# CAPACITY OPTIMIZATION OF SUBMARINE CABLE THROUGH SMART SPECTRUM ENGINEERING

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**Abstract:** New generation flexible and coherent transponders offering multiple, selectable or tunable parameters such as modulation schemes and channel wavelength tuning are now being deployed in line terminal equipment. Spectrum engineering consists of selecting the optimum transponder parameters to match each channel format to line performance within the system bandwidth to optimize the submarine cable capacity to the required transmission performance.

## 1. INTRODUCTION

Until recently, transponders offered a single modulation format associated with fixed wavelength grid. New flexible transponders have become available and propose multiple modulation formats and parameters that can be software selected, thus opening a wide range of system optimization. This optimization can target either minimum cost per bit or maximum system capacity.
This new transponder flexibility, discussed in this paper, is more than an additional feature of the transponder as it will dramatically change the way we install and operate submarine networks.

## 2. EARLY DAYS OF SPECTRUM ENGINEERING

Spectrum engineering started with Wavelength Division Multiplexing (WDM) which required transmitting channel power pre-emphasis optimization to equalize received OSNR in order to get homogeneous transmission performance across the WDM multiplex [1].
Spectrum engineering continued with using a of mix of Differential Phase-Shift Keying (DPSK) and On-Off Keying (OOK) modulation formats to optimize the transmission performance whatever the channel wavelength in the bandwidth of Non-Zero Dispersion-Shifted Fiber (NZDSF) systems. For these systems, OOK channels were set in the center of the multiplex while DPSK channels were set on the edges [2].

## 3. FLEXIBLE TRANSPONDERS

Coherent optics and powerful Digital Signal Processing (DSP) make flexible coherent transponders emerge that propose multiple software selectable parameters to optimize system margin and/or capacity.
The list of parameters, limited for the first generation of transponders to a few available modulation formats and selectable symbol rates will become longer with time to expand the flexibility of the transponders. In this paragraph, focus will be put on the following parameters: modulation formats, symbol rate and gridless wavelength assignment.

### *Modulation formats*

Contrary to earlier generation flexible transponders compatible only with PDM-BPSK and PDM-QPSK, future products will propose a much wider range of modulation formats such as, but not limited to, PDM-BPSK, PDM-QPSK, PDM-8QAM and PDM-16QAM (Figure 1). The benefit of increasing the number of bits per symbol, i.e.: increasing the bit rate, is an increase in spectral efficiency. The drawback is that there is a higher sensitivity request that can result in a loss in transmission reach. For example, 4 bits per symbol are encoded in PDM-16QAM format as opposed to only 2 bits per symbol encoded in PDM-QPSK format. When compared at the same symbol rate, the PDM-16QAM format shows a spectral efficiency double than the PDM-QPSK format. Unfortunately, this higher spectral efficiency comes at the expense of Signal to Noise Ratio sensitivity which is reduced by 7dB, corresponding to a 5 times reduction in reach.

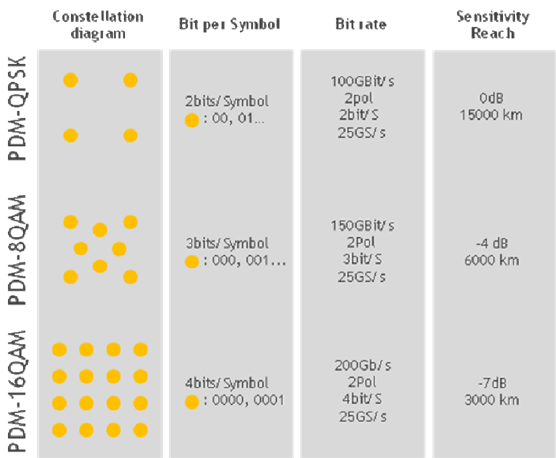


**Figure 1: Modulation formats and bit rates for a 25G Symbol/s rate**

In addition to the format itself, pulse shaping is applied to minimize interferences between carriers to bring closer channel spacing to symbol rate [3].

