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An Installation Project of an Optical Fiber Backbone Line

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The purpose of this thesis was to plan, install, splice and measure an optical fiber backbone line for cables holding up to 864 fibers. The thesis also includes a section about physics behind fiber optics.

The project started from planning the fiber line installation and then moved on to installation. Installation was the most time-consuming part of the project. After completing the installation the planning phase for splicing was started. This included team and work area management and planning the schedule for fiber splicing. The practical part of splicing consisted of work area preparation, fiber cable preparation and splicing. The measurement phase was started after agreement with the customers on the wave lengths and format of the measurements. The measurements are currently in progress, and most of the results have been satisfactory. From over 2000 measurements under 10 percent did not reach the required quality level.

The lines will be used in a telecommunication backbone line and will support the western part of the capital area.

Keywords	Optical fiber, planning, installation, measurements

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Insinöörityön tavoitteena oli suunnitella, asentaa, hitsata ja mitata valokuiturunkolinja monella eri kuitukaapelikoolla. Työssä perehdyttiin myös valokuituteknologian takana olevaan fysiikkaan. Työssä suunniteltuja runkolinjoja tullaan käyttämään maanlaajuisessa tiedonsiirrossa, ja ne tukevat pääkaupunkiseudun länsipuolta.

Projekti aloitettiin kuitukaapelin asennuksen suunnittelusta, ja siitä jatkettiin kuitukaapelin asennuksella, joka oli koko projektin eniten aikaa vievä osa. Tästä projekti jatkui hitsauksien ja henkilöstön aikataulujen suunnittelulla. Hitsauksen käytännön osio alkoi työaseman ja kaapelin valmistelulla, minkä jälkeen hitsaus voitiin aloittaa. Kun kuitujen hitsaus oli onnistuneesti suoritettu, päästiin aloittamaan mittauksien suunnittelu. Tähän osioon kuului neuvotella asiakkaan kanssa siitä, millä aallonpituudella mittaukset suoritetaan ja mikä on palautettavan tiedoston formaatti.

Mittaukset valmistuivat, ja suurimmaksi osaksi tulokset olivat tyydyttäviä. Noin 2 000 mittausta suoritettiin, ja vain alle kymmenen prosenttia tuloksista oli asetetun mittaustavoitteen alapuolella. Työ osoitti suunniitelun olevan tärkeä osa minkätahansa projektin osa. Totesin myös kommunikoinnin taytyy olla selkeää esimiesten, ja alaisten välillä.

Avainsanat	Valokuitu, suunnittelu, asennus, mittaus, tiedonsiirto

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Appendix 1. Splicer Datasheet

Abbreviations

APC	A snap-in connector but has a fiber part cut in the angle.
LC	1,25-millimeter snap-in connector
MM	Multi-mode
SC	Snap-in connector
SM	Single mode

1 Introduction

To process this final year project, I was part of a team that was tasked for planning, splicing and installation of backbone optical fiber cables that will be used for data communication of telecommunication operators. Once operational the network has the capacity to cover traffic up to one third of the capital city tele and data communications.

There were four major lines that we were tasked to make, one 96-fiber cable, two 432-fiber cables and one 864-fiber cable. There were also a few smaller installations for cable sizes of 192-fiber cables. The potential traffic of this backbone network will possibly cover up to one third of the capital city tele and data communication traffic. All these fibers need to be fusion spliced in order and the fibers have a standardized color order. This order varies depending on the country.

The time reserved for completing this project was estimated to be about a year. The goal was to splice the optical fiber connections and measure them using a fiber radar. This thesis will describe the different phases of the project and the technologies that were used, also the equipment used will be described. This project was started in the autumn of 2015 and cable installation was finished in the spring of 2016. The splicing part of the project began in the summer of 2016 and continues for the time being.

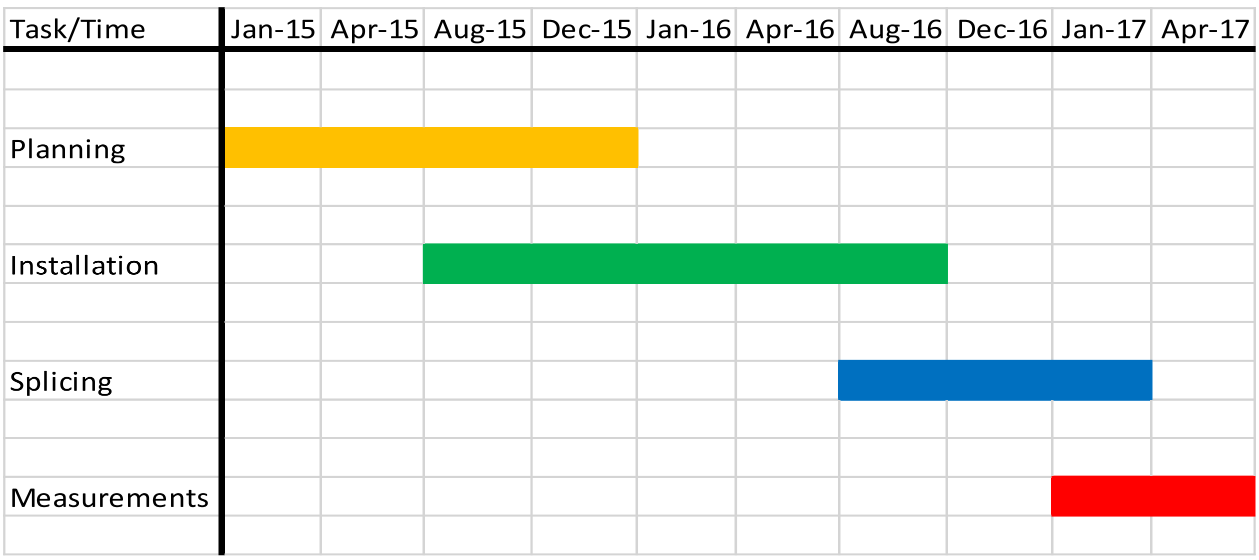


Figure 1. Project timetable.

2 Introduction to fiber optics

Optical fibers are not a new technology .The physics behind fiber optics was discovered in 1840s and refined for data transmission in 1960-1980. In Finland fiber optics was used for the first time in the 1980s. The test was a huge success and this technology has been used ever since. The use of optical fiber connection to home was introduced in the Rautavaara project in 2000. Since then a fiber connection has been made easier for an everyday user to acquire. Most of the connections handled by the switching points were for single-family homes in the countryside where getting a connection would be extremely hard otherwise. [12]

The reason why optical fiber replaced copper/ Ethernet in subscriber lines was that it has a faster and more reliable connectivity. Since in the fiber cable the information is transferred with laser light, the information is transformed into zeros and ones by the router or switch port and the laser on the port blinks rapidly, thus shooting the light into the fiber. The fiber is actually a glass-based tube that has different density in the core and the outer layer. This causes the light that is traveling in the fiber bend, so that is does not escape the fiber unless the fiber makes a greater than 90-degree angle or there is fracture. [2]

There are two main types of fibers, multi-mode fiber and single-mode fiber. In the multi-mode fiber the core is larger than in the single more fiber, thus allowing more sending and receiving wavelengths to be used. Multi-mode has three different subtypes, Graded-Index, Step-index and Photonic fiber. These type will be presented in section 2.1. In the single-mode fiber the core of the fiber is much smaller than in the multi-mode. In single-mode fiber there are only two wavelengths in use 1550mn and 1310mn only these wavelengths are used, because they are have been proven to cause least loss. [8]

The fiber is relatively fragile and therefore the cabling that protects the fiber is extremely strong. The protective layer consists of hardened plastic, different types of metal layers that differ depending on the cable type and inner plastic layer that is more flexible. This makes the cable harder to peel, but it also protects the fibers from anything that might case the fiber to break or be damaged.

