METHODS AND LIMITS OF WET PLANT TILT CORRECTION TO MITIGATE WET PLANT AGING

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Abstract: Submarine wet plants represent a significant long-term investment, and any extension of useful life, or correction to factors that may threaten the expected economic lifetime, can be very valuable to cable owners. One factor that can threaten the optical performance of a submarine cable is the accumulation of tilt along the repeater chain. Tilt is often caused by the addition of loss due to repairs and can cause not only degradation of system OSNR, but higher than average launch powers throughout, leading to significant non-linear propagation penalties, particularly on dispersion managed cables. In this paper, we present laboratory measurements where varying degrees of tilt are induced in a submarine line system via excess losses, representing submarine cable repairs. The extent of correction via pre-emphasis and other tilt management techniques at the terminal (SLTE) is investigated.

1. INTRODUCTION

Tilt in submarine repeater systems is typically a result of increased loss due to some combination of repairs and cable aging. Link budgets must account for these repairs and aging [1,2]. When an Erbium based amplifier operates at a gain greater than that for which it was designed the result is dynamic gain tilt where short wavelengths are emphasized at the expense of longer wavelengths.

In this paper we investigate the effects of Erbium induced dynamic gain tilt in an approximately 5000km linear test system. Various loss distributions are investigated as well as various ways to mitigate their effects.

System Description

This investigation utilized a nearly 5000km linear laboratory system comprised of 70 spans with 69 submarine amplifiers. The details of the system are captured in the table below (**Table 1**).

5000km Lab System Specifications		
Parameter	**Value**	**Units**
Wavelength Range	1535 - 1563	nm
Output Power	15.0	dBm
Average Span Loss	15.0	dB
Number of spans	70	
Total Distance	4877	km
Number of EQs	10	

Table 1: Linear System Specifications

The system is representative of many dispersion managed systems with the following fibre and repeater configuration (Figure 1).

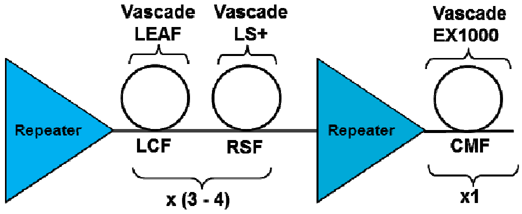

Figure 2: Linear System Fibre Design

System Characterization

The system was characterized in its as built state. As depicted in Figure 2 the end to end gain of the system is very flat. Note that all plots are presented in decreasing frequency, while the text refers to the more familiar wavelength designation when describing optical effects such as tilt.

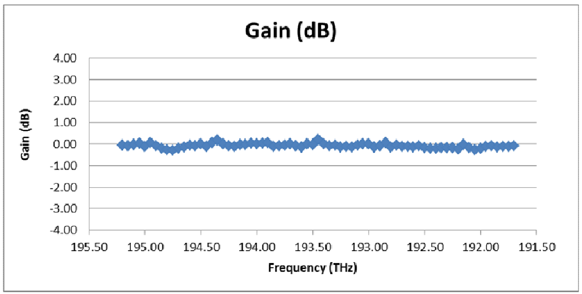

Figure 2: End to End Gain of the System

Figure 3 shows that the delivered OSNR of the system is biased towards the long wavelengths (lower frequency) due to wavelength dependent loss (WDL) of the fibre and slight noise figure (NF) tilt of the amplifiers.

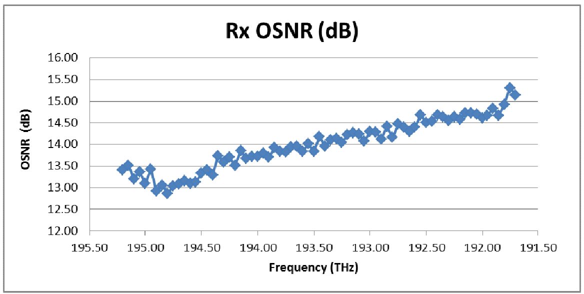

Figure 3: Delivered OSNR of the System

The power evolution of the system is displayed in the 3D plot in Figure 4. Of note is the fact that the long wavelengths benefit due to WDL and Stimulated Raman Scattering (SRS) and these effects are typically corrected at each of the 10 equalizers. This is the baseline power evolution of the system and all further power evolutions presented in this paper are normalized to this.

