TRACKING THE END-OF-LIFE OF A SUBMARINE CABLE

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Abstract: Many submarine cables are around 15 years old, and exhibit a remarkable health. FIT rates are low, since these cables are in their middle life. However, as submerged equipment is qualified for a 25-year lifetime, an increase of FIT rate possibly linked to wear out may be observed as it approaches 25 years.

As an early warning for cable ageing would be extremely useful, we describe how a regular analysis of the wet plant parameters could detect early minor changes before any transmission quality degradation.

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1. TYPICAL DESIGN FOR RELIABILITY OF A SUBMARINE NETWORK

Today, all submarine systems in operations are based on the fibre amplification technology that started to be broadly deployed after mid-1995. Many submarine cable systems are thus 10-15 years old, and exhibit a remarkable health, proving the robustness of fibre optic technology.

Submarine networks are traditionally designed with reliability in mind and huge qualification efforts are devoted to this key parameter of the life of a system.

Submerged systems are qualified for a 25-year lifetime and their reliability diagram will definitely follow the well-known bathtub curve depicted in figure 1 (providing the failure rate as a function of time).

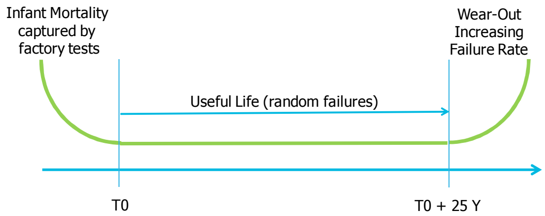


Figure 1: Typical Bathtub Curve

Burn-in techniques can be used by suppliers to remove the infant mortality so as to reduce the probability of failures in the early life of the system (i.e. before T0).

As a result of qualification, the behaviour of the submerged equipment is widely predictable and stable in the T0 to T0+25 years period. FIT rates are low and stable, as expected, since these cables have just passed their middle life. However, nothing can be predicted about its ageing speed when approaching and exceeding qualification time.

Qualification is done to prove that FIT rates will not increase above the design specification up to 25 years. An increase of FIT rate has to be expected as its 25-year lifespan approaches or is exceeded. One or several technologies will first reach their wear out regime and start to increase failure rate up to the time when repair will become non manageable.

One should stress that the failure mechanisms that will appear first are not predictable since they are outside the observation window of the qualification. We should also note that homogeneous technologies may lead to a synchronised wear out.

For a comprehensive study on reliability aspects of submarine networks, please refer to [1], and the related book reference.

Furthermore, most of the veteran systems have been regularly upgraded to the maximum possible capacity as soon as new technology allowed for it: the original margins have been consumed to achieve higher channel count. So, degradations in the wet plant performance could lead to a significant decrease in capacity.

An early warning for cable ageing would be extremely useful, considering that 2 to 3 years are typically needed between “start of planning” of a new cable and “ready for service”.

2. EFFECTS ON NETWORKS

Analysing in detail and on a regular basis all available system data could provide early warning signs concerning the submerged plant performance evolution.

The analysis looks more practical with high level parameters of the live system, such as the Q factors of existing traffic across the spectrum, or the gain shape of the system.

Nevertheless, Q factor measurement has a very low sensitivity to early ageing. For example a distributed large 10dB loss in a 100 repeaters system leads to only 0.1 dB Q factor variation, which is not measurable.

Indeed, during the life of the system, additional new wavelengths are often installed using cutting edge technology. These wavelength upgrades may also mask the Q factor ageing of the system as the total capacity continuously increases with the same margins.

So, Q factor follow-up is certainly useful in the long term, but tracking the system ageing and the network health cannot be uniquely based on this parameter.

Gain spectral shape analysis is more sensitive, but is complicated by the need of a reference with time, and also complicated by the change of channel loading with successive upgrades.

We show below in this paper that the parameters below provide more sensitive information, with in addition access to local signatures of failures:

- Repeater sanity check by remote supervision, when available

- Repeater and fibre span sanity by high-resolution COTDR, possible on almost all systems, and with spectral variations.

Although most analytic data and techniques are available to network operators for long term monitoring, gathering and properly interpreting these data often requires a specific expertise including a deep understanding of the wet plant design and optical behaviour: for instance, the correct interpretation of Q factor variations that are not necessarily linked to a repeater malfunctioning.

Repeater long term monitoring is then required to check any other variation into the line, and analyze it.

Field experience confirms that the wet plant analysis has to encompass several parameters and techniques to be effective.

In the next section we provide various examples of preventive maintenance techniques on the wet plant, either based on the usage of an active supervisory system when available, or complemented by data obtained by an in-service COTDR run.