2.1 Physics of optical fibers

As the laser travels in the fiber, it is transmitted in two different wavelengths, namely 1310 and 1550 nm (nanometres). These wavelengths guarantee that incoming and outgoing information do not interfere with each other. The wavelengths are also used to measure the quality of the fiber after the splicing is done. When two fibers are spliced, the connected area of two separate fibers does not have as good optical quality as the original fiber. Therefore the connected area causes attenuation that might create interference in the signal. The working standard of network operators for this connection attenuation is at a maximum of 0.02 dB. If the attenuation is higher, the connection needs to be redone. On connectors of the switch the attenuation can be up to 0.2 dB depending on the connector. In today's fiber optics, the most common connector types are SC (standard connector) and LC (little connector). These two have been used as standard connector types for 10 years. In 2014, a new connector type called APC was published. This connector type is close to the SC connector, but the tip of the fiber on the connector is cut in to angles of 8-degrees making the attenuation of the signal much smaller than in SC or LC. The APC connector has been used as a standard connector over SC/LC since the beginning of 2015.

As mentioned, on optical fiber cable acts like a small and flexible glass tube which has two layers. These layers are usually made out of ultra-pure glass also called silicon dioxide. The outer layer, called cladding, has a lower index of refraction than the core. These layers can be clearly seen in the Electron microscope picture (figure 7).

Information is transmitted through the fiber via a high intensity laser that produces coherent light and LEDs that produce incoherent light. There are LEDs developed that have multiple quantum wells giving them access to a broader selection of spectrums thus allowing local-area WDM (wave division multiplexer) networks. [6]

Light travels in an optical fiber via reflecting along the edges of the two glass layers. As long as the light pulse traveling in the core hits the surface of the cladding at an angle greater than 44.35 degrees, it keeps bouncing back on in the inner layer of the fiber without refracting to the outer layer, as demonstrated in figure 2. However this only applies to MM fibers since light travels differently in an SM fiber. [5]

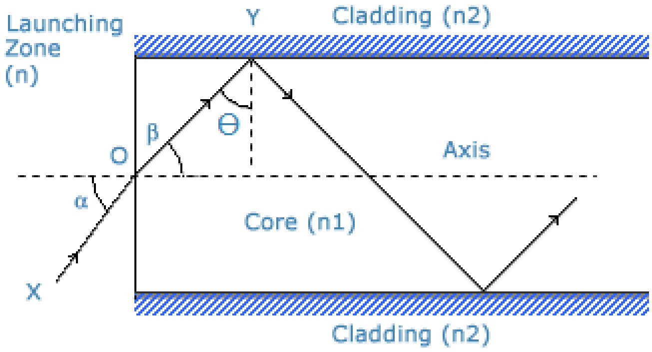


Figure 2. Light in the cable. Copied from [5].

Function for Refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad [11]$$

Function for Total Internal Reflection:

$$\frac{n_1}{n_2}\sin\theta_1 > 1 \;\; or \;\; \theta_c = \sin^{-1}(\frac{n_1}{n_2}) \qquad [11]$$

Splicing happens when two ends of fibers are connected together with an electric arc that causes high heat at the ends and joins the two fibers together. The two ends that have been joined in the splice will be as strong as a regular fiber. The quality of the completed splice is measured with Snell's law. [4]

Snell's Law:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1} \qquad [11]$$

2.2 Single mode fiber

A single mode optical fiber is mainly used for point-to-point connections. It allows high capacity data transfer via pulses of light, showing hardly any dispersion, because the light travels vertically in the core of the fiber instead of bouncing from the edge of the core and cladding. Compared to the MM fiber, the SM fiber attenuation of a pulse is almost unnoticeable. The single mode fiber splice requirements are stricter, because light travels vertically inside the fiber, thus being more sensitive to inconsistencies in the whole of the fiber line. An SM fiber connection usually has one signal per each direction with separate wavelengths. These wavelengths are usually either 1310 nm or 1550 nm. The glass core is 9-10 micrometres in diameter. The diameter of cladding is 125 micrometres and coating is 250 micrometres.

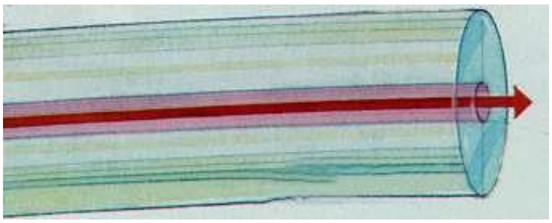


Figure 3. SM fiber. Copied from [7].

2.3 Multi-mode fiber

The MM fiber is bigger in size than the SM fiber, but the structure is the same. The MMS fiber has a core size of 50-100 micrometres. Cladding is 125 micrometres and coating is 250 micrometres. Because of the large core, multiple different modes can be sent at the same time in the same direction. The major defect with MM fiber is the distance restriction in its use: it can hold a 100 Gbit/s connection only up to 100 meters, a 10 Gbit/s connection up to 500 meters and 1 Gbit/s connection up to one kilometre. In closed industrial areas, like factories, MM fiber connections are often used, because the large and complex machines require a big capacity for their communication and surveillance data and that can be achieved using a single MM fiber cable. [6]

MM fiber cables come in two major types: one is called Graded-index MM fiber and the other is Step-index MM fiber.

In Graded-index MM fiber, the refractive index of the core diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light near the cladding to arrive at a receiver at about the same time as the slow but straight rays in the core axis. As a result, a digital pulse suffers less dispersion. [7]

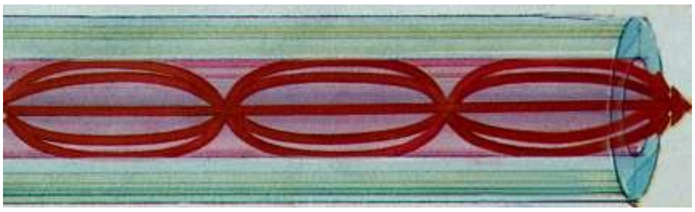


Figure 4. MM fiber Graded-index. Copied from [7].

The Step-index MM fiber has a large core, up to 100 microns in diameter. As a result, some of the light rays that make up the digital pulse may travel via a direct route, where others bounce off the cladding. The alternative paths cause the different groupings of light rays, referred to as modes, to arrive separately at a receiving end. The pulse, an aggregate of different modes, begins to spread out, losing its well-defined shape. The reason why spacing is left between pulses is to prevent overlapping of bandwidths where the information is sent. Consequently, this type of fiber is best suited for transmission over short distances, in an endoscope, for instance. [7]

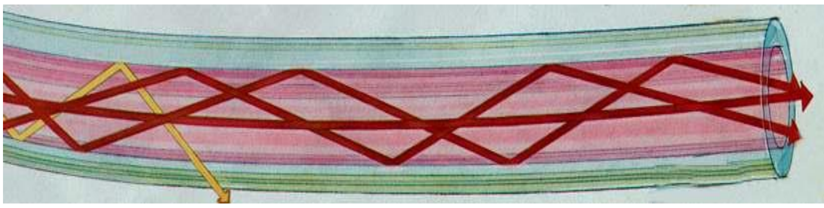


Figure 5. MM fiber Step-index. Copied from [7].

"Third and least use type of fiber is Photonic fiber. The transmission of light is done with number of cavities around the core. Core consists of glass or air. This type of fiber is not widely or at all used because the performance of this type does not meet the requirements or performance level of other fibers." [7]

2.4 Fiber optic connectors

The optical fiber cables are terminated in the switch with fiber optic connectors. There are many types of connectors, but the most common are SC/PC and LC/PC connectors. Both types are snap-in connectors being easy and safe to remove and attach. Lately, a new and improved version of these standard connectors has been made, called the APC connector. The APC connector has two subtypes: SC/APC and LC/APC. These connectors can be observed in figure 6.

Figure 6. Fiber connectors. Copied from [9].

The improvement in the APC connector was made on the surfaces that touch, as seen in figure 7. The PC of Flat PC type connectors have a larger change for reflection of light because of the flat surface. APC connectors are cut in 8-degree angle to reduce the change of reflection back to the source when connected. Different connector types are also used in different areas of networking. The FC and ST types are mostly used in telecommunications, for example in mobile base stations or in apartment buildings. The SC and LC types are used in backbone networks. Lately SC and LC types have been used in the same places as FC and ST types.

