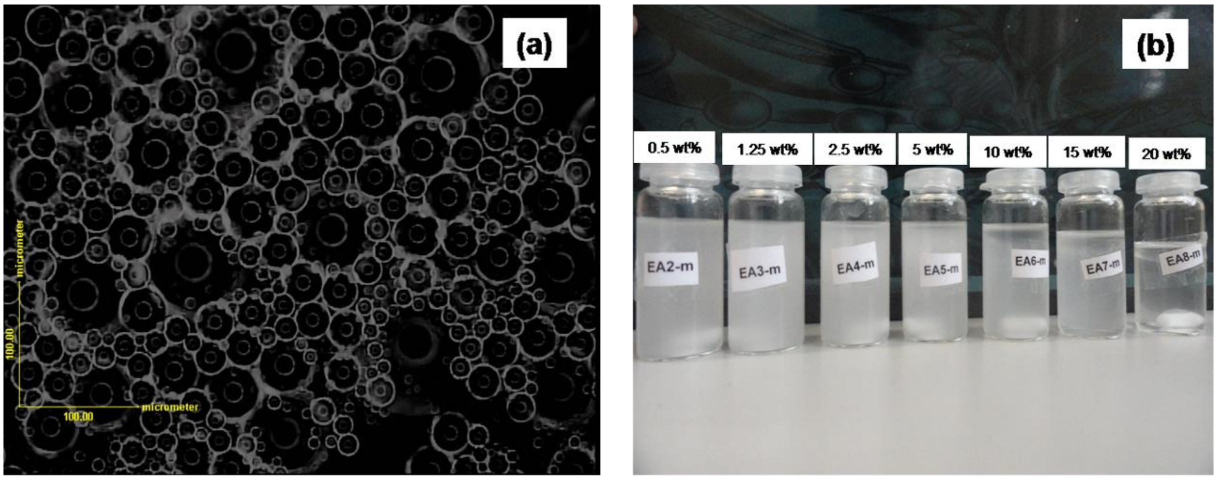


***Figure 14** : (a) Optical microscopy image of the microemulsion and (b) emulsions prepared in the presence of different concentrations of oil.*

Using this impregnated tape, the cleaning performance was significantly improved as shown in Figure 15.

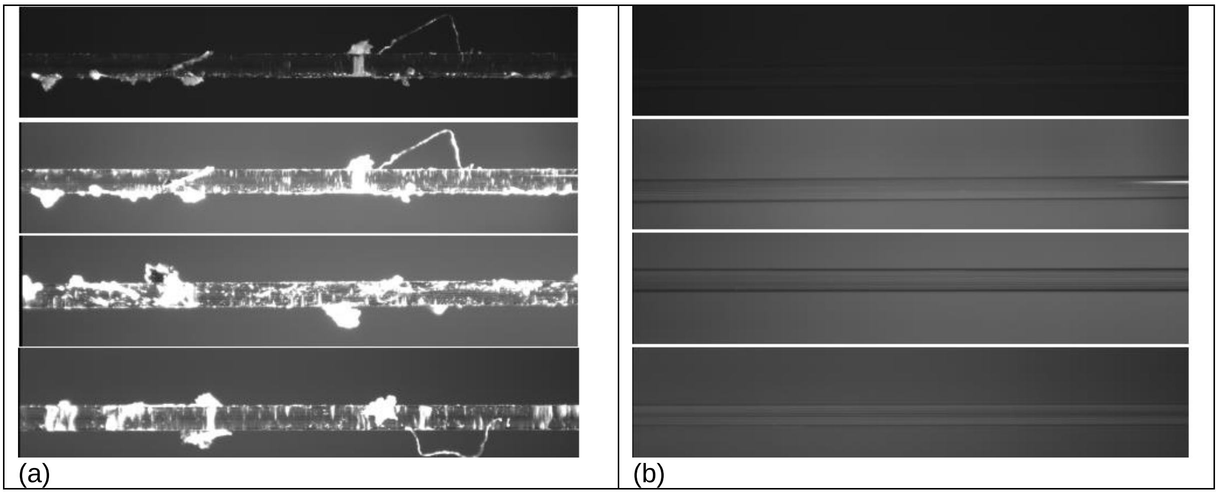


***Figure 15** : (a) Different viewing angles of miller-stripped fiber (b) same fiber after cleaning with the impregnated tape.*

2. <u>Plasma treatment</u>

To smoothen the surface and remove unwanted irregularities from the cleaving process, a plasma process was investigated to shape the geometry of the fiber tip. A setup was made by DEMCON as shown below in Figure 16.

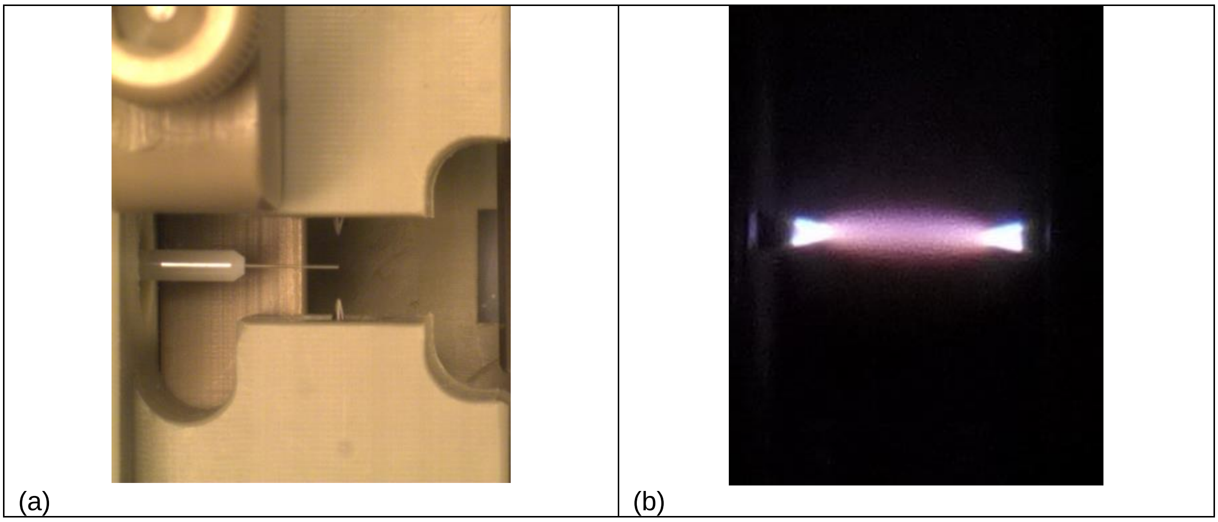


***Figure 16** : (a) top view of fiber positioned in between two electrodes (b) arc discharge created over the electrodes.*

The shaping of the tip as a function of the exposure to the arc discharge is shown in Figure 17a.