Please refer to [2], for a comprehensive study on supervision of submarine networks with optical amplifier systems. Refer to [3], for a comprehensive study on fault localization using coherent Rayleigh backscatter reflectometry in submarine networks.

3. EXAMPLES

In this section we have collected a number of representative examples to show how the various detection / monitoring techniques may interwork to provide the best possible analysis of the status of the network.

3.1 Repeater with a degraded output power without Q factor variation

In some systems with low gain repeaters and over high distance, passive component degradations or a repeater pump failure can decrease a repeater output power with a very low impact on the Q factor at receiver side.

This small Q factor degradation (for example less than 0,1dB) could pass undetected under the eyes of a network operator monitoring the Q margins.

If a wet plant supervisory system is available, a repeater interrogation scan can help clarify the issue.

In the example shown below, a pump failure in repeater B led to an output power decrease of 1,1dB. Adjacent repeaters interrogations show an input power decrease at repeaters A (Y direction) and C (X direction). This symmetric configuration of O/P and I/P degradations, would rather drive the diagnosis towards the failure of a pump in repeater B.

Repeater Name	DIR	I/P (dBm)	O/P (dBm)	DIR	I/P (dBm)	O/P (dBm)	Pump Current 1 (%)	Pump Current 2 (%)
A	X	1.0	15.5	Y	-0.4	15.5	70	70
B	X	1.0	14.4	Y	1.0	14.4	100	100
C	X	-0.2	15.5	Y	1.0	15.5	80	80

Figure 2: Repeater Interrogation

In this example, the pump current of the remaining healthy pumps was automatically increased in order to maintain sufficient output power in both directions of B repeater. The impact on the

Q factor was therefore less than 0,1dB. No impact is here observed on the output power of the neighbour repeaters (A and C). On the other hand, it would be difficult to spot a small gain variation of less than 3 dB on a COTDR trace.

In other cases, the O/P, I/P configuration found after repeater interrogations may be asymmetric, as shown in figure 3.

Repeater Name	DIR	I/P (dBm)	O/P (dBm)	DIR	I/P (dBm)	O/P (dBm)	Pump Current 1 (%)	Pump Current 2 (%)
A	X	1.0	15.5	Y	0.8	15.5	70	70
B	X	1.0	15.4	Y	1.0	15.4	75	72
C	X	-0.2	15.5	Y	1.0	15.5	80	80

Figure 3: Repeater Interrogation With Asymmetric O/P, I/P

In this case, a reduction of the O/P of repeater B is associated to a reduced I/P at the following repeater C on X direction, but no variations are observed on repeater A in Y direction (asymmetric configuration).

Again, the impact of the Q factor is very small and no pump current variation is reported: the analysis would rather suggest a passive component problem at the extremity of repeater B, X direction only or an increased attenuation on the BC span for the X direction fibre: this last case can be further investigated by a COTDR run.

3.2 Repeater with low I/P

When a repeater exhibits a low input power, it is useful to distinguish two cases:

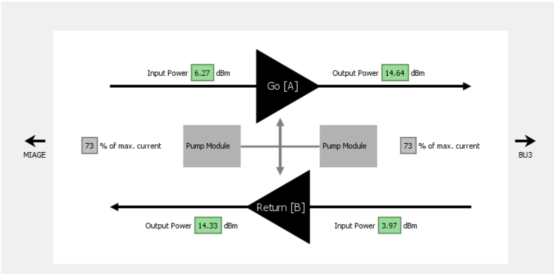
1- Span degradation
2- Preceding repeater issue

Span degradation

This first case is the most frequent, because a repeater low input power often results from a cable or from fibre degradation, but this is one of the situations that need careful investigation if the intention is to track the end-of-life of a submarine link.

The traffic is instantaneously interrupted in the case where the cable is cut, but it may not be strongly affected in the case of increased attenuation. When investigated, the repeater at the end of the span will exhibit a reduced input power, below the expected nominal value. If an active supervision system is available, a threshold crossing alarm can be raised at the Network Operation Centre (NOC) or even on the Smartphone of the Manager on duty (Cf. Figure 5).