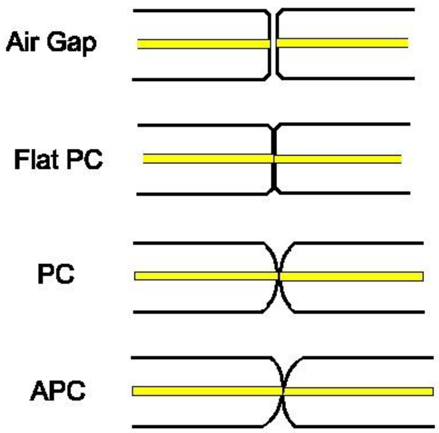


Figure 7. Connector contact surfaces. Copied from [10].

3 Cable installation to the tunnels

The goal of the project was to install a fiber optic cable network in the underground tunnels. The phases for the work were split in to four major sections planning, preparation, splicing and the measurements.

In each phase it is important to keep the work area clean, since optical fibers are extremely small and quite fragile. If a smallest amount of grease, dust or fine concrete dust gets into the fusion splicer when the splicing is started, it cause the weld to be faulty. In worst case the fusion splicer's cameras that are inside the splicing chamber could be damaged and would have to be sent to Japan to be fixed or replaced.

Cables were installed in a concrete platform in hard plastic pipes. Fiber optic cable sizes were 864, 432, 192 and 96. The numbers stand for the number of fibers in a single cable. Usually the working areas were tight and most of the work had to be done by hand.

3.1 Planning

The planning phase was conducted in autumn of 2015 and the time given for this this part of the project was only a few weeks. The original idea was that the backbone fiber optic cables were to be pulled from end to beginning from a single roll of cable. The way each splicing point would have been conducted according to the original plan was that around 100 meters of cable was to be pulled from the basement to the designated splicing room situated from 2-5 stories up from the basement, which is a 6-15 meters difference in elevation.

Planning of cable installation started with seeing the blueprints for cable routes and the rooms for fiber racks were stationed. After selecting routes based on the blueprints began checking the physical routes. In case the originally selected routes would not have necessary cable shelfs or rooms would change making the route unusable, there would be a secondary route that would be used. Areas where cables were pulled have pipes between them and one pipe for each of our cables was designated for installation. After these issues were clear, the installation of fiber cables could begin.

Planning for the splicing part was slightly challenging since there were three splicing teams to be managed and each of them was splicing fibers for different customers. The splicing order was also made for each ordered fibers. Splicing orders were rather easy to create since the panels sized for each customer are fixed and preordained, so the fibers that were not to go to panels were spliced to next fibers going onwards to the next point. The teams were assigned one per station and changed places since splicing should take same amount of time for each team. If one team finished their splicing before the other teams they would be taken to a station that was not occupied.

The measuring part of planning included acquiring the measurement standards from customers and finding out how they wanted the measurements to be returned. Two out of four customers wanted their results to have a pdf report with the original file that is in msor format. Msor is special file type created by fiber radar and can only be ready by the radar or a PC application provided by the radar manufacturer.

After the planning phase, work inspections were carried out and it was realized that the original plan for cable installation was not going to work. For once, the cable roll would have a weight of multiple tons and we would have needed a dedicated machine to move and spin the roll. Moreover, the cable would not be able to stand the high amount of tension caused by the overall 14-kilometre-long pull. Not to mention the cable route was like a serpentine; pulling the cable would break it through friction.

It was clear a revised plan was needed. After consulting customers, it was decided to have, one roll between each point, which required us to estimate the length using the architect’s plans and measuring. Altogether, there were eight points from where the cables needed to be pulled in the work area. The cable was also pulled to other important areas between the major splice points, the number of these areas varied from a minimum of one a maximum of five. A rough outline of the cable route can be seen in figure 8. Engineering part of this project was mostly in the way specifics were completed if problems were noticed.

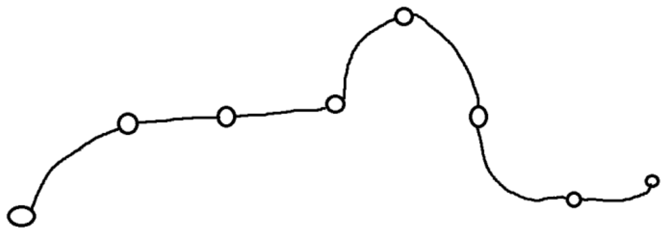


Figure 8. Cable route outline.

3.2 Applying to practise

After completing the planning we began installations. For this part of the project, a team of three people was assembled. The set of tools was fairly limited. Small working areas that changed every half an hour caused the tools to be small and light enough to be carried through the whole tunnel length. Our team had a small cart to push along the tunnel and to move tools around. The most important tools was TEPA, which is a power drill attached to a metal frame that uses the rotary power to pull the cable as seen in figure 9. Because the way the cables were made we could not use vehicles to pull the cables, most of the pulling had to be done by hand or with TEPA. The cable structure is be introduced later in section 4.2.

Figure 9. TEPA

Logistics was one of the most challenging issues we had to overcome in the crowded work areas. The cable rolls were from 250 up to 1500 kilos in weight and they had a diameter up to three meters. Naturally cable rolls were always moved with a heavy lifting machinery. After cable rolls were on their planned pulling areas, the cable installation could be started. This procedure usually lasted up to two hours, delays caused by overused and crowded roads. The simplest case for the cable installation was just to pull the cable into one man hole after another until a designated area was reached. In most of the cases, the man holes had other cables in the way and those had to be moved out of the way. There were also problems with sharp edged in the man holes that could damage the cable. Sometimes the man hole cable routes would not be aligned. In these cases, our team would install a cable roll that eased the cable through the man hole.

The cable ends were taken to the designated rooms used as splice points. Rooms were often located in 6-15 meters above the tunnel and served as entry points from where the cable would go into the buildings. Inside the buildings, the cable was terminated in standardized cabling racks that held multiple other cables. In some cases, the existing area to pass through the floor of the room did not have any free space, so our team had to use a diamond drill to make a new hole to the upper floors to get to the room. This method was only used a few times throughout the whole installation process.

3.3 End result

For the cable installation end result, the outcome followed the plan outlines and was acceptable. There were a few rare cases where the team had to divert from the plan given to them and had to take the cables through a route not planned to be used originally.

4 Splicing

The time reserved for completing all the phases was slightly over a year and the given time just enough for cable installation and cable preparation. The time required for fusion splicing was re/estimated, so this section would take around a year. The measurement part of the project was estimated to be started at the end of November. The tools used in the phases were knifes, a cutter, a fusion splicer, a fiber radar with control measurement ends and a fiber connector cleaner.

4.1 Equipment

The equipment used in the project was quite basic. It included cutters, a knife for peeling the cable, fiber cutters, a diamond cutter and a fiber splicer. The fiber cutters are only meant for cutting the fiber itself and the diamond cutter is used to cut the tip of the fiber to an angle of less than three degrees. As additional equipment, we used protective fiber straws that were put on the area where the protective plastic was peeled off.

The fiber splicer, or fusion splicer, uses an electric arc to heat up the two fiber ends to the point where the joining point of the tips is almost unrecognizable. The device itself is a 15-centimeter cube that holds the splicing and an oven for the fiber straws to be shrunk to provide proper protection for the area of the fiber that was spliced. The device has a battery that lasts up to a day for continuous splicing. Equipment for spicing can be seen in figure 10. As the charge from the battery fades, the end result will become increasingly worse to the point the splicing has to be redone. This problem does not occur when the device is powered by constant 230 volts from a wall socket. The other methods of splicing include laser, gas flame and tungsten filament splicing. These methods are old and proven to be not as effective as fusion splicing. Overall the most important equipment used though this project were the cutters and the splicer. [2]

Figure 10. Optical fiber splicing equipment and Fusion Splicer.

4.1.1 Technical information of Fusion Splicer 70S

Fusion splicer 70S was the model of the splicer used in the splicing part of this project. The splicer is equipped with a wall-socked charger that can be used as a power source, a BTR-09 battery that lasts up to three hours of continuous splicing or 200 hundred splice cycles, splices single and multi-mode fibers and has two cameras whose magnification is up to 320-times a normal view it has an oven for protecting sleeves, works with 40 millimetres and 60 millimetre sleeves and the splice protector shrink time is around 14 seconds. Fusion splicing electrodes handle up to 3000 arc discharges. Splicer machine and carrying case seen in figure 11. (Appendix 1) [6]

Figure 11. Fusion splicer 70S. Copied from www.aflglobal.com [6].