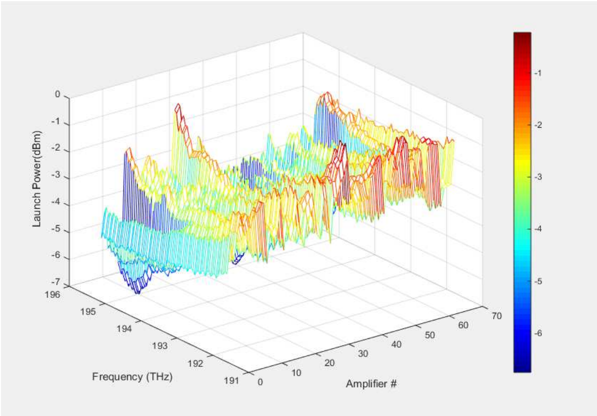

Figure 4: Power Evolution through the System

2. DISTRIBUTED LOSS

The first set of experiments looked at the effect of a distributed excess loss in the system. Different levels of distributed losses were investigated from a total of 8dB to 25dB. The example of 4x4dB=16dB excess loss is reported here as representative of this type of loss. This loss was accomplished by adding a constant loss across wavelength at four of the equalizer sites.

As expected [3,4] the system tilts (Figure 5) emphasizing the short wavelengths to the detriment of the long wavelengths (+2dB to -3dB).

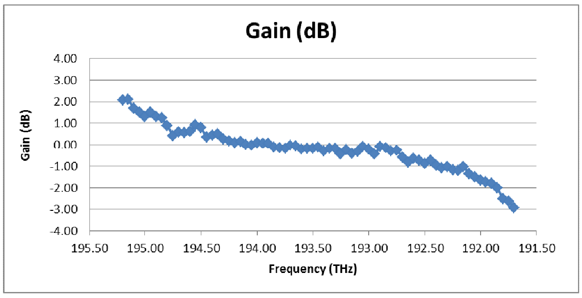

Figure 5: End to End System Gain with 4x4dB Distributed Loss

Accordingly, the OSNR also tilts with respect to the baseline measurement as shown in Figure 6.

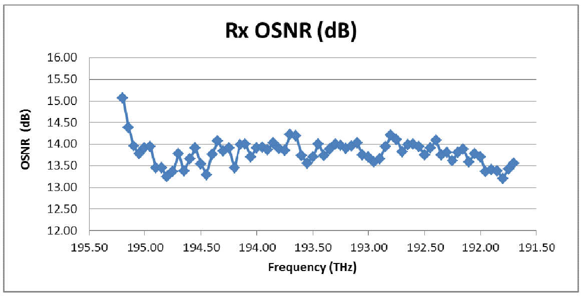

Figure 6: Delivered OSNR of the System with 4x4dB Distributed Loss

Figure 7 shows a normalized power spectrum for the system and the increase of tilt at each of the discrete points can be observed. It should also be noted that the effects of spectral hole burning are working to reduce the gain at short wavelengths thereby reducing the net tilt experienced.

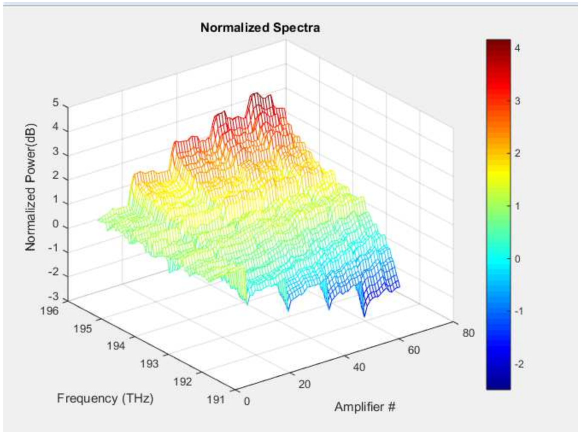

Figure 7: Normalized Power Evolution with 4x4dB of Distributed Loss

An attempt was made to compensate for this tilt by pre-emphasis at the transmit side. This resulted in even a greater tilt induced across the system (+4dB to -4dB) as shown in Figure 8 because the reduced effects of spectral hole burning.

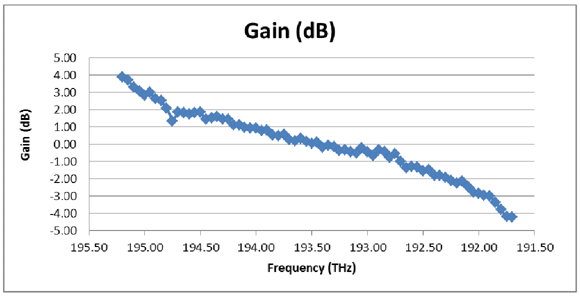

Figure 8: End to End System Gain 4x4dB Distributed Loss with Transmit Pre-emphasis

The pre-emphasis did provide a small amount of received OSNR equalization (Figure 9), but more importantly it better equalized the power throughout the system (Figure 10) which improves the channels' non-linear performance.

