Technical solution and implementation of the Svalbard fibre cable

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Longyearbyen in Svalbard at 78° North is an ideal location to support polar orbiting satellites. All 14 daily passes of a typical sun synchronous orbit are visible with satellite contact every 7 and 17 minutes.

SvalSat was developed in the period 1996–1999 as a joint effort between NASA and the Norwegian Space Centre. It has been supporting NASA earth observation satellites through an Intelsat satellite at 1° W. The available transmission rate is around 55 Mb/s and in addition there are some ISDN lines and one 2 Mb/s line. SvalSat has now grown to be the world's largest polar ground station to serve earth orbiting and polar weather satellites.

A fibre optic telecommunications cable between the Norwegian mainland and Svalbard now replaces the Intelsat connection. It was deployed in 2003, and put into operation in January 2004. The article provides an overview of the technology used together with explanations of the different building blocks of the complete transmission system. The cable and additional equipment has an expected lifetime of 25 years and the current capacity utilisation is 10 Gb/s. Telenor Networks is responsible for the technical implementation of the project, as well as the operation and maintenance.

Introduction

This article provides a technical overview of the fibre optic cable and the necessary components to make up a complete transmission system. The items covered are the cable technology itself, the repeater systems including the power feeding, as well as the monitoring and maintenance systems.

The cable system

Overview

The fibre optic cable system goes between Harstad and Longyearbyen via Andøya. The US Company Tyco has delivered the system. Tyco has its roots in the well-known corporation Bell. There are two separate cables for redundancy; only one is carrying traf-

Figure 1 The SvalSat Earth station is placed at Platåberget, outside Longyearbyen, Svalbard

Figure 2 Two separate fibre optic cables are laid between Harstad on the Norwegian mainland and Longyearbyen on Svalbard. It goes via Breivika on the island of Andøya, before leaving the North Norwegian coast

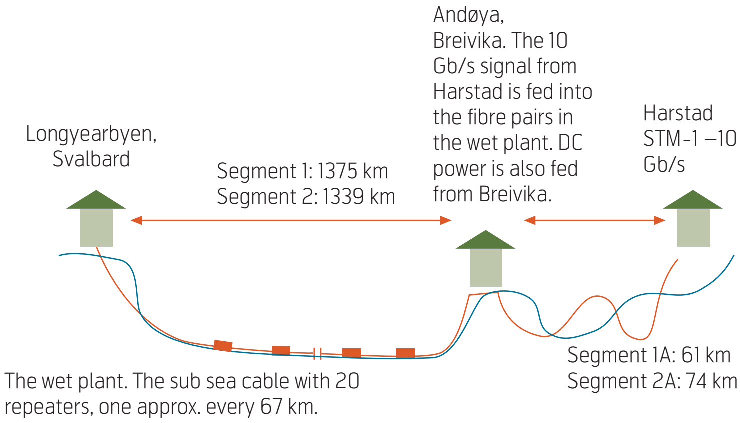


Figure 3 The two separate cables; Segment 1 and Segment 2, are 1375 and 1339 km, respectively. They are partly buried under the sea floor. The cables between Breivika and Harstad (1A and 2A) are both sub sea and land cables with a length of 61 and 74 km, respectively

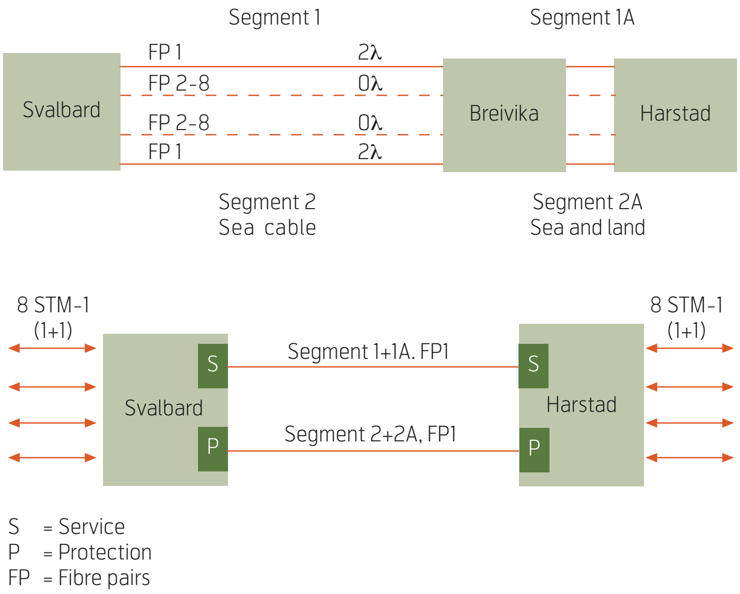


Figure 4 The fibre cable segments contains eight fibre pairs, of which only one is currently used

fic at a time. Each cable has 20 optical repeaters, spaced approximately 67 km apart, to keep the signal power up on the more than 1300 kilometre travel between Andøya and Svalbard. The repeaters are actually amplifiers, which do not regenerate the signal but amplify it. DC power to the repeaters is fed from Andøya. Each repeater has eight amplifier pairs (one per fibre pair) and a 'high loss loop back' for monitoring.

The two separate cables are called Segment 1 and Segment 2. Segment 1 is 1375 km with 172 km buried at an average depth of 2 m below the ocean floor to keep the cable safe from external hazards. Segment 2 is 1339 km and is buried for 173 km at the same average depth as Segment 1. Between Breivika and Harstad, the cables are called Segment 1A and 2A, both sea and land cable is used. Segment 1A is 61 km and Segment 2A is 74 km long. These sections are so short that optical repeaters are not needed.

System configuration

Of the eight available fibre pairs in each cable segment, only one is currently used. To use the remaining pairs, additional equipment must be installed in Svalbard and Harstad. One fibre pair has more than enough capacity for today's traffic load. If Segment 1 should fail, the traffic will automatically be switched to Segment 2.

The fibre optic cable

Different types of cable are used on the way to Svalbard. The type of cable used depends on the risk of damage. Close to shore where the risk of damage from fishing equipment and ships' anchors is significant, the cable has a thicker armour to protect the

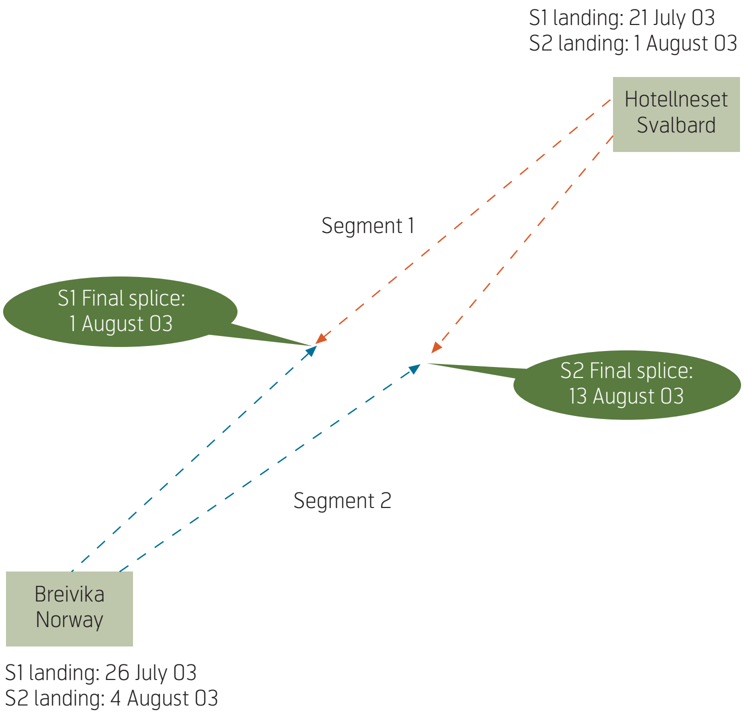


Figure 5 The two cable ships deployed the cable from each end and met midway where the ends were spliced

