SYSTEM MARGIN FOR REAL

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Abstract: Operating margin is specified as the difference between measured bit error rate (BER) and the forward error correction (FEC) limit BER of the submarine line terminal (TTE) receiver and is expressed in terms of Q factor[1]. However, this margin does not directly relate to the amount of repairs or aging that the system can tolerate because, while repairs and aging add losses which reduce power, the effect on Q is not solely reduced by the decrease in power but is also somewhat improved due to the reduced impact of fiber non-linear impairments.
This paper describes the results of tests on a system during its commissioning phase. These tests consisted of reducing the repeater optical output power in sections of the system (which mimics the effects of pump failures, repairs and fiber aging) and measuring the resulting Q changes.

1. INTRODUCTION

Subsea systems are designed to tolerate repairs, aging and pump failures, with the power budget including margins to accommodate each of these factors. In general, margin is determined by measuring the system Q and comparing it with the minimum at which the system can operate. Relating this margin to a number of repairs and a degree of fiber aging is done by calculating how much the OSNR could be degraded before the Q margin is reduced to an acceptable minimum.

It is not practical to measure the effect of a repair but, during a recent installation, there was the opportunity to do Q measurements on a 100Gb/s QPSK channel as amplifier outputs were systematically reduced. This is a perfect simulation of repeater aging/pump failure in a linear system as it has similar effects to those produced by fiber aging and repairs, in that all result in lower power levels at the amplifier inputs.

On real systems fiber aging and repairs will produce somewhat different results if there are non-linear effects, as is typically the case. **Figure 1** shows how the power between along the fiber differs due to 3 scenarios, a power drop at the repeater output, a repair in the middle of a span and fiber aging. Note that all produce exactly the same reduction in input power at the next repeater.

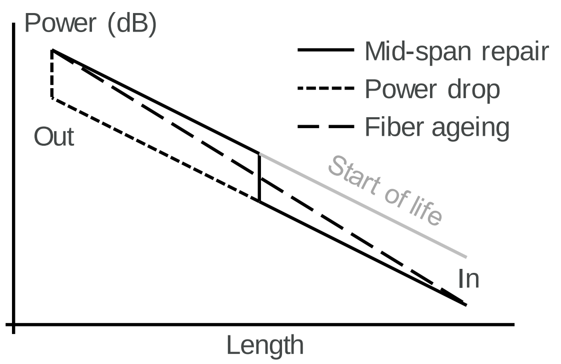

Figure 1: Power profile along a fiber section

These differences mean that mid-span repairs and fiber aging have higher path-averaged power levels than a power drop at the repeater output. In all cases there will be

[1] Q is directly related to BER. By common usage the term "Q" is used to mean the Q^2 value expressed in dB units.

some reduction in non-linear penalty, which will be greatest for the case of a power drop.

2. SYSTEM DESCRIPTION

For reasons of confidentiality, detailed system parameters are not included, but the line section under test included 10 subsea amplifiers and a simplified schematic and losses of key sections are summarized below.

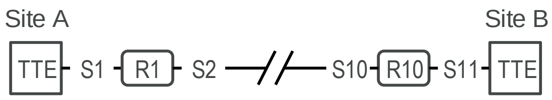

Figure 2: System Configuration

The span losses are all 23.2 +/- 0.3 dB except for one which was 21.9 dB, the shore end losses are 17.7 and 19.4 dB.

All the repeaters had essentially the same noise behavior, but the optical amplifiers in the terminal equipment (TTE) had a noise figure of approximately 5.5 dB, which is >2.5 dB higher than that of the repeaters.

3. CHANGING ALL REPEATERS

The total output power of all 10 repeaters was reduced in 1.0 dB steps to maximum of 7.0 dB total, which is the limit of adjustment while retaining the same gain shape as shown in **Figure 3**.

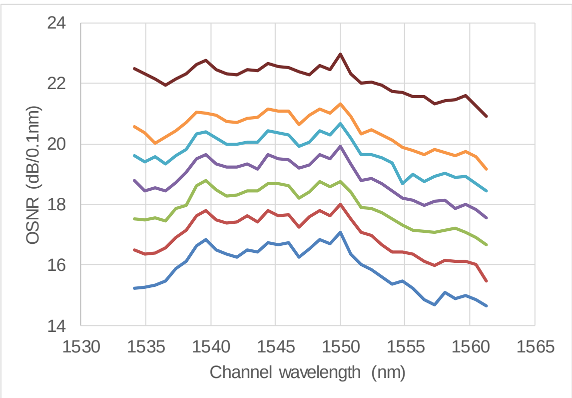

Figure 3: OSNR at various output powers

The resultant change in Q is shown in **Figure 4**.