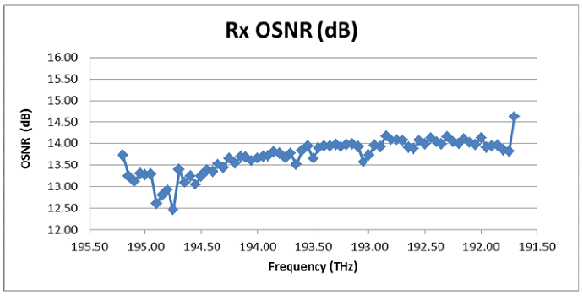

Figure 9: Delivered OSNR of the System with 4x4dB Distributed Loss with Transmit Pre-emphasis

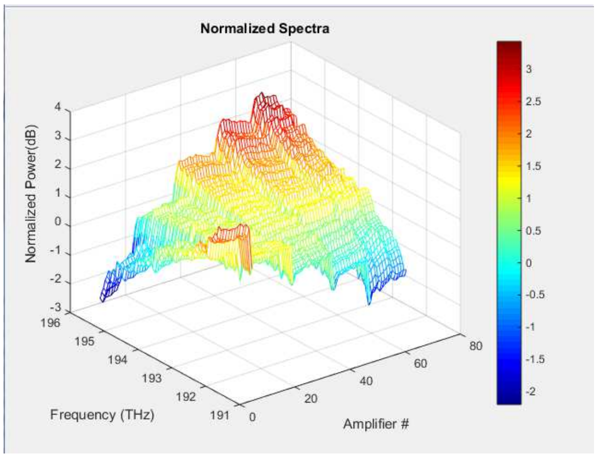

Figure 10: Normalized Power Evolution with 4x4dB of Distributed Loss with Transmit Pre-emphasis

It can be seen that transmit pre-emphasis can mitigate some of the effects of distributed losses.

3. LUMPED LOSS

In contrast to the distributed loss case, the effects of a lumped loss were also investigated by adding losses from 5dB to 15dB at different points in the system.

An excessive 15dB lumped loss is presented here to dramatically illustrate the sometimes subtle effects of these types of loss elements. A 15dB loss element was introduced into the second span of the linear test system described previously.

The end to end system gain is presented in Figure 11 and shows a surprisingly low tilt manifestation.

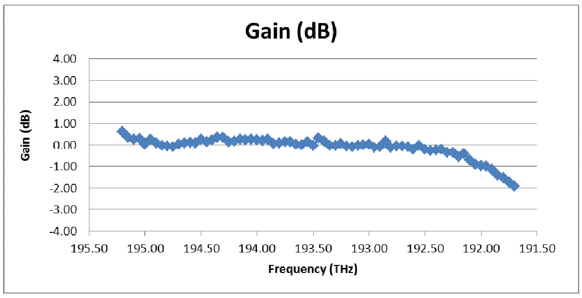

Figure 11: End to End System Gain with a 15dB Excess Loss in 2nd Span

To understand this result the power evolution through the system must be explored. In Figure 12 it can be seen that a large tilt is induced at the second span followed by a decay of this tilt in subsequent spans caused by spectral hole burning [5,6].

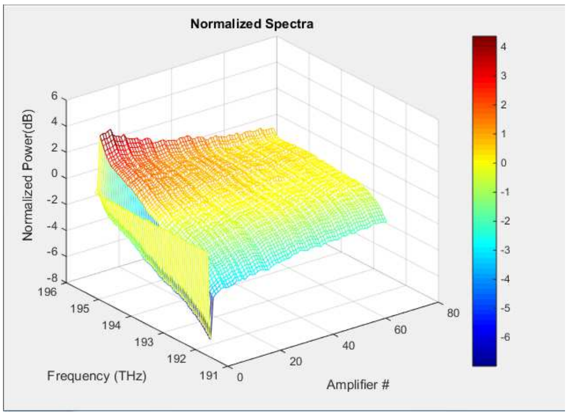

Figure 12: Normalized Power Evolution with 15dB Excess Loss in 2nd Span

An attempt was made to counteract this tilt through transmit pre-emphasis. Intuitively, this would seem easy to counter-act. However, additional pre-emphasis actually increased the net tilt of the system through the reduction of spectral hole burning.

Figure 13 shows the end to end gain through the system with pre-emphasis which paradoxically shows more end to end tilt than the uncompensated system.