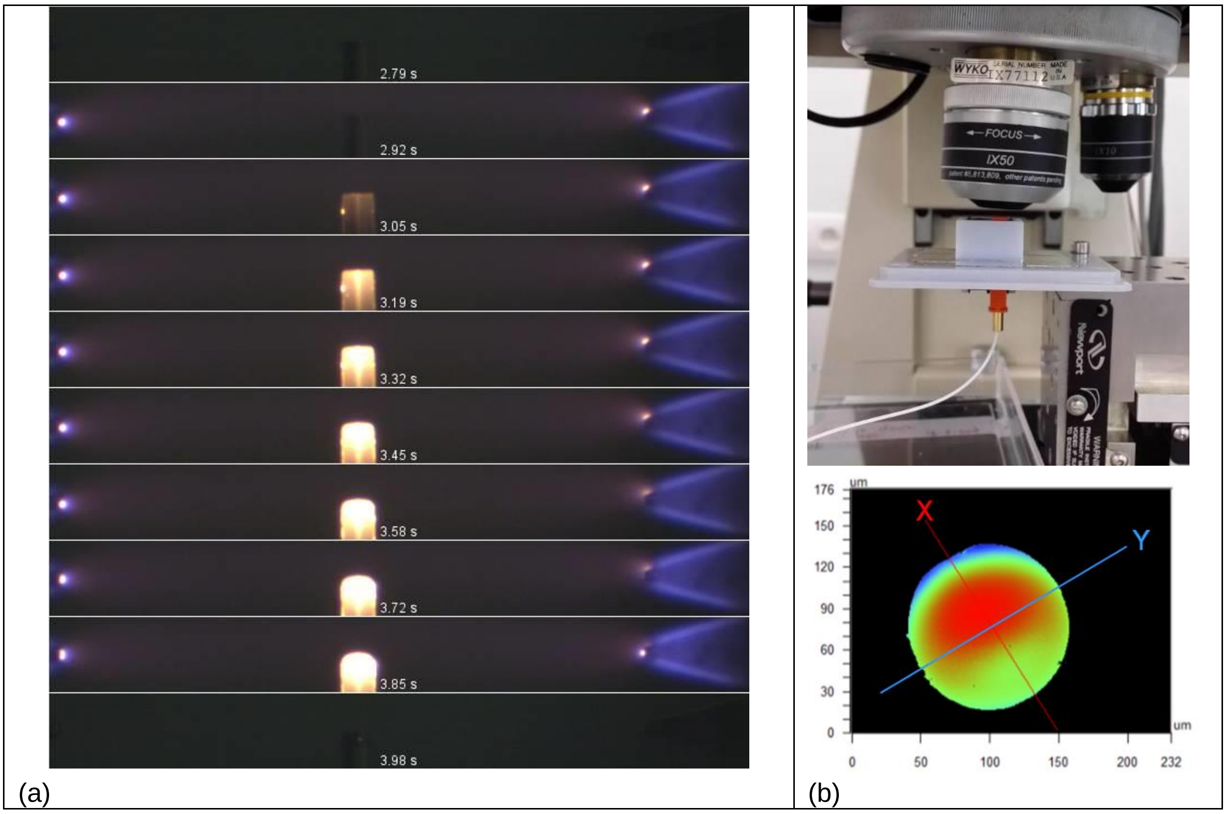
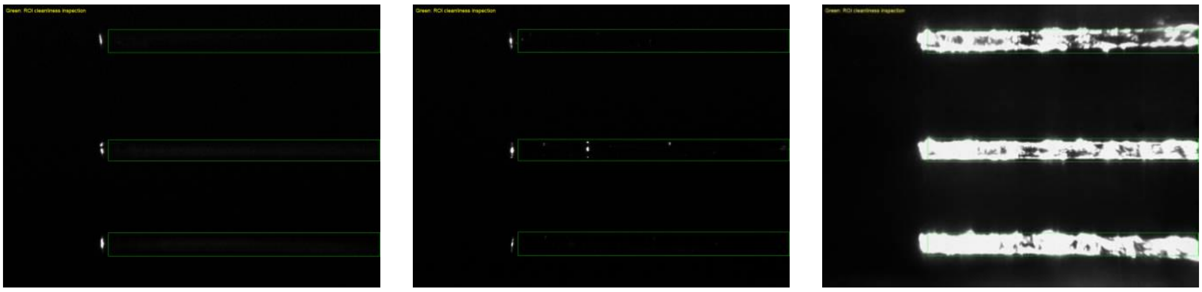


***Figure 17** : (a) Snapshots of fiber showing shaping of tip over time (b) Equipment and impression of analysis result to determine geometry*

VUB analyzed the actual geometry of the 125 µm tip with the help of their specialized profilometry equipment. An impression of the equipment and analysis result is depicted in Figure 17b.

3. Visual inspection

It was decided that the tool should also contain a quality inspection to make sure that the process train of stripping-cleaning-cleaving-arcing was performed correctly. Several image processing routines and illumination schemes were evaluated, an impression of which is shown in the following figures.



(a) (b) (c)

Figure 18 *: Dark field images of (a) Clean fiber, (b) Medium fiber and (c) Dirty fiber.*

In Figure 18 the fiber is illuminated from the top and only light from the cleaved angle (the tip) and light scattered by coatings remnants make it to the camera. That way a simple algorithm can be made to calculate the amount of debris left on the fiber.