***Gridless wavelength***

Transponders equipped with gridless laser tuning function allow an arbitrary wavelength to be set for transmission. When this function is coupled with adequate multiplexing and de-multiplexing architecture in the terminal equipment, limitation in spectral efficiency dictated by a gridded wavelength plan can be overcome with a gridless wavelength.

***Symbol rate***

Symbol rate can also be selectable to decrease or increase the Forward Error Correction (FEC) overhead in order to adapt the symbol rate to the required channels spacing. Typically, a 100Gbit/s PDM-QPSK with 15% overhead has a symbol rate of 30GS/s while a 100Gbit/s PDM-QPSK with 25% overhead has a symbol rate of 33GS/s. The use of a lower symbol rate, 30GS/s instead of 33GS/s, makes a 3GHz narrower channel spacing possible provided that a 0.7dB reduction in the net coding gain of the FEC is accepted [4].

## 4. SMART SPECTRUM ENGINEERING

The transponder flexibility opens the way to smart spectrum engineering targeting different optimization objectives:

- Postponement of investment in the terminal by only installing the hardware resources necessary to reach the transmission performance at beginning-of-life. This approach is also known as ‘Time Based Service’
- Maximize the ultimate capacity by maximizing the efficiency of each spectrum portion.

These objectives can occur sequentially during the life of a submarine system.
An efficient Smart Spectrum Engineering shall take in to account:

- actual system data including bandwidth utilization, and performance margin versus requirements of the already installed channels

- operator requirements for capacity and margin,

The data and requirements analysis shall generate a solution which offers:

- an optimum proposal for bandwidth allocation and hardware utilization
- a plan for smooth implementation in the submarine network

## 5. TIME BASED SERVICE

At system beginning-of-life, as the margin provisioned for system ageing and repairs has not yet been consumed, transponder flexibility allows a capacity higher than normal to be delivered by a given hardware. This ‘over-boost’ setting can be used to match the required capacity with a reduced installed terminal hardware. Similarly, a higher capacity can be delivered with a terminal hardware sized for a nominal capacity.

As an example, the PDM-8QAM format with 50GHz channel spacing will provide the same spectral efficiency as the PDM-QPSK format with 33GHz channel spacing, with about 2dB less margin taking into account the OSNR gain due to channel spacing and OSNR sensitivity loss due to modulation format (Figure 2**Erreur ! Source du renvoi introuvable.**).

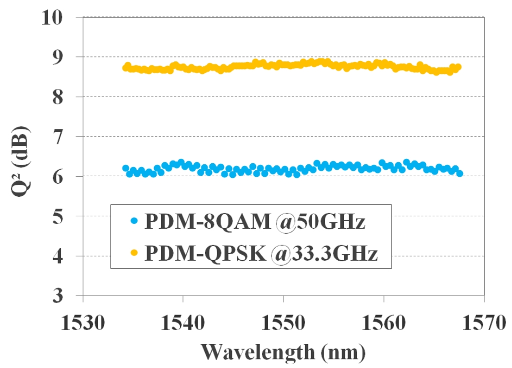


**Figure 2: PDM-8QAM @50GHz and PDM-QPSK @33.3GHz after 4000km**

The advantage of choosing a modulation format with a higher spectral efficiency, the PDM-8QAM format carries 3 bits/symbol while PDM-QPSK carries 2 bits/symbol, is that the same capacity can be provided with a 33% reduction in the number of installed transponders.

This approach is effective even if improbable and unplanned events, like multiple cable cuts on the cable, occur during the life of the system. If this happens, a software reconfiguration of the transmission system from PDM-8QAM to PDM-QPSK can recover the necessary transmission margin and performance. The capacity gap resulting from this operation will be recovered by adding hardware resources in the terminal equipment.

Contrary to the traditional approach where the entire set of resources is installed at day one with unused extra margin for a large portion of the life of the system, the benefit of this approach is that hardware resources are dimensioned to the actual need, thereby shifting the investments in terminal hardware.