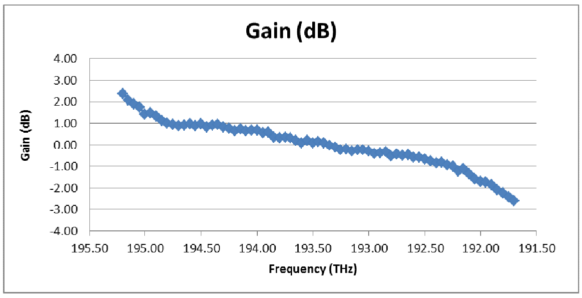

Figure 13: End to End System Gain with a 15dB Excess Loss in 2nd Span with Transmitter Pre-emphasis

Again, looking at the power evolution through the system (Figure 14) provides a clearer picture as to what is occurring. The pre-emphasis is not effective in counter acting the induced tilt and furthermore does little to lower the average launch powers in the short wavelength end of the band which suffers from much greater non-linearities.

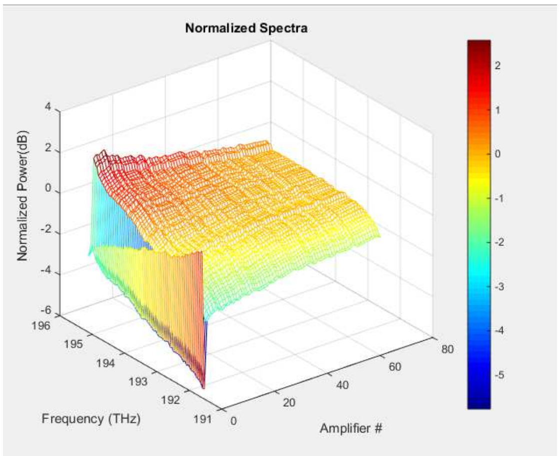

Figure 14: Normalized Power Evolution with 15dB Excess Loss in 2nd Span with Transmit Pre-emphasis

It should also be considered that an excess loss at the head end of the system will appear as an excess loss at the tail end of the system in the other direction.

Figures 15 and 16 illustrate what the same excess loss would look like if measured in the other direction. It should be noted that a large directional difference is observed for the two end to end gain curves (+/-4dB to less than +/-1dB). If this were encountered in the field, where gain and power can be measured at link end points only, it may at first appear puzzling, and perhaps be interpreted as fundamental directional performance difference.

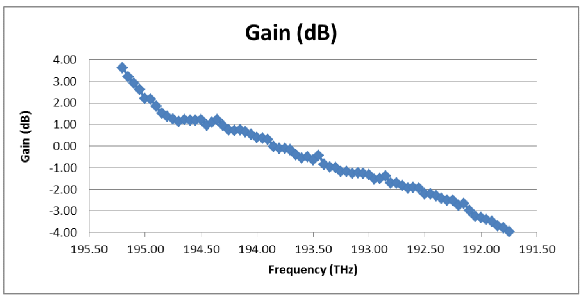

Figure 15: End to End System Gain with a 15dB Excess Loss in 68th Span

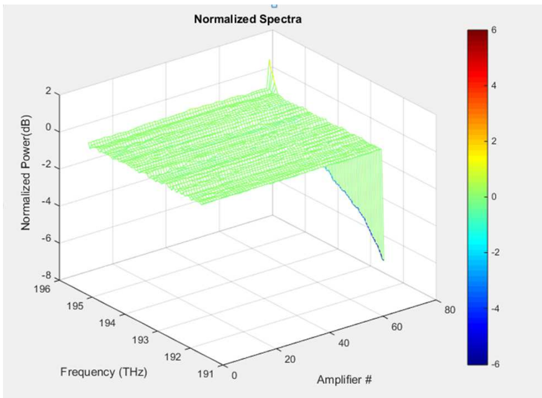

Figure 16: Normalized Power Evolution with 15dB Excess Loss in 68th Span

It should be clear that transmit pre-emphasis would be ineffective in this case despite what the end to end gain through the system might imply.

For these excessive lumped loss scenarios a repair repeater is the best remedy. This was done in this laboratory experiment and effectively returned the system back to the normalized baseline. To perfectly execute such an activity, accurate knowledge of the span(s) in which excess lumped losses have occurred is required. This could be determined via the wet plant monitoring system in place, and correlated to any repair history available.

4. CONCLUSIONS

Transmitter pre-emphasis can be an effective tool for compensating some aging effects in submarine cables, in particular small distributed losses or fibre aging. However, it is ineffective in the presence of other aging phenomena such as large bulk losses due to repair. Spectral hole burning actually works to correct the effects of tilt due to unequal spectral loading of the Erbium based amplifiers. For larger bulk losses, identifiable by their directionally asymmetric end-to-end tilt, the most effective method of correction is a repair repeater.

5. REFERENCES

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