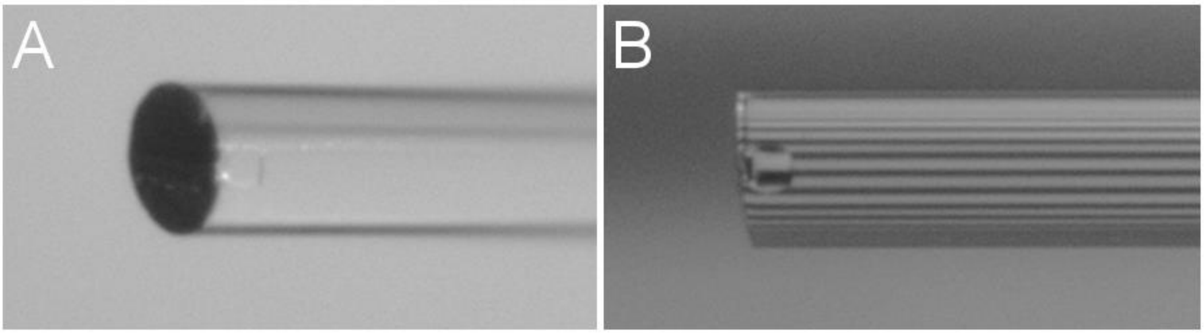


Figure 19 *: (a) Chip-off can be barely distinguished using direct illumination (b) Chip-off clearly visible as distortion of stripe pattern*

In Figure 19 a stripe pattern is used to illuminate the fiber from the side such that chip-offs (an artifact that can occur during the cleaving process) are clearly visible.

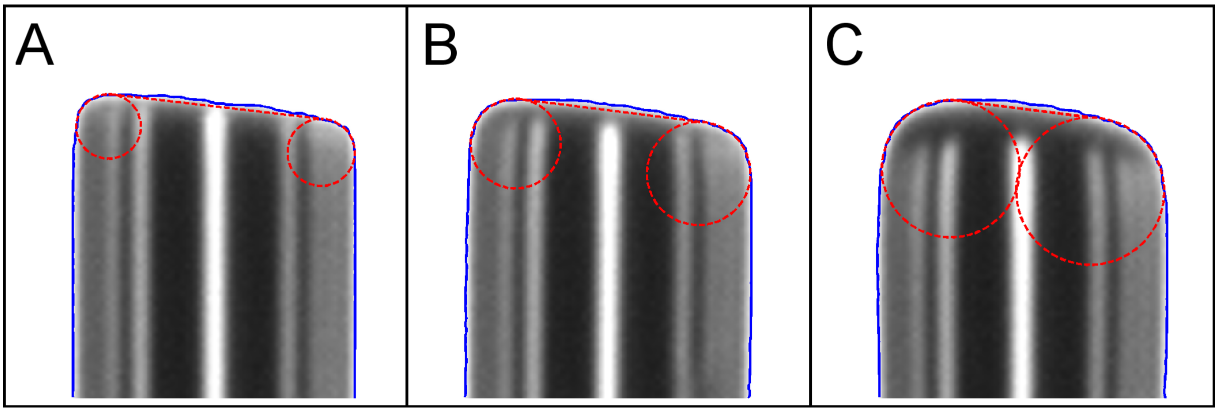
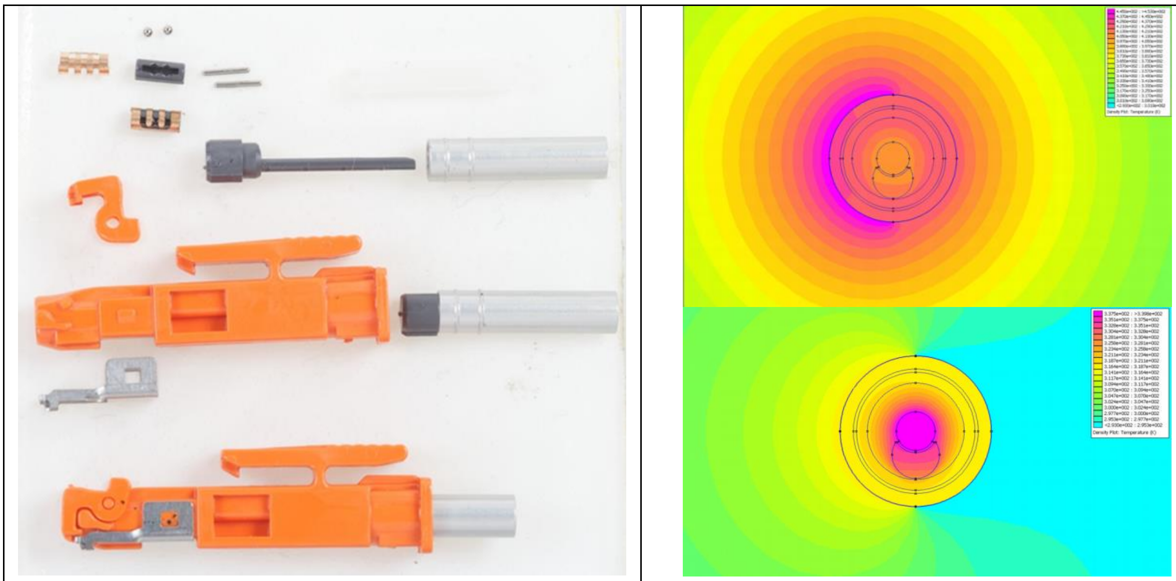


Figure 20 *: Image processing routine to quantify the fiber tip deformation as a result of the plasma treatment. Two circles (dashed red) and a connecting line segment (dashed red line) are used to quantify the degree of deformation after plasma exposure for (a) 0 ms, (b) 500 ms and (c) 1000 ms.*

In Figure 20, an edge detection algorithm finds the actual profile and orientation of the fiber (blue line), which is then best fit by a combination of two circles and a straight line segment (red). These parameters are used to quantify the degree of fiber tip shaping after exposure to the plasma.