Flexible transponders offer the formidable opportunity to convert margins available in the wet plant into hardware cost savings in the terminal equipment.

## 6. SPECTRUM ENGINEERING & APPLICATION TO GLOBENET SEGMENT 4

The objective of this transmission test performed on the Globenet submarine system is to demonstrate the maximum ultimate capacity of the system taking advantage of the flexibility of the transponders to maximize each portion of the spectrum.

An on-site test was performed with 100Gbit/s PDM-QPSK transponders on one fiber pair of the Globenet Segment 4 cable (Figure 3), connecting Fortaleza (Brazil) to St David’s (Bermuda). This NZDSF based segment, the longest of the Globenet submarine network installed in the year 2000, is 5400km long and was designed for a 0.34Tbis/s capacity per fiber pair using 10Gbit/s technology.


**Figure 3: Globenet Submarine Map (Segment 4 in green)**

The chromatic dispersion mapping is a mix of NZDSF fiber with negative CD (-2ps/nm/km) and compensation fiber with positive CD (+18ps/nm/km) to nullify the cumulated zero-dispersion at 1553nm, corresponding to the multiplex central wavelength. Even if nullified at central wavelength, the cumulated CD ranges from -3500ps/nm to +3500ps/nm across the optical bandwidth and leads to non-linear propagation impairment dependence to wavelength.

The available optical bandwidth of Globenet segment 4 is close to 2THz corresponding to 50 channels at 40GHz or 40 channels at 50GHz.

Firstly, the transmission performance across the bandwidth was sampled across the optical bandwidth using 100Gbit/s PDM-QPSK with 40GHz channel spacing with constant received Optical Signal to Noise Ratio (OSNR) to evaluate the performance sensitivity versus wavelength (Figure 4). The recorded performance shows the impact of zero cumulated CD around 1553nm leading to a 1dB lower performance.

In order to improve the performance of the channels located in the centre of multiplex, the channel spacing was increased from 40GHz to 50GHz to increase the OSNR and reduce the non linear interactions between channels. The performance was in turn increased by 1dB.

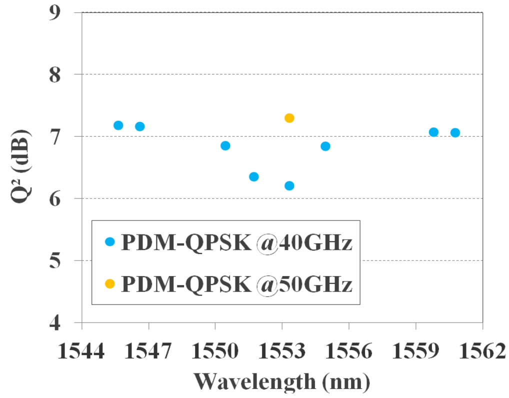


**Figure 4: Globenet segment 4 average $Q^2$ performance with 100Gbit/s PDM-QPSK**

In order to reach flat performance (i.e. about 7dB $Q^2$) across the optical bandwidth, 50GHz spaced channels will have to be installed in the center of the multiplex (i.e. 1550nm – 1556nm range) while 40GHz spaced channels have to be installed on the edges.

The use of adequate channel spacing, across the multiplex allows us to reach 4.5Tbit/s capacity using 100Gbit/s PDM-QPSK channels with constant transmission performance. On-site spectrum engineering tests have validated a 4.5Tb/s ultimate capacity per fiber pair corresponding to a 13 fold increase capacity using currently available transponders.

## 7. CONCLUSION AND OUTLOOK

A spectrum engineering test performed on Globenet segment 4 demonstrates that 4.5Tbit/s capacity can be extracted from this existing submarine wet plant designed for 0.32Tbit/s.

Smart spectrum engineering aims to leverage flexible transponder value optimizing the network efficiency that could translate into minimizing the hardware to be installed and maximizing the ultimate capacity of submarine networks. In the future, each transponder might be able to gauge its part of the spectrum and the full multiplex to adapt itself to the best global efficiency.

## 8. REFERENCES

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