Figure 7 The cable ship 'Cable Innovator' covered the distance from Breivika to the point where it met the other cable ship, 'Maersk Recorder', to splice the two ends

Figure 8 The cable ship 'Maersk Recorder' covered the distance from Longyearbyen to the point where it met 'Cable Innovator', to splice the two ends

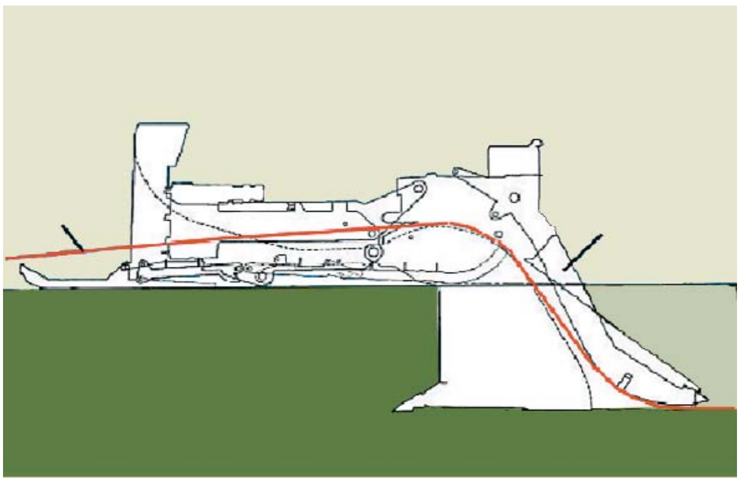


Figure 6 Example of the type of plough used to bury the cable

fragile fibre pairs. The cables are also buried in the ocean floor close to shore where the water is relatively shallow, and a special plough is used to do so. Two cable ships were used to lay the cables because one ship alone could not hold the amount of cable necessary to cover the distance. One ship started from Longyearbyen and one from Breivika, and they met midway to splice the two ends. The two ships then returned to lay the second cable, see Figure 5.

The different cable types used are from the SL 21 family shown in Table 1. The SL 21 provides the optical path for the undersea digital transmission, supervision signals and a power path for the optical amplifiers.

It is not only the armour that varies, but also the type of optical fibre. In this system three different fibre types are used:

- Large mode field fibre (LMF)
- High dispersion shifted fibre (HDF)
- Non dispersion shifted fibre (NDSF)

The different fibre types affect the signal in different ways, so to minimise distortion the design includes different fibre with different characteristics.

The optical repeater

There are 20 optical repeaters on each segment, 40 in total. There is a repeater approximately every 67 kilometres. The repeaters have eight optical amplifier pairs each, one per fibre pair, and operate on DC power fed from Breivika. The system is what we call a 'single end feed system'. Each repeater also contains a 'high loss loop back' (HLLB) used for monitoring purposes. The Tyco repeaters use state-of-the-art optical technology to achieve high performance and reliability. The repeater amplifies multiple channel signals on multiple fibre pairs and is designed for a lifetime of 25 years on the ocean floor and on board cable ships during laying, burying and repair operations.

The repeaters are designed using the minimum number of components necessary. In this way, the risk of failure is minimised. Each repeater contains eight amplifier pairs to accommodate the eight fibre pairs. Each amplifier pair consists of the components necessary to support all wavelength division multiplexed channels on a fibre pair. The maximum number of wavelengths that may be used is 32. Each amplifier pair contains two erbium doped fibre amplifiers (EDFAs) that provide broadband amplification on two transmission paths in opposite direction. Each amplifier also has its own power supply and operates independently so a failure on one amplifier pair will not affect the amplifier pairs on the other fibre pairs.

Figure 13 shows one amplifier pair, including the laser pump unit (LPU) and the loop back coupler module (LCM). The LPU includes four 980 nm laser pump modules. The output is combined using wave-

Cable type	Application	Features
LW	Benign, sandy bottom. Depth to 8000 m	Core cable, light protection. Medium-density polyethylene white jacket, providing improved visibility when submerged
SPA	Somewhat rocky bottom; Risk of shark attack Depth to 6500 m	Metallic tape and high-density polyethylene white outer jacket applied over core provide additional abrasion protection and hydrogen sulfide protection
LWA	Rocky terrain; moderate risk of trawler damage. Depth to 1500 m Typically used for burial (depth to 1200 m buried)	Light armor wire layer applied to core cable(a)
SA	Rocky terrain; high risk of trawler damage. Depth to 1000 m (depth to 800 m buried)	Heavy armor wire layer applied to core cable(a)
DA	Very rocky terrain; high risk of trawler damage; moderate risk of abrasion. Depth to 400 m	One armor wire layer applied to LWA cable(a)

(a) Tar-soaked nylon yarn is used for the outer jacket of armored cable.