4. Connector placement

For the connector placement, a scheme was developed in which a pre-assembled heat shrink would fixate the fiber to the connector. Several thermal simulations were performed and a module was built with which the fiber could be fixated to the connector in less than 60 seconds (see also Figure 21).



(a) (b)

Figure 21 *: (a) breakdown of connector assembly, (b) thermal simulations showing the fiber (inner circle) within the metal tube of the connector which acts as a thermal interface between tool and connector.*

5. VECTOR Installation tool

Last but not least the above process steps – which were examined using table top stations – needed to be integrated in the tool that was then used for the field trials executed by Telekom Deutschland and Telecom Italia.

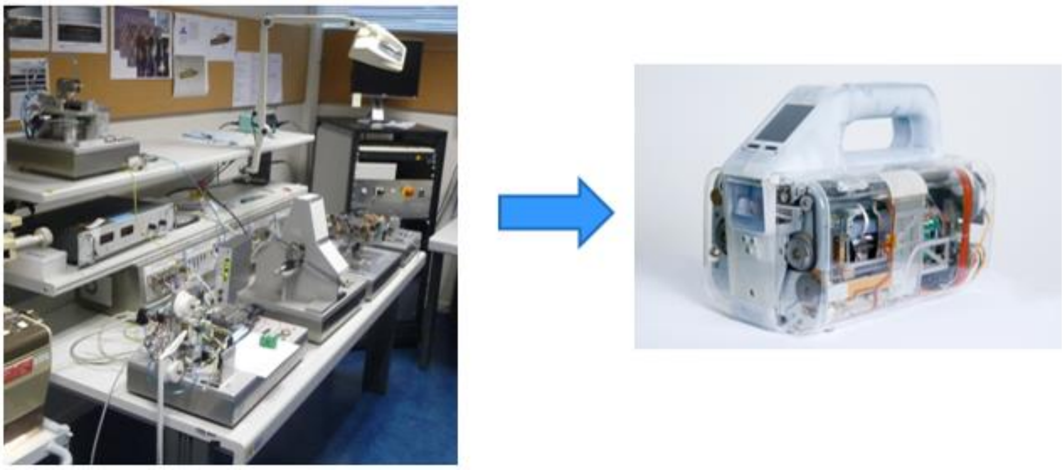


Figure 22 *: The VECTOR processes were evaluated using table top stations and their results needed to be integrated into a hand-portable tool.*

4.4 Work package 4 : Demonstration and field trials

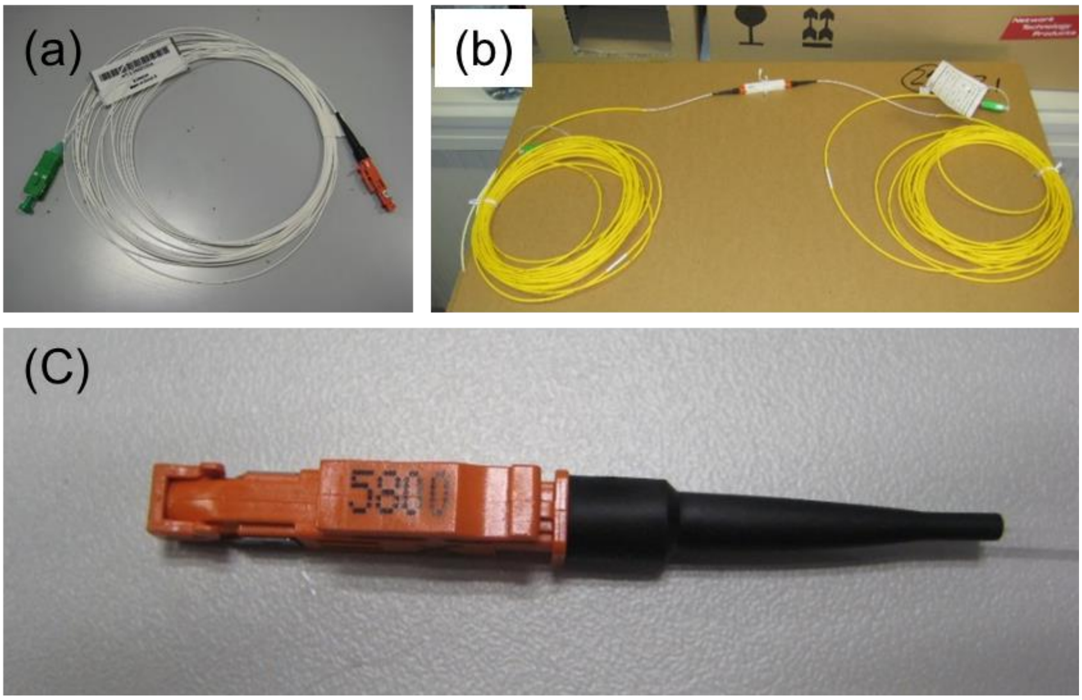


***Figure 23** : Different fibre terminations during end trials: (a) 900µm tight-buffered (TI); (b) 900µm semi-tight-buffered (DT) ; (c) 200µm primary coated (TI).*

Two sessions of user trials took place during the VECTOR program. Mid-project user trials were scheduled during Year 2 (2014) to assess the maturity of the connector consumables. End-trials took place in 2015 involving the whole VECTOR connectivity system. The main difference between the mid-trials and end-trials is the connector installation. During the mid-trials, connectors were installed by TEC and pre-terminated samples were shipped to Telecom Italia (TI) and Telekom Deutschland (TD) for evaluation. During the end-trials samples were installed at their premises by the end-users and extensively tested.

- **Flexibility** and **comprehensiveness** of the VECTOR solution were assessed by terminating a large samples of different cables that are representative of TD and TI's FTTH/P network
- **Ease of use** and **ergonomics** were verified by making end-user operate the tool independently with minimum support and instruction from TEC and DEMCON
- **Statistical Performance** of the system against specifications was assessed by performing optical testing on a large statistical sample of terminated fibres (>350 connections).