4.2 Preparation

In the preparation phase, concentration was on cabling, cleaning the initial working area and peeling the cables. Cabling started with taking the smallest backbone cable, which held 96 fibers, to the splicing area. After the cable was inside, next objective was taking the cable to the designated room, which was usually located one floor above. After the smallest cable was in the splicing area, same was done to other cables. After all the cables were in place, next step was building the rack that held the corresponding customer panels with connectors and boards that hold spliced fibers. Completed rack seen in figure 12.

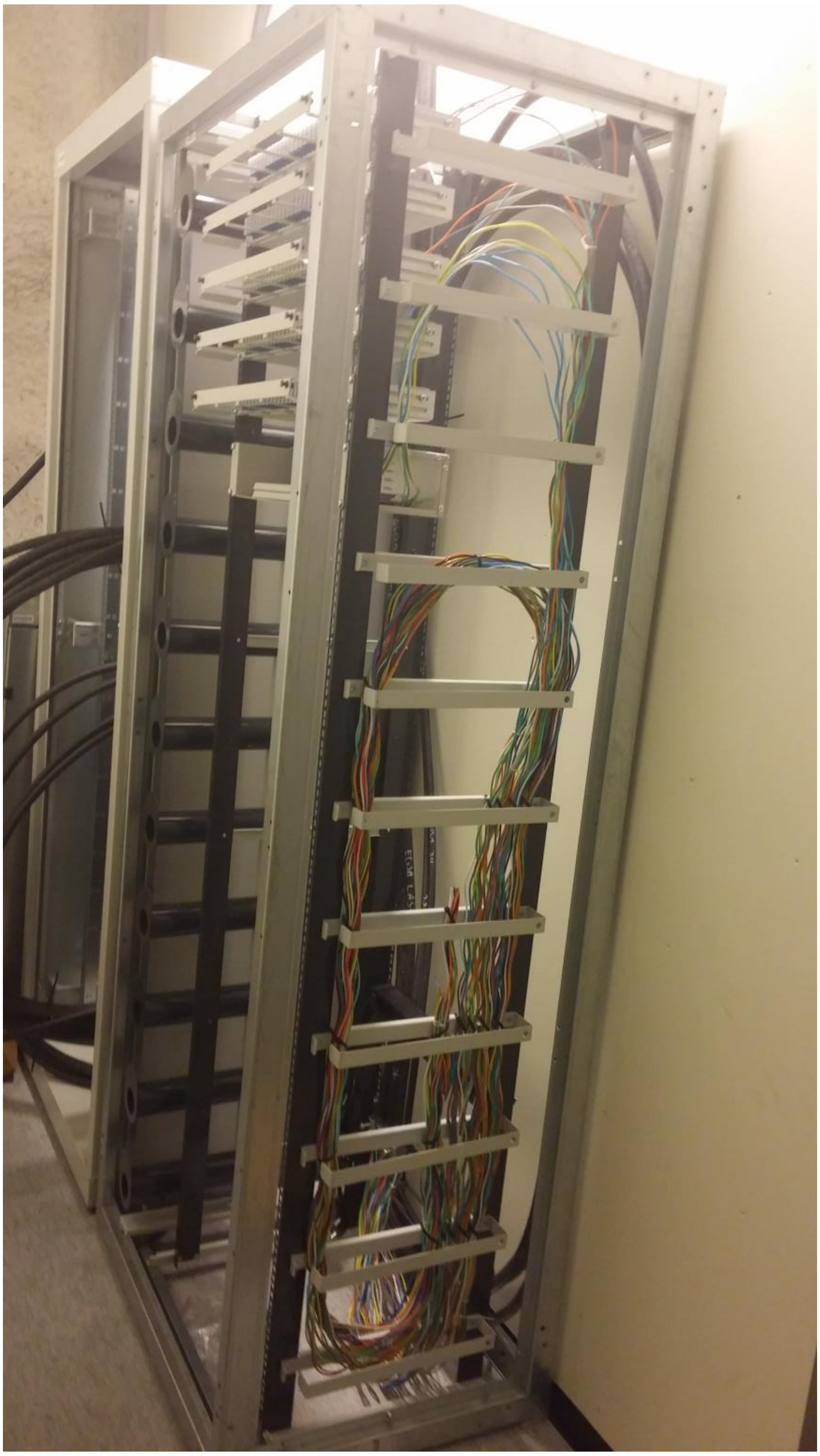


Figure 12. Bundles tied to fiber rack.

Next started the initial cleaning phase where the room was emptied from the extra material and swept clean from concrete dust. After that we moved to the peeling phase. It is one of the critical parts of the work, because one has to use a lot of precision to get through the tough and flexible shielding of the fibers. If too much force is used, the knife would cut through the plastic cover and damage the fiber inside. After the layer of plastic and cloth protection was removed, the fiber bundles were exposed. The bundles were color-coded and separated in different bundles based on the size of the cable. The cable size of 864 fibers would have three bundles, 432 has two and 192 and 96 cables both have only one bundle. Differentiating the bundles is important for the splicing order, because each bundle holds up to 12 plastic tubes. In the cases of 192, 432 and 864 each of the tubes holds 24 fibers that are separated in to 12-fiber bundles by an extremely thin string.

As seen in figure 12 the plastic tubes are separated by small zip ties and straightened afterwards for the removal of the plastic cover. For some of the splices, the fiber is put on the connector panel as seen in figure 13. Other splices are done in optical fiber splice modules that can hold up to 48 fibers. In that case, there are two fiber pipes per module. After this is done the fibers are cleaned from protective gel, which is used to keep any moisture off them. Fibers are also measured to the right length, so that they can be folded to their place. After all this is done the splicing can begin.

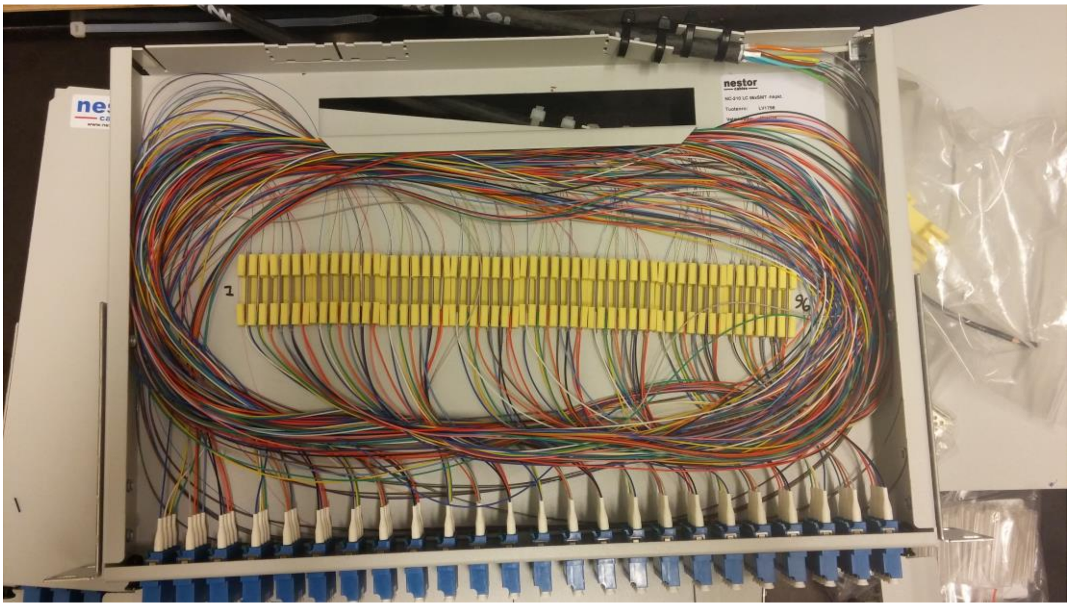


Figure 13. Optical fiber connector panel.