Table 1 SL21 cable types

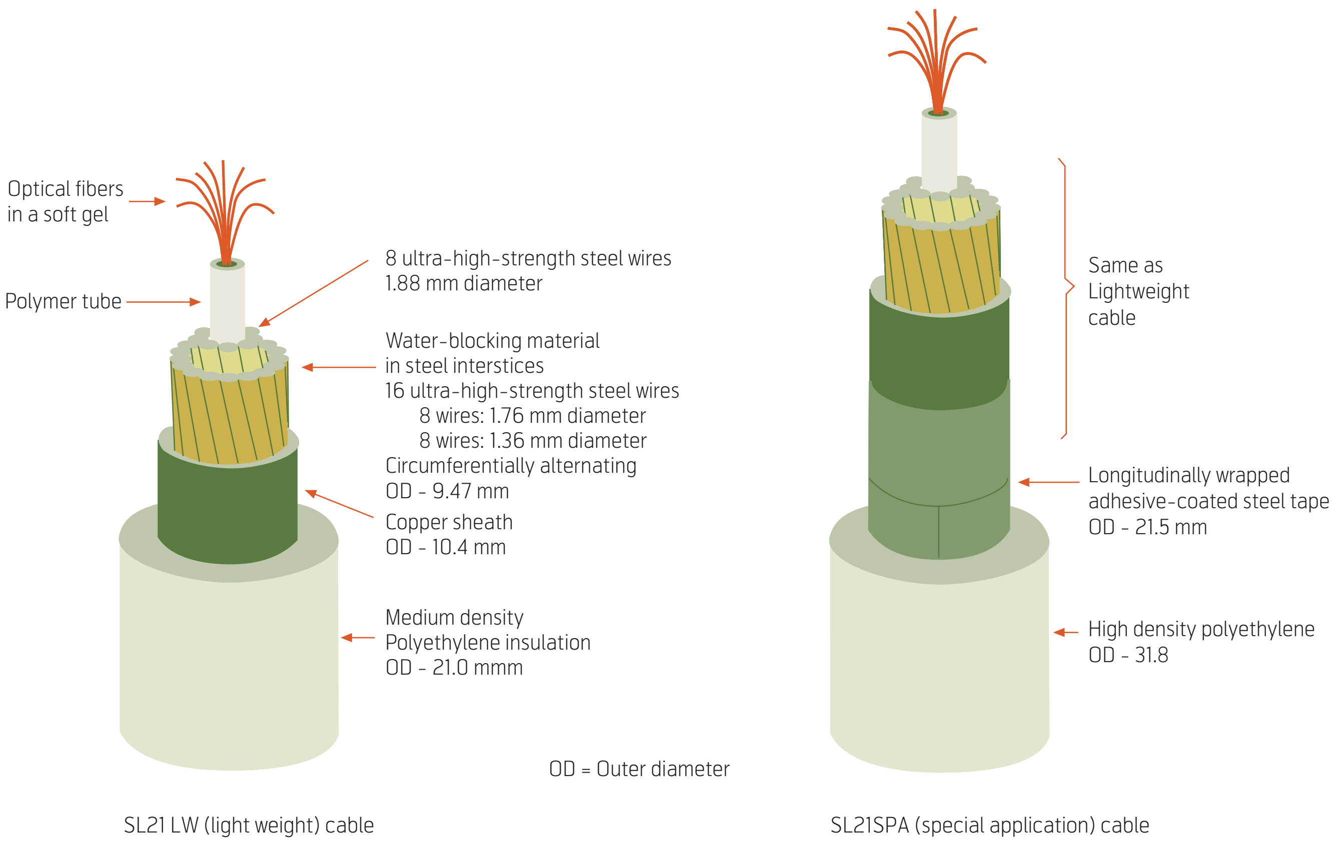


Figure 9a The cables used are from the SL21 family of cables

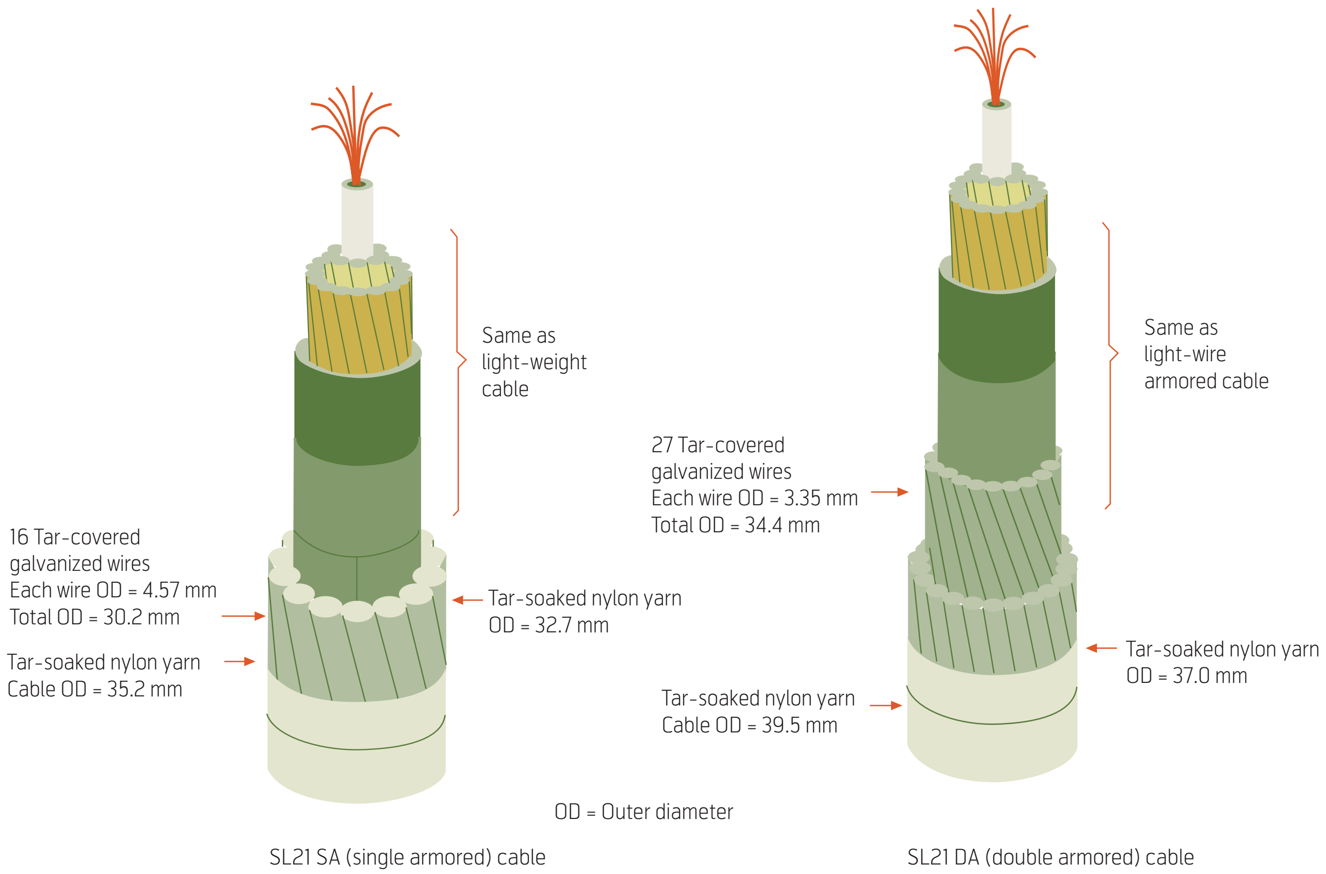
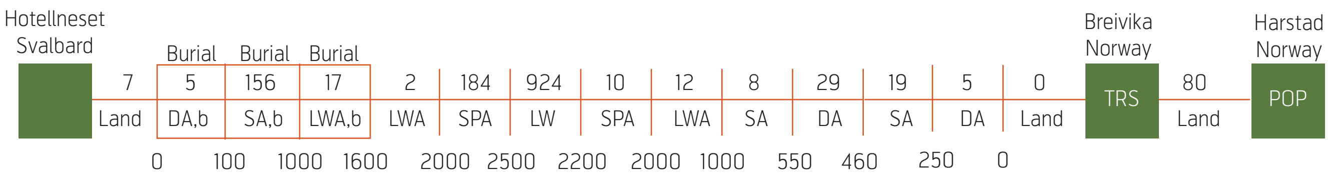


Figure 9b The cables used are from the SL21 family of cables (continued)



Summary of cable types, quantities & spares		
Type	Length	Spares
Land	87	
DA	34	2
DA,b	5	

Figure 10 The Straight Line Diagram (SLD) shows where the different fibre types are used. Segment 1 is used as an example

length division multiplexing or polarisation beam combiner as the figure shows. The 3dB-coupler splits the output of the LPU so that the LPU pumps the EDF of each fibre of a fibre pair. This provides redundancy as well as uniform amplification in each direction through the amplifier.

The LCM provides a wavelength selective, high loss loop back (HLLB). The LCM also provides a broadband loop back for the optical time domain reflectometer (OTDR) and the coherent time domain reflectometer (COTDR). These are both used to monitor the state of the sub sea cable system. They can