Trial's outcome

Samples

- 140 samples successfully installed out of 144 attempts (trial yield: 97%); Examples of the installed samples are shown in Figure 23 for different cable diameters.
- A total of **21 cable types** successfully terminated, fibre types included G.652.B, G652.D, G.657.A1, G.657.A2, G.657.B2, G657.B3
- Coating diameters ranging from 200µm to 900µm tight and semi-tight buffered from different manufactures and ranged from G.652 to G.657 types.

Optical testing

Consistent results were achieved by the users during the trials. Such results are in line with optical tests performed independently by TEC in its Kessel-Lo labs.

In particular the following tests were performed on **VeC-VeC** connections:

- IEC 61300-3-34 Insertion Loss in Random Mating → 0.07dB average optical loss; IL< 0.17dB in 97% of the connections (@1310nm)
- IEC 61300-3-6 Return Loss in Random Mating → RL > 64dB (75dB for most of the connections)
- IEC 61300-2-2 Endurance to multiple mating → test passed
- IEC-61300-2-22 Temperature cycling in air → excursion loss 0.3dB during the first high temperature cycle, no further excursion later.

The statistical distribution of the Insertion Loss measured over multiple cable types during the trials is shown in Figure 24a,b. Results comply with grade B.

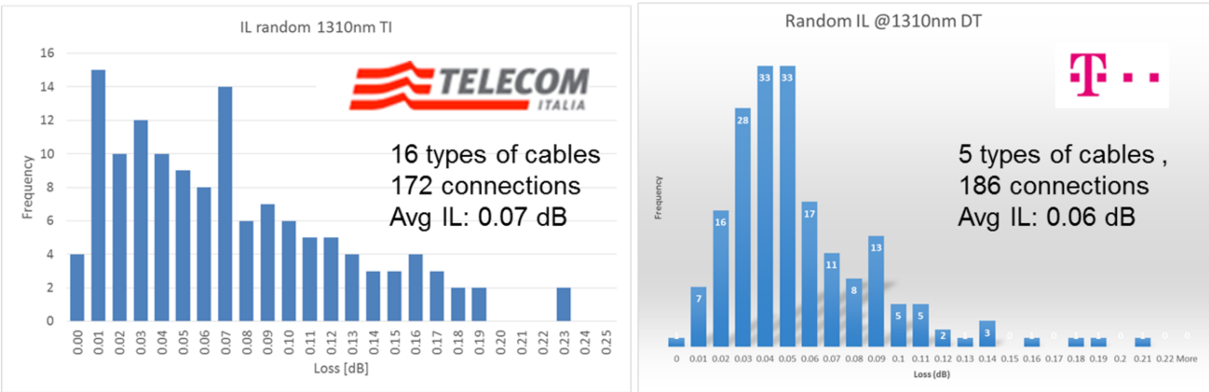


Figure 24 *: Insertion Loss distribution measured by the end-users during the VECTOR end-trials. Data are obtaining via random mating a subset of the installed connectors against each-other according to IEC 61300-3-34.*

A summary of the results achieved by the VECTOR consortium during mid-project trials and end trials in highlighted in the table below.

	Mid-project trials 2014	**End-trials 2015**
Cables types	11 cable types	23 cable types
VeIT yield	Not assessed as tool not available	97%
Insertion loss measurement	System not fully stable.	System stable. Consistent optical results from both end-users
IL in Random Mating IEC 61300-3-34	Close to grade B; Avg IL=0.11dB IL<0.25dB for 96% of connection (TI) ; Avg IL=0.19dB IL<0.25dB for 90% of connections (TD)	Meets grade B ; close to grade A* Avg IL=0.07dB IL<0.25dB for 98% of connections (TI) ; Avg IL=0.06dB IL<0.14dB for 97% of connections (TD)
RL in Random mating IEC 61300-3-6	Close to grade 1 RL>60dB 98% of samples	Meets grade 1 RL>60dB 100% of samples
IL in Temperature cycling IEC 61300-2-22	IL excursions up to 0.6dB during the first few hot cycles; excursion disappears as mechanical parts settle	IL excursion still observed on few samples, but limited to 0.3dB and on the first hot cycle only.
RL in Temperature cycling IEC 61300-2-22	Meets specifications	Meets specifications
Endurance IEC 61300-2-2	Meets specifications	Meets specifications

4.5 Work package 5 : Dissemination

The objectives of WP5 were to disseminate knowledge generated in the VECTOR project, to study the wider socio-economic impact of the knowledge generated in VECTOR, to promote the exploitation of the VECTOR results and to investigate 'take-up' actions based on the outcome of the VECTOR project. This WP5 consisted of 2 tasks, i.e. Task 5.1 on Dissemination and Task 5.2 on Exploitation. Only Task 5.1 on Dissemination is covered in this Final Report.

The main dissemination activities that have been conducted in the frame of Task 5.1 during the execution of VECTOR include:

- The setting up of a public website of VECTOR
- The production of **2 versions of a promotional movie** about VECTOR and the posting of that movie on youtube.com
- The publication of **2 press releases** about VECTOR
- The organization of a **VECTOR workshop**
- The preparation of scientific and technical dissemination activities, consisting of **2 peer reviewed journal publications**, the delivery of **19 technical presentations**, and the presence at **11 technical fairs/exhibits**.

These are reported in more details below.

1. <u>Website</u>

The VECTOR public website can be accessed through the url www.vectorfp7.eu.The website displays information of a fairly general nature about the project. The home page gives a first introduction to the project. It displays an adequate reference to the EU funding for the project by means of the following acknowledgement "This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 318247" at the bottom of the webpages. The impact achieved by the public website of VECTOR can be summarized by the website access statistics that have been obtained using the google analytics tool. In the period March, 2013 – September, 2015, 4075 first time visitors have accessed the website (Figure 25). Whilst most visits came from Belgium, Germany and Portugal, i.e. countries represented by VECTOR beneficiaries, many visits were also received from USA, Brazil, China and the UK.