Normal situation:



After a cable cut:

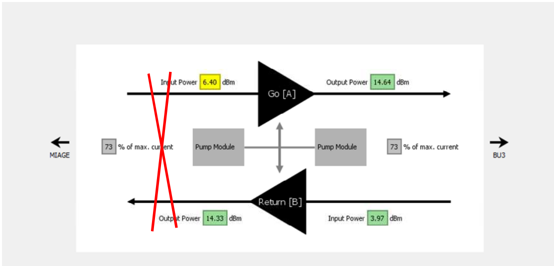


Figure 4: Threshold-Crossing Alarm At Repeater After a Cable Cut

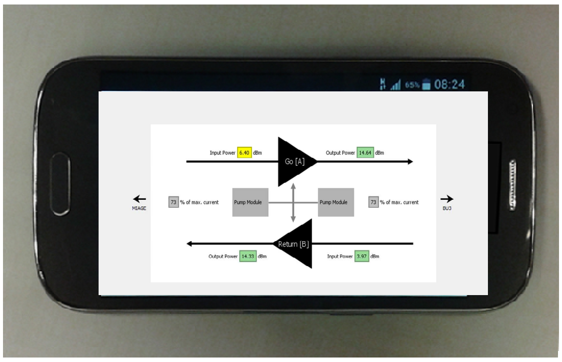


Figure 5: Repeater Level Status on Smartphone

In the repeater interrogation shown below, an input power drop is observed at repeater N in the X direction. The repeater nominal input power is 4dBm.

Repeater Name	DIR	I/P (dBm)	O/P (dBm)	DIR	I/P (dBm)	O/P (dBm)	Pump Current 1 (%)	Pump Current 2 (%)
N - 1	X	4.0	14.3	Y	4.4	14.4	73	75
N	X	2.0	14.2	Y	4.2	14.2	79	78
N + 1	X	3.8	14.4	Y	4.2	14.5	71	73

Figure 6: Another Repeater Interrogation

The interrogation of repeater N-1 does not show any particular issue as nominal values can be measured: an additional analysis is required to understand the root cause of this input power decrease into repeater N.

A COTDR measurement can be performed in order to check the fibre quality in the X direction, and particularly between repeater N and N-1.

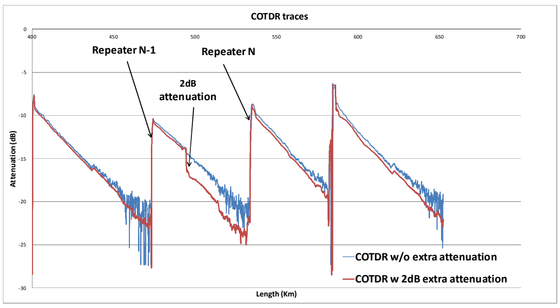


Figure 7: COTDR Traces Performed At 1547nm Wavelength

The COTDR trace shows an unexpected attenuation in the fibre span between repeaters N and N-1 at 41.2km from repeater N.

This increased span attenuation may be generated either from an external aggression or from single fibre degradation: if this is an isolated event, it should not be considered as a sign of a possible approaching end-of-life.

Preceding repeater issue

In some other rare cases, the span is not the cause of the reduced input power observed at repeater N: a degradation of the output power at repeater N-1 can lead to a reduction of the input power at the following repeater N and to a pump current increase at N.

To clarify this situation, the results should be carefully analysed to understand the optical behaviour of the neighbour repeaters and to find the root cause and this may require in-depth knowledge of the relevant repeater design. For instance, some types of repeaters have pump coupling 50/50, other 70/30. The behaviour of the repeaters may be misinterpreted as failures or ageing whereas they are not.

In the repeater interrogation shown below, input power degradation is observed at repeater N-1 and at repeater N in the return direction. The repeater nominal input power is -2,20dBm.

Repeater Name	DIR	I/P (dBm)	O/P (dBm)	DIR	I/P (dBm)	O/P (dBm)	Pump Current 1 (%)	Pump Current 2 (%)
N - 1	X	-2.1	10.3	Y	-5.7	9.1	54	47
N	X	-0.6	10.8	Y	-13.5	5.1	100	2
N + 1	X	-0.7	10.4	Y	-2.2	10.2	24	80

Figure 8: Repeater Interrogation

This is a typical case where repeater N could be suspected of having a faulty pump, but careful supervision data analysis allows us to conclude that it behaves as expected and therefore it is not faulty. The issue has to be found in span from N to N+1 or at repeater N+1.
Again, the analysis of table of figure 8 ensures that repeater N+1 has nominal output power and therefore the issue is linked to an unexpected increased attenuation of span from N to N+1.

A COTDR measurement can now be run to precisely locate this extra attenuation.

The COTDR trace here under confirms a fibre span issue close to repeater N+1 as well as the managed power decrease of the N repeater.