Figure 11 The cable ship installing the cable off the coast of Breivika

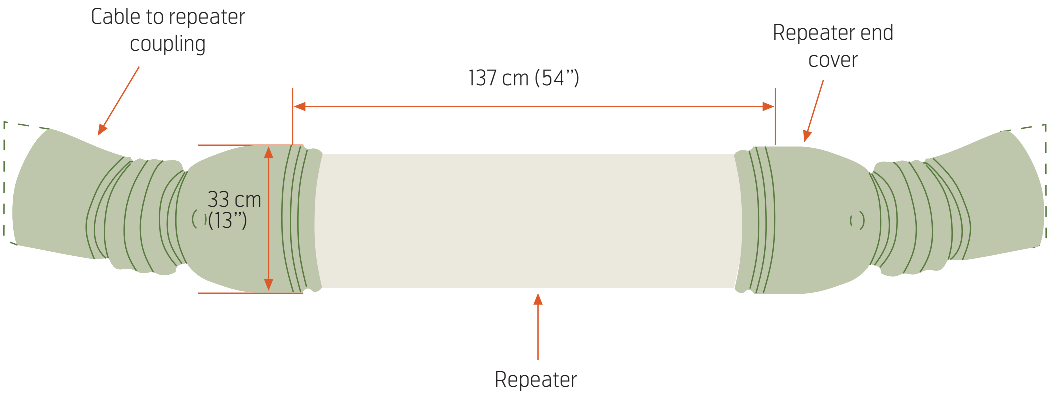
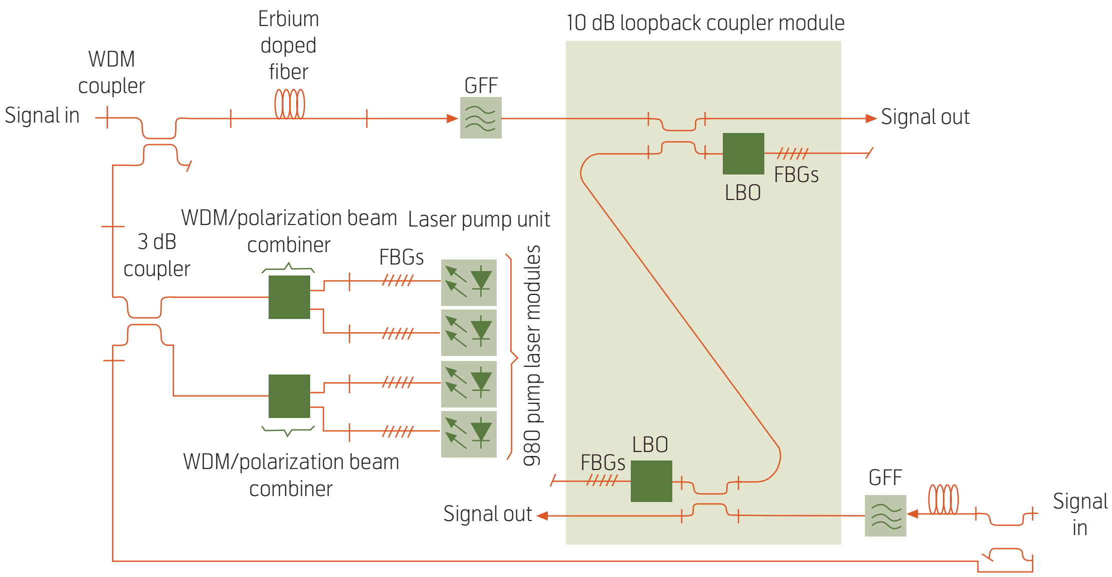


Figure 12 The optical repeater is quite large and weighs approximately 750 kg in total, including the couplings on each side. A total of 40 repeaters are installed



WDM = wavelength division multiplexing
GFF = gain flattening filter
LBO = line buildout
| = fusion splice
–+– = optical fiber termination
-///- = fiber bragg grating (FBG)

Figure 13 One amplifier pair includes a laser pump unit (LPU) and a loop back coupler module (LCM)

also be used to determine the location of a fault that has occurred.

The optical amplifiers are pumped with a 980 nm pump laser source. Pumping at this wavelength results in an optical bandwidth of the amplifier that is greater than 20 nm centred around 1551 nm. The noise figure for such a 980 nm pumped EDFA is less than 5 dB. Figure 14 shows a typical EDFA gain and noise characteristics. As we can see, the noise is way below the signal at the operating range of the amplifier.

Gain compensation

The length of the EDF (Erbium-Doped Fibre) and the pump level determines the gain and noise characteristics of the amplifier. At very low input the gain and noise characteristics are constant. Then when the power is increased the gain of the repeater will eventually start to decrease. When the input power level is raised sufficiently the gain of the amplifier will be 0 dB as shown in Figure 14. This gain compression characteristics of optical amplifiers make them especially suitable for transmission system applications because the power level along a chain of amplifiers in a transmission system is self-correcting and self-limiting. This means that if an amplifier for one reason

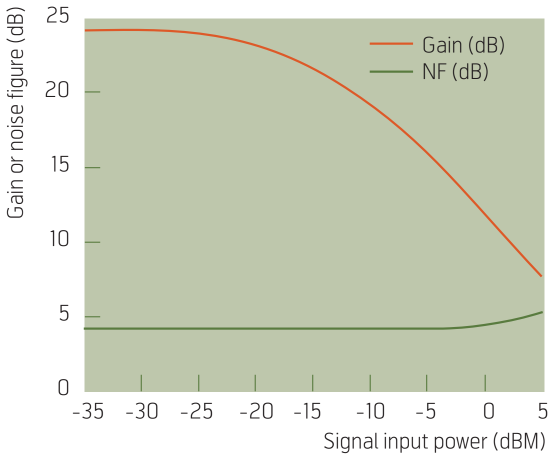


Figure 14 Gain and noise figure as a function of input power for the erbium doped fibre amplifier (EDFA)

or another gets a drop in input power, the gain in this amplifier will increase to compensate for that low input power. There can be different reasons for a drop in input power. Some examples could be a degraded pump in the previous amplifier, component aging, a degraded splice or a repair. This results in a lower input power to the next amplifier, which has to compensate for the low input by increasing its gain. The following amplifiers in line will compensate for the power loss until the signal is back at its equilibrium level.

Mechanical design

The eight amplifier pairs are mounted on assemblies inside a high-pressure container. The material used is copper-based alloy that withstands corrosion and supports hydrostatic pressure to a depth of 8000 m. Cathodic protection of the housing is not necessary. The high-pressure container protects the electrical and optical elements in the repeater from the ocean environment and provides a high strength connection between the cable terminals. The container consists of a cylindrical body and a repeater cone in each end connecting the body to the coupling hardware for the cable. The cable is connected to the cones using a special coupling. The coupling provides a path for both dc-power and an optical connection via splicing of cable and repeater signal from the cable to the repeater.

The lives of electronic components increase with decreasing temperature, therefore the amplifiers inside the repeater are mounted on a heat transfer plate to keep the temperature down. The seawater outside the repeater keeps the repeater temperature down.

To prevent the repeater from corrosion, the parts that are exposed to seawater are made of a tested copper based alloy. The parts carrying the electrical power are insulated from the seawater using a thick layer of extruded polyethylene.

The Power Feed Equipment

The Power Feed Equipment (PFE) provides power to the optical repeaters. The PFE is located in Breivika. In this system single end feeding is used. Systems that are fed from both ends are safer, but the power supply in Breivika should provide enough redundancy to make the system reliable. The primary return current path is the seawater and the seabed.

The PFE converts the –48 V battery supply at the cable station in Breivika to the regulated voltage needed for the system. The PFE feeds the system with a constant current of 1.1 A at 2500 V. A generator back-up maintains the 230 V mains voltage used to feed the –48 V battery system in case of a mains power failure.

In normal operation the two converters are serially connected, each supplying half of the load to the cable. Each converter can supply the cable system on its own, so if a problem occurs at one converter or it has to be stopped for maintenance reasons the other converter will automatically take over the load, providing active redundancy. The monitor functions are also redundant. The switches allow converters and monitors to be reconfigured for in-service testing and repair. In the Svalbard system the cable is a single-end feed system, but for systems that are dual-end feed the system will automatically switch to single-end feed if one PFE fails completely.

The output from the PFE can be in constant current mode or constant voltage mode. At normal operation, constant current mode is used.

The parameters monitored on the PFE are output voltage and current, station ground current, seabed voltage and converter output voltage and current. The PFE is monitored using the Tyco Element Manager System (TEMS). There are three installed, one in Harstad, one in Longyearbyen and one at Telenor's Network Operation Centre, which provides 24 hours surveillance of the system.

To protect the undersea system the PFE will shut down if the voltages or currents exceed certain threshold values.