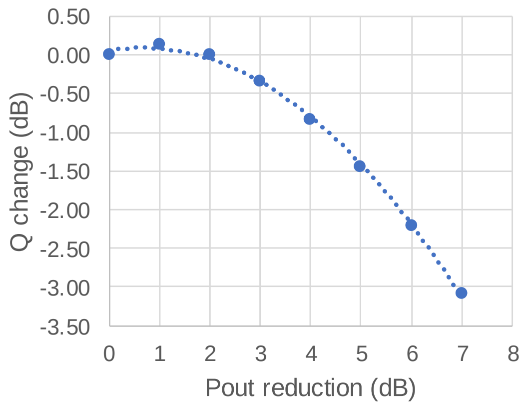

Figure 4: Power change in all sections

The measurements were evaluated over a period of time and it was determined that the Q measurements have a standard deviation of 0.1 dB.

Initially the power reduction improves Q, indicating that there are some non-linear penalties. After this initial reduction, the Q drops, approaching a slope of 1, as expected. The relatively high non-linearity is unsurprising as the maximum power is at a level where non-linear penalties would be expected. However, the penalty is somewhat lower than that predicted by the Pogglioni Gaussian Noise model [1].

The result also shows that the system has significant margin to tolerate repairs or aging and (as expected) that the Q margin is not a direct indicator. For example, if there were a Q margin of just 1.5 dB, then one could tolerate up to 5.0 dB of extra loss or signal reduction in every section.

4. CHANGING A SINGLE REPEATER

This test consisted of changing the power output of just repeater R1, the one nearest the transmitter at Site A, while measuring the Q at Site B. In this case repeater R2 compensates for almost all of the change in input power and its output is barely changed.

This result, shown in **Figure 5**, demonstrates a similar trend to that observed when all the repeaters were changed, but the effect is much smaller. If the sections were all identical one would expect the effect to be 1/11 as there are 11 spans. The observed change is ~1/10, which can be explained by the TTE receive amplifier having a higher noise figure than the repeaters.

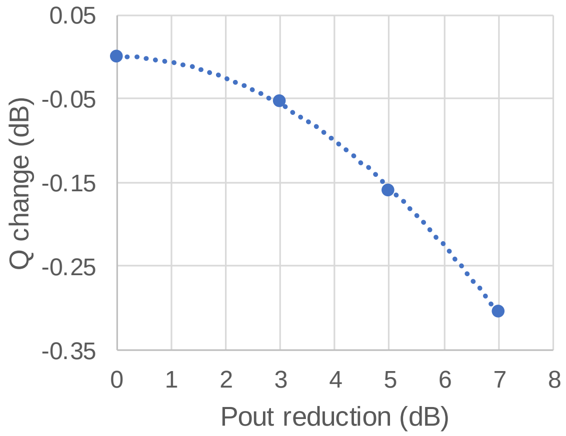

Figure 5: Power change in section S2

The same test was also done by changing the power produced by R5, which has the effect of reducing power in section S6.

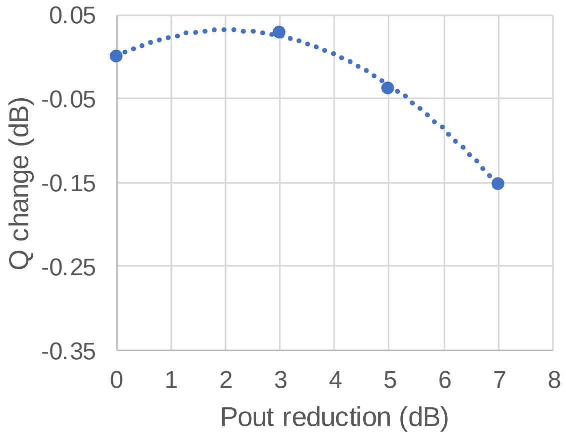

Figure 6: Power change in section S6

The trend, shown in **Figure 6**, is similar to that seen before, although in this case the effect of fiber non-linearity is much more obvious and the overall Q change is somewhat less. This is likely to be due to differences in power and loss and shows (as expected) that the impact of a given repair or aging will vary from section to section.