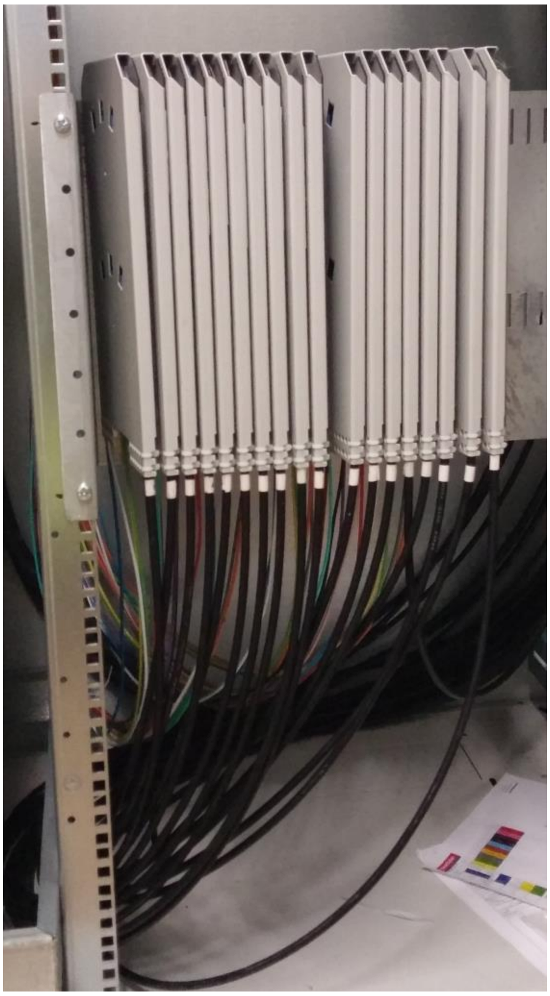


Figure 14. Optical fiber splice module.

The time to prepare each cable varied. Even each 432-fiber cable took a different time to prepare. The 96-fiber cable took around two hours to peel and to prepare for splicing. The 192-fiber cables were prepared together with one set of 432-fiber cables. The process for this was more complex since the cable handling with these bigger cables depends greatly on the design of the rack.

As seen in figure 15, the A type was easy to work with because the fiber modules make the splicing and handling of the fiber extremely easy and clean. Type B was challenging to say the least. Fiber pipes needed to be pealed up to five meters instead of the usual two-meter distance. Also handling the pipes like this needed to be done with care and precision because the bundles would be mixed up really easily. The 862-fiber cable was prepared in the same way as type A, but has the difference of the cables going to a separate cabin which is mounted to the panel rack itself as seen in figure 16.

Figure 15. On left A type 432 rack. On right B type 432 rack.

Figure 16. 864 panel rack and splicing cabin.

The standard number and color-ordering for optical fiber bundles is shown in figure 17. This ordering is followed in Finland and in Europe. [10] Note that colour coding in figure 20 and 21 follow the standard colour order but a black bar is added to each new 12-fiber bundle.

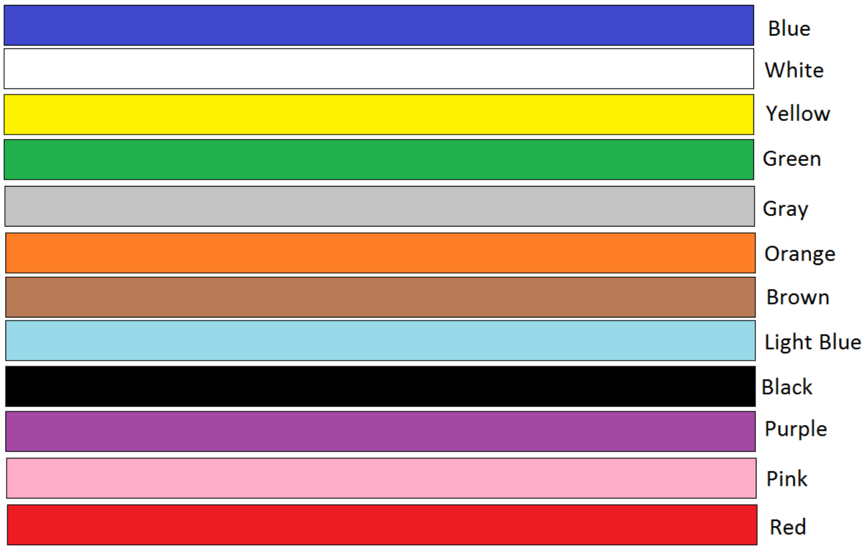


Figure 17. Standard Finnish colour order. Copied from [10].

For the optical fiber cable holding 96 fibers, each of the pipes holds 12 fibers and there are eight pipes in this cable. These pipes are made of medium strength plastic cover.

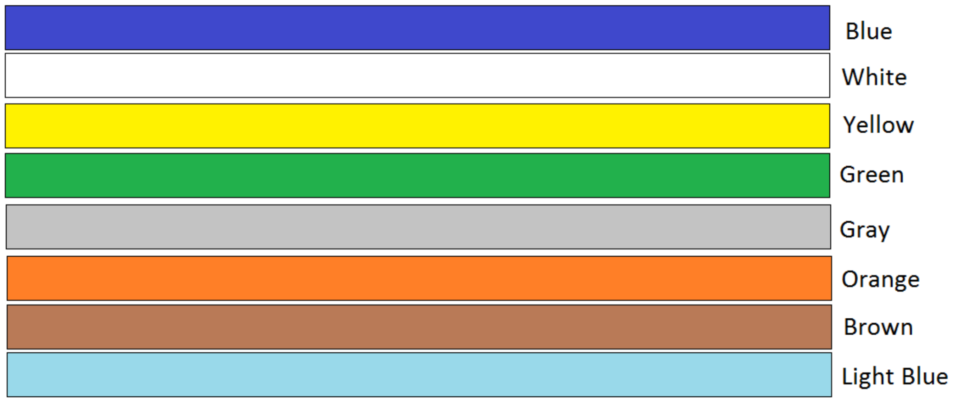


Figure 18. Fiber pipes in 96 sized cable.

Optical fiber cable holding 192 fibers has 8 pipes and each of these pipes has 24 fibers in them. These fibers are divided in to 12 fiber bundels and one bundle has a vblue string around it and the other one has a white string. These strings help splicing the fibers in the right order. The pipes themselves are made of hard plastic and for removing the pipes it is suggest to use a dull knife and medium amount of force.

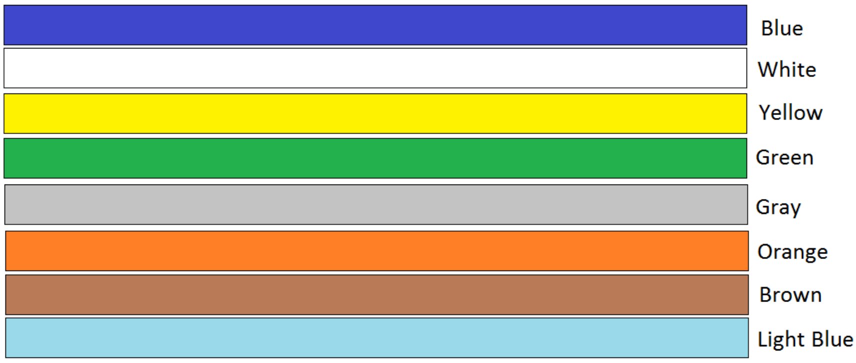


Figure 19. Fiber pipes in 192 sized cable.

Fiber cable holding 432 fibers has 18 pipes. Since the pipe number exceeds the standard 12 color order, the pipes after pipe number 12 have black stripes on them signifying them belonging to another bundle of pipes. Otherwise the pipes are just like in the 192-fiber cable.

Figure 20. Fiber pipes in 432 sized cable.

An optical fiber cable holding 863 fibers has 36 pipes. The pipe differentiating is similar to the 432 sized cable but pipes after number 24 has two lines. Otherwise the cable is similar to the 432 version.