The PFE can operate on either Ocean Ground or Building Ground. In normal operation ocean ground

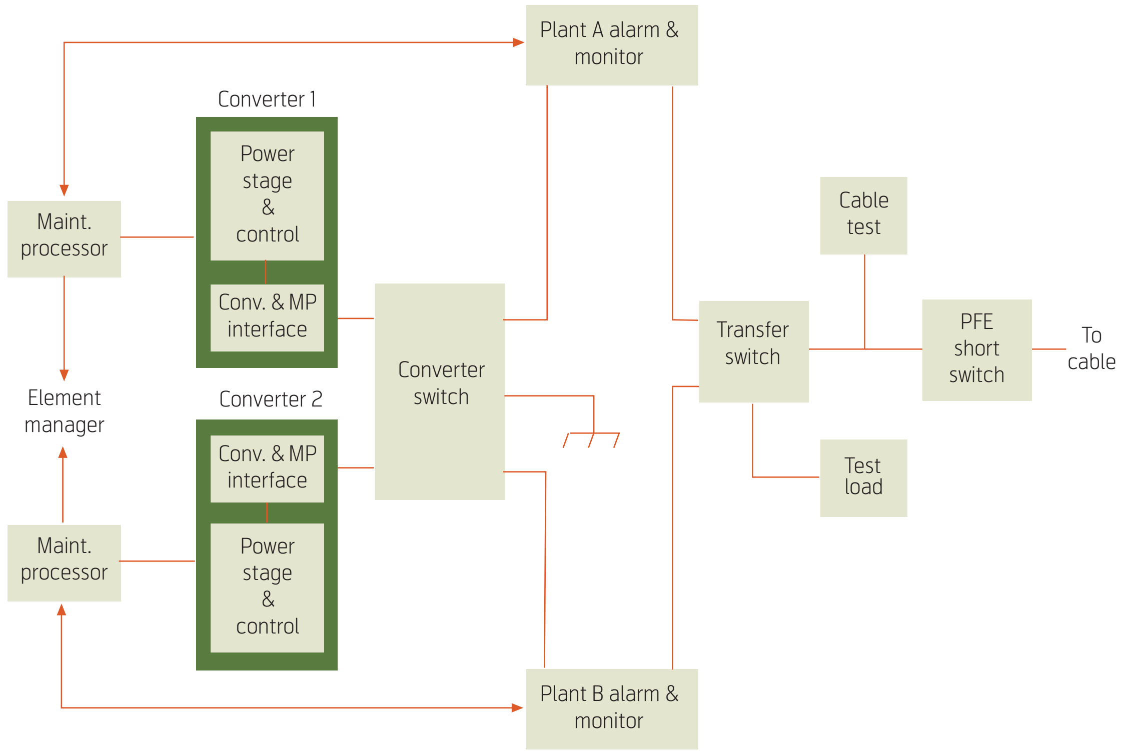


Figure 15 Power feed equipment (PFE) architecture

is used. To limit the risk of damage due to lightning strikes an Ocean Ground Protection Panel (OGPP) is installed. The OGPP provides isolation between ocean ground and building ground.

If there is a problem serious enough for picking up a part of the cable for repairs being necessary, the PFE can provide a 4 to 5 Hz sine wave on its high voltage output. This signal can be detected by the cable ship to locate the cable on the ocean floor.

Line Terminating Equipment

The LTE terminal equipment platform provides an interface between the terrestrial network and the undersea system.

The LTE provides powerful Forward Error Correction (FEC), precision wavelength control and high stability receivers and transmitters.

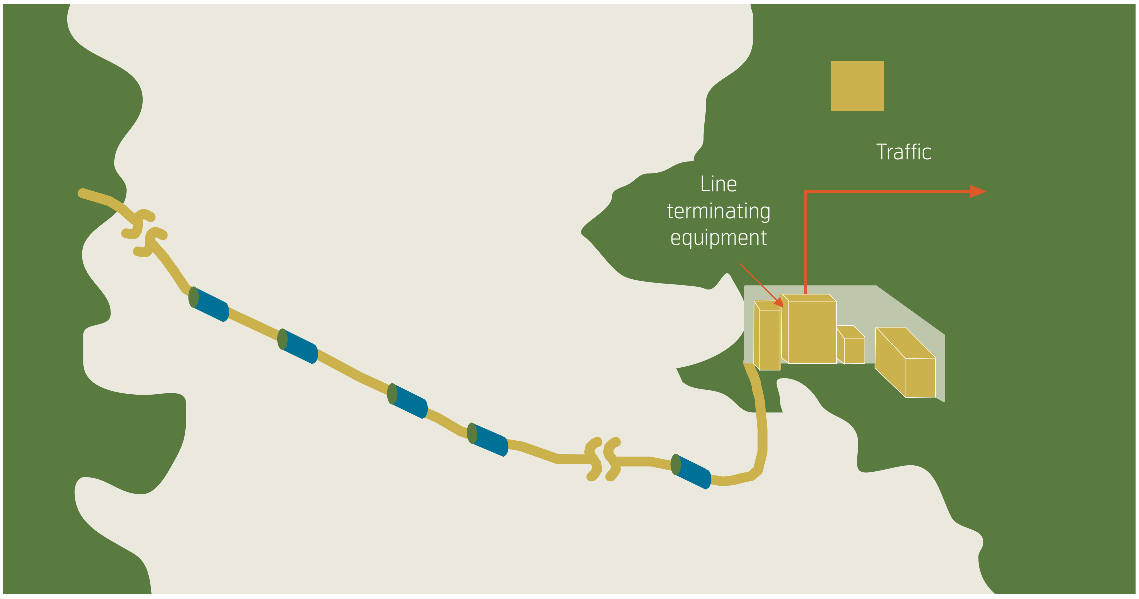
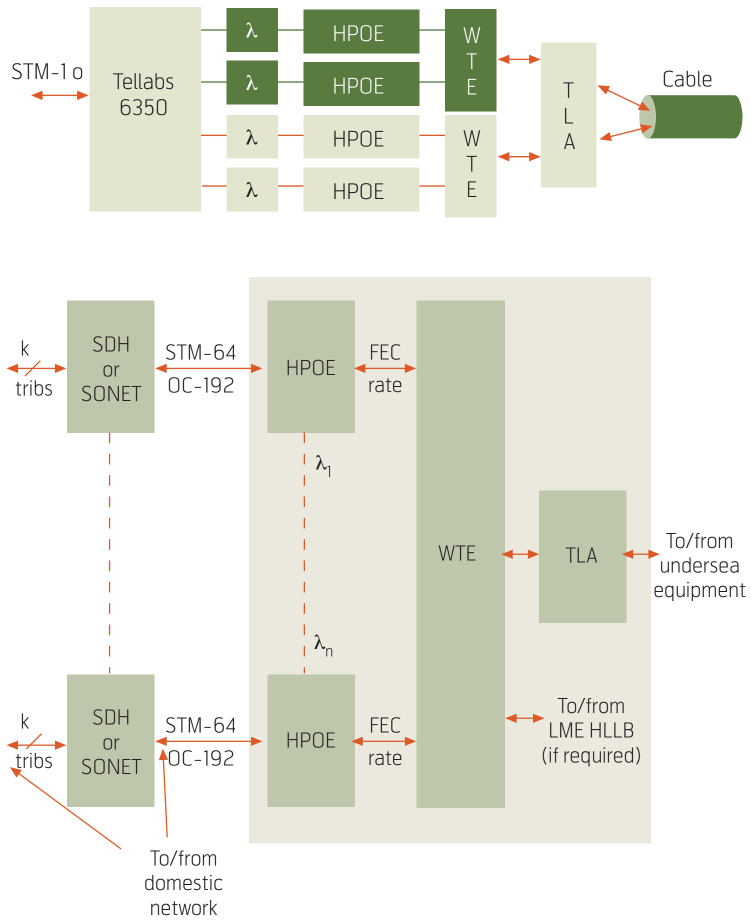


Figure 16 The Line Terminating Equipment (LTE) converts the STM-1 signal from the Telenor network into a 10 Gb/s signal suitable for long distance sub sea transmission



FEC = forward error correction
HLLB = high-loss loopback
HPOE = high performance optical equipment
LME = line monitoring equipment
LTE = line terminating equipment
SDH = synchronous digital hierarchy
TLA = terminal line amplifier
WTE = wavelength termination equipment

Figure 17 The Line Terminating Equipment (LTE) used in the Svalbard cable system

The LTE uses ‘clear-channel transmission’; i.e. it is independent of the protocol used. In our case, the input is an SDH signal, but any protocol may be used.