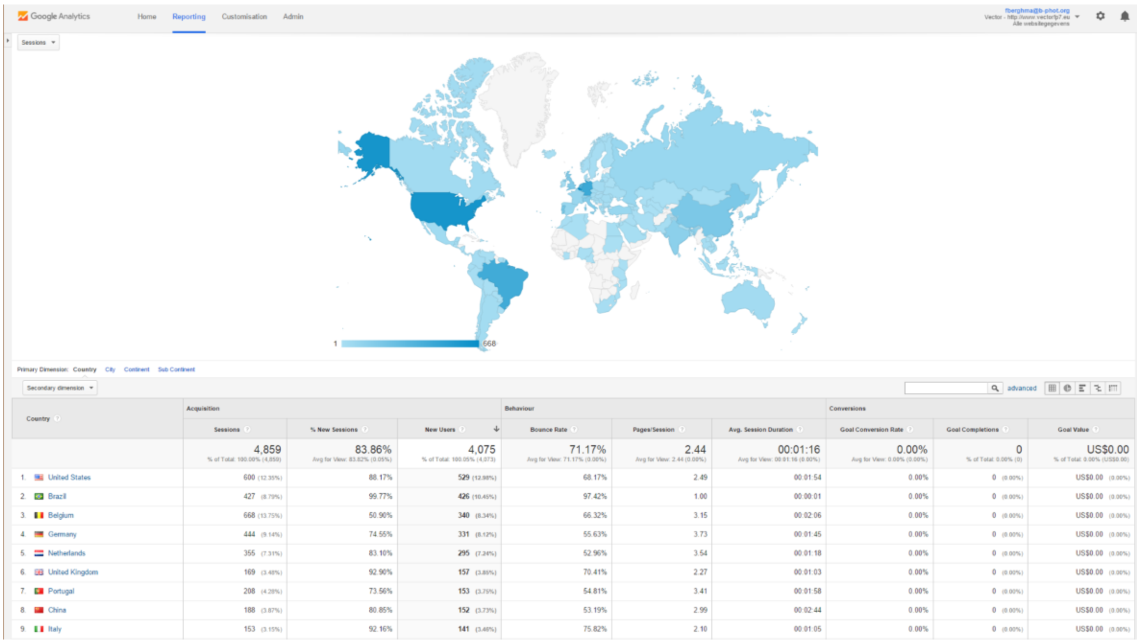


***Figure 25** : Google analytics geostatistics for www.vectorfp7.eu for the period March 10, 2013 – September 30, 2015.*

2. Final VECTOR movie

The VECTOR movies are a major general dissemination tool of VECTOR. Their intention is to explain to a non-specialized audience what VECTOR is about, what it intended to develop, how it succeeded in doing so and what overall impact it achieves. The production of the movie has been subcontracted to Mad Monkey Studio's (www.madmonkey.be), which is a company that delivers video productions for non-profit organisations. The first version of the movie has been posted on the VECTOR website and on youtube on 3rd April 2013, with an update uploaded on 17th April 2013. The link to this first version on youtube is http://www.youtube.com/watch?v=RzhDDlpK6iY. This first version has received 459 views. The second and updated version has been posted on youtube on 16th July 2015 with link www.youtube.com/watch?v=OKDY3kObDX4 (Figure 26). At the time of reporting this new movie has received over 100 views.

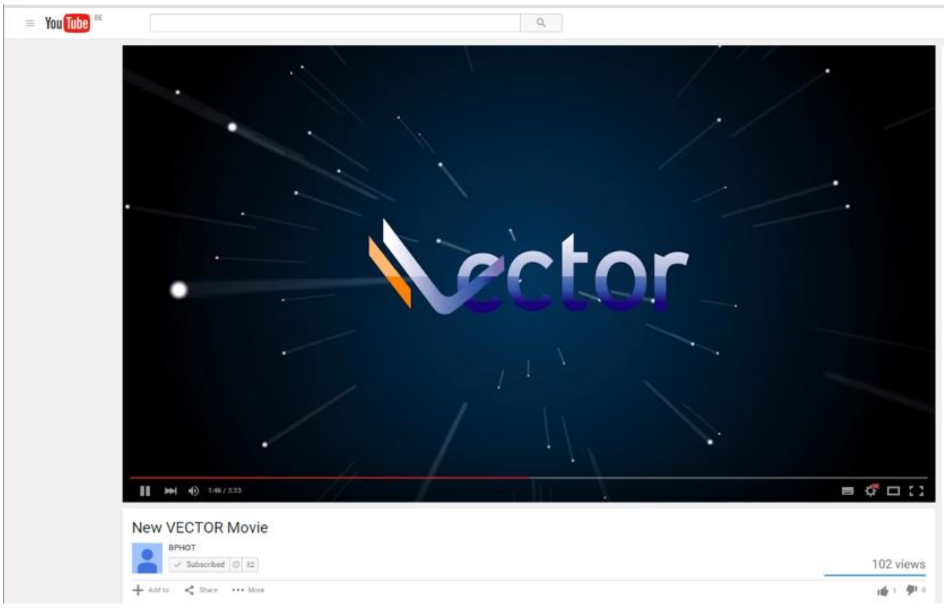


Figure 26 *: Screenshot of the VECTOR movie available on youtube.*

3. Press releases

VECTOR has produced 2 press releases. A first and early press release about VECTOR has been issued by the Project Coordinator and by VUB with the start of the project. It was the first dissemination activity of VECTOR that announced this European initiative and that provided early background information about a European effort financed by the European Commission to make optical fiber connections fast and reliable in order to accelerate the roll-out of fiber optic communication networks in Europe. The press release has been officially published on October 31, 2012 and is also available on the VECTOR website (www.vector-fp7.eu). This press release has been echoed on several websites (e.g. http://optics.org/news/3/11/17) and published on VECTOR beneficiary websites as well.