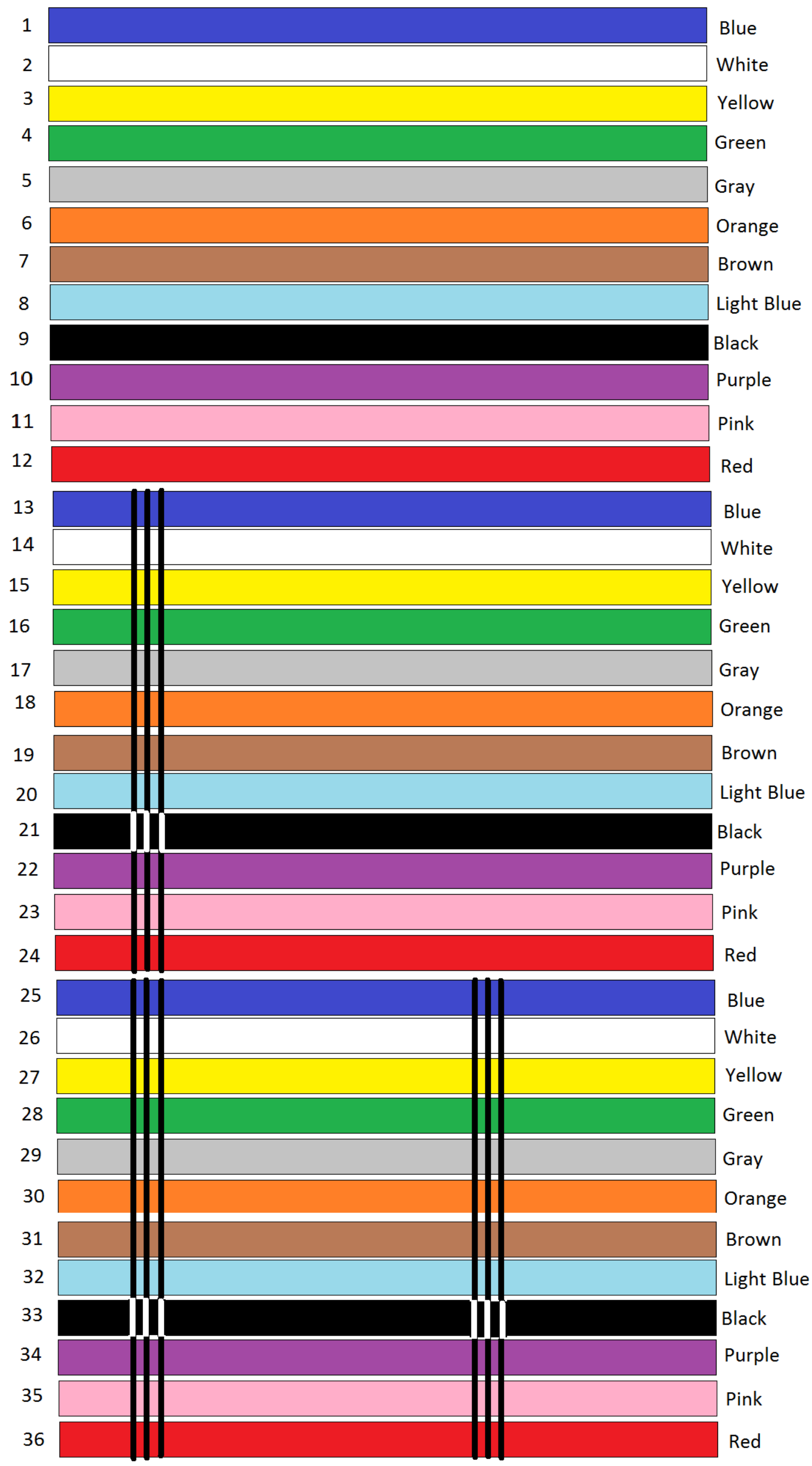


Figure 21. Fiber pipes in 864 sized cable.

4.3 Splicing

During splicing, the first task is to check the color ordering. The ordering is extremely important making it easier to find and fix faulty lines. Additionally, it needs to be followed during the splicing; otherwise the entire process needs to be redone. Because there were two different color orders, a standardized one, and one for the cables coming from the rack, we used two persons, one for each color order, to complete the task.

The splicing process itself requires deep concentration, patience and precision. The splicing started with selecting a fiber with the right color from a bundle with also the right color. After cleaning the fiber, the outer layer of the colored plastic needs to be peeled off with a specially-designed cutter. The peeled part of the fiber is to be fused with another fiber. But before that it needs to be cleared from plastic covers and cleaned for the last time with an alcohol swipe. Only then is the fiber cut into less than 3-degrees angles with the diamond cutter.

After fiber ends are prepared, they are placed into the splicer and they are fused. The fused section is placed into a small oven meant for shrinking the plastic cover over the spliced are for protective purposes. It is important to keep the work area clean throughout this process, and change the cleaning swipes often to avoid bad welds. Figure 22 displays ongoing splicing.

The splicing machine takes the inserted fiber ends and aligns them using the cores. In this part it is important that fibers are placed properly or the machine will not be able to begin the splicing procedure. Sometime when cores are not perfectly aligned or if they are moved, splicing process may start and create impurities or splices with unaligned cores. This in most cases causes the numerical aperture value of spliced sections be too high and the splice must be done again.

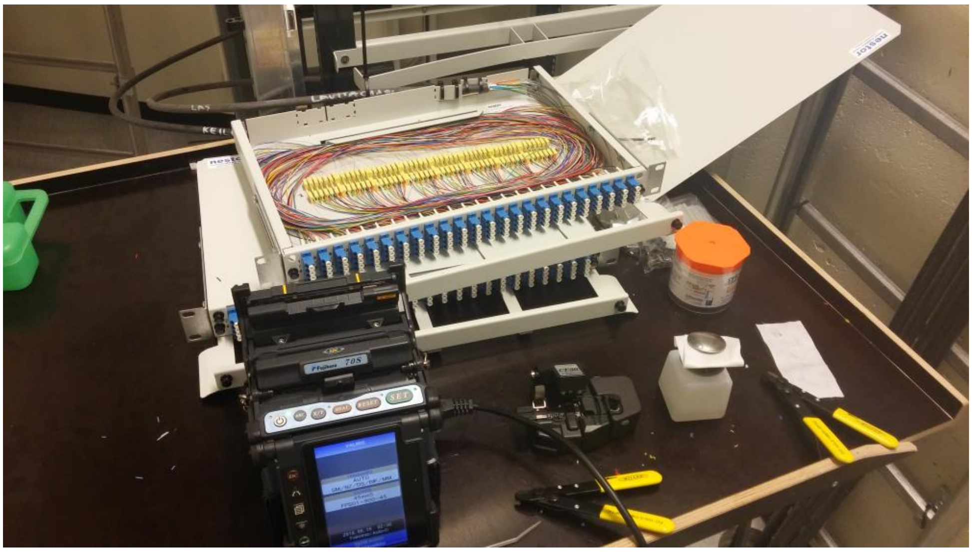


Figure 22. Splicing area.

This part of the project took the most time, as we spent approximately 36 hours splicing the fibers in a maximum of 12 hours at a time. Splicing itself went well and the instructor was satisfied with the quality of the welds.

5 Measurements after installation

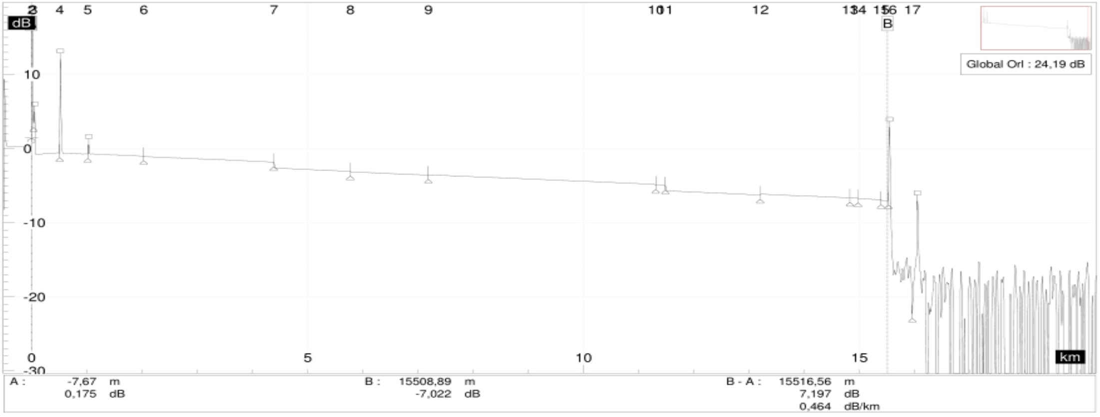
The purpose of optical fiber measurements is to verify the quality of the fusion splices as well as the quality of the installed optical fiber cable line. These quality checks are then documented and provided to the customer.