5. SHORE-END TESTS

The repeater power can only be changed by 7.0 dB, which limits the range of losses that can be assessed using this technique, although it would be an extreme case where the span losses were to change by more than this. It is possible, however, to simulate an increase in the loss of the shore-ends simply by adding attenuation between the incoming line fiber and the TTE. The results of doing this at Site A while measuring Q at Site B are shown in the next figure.

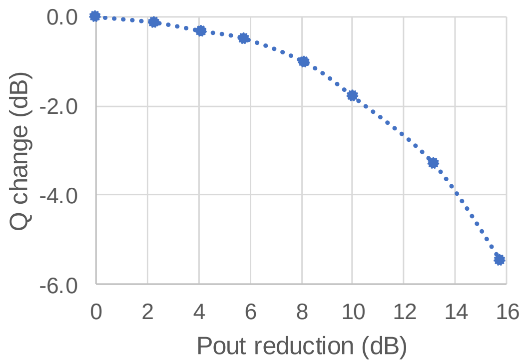

Figure 7: Power change in shore end

Here it is interesting to note that there is not much change until the power has been reduced by around 6 dB, after which the Q starts to drop more rapidly.

At very large power reductions the first amplifier is at such a low input level that it is contributing more noise than the all the other amplifier put together and this results in the gradient approaching unity.

There is however, a second effect which should be considered. At normal input levels an amplifier operates in compression: its gain will increase if the input signal is reduced, thus making the output power approximately constant. This compensation, however, is good over a limited range and at some point the output power will start to drop and the next amplifier will also have a smaller input and thus increase its gain. This results in slightly higher noise increase than if the first amplifier's output were constant, as is normally assumed in simple noise calculations.

Measurements of amplifier input powers were made, with the results shown in the following figure.

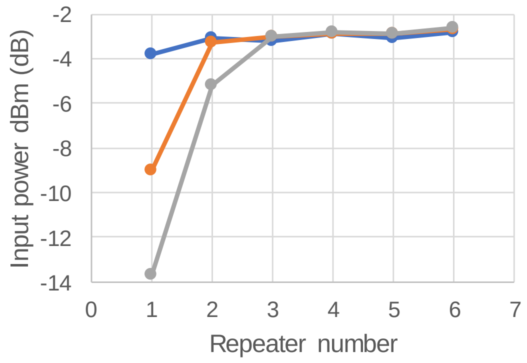

Figure 8: Effects of input level changes

The upper line shows the normal input power levels, which are more-or-less the same for all the amplifiers. Reducing the input power to the first amplifier by 5 dB has almost no effect on any of the following amplifiers, but a 10 dB change creates a 2 dB drop in the input to the second amplifier. Following amplifiers, however, remain at their normal levels.

It is also interesting to note that up to 15 dB can be added to a single section without dropping below the Q threshold. This means that the system is able to tolerate a cluster of repairs in a single section. Alternatively, this robustness to very large span losses was used recently to glass-through an intermediate line amplifier site as a disaster planning technique for the site, which can be in danger of being flooded in a hurricane situation. The system continued to operate error free, albeit with reduced margins, with the length of the shore end span effectively increased by 40 km.

6. SUMMARY

This work has measured the real-world operating margin of a subsea cable system, using repeater output reduction and increase of shore-end loss to explore the resulting Q changes. As discussed in Section 1, this is a perfect simulation of pump aging/failure, but it is slightly optimistic regarding repairs and fiber aging if there is non-linear behavior.

The effect of a non-linear relationship between Q and power can be quite significant. In the case of the work reported one sees how a Q margin of 1.5 dB translates into around 5 dB of potential repair / aging margin. This is clearly important in terms of the construction of a system power budget where ignoring these effects may result in over-engineering, with the potential of unnecessary expense.

The ability of the shore-ends to tolerate large loss increases suggests that it may be prudent to consider revising current thinking on margin planning and system design in certain areas.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] P. Poggiolini, “The GN model of non-linear propagation in uncompensated coherent optical systems,” Journal of Lightwave Technology 30(24), 3857–3879 (2012).