The LTE processes the 10 Gb/s signal for ultra long haul:

- Up to 10,000 km without regeneration
- Dynamic pre-emphasis
- Wavelength multiplexing and de-multiplexing
- Dispersion compensation
- Pre- and post-amplification
- Automatic wavelength adjustments
- Chirped return to zero (RZ) modulation

The LTE consists of the following building blocks:

- High Performance Optical Equipment (HPOE)
- Wavelength Terminating Equipment (WTE)
- Terminal Line Amplifier (TLA).

The High Performance Optical Equipment provides special transmit and receive line signal processing, the Wavelength Terminating Equipment provides optical wavelength processing, and the Terminal Line Amplifier amplifies the signal before sending it into the sub sea system. One HPOE is needed per channel, but two are actually used per wavelength to provide redundancy. In the Svalbard project two wavelengths are used.

The input from the Telenor network is an SDH STM-1 (155 Mb/s) signal. At both ends, Harstad and Longyearbyen, the STM-1 signal is fed into Tellabs STM-64 equipment. The output from the Tellabs STM-64 is sent to the LTE equipment. The STM-64 signal has a bit-rate of 9,953 Gb/s. The first module in the LTE is the High Performance Optical Equipment (HPOE). Each LTE has two HPOEs for redundancy. In the HPOE extra Forward Error Correction (FEC) bits are added to the STM-64 signal making the new bit-rate 10,664 Gb/s.

For the receive operation the opposite sequence is engaged.

Functions:

Transmit direction:

- Reception and optical/electrical (O/E) conversion of the STM-64 input signal
- FEC encoding
- Insertion and encoding of overhead bytes for FEC
- Insertion of user communication channels into the FEC overhead data
- Optical line signal generation
- Post amplification

Receive direction:

- Reception and O/E conversion of the 10,664 Gb/s signal
- FEC decoding and bit error correction
- Generation of line performance parameters
- Extraction of the user channel from the FEC overhead for inter station communication
- Generation of the STM-64 optical output signal

High Performance Optical Equipment (HPOE)

The HPOE accepts any signal having a one-zero density consistent with STM-64/OC-192 protocols, the bit-rate being 9,953 Gb/s. The signal is converted to electrical, and FEC overhead bytes are added making the bit-rate 10,664 Gb/s.

In addition to the Forward Error Correction, the HPOE provides phase modulation, automatic transmit and receive direction channel optimisation, FEC performance parameters and a unit alarm interface. The output power is 9 dBm regardless of the input power.

Forward Error Correction (FEC)

FEC is a technique used to detect and correct digital transmission errors. The forward error correction code improves the signal to noise ratio (S/N) with 4 to 4.7 dB. The HPOE adds overhead bytes used to detect and correct errors that may occur in the undersea system. In other words, redundancy is added to the transmitted signal.

The performance of the FEC is shown in Table 2.

Wavelength Termination Equipment (WTE)

The Wavelength Termination Equipment (WTE) is used to provide optical wavelength processing. The WTE does automatic wavelength pre-emphasis, wavelength multiplexing and demultiplexing, sidetone LME wavelength combining (the Line Monitoring Equipment is explained later), and wavelength dispersion compensation. Figure 20 shows the WTE's location, while Figure 21 shows a more detailed view.

The Optical Pre-Emphasis Equipment (OPEE) provides channel equalization by adjusting the optical power of each channel prior to transmission such that all have the same end-to-end line error performance. The OPEE maintenance circuit automatically determines the appropriate channel pre-emphasis based on detected FEC error.

Because the response of the sub sea system is known the output signal can be adjusted for this before it reaches the undersea system. This is called pre-emphasis. Figure 22 shows the principle of this.

The optical filters, splitters and combiners are passive components as shown in Figure 23.

Terminal Line Amplifier (TLA)

The Terminal Line Amplifier (TLA) provides high-availability optical, wideband gain. The TLA may be used in constant output power mode or constant gain mode. The TLA can be used both in transmit and receive directions for post- and pre-amplification, respectively. The TLA contains two laser pumps, one is a 980 nm at 150 mW constant output and the other is a 1480 nm with a maximum output of 160 mW. The optical signal amplification is done by using erbium-doped fibre amplifier (EDFA) technology. This is a well-developed method for amplification of optical signals without optical to electrical conversion and regeneration of the signal. The TLA has two

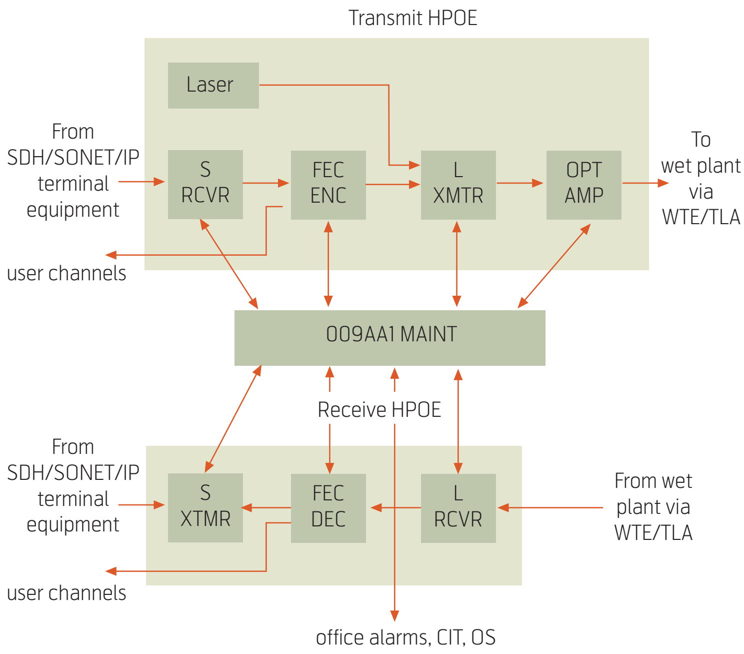


Figure 18 The High Performance Optical Equipment (HPOE)

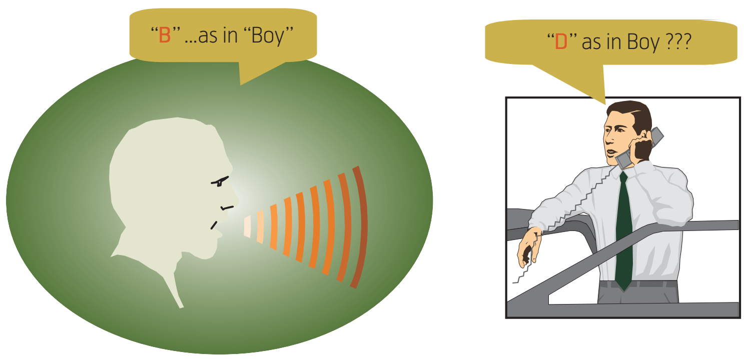


Figure 19 By using FEC you get increased system capacity, longer transmission distances are possible and repeater spacing may be increased. The optical power can be lower, the pump power gets lower and there are less non-linear impairments