When optical fiber cables are installed, the accepted signal loss value given by the factory must remain the same throughout the installation. Fusion splices have tight requirements. It is required that the loss is equal or under 0.1 dB on average. If a single splice has a larger or equal loss than 0.2 dB, it needs to be repaired to prevent any failure in data transfer. The signal loss of optical fiber connectors on a fiber panel can be a 0.4 dB at maximum. If the threshold value is exceeded, one can try cleaning the connector. If that does not work, the connectors need to be changed as in most cases the splices must be redone.

5.1 Measurement method

The measurements of fiber lines were done with a fiber radar. The radar uses pulses of 1310 nm and 1550 nm light to measure the quality of the fiber line. Those are the same wavelengths that are used in routers and switches. The way the radar measures the condition of the fiber, is based on the returning reflections to the point where they are originated. The reflections might differ depending on the selected wavelengths of the measurements. As the reflections from the signal return to the radar, they are recorded, analyzed and visualized with a graph. In other words the fiber radar measures the numerical aperture value of the splices and connectors.

In figure 23, the bigger fractures or extreme angles are seen as drops downwards, and the ends of the fibers are seen as spikes upwards. When taking the measurements, there is a control piece attached to both ends of the fiber line. This control piece contains 500 meters of fiber folded in to a small box. The control piece helps to get a clearer result especially when the fiber line is short. Cleanliness is an especially important factor, when taking a measurement, because even a small speck of dust can cause a faulty result, or ruin a tip of a fiber. If there is any dirt at the end of the fiber being measured, it will be seen as a big spike. The dirt would sometimes burn into the measured fiber and cause the line to have a bad connectivity.



Table

	Event (16)	Distance (m)	Loss (dB)	Reflectance (dB)	Slope (dB/km)	Rel. Dist. (m)	Section loss (dB)	Total loss (OTDR) (dB)
1		-506,48		-39,89				
2		0,00	0,012	-23,53	0,330	506,48		
3		35,81	0,748	-49,48		35,81	0,000	0,012
4		506,48	-0,093	-33,18		470,66	0,154	0,914
5		1018,07	-0,021	-59,39	0,172	511,59		
6		2028,46	0,059		0,299	1010,39	0,303	1,192
7		4389,45	0,804		0,316	2360,99	0,747	1,998
8		5773,31	0,065		0,325	1383,85	0,450	3,251
9		7190,41	-0,047		0,311	1417,11		
10		11308,72	0,093		0,313	4118,31	1,683	4,999
11		11485,22	0,714		0,350	176,50	0,062	5,153
12		13201,61	-0,125		0,331	1716,39	0,569	6,437
13		14831,03	-0,044		0,311	1629,42		
14		14974,28	0,054		0,686	143,25	0,563	6,875
15		15393,78	0,084		0,376	419,50	0,157	7,170
16		15529,35		-38,84		135,57		
17		15959,09		-40,90		429,74		

Figure 23. Optical fiber line example picture.

5.2 Technical information of SmartOTDR fiber radar

In this project the fiber radar type was the SmartOTDR Fiber optical multi-test tool. The smart version of fiber multi-test tool is a smaller version for the radar and has a few features less. This tool includes features such as a 5 inch TFT color touch screen, an Ethernet plug in, two 2.0 USB connectors for a microscope or a keyboard, an audio jack for a headset, a led indicator for charge and for indicating when testing is active. [3]

Figure 24. Optical fiber radar.

5.3 Results

To check the quality of splices and to ensure the fiber cable is intact, every splice must be measured with the fiber radar. The radar gives the accurate distance and quality analysis of the fiber line in a matter of minutes and the recording is extremely reliable.

In the following, the measurement reports of three different fiber lengths are seen. The first one, in figure 25, has the length of 650 meters, the second one, in figure 26, has the length of 1500 meters, and the final one, in figure 27, has the length of 2500 meters. With the growing distance, the attenuation increases. The fibers have attenuations of 0.118 dB, 0.585 dB, and 0.794 dB respectively to the order of length. The attention is greatly influenced by the distance and cabling route. Additionally, the way cable is handled when it is being installed,and any sharp corners, too tight zip-ties or any kind of pressure on the cable may affect the quality of a measured fiber line.

Tapahtuma		Etäisyys	Vaimennus	Heij.	Vaimennuskerroin	Alue	Kok.Vaim.
		m	dB	dB	dB/km	m	dB
1		5.15	0.000	-53.17		5.15	0.003
2		648.79		-36.09	0.383	643.63	0.118

Figure 25. 650 meters.

Figure 26. 1500 meters.

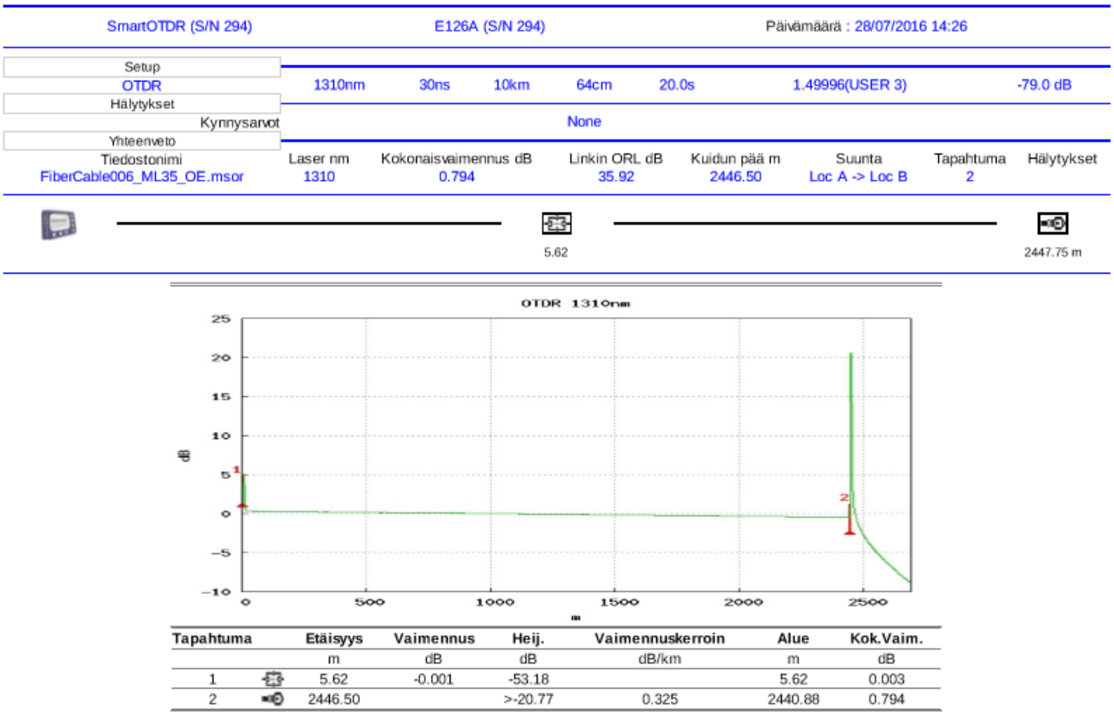


Figure 27. 2500 meters.

The end spikes are of fibers 2 and 3 (as seen in figures 26 and 27) is different from the spike of the first fiber (in figure 25). The reason why the curve is smoother in the two cases is that they have a connector at the other end unlike in the differing case where there is no connector. Another significant spike is at the start of the line. This spike is created by the connection of the measurement fiber connector and the connector in the panel. The size of the spike may vary and the attenuation caused depends on the connectors cleanliness. These measurements were taken with UPC connectors. If the connectors used were APC, the spike at the start of the line would not be there. The difference with an UPC connector and an APC connector is the way the result picture is represented. There is a spike upwards on points where two connectors are aligned, which causes a small air cap between the ends and it is shown as a spike. In the APC connector the spike is not formed because the tips of the connectors are cut in seven degree angels and the air gap is non-existent. All fiber lines represented in the figures are exemplary and in perfect condition.

6 Conclusions

For this project the main objectives were to plan, prepare, splice and measure core backbone fiber lines meant to be used in a national scale. The secondary objectives were examination of the measurement picture and how to manage a large scale splicing operation and multiple subcontractors.