A final press release (see text in Figure 27) about VECTOR has been prepared by the Project Coordinator and by VUB following the end of the VECTOR research project. This was the last dissemination activity scheduled within the funding period of VECTOR, with the objective to announce the main achievements and the technical success of VECTOR, with inclusion of quotes from the telecommunication operators as end users of the VECTOR technology. The press release is to be sent to a list of technical magazines and press contacts and published on CommScope's blog http://www.commscope.com/Blog/ addressing thousands of recipients across the globe. Reporting on the impact of this final release in this document is not possible as the final press release still needs to be published. The required approval of the publication by CommScope's marketing and corporate PR department is pending.

PRESS RELEASE

VECTOR PRODUCES NOVEL, FAST AND RELIABLE OPTICAL FIBER CONNECTIONS

Brussels, December 4th, 2015 - Novel optical fiber connectivity solutions are required to accelerate the deployment of optical fiber communication link-based high speed internet access. In order to distribute signals in fiber optic networks, optical fibers need to be connected with each other, preferably in a reconfigurable manner. Installing connectors on such tiny glass optical fibers in the field currently requires highly specialized personnel and a multitude of dedicated tools. Dust and dirt made it almost impossible to achieve field connections with a quality level close to that attainable in a factory or lab environment. The VECTOR project provided a ground-breaking solution to this problem.

The VECTOR solution builds on a ferrule-less connector granting ultra-high optical performance and on a fully automated installation tool allowing for field installation by a general-skill technician. A major result is the optical performance of the ferrule-less VECTOR connector, which meets and exceeds the very severe so-called 'grade B' insertion loss specifications for optical connectors, in accordance with the International Electrotechnical Commission's IEC 61300-3-34 international standard for random mated connectors. The connectors do not require cleaning between mating/unmating cycles: they possess a unique self-cleaning feature that keeps the fibre tip dust free and ensures low connection loss and high repeatability.

Telecom Italia and Telekom Deutschland – two major European telecommunication operators – evaluated the connector in their laboratories. Paolo Pellegrino from Telecom Italia testifies that 'testing VECTOR samples in Telecom Italia has been an amazing lab experience: we measured optical connectors and we obtained results that were only achievable with optical splices so far'. Elmar Pellenz from Telekom Deutschland confirms that 'the optical performance values obtained during extensive laboratory tests on a large set of assembled VECTOR connectors in the facilities of the network operators were very good to excellent. The requirements laid down in Grade B and even better can be met with this technology'.

The VECTOR connector is designed to be field-installable but can also be factory-installed. The process for installing the connector is far easier and less labour intensive than a ferrule-based connector. When compared to other field-installable connectors, the VECTOR connector is the least skill-sensitive.

Stephane Berghmans, project coordinator at CommScope is proud of the final result and believes that 'the VECTOR solution is what we needed to bring affordable ultrafast internet connections to all European households'.

Check out VECTOR technology at work: www.youtube.com/watch?v=OKDY3kObDX4

VECTOR (Versatile Easy installable Connector implementing new Technologies for accelerated fiber Optic network Roll-outs in Europe) was a European Commission funded research and innovation initiative in which universities and telecom industry teamed up to develop an innovative, low-cost and easy field-installable optical fiber connector technology. It exploits the latest developments in the field of heat-shrinkable materials, nano-materials, high-tech gels, micro-fabrication and micro-mechanical alignment systems to achieve optical connections with superior specifications. Partners from all over Europe have teamed up to achieve the project objectives. The project was coordinated by CommScope. VECTOR also relied on important contributions from DEMCON Advanced Mechatronics BV (The Netherlands), Celoplás – Plásticos para a Indústria SA (Portugal), Vrije Universiteit Brussel and Universiteit Gent (Belgium), Telecom Italia S.p.A. (Italy) and Telekom Deutschland GmbH (Germany).

Stephane Berghmans
Project Coordinator
Stephane.Berghmans@commscope.com
Mobile: +32 473 55 62 34

***Figure 27** : Final VECTOR press release*

4. VECTOR workshop

VECTOR organised a final workshop in order to disseminate its results, including selected information on the successful field trials, to interested representatives from academia and industry. The workshop was organised at the TE Connectivity (now CommScope) premises in Kessel-Lo (Belgium), more particularly in the EMEA Learning Center. The workshop was publicly announced on the VECTOR website and additional targeted invitations and eventually welcomed 43 participants. The programme of the workshop is provided in Table 1 below.

08h30 – 09h00 Registration and Coffee

09h00 – 10h45 Session 1 – Fiber connectivity

09h00 “Introduction” – Stephane Berghmans, Commscope
09h05 “Optical connector assembly from the operators perspective” – Elmar Pellenz, Telekom Deutschland
09h20 “State of the art of fiber connector technology” – Daniel Daems, Commscope
10h00 “Ferrule-less technology for an access network solution” – Peter Merlo, Commscope

10h45 – 11h15 Coffee Break

11h15 – 13h15 Session 2 - Microfabrication and micromachining

11h15 “Micromoulding challenges” – Marcos Sampaio, Celoplás
11h55 “Micro Power, the standard machine for small and micro parts” – Gerald Plöchl, Battenfeld
12h30 “Ultraprecision diamond tooling and hot embossing as alternative microfabrication and replication technologies” – Jürgen Van Erps, Vrije Universiteit Brussel

13h15 – 14h15 Lunch

14h15 – 15h45 Session 3 - Materials

14h15 “Polymer meccano: chemistry at its best for optical applications” – Peter Dubruel, Universiteit Gent
14h45 “Microcapsules and their applications: from textiles to composites materials” – Roberto Texeira, Devan Chemicals
15h15 “Concept and applications of electrospinning” – Marc Simonet, IME Technologies

15h45 – 16h15 Coffee Break

16h15 – 17h45 Session 4 - Mechatronics

16h15 “The VECTOR installation tool” – Martijn de Witte, DEMCON
16h45 “Inventive system development” – Ad Vermeer, Adinsyde
17h15 “The making of a factory in a box” – HenkJan van der Pol, DEMCON