Feature	Specification or applicable standard
Line bit error rate	Delivered bit error rate
10^{-4}	$\leq 10^{-9}$
10^{-5}	$\leq 10^{-13}$
10^{-6}	$\leq 10^{-17}$
Error correction protocol	Reed-Solomon 14/15, per ITU-T G.975

Table 2 Specifications and performance of the Forward Error Correction (FEC) scheme

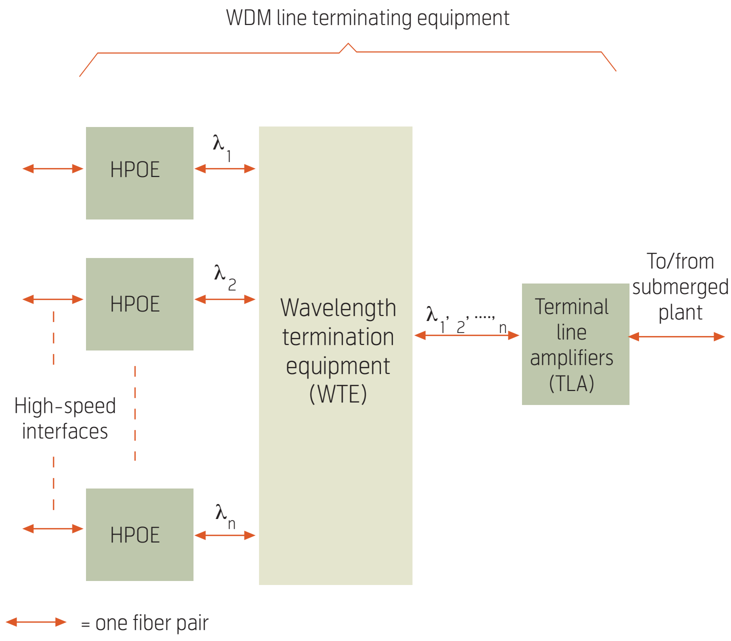


Figure 20 The Wavelength Terminating Equipment (WTE)

stages. The first stage holds the 980 nm laser pump and gain-flattening filter, and the second stage holds the 1480 nm laser pump. Passive components are used in the TLA because they are usually more reliable than active ones. The TLA also has a maintenance circuit pack, which monitors the components, records the output power, bias current and semiconductor chip temperature. Any value outside the limits of normal operation will trigger an alarm.

Multi Side-Tone Line Monitoring Equipment (MST LME)

The LME is used to monitor the condition of the undersea system. The LME consists of an equipment rack, a computer and a workstation. The LME operates together with the loop-back coupler modules in the repeaters and in the LTE (Line Terminating Equipment). The whole system is called the Line Monitoring System (LMS). At start-up of the sub sea system a delay calibration has to be performed. The Multi Side-Tone (MST) LME injects an optical 2.5 MHz, three level (–1, 0 and 1) pseudo random square wave signal directly into the outgoing fibre through the LTE into the sub sea system. The injected signal is called the LMS signal. The injected signal comprises two wavelengths which are different from the ones used for the transmission itself, hence the name MST LME. The LTE and all the repeaters contain a ‘high loss loop-back’ coupler module, which sends a fraction of the LME signal back in the receive direction and back to the LME. The location and loop-gain of each repeater and LTE is measured during the time the signal takes to reach a particular repeater. The results are stored in a database as a ref-