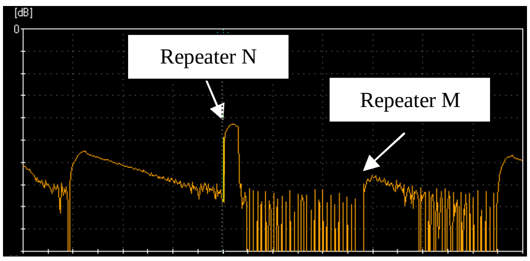


Figure 9: COTDR Traces Performed At 1550nm Wavelength

3.3 Tilt Analysis Using a COTDR

We demonstrate below that the use of a COTDR can help track a spectral tilt and locate any increase in the attenuation of the submerged line by observing the shape and the tilt of the COTDR trace.

Indeed, increased in-line attenuation induces a system gain tilt as shown in the following figure. The slope of the tilt depends on the extra loss introduced in the system (0.017dB/dB/nm).

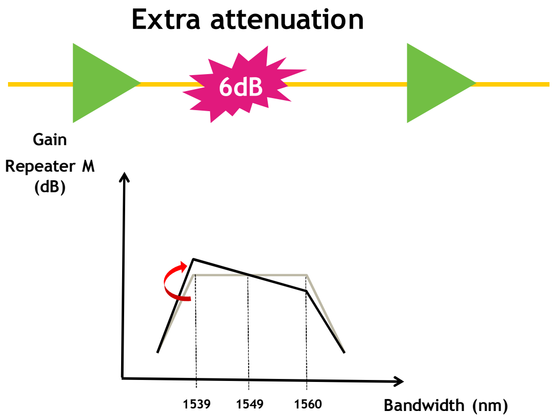


Figure 10: Repeater Tilt Generation Due to Increased Attenuation

In order to detect an in-line tilt by a COTDR, the key parameter is the choice of the wavelength setting. Performing a measurement using a channel set in the middle of the repeater wavelength comb does not allow observing any tilt, as Figure 10 easily shows: the gain of the repeater M at 1549nm does not change after an attenuation increase at his input.
On the other hand, the gain is increased at 1539nm and decreased at 1560nm. These gain modifications can be observed on the COTDR traces.

Figure 11 shows the relevant COTDR traces obtained separately at three different wavelengths: 1539nm, 1549nm and 1560nm.

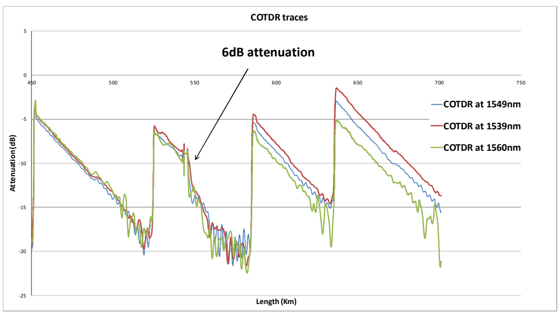


Figure 11: COTDR Traces Using Different Wavelengths Following An In-Line Increased Attenuation

We can observe that the curve of the COTDR trace performed at 1539nm is above the one performed at 1549nm (middle of the repeater bandwidth) after the span with the increased attenuation. For the 1560nm wavelength, the curve is below the one at 1549nm. These COTDR traces confirm the presence of an in-line tilt. Therefore, the wavelengths chosen to observe an in-line tilt using COTDR traces must be set at the repeater bandwidth limits.

Line tilt is not always a sign of degradation as it can appear, for instance, after certain repairs in deep water when large portions of spare cables have been added in one single span: however, an unexpected line tilt is one of the elements that allow tracking the signs of age in a submarine link.

One can stress that the tilt origin demonstrated above is localized with the precision of a span, while all the other techniques measuring end-to-end spectral tilt does not provide any visibility to the inhomogeneity of this tilt along the system.

4. CONCLUSIONS

Tracking the early signs of ageing in submarine networks requires an in-depth knowledge of the wet plant equipment behaviour and the availability of advanced monitoring tools.

Q factor variations are quite insensitive to any microscopic changes inside the system, and could completely mask the early signs of ageing.

We show in this paper that when the system has access to a diversity of monitoring, including active supervisory and COTDR, one can identify very early signs of degradation and in addition investigate the origin of the issue.
There is a clear advantage in disposing of various tools like an active supervisory system and an in-service COTDR as, in many cases, one single tool is not enough to perform the analysis.

We especially show in this paper on one hand that active supervisory can provide a unique view of a very small loss variation in any part of the system, and on the other hand that a COTDR trace at the two ends of the useful spectrum provides access to the localisation of a wavelength tilt inside the system.

Regular monitoring of the system will allow us to identify signatures of new events and eventually their repetition, announcing an acceleration of ageing before any warning of the transmission quality. It will give us a longer time to plan an action plan, either to correct the system, or to plan its replacement.

This paper is supported by the Suboptic working group on the extension of the system lifetime.

5. REFERENCES

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