17h45 – 19h15 Reception & Networking

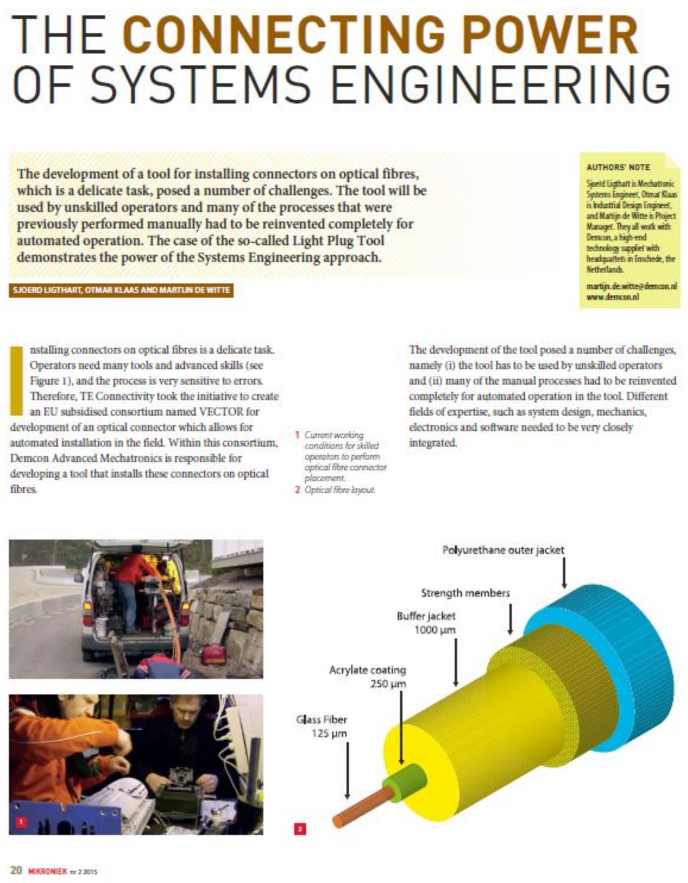
Table 1 *: VECTOR workshop programme*

5. Scientific Publications and technical dissemination

VECTOR has produced the following two joint peer reviewed journal publications.

- E. Ebraert, J. Van Erps, S. Beri, J. Watté, H. Thienpont, “Optomechanical design of a buckling cavity in a low-cost high-performance ferruleless field-installable single-mode fiber connector’” OPTICAL ENGINEERING, Volume: 53 Issue: 10, Article Number: 106102, DOI: 10.1117/1.OE.53.10.106102, Published: OCT 2014
- O. Klaas, S. Ligthart, M. de Witte, “The connecting power of systems engineering”, MIKRONIEK, Volume: 2, 2015, Published: APR 2015 (Figure 28)

This is a low number compared to the target of 10 journal publications that was initially put as an objective by the consortium. This underperformance during the execution of the project stems from the successful results and potential exploitation opportunities that prompted the need to take adequate IP protection measures before publication of the technical results and from the required compliance with the IPR agreements made between the academic and industrial beneficiaries of VECTOR in the Consortium Agreement. Considering that all protection measures and exploitation strategy are in place now, the consortium will make effort to still reach that objective of 10 publications and has made concrete plans to do so.



THE CONNECTING POWER OF SYSTEMS ENGINEERING

The development of a tool for installing connectors on optical fibres, which is a delicate task, posed a number of challenges. The tool will be used by unskilled operators and many of the processes that were previously performed manually had to be reinvented completely for automated operation. The case of the so-called Light Plug Tool demonstrates the power of the Systems Engineering approach.

SJOERD LIGTHART, OTMAR KLAAS AND MARTIJN DE WITTE

AUTHORS' NOTE

Sjoerd Ligthart is Mechatronic Systems Engineer, Otmar Klaas is Industrial Design Engineer, and Martijn de Witte is Project Manager. They all work with Demcon, a high-end technology supplier with headquarters in Enschede, the Netherlands.

martijn.de.witte@demcon.nl
www.demcon.nl

Installing connectors on optical fibres is a delicate task. Operators need many tools and advanced skills (see Figure 1), and the process is very sensitive to errors. Therefore, TE Connectivity took the initiative to create an EU subsidised consortium named VECTOR for development of an optical connector which allows for automated installation in the field. Within this consortium, Demcon Advanced Mechatronics is responsible for developing a tool that installs these connectors on optical fibres.

The development of the tool posed a number of challenges, namely (i) the tool has to be used by unskilled operators and (ii) many of the manual processes had to be reinvented completely for automated operation in the tool. Different fields of expertise, such as system design, mechanics, electronics and software needed to be very closely integrated.

1 Current working conditions for skilled operators to perform optical fibre connector placement.
2 Optical fibre layout.

20 MIKRONIEK nr 2 2015

Figure 28 *: First page of the DEMCON publication in Mikroniek.*

VECTOR has also conducted technical dissemination activities at dedicated workshops, meetings and international conferences and has participated in technical fairs. This resulted in a total of 14 technical presentation, the organisation of company booths at 9 technical fairs and exhibits and in the organisation of backroom meetings and dedicated workshop sessions by TEC's Fiber Innovation Department. By doing so the VECTOR solution was presented to 23 CTO/CEO level managers of international carriers/operators and to about 30 international operators of which:

- Bezeq (Israel)
- British Telecom (United Kingdom)
- Deutsche Telekom (Germany)
- DFA Telecom (Italy)
- Jazztel (Spain)
- Kingston (United Kingdom)
- Konza
- KPN (The Netherlands)
- Mobily (Saudi Arabia)
- Orange France (France)
- Orange Poland (Poland)
- Reggefiber (The Netherlands)
- Rostelecom (Russia)
- Skanova (Sweden)
- Saudi Telecom Company (STC) (Saudi Arabia)

- Stofa (Denmark)
- Swisscom (Switzerland)
- Telecom Austria (Austria)
- Telecom Italia (Italy)
- Telefonica (Spain)
- Telenet (Belgium)
- Teliasonora (Sweden – Finland)
- T-Mobile Czech (Czech Republic)
- Turk Telecom (Turkey)
- Vodafone (United Kingdom).