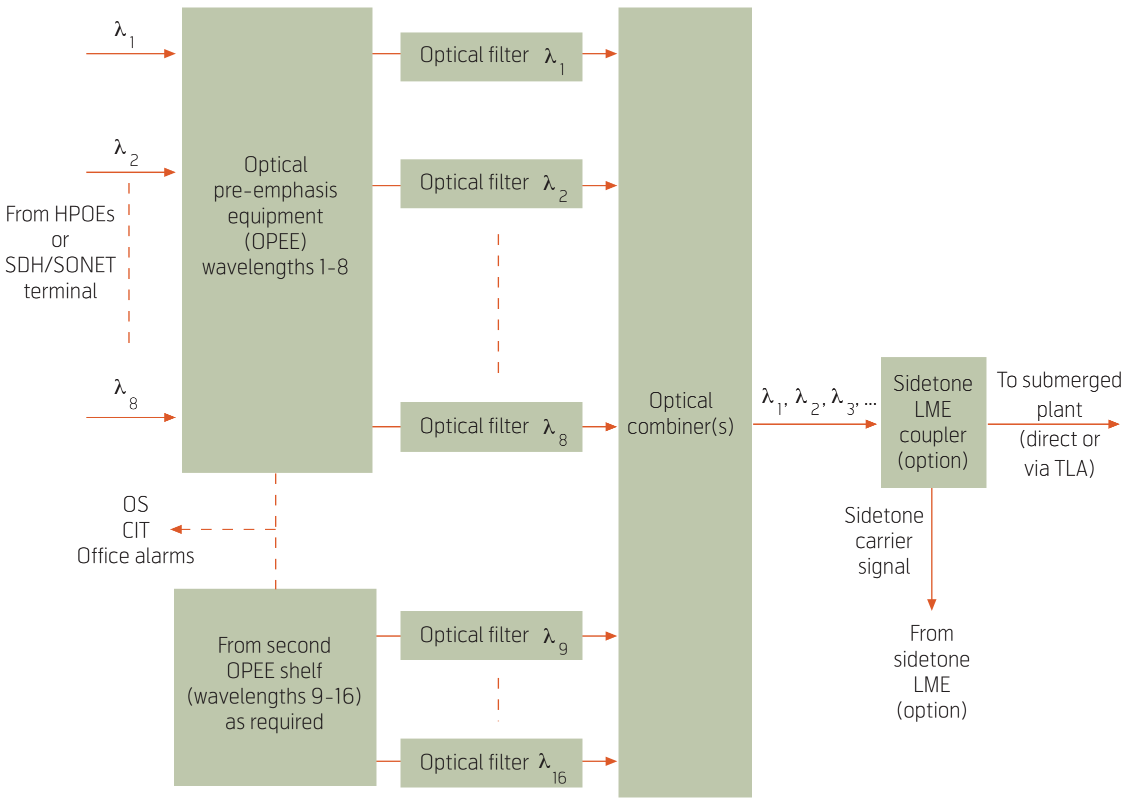


Figure 21 Detailed diagram of the WTE

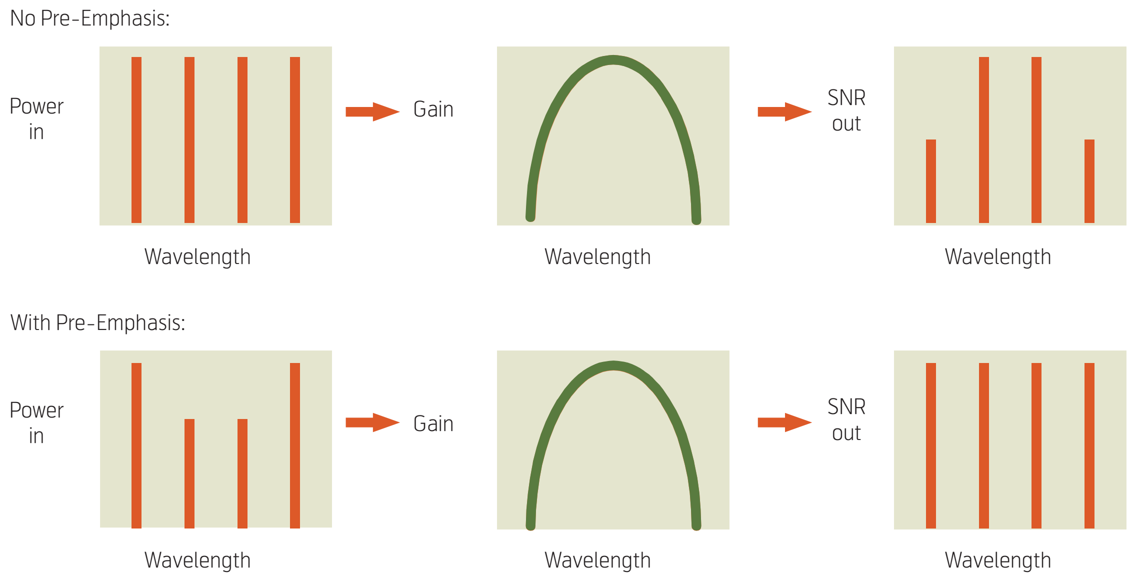


Figure 22 Principle of pre-emphasis

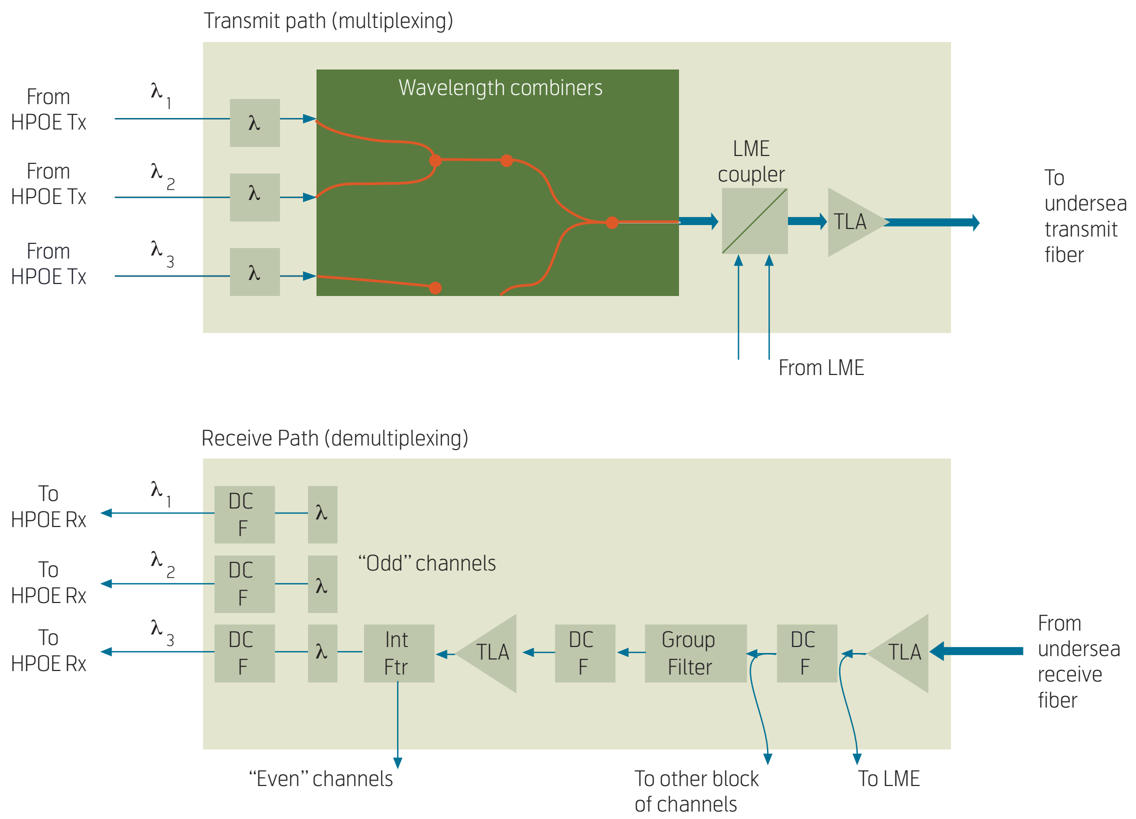


Figure 23 Optical filters, splitters and combiners

erence to future monitoring runs. In this way we can look for changes that may indicate a problem with the undersea system. If the system is altered in any way, a new baseline has to be established. Periodic monitoring runs are performed. If a fault has occurred in the undersea system the monitoring run will differ from the baseline. The test-run results can be analysed manually by comparing the signature from the test-run with a library of fault scenarios. This will give us the opportunity to determine what the fault may be and where it may be located. The LME also has an automatic signature analysis function. The faults that may be determined are laser-pump failures, fibre breaks, cable breaks or changes in gain and loss. One of the wavelengths from the MST LME is placed near or below the lowest traffic wavelength and one

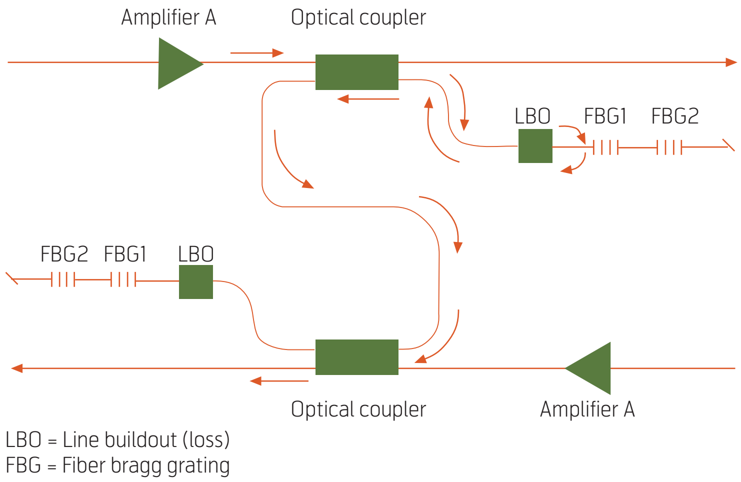


Figure 24 The repeater High Loss Loop Back (HLLB) path

near or above the highest traffic wavelength. In our system only one wavelength is used for traffic, but in other sub sea systems engaging more wavelengths, this method is used.

Repeater High Loss Loop Back (HLLB) paths

Each repeater has a High Loss Loop Back (HLLB) path used for the LMS signal as shown in Figure 24.

Using optical couplers, the signal is looped back after the amplifier in the repeater. In case one of the optical pumps of each amplifier fails the loop gain will be changed and the LMS signal will have a different shape baseline telling us that we have a problem with a repeater. The laser pumps are very reliable and one failed pump does not require the repeater to be picked up for repair. The repeaters after the one with a fault will restore the signal strength up to the normal value. The MST LME may be used to monitor the undersea system both in service and out of service. For out of service monitoring a more powerful LMS signal may be used.

The management system

The management system used for the Tyco equipment is called TEMS (Tyco Element Manager System). The TEMS provides network management functions for the line monitoring equipment (LME), the line terminating equipment (LTE) and the power feed equipment (PFE). The 24-hour surveillance is done from Telenor's Operation Centre at Fornebu, while monitoring runs and other management functions are done from Longyearbyen and Harstad, where the two other TEMS workstations are located. All functions cannot be performed from the TEMS; some have to be done using a laptop computer directly connected to the equipment in the cable station.

Summary

A fibre optic telecommunications cable was deployed between the Norwegian mainland and Svalbard in 2003, and put into operation in January 2004. The article has provided an overview of the technology used together with explanations of the different building blocks of the complete transmission system. The cable and additional equipment have an expected lifespan of 25 years and the current capacity utilisation is 10 Gb/s.

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