The objectives were achieved for the most part. The measurement part is not completed at this stage of the project, since there are missing or incomplete measurement requirements and unspliced endpoints. The amount of knowledge and experience gained from this project was massive. It was a good learning experience to see the whole picture of handling a large project, acquiring and ordering materials and leading multiple workgroups. These experiences will be useful in the future as they have provided a deep understanding of the phases and complexities of managing a large network building project.

The parts of the project I excelled at were cable preparation, splicing and managing other fiber splicing groups. After discussion with my employer, the areas where I have a need for improvement are material ordering and management of material that are needed for each work area. In conclusion, the project was a good experience and I had the chance to see what it takes to manage a large-scale project and how communication between customer and work area management works. Also my co-operation and task management for the subcontractors was executed as planned and their material needs were always provided in time so no delays occurred. This project was a small part of the Länsimetro project.

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Appendix 1: Splicer datasheet

AFL

Fusion Splicing Systems

70S

In case with lid detached

Fujikura 70S Fusion Splicer

The Fujikura 70S is the world's fastest and most robust core alignment fusion splicer. Incorporating the proven ruggedized features pioneered by Fujikura, the 70S has added automated and enhanced user control features to increase splicing efficiency. A user programmable, automated wind protector expedites the splicing process by automatically closing to initiate the splice process, and opening upon splice completion. Fully programmable "auto open sheath clamps" open one or both sheath clamps, after the tensile test, to prepare the fiber for removal. A new automated "clamshell design" tube heater applies heat to both sides of the splice protection sleeve resulting in a 14-second shrink time. The result is a total splice process time of approximately 21 seconds! Ruggedness and durability are greatly enhance by a mirror-less optical system and "severe-impact resistant" monitor. Battery capacity is now 200 splices/shrinks. An innovative transit case doubles as a built-in or mobile workstation and makes splicing easier than ever before.

Features

- Automated and programmable wind protector
- 14-second automated tube heater
- Fully ruggedized for shock, dust and moisture
- Li-ion battery with 200 splices/shrinks per charge
- 5 mm cleave length for splice on connector or small package needs
- Sheath clamp or fiber holder operation
- On-board training and support videos
- Internet software upgrades
- Multi-function transit case with integrated workstation

Ordering Information

DESCRIPTION	AFL NO.
70S Fusion Splicer (machine only) **Includes:** ADC-18 AC Adapter, ACC-14 AC Cord, ELCT2-20A Spare Electrodes (pair), S70C Sheath Clamp, USB Cable, Alcohol Pot, Screw Driver, Splicer Carrying Strap, Quick Reference Guide, Video Instruction Manual and CC30 Transit Case with Carrying Strap	S015580
70S Fusion Splicer Kit (with cleaver) **Includes:** CT30A Cleaver, ADC-18 AC Adapter, ACC-14 AC Cord, ELCT2-20A Spare Electrodes (pair), S70C Sheath Clamp, USB Cable, Alcohol Dispenser, Screw Driver, Splicer Carrying Strap, Quick Reference Guide, Video Instruction Manual, and CC30 Transit Case with Carrying Strap	S015590
70S Fusion Splicer Kit (with cleaver, battery and cord) **Includes:** BTR-09 Battery, DCC-18 Battery Charge Cord, CT30A Cleaver, ADC-18 AC Adapter, ACC-14 AC Cord, ELCT2-20A Spare Electrodes (pair), S70C Sheath Clamp, USB Cable, Alcohol Dispenser, Screw Driver, Splicer Carrying Strap, Quick Reference Guide, Video Instruction Manual and CC30 Transit Case with Carrying Strap	S015591
One Year Extended Warranty	S012996
Two Year Extended Warranty	S013000

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Appendix 1: Splicer datasheet

AFL Fusion Splicing Systems

Fujikura 70S Fusion Splicer

Recommended Accessories for the 70S

DESCRIPTION	AFL NO.
Cleavers	
CT-06A Cleaver	S015276
CT-30A Cleaver	S014080
Fiber Holders	
FH-60-250 Fiber Holder (pair)	S014548
FH-60-900 Fiber Holder (pair)	S014549
FH-60-160 Fiber Holder (pair)	S014690
FH-60-LT900 Fiber Holder (pair)	S015181
FUSEConnect® Accessories	
FH-FC-20 (900 µm within 2.0 mm sheathing) (each)	S014696
FH-FC-30 (900 µm within 3.0 mm sheathing) (pair)	S014695
FH-FC-900 (900 µm cable) (each)	S014697
CLAMP-FC-2000 (pair)	S014705
CLAMP-FC-3000 (pair)	S014704
Sheath Clamps	
CLAMP-S70C Sheath Clamp (Coating diameter from 100 µm - 1000 µm (5-16 mm cleave))	S015586
CLAMP-S70D Sheath Clamp (900 µm diameter loose tube fiber (5-16 mm cleave))	S015862

DESCRIPTION	AFL NO.
Batteries and Power Cords	
ADC-18 AC Adapter	S015585
ACC-14 AC Power Cord	S014536
BTR-09 Battery	S015581
DCC-18 Battery Charge Cord	S015582
DCC-12 Power Cord (connects AC Adapter to cigarette lighter socket)	S013552
DCC-13 Power Cord (connects AC Adapter to power source via alligator clips)	S013556
Miscellaneous	
ELCT2-20A Electrodes	S013532
Portable Tripod Workstation (see product profile for more detail)	S014773
ASW-02 Splicing Workstation (see product profile for more detail)	S010532
JP-06 J-PLATE (70/19 Series)	S016100
SL-01 Sleeve Loader	S015674
Worktable Upper	S015779
Worktable Lower	S015780
Inner Box Set	S015979
USB Cable	S014777
CC-30 Transit Case	S015587

Specifications

PARAMETER	VALUE
Model	70S Fusion Splicer
Applicable Fibers	Single-mode (G.652 & G.657), Multimode (G.651), DS (G.653), NZDS (G.655)
Cladding Diameter	80 - 150 µm
Coating Diameter	100 µm to 1,000 µm
Fiber Cleave Length	5 to 16 mm
Typical Average Splice Loss	0.02 dB with SM, 0.01 dB with MM, 0.04 dB with DS, 0.04 dB with NZDS, measured by cut-back method relevant to ITU-T standards
Splicing Time	SM FAST mode — 7 seconds; SM AUTO mode — 10 seconds; AUTO mode — 15 seconds with SM fiber
Arc Calibration Method	Automatic, real-time and by using results of previous splice when in AUTO mode, manual arc calibration function available
Splicing Modes	100 preset and user programmable modes
Splice Loss Estimate	Based upon dual camera core axis alignment data
Storage of Splice Result	Last 2,000 results stored in the internal memory
Fiber Display	X or Y, or both X and Y simultaneously. Front or rear monitor display options with automated image orientation
Magnification	320X for single X or Y view, or 200X for X and Y view
Viewing Method	Dual cameras with 4.7 inch TFT color LCD monitor
Operating Condition	0 to 5,000 m above sea level, 0 to 95%RH and -10 to 50°C respectively
Mechanical Proof Test	1.96 to 2.25N
Tube Heater	Built-in tube heater with 30 heating modes; auto-start function
Tube Heating Time	Typical 14 seconds with FP-03 sleeve, 17 seconds with FP3 (40), 5-16 seconds with Fujikura micro sleeves
Protection Sleeve Length	60 mm, 40 mm, micro
Splice/Heat Cycles with Battery	Typical 200 cycles with power save functions activated
Electrode Life	3,000 Arc Discharges
Power Supply	Auto voltage selection from 100 to 240 V AC or 10 to 15 V DC with ADC-18, 14.8 V DC with BTR-09 battery
Terminals	USB 1.1 (USB-B type) for PC communication. Mini-DIN (6-pin) for HJS-02/03
Wind Protection	Maximum wind velocity of 15 m/s. (34 mph)
Dimensions	146 W x 159 D x 150 H (mm) / 5.75 W x 6.25 D x 5.9 H (inches)
Weight	2.5 kg (5.5 lbs) with AC adapter ADC-18; 2.7 kg (5.95 lbs) with BTR-09 battery

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