HOW TO STAY FIT: IMPROVING PERFORMANCE AND FLEXIBILITY IN TERMINAL EQUIPMENT

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Abstract: In 2004 we described a new generation of Alcatel submarine line terminal equipment adapted to the prevailing market conditions. Whilst there has been no particular market requirement to revise the terminal core, technology advancement and functional evolution have led to many changes, resulting in a notably different terminal, a closer fit to today's wider-ranging market needs. We focus on two specific topics; the improvement in performance realized through the use of DPSK transponders in place of the traditional CRZ modulation format and secondly the functional evolutions that have been considered as a result of a number of diverse requests.

1. INTRODUCTION

At SubOptic 2004 we described a new generation of submarine line terminal equipment. This new generation of equipment was realized around a common platform of core units and management system, with the addition of a family of application-specific building blocks selected to create the optimum terminal for the specific requirement. In this paper we bring this story up-to-date.

2. COMMON PLATFORM DESIGN ETHOS

The original concept that determined the fundamental structure of the new generation terminal was to create a strong network platform, which would be capable of supporting a family of terminals, optimized for different applications, ranging from transoceanic submarine systems to terrestrial long haul and metropolitan links.

The adoption of this common platform approach has been proven to be a solid strategy which has reaped multiple benefits. There has been no particular market or customer requirement to modify the core of the new terminal, but that is not to say that the available options or make-up of the terminals are unchanged. On the contrary, technology advancement and the need for functional evolution have led to many modifications and additions to the family of building blocks, resulting in a notably different terminal, one that is more fully adapted to today's wider ranging market place.

Naturally, such diverse systems require different levels of performance, linked closely with corresponding cost targets and the diversity of performance and cost is significantly increased today. At the top end of the market, DPSK transponders are replacing (C)RZ transponders for the optimum performance over transpacific distances, both at terminal level and in terms of the number of submerged repeaters. With DPSK however comes a far from negligible increase in transponder cost that must be justified versus the overall benefit.

At the opposite end of the scale, cost reduction, endemic throughout the industry in recent years, has given birth to the new "regional" terminal, as well as prompting numerous other initiatives aimed at helping restore the margin in submarine contracts. A single unit is now available for use in submerged line loading of partly equipped systems, bringing operational and industrial benefits while for the customer, significantly reducing the cost of spares.

Clearly flexibility is key in today's market place, not just in adapting the terminal configuration, but also in the type of traffic that can be presented at the client interfaces. New client interfaces for 10G Ethernet LAN traffic, 4 x 2.5Gbit/s SDH and 9 x 1G Ethernet LAN concentrators now come as standard options on most submarine Requests for Tender and constitute an important functional evolution of submarine terminal equipment.

3. DIFFERENTIAL PHASE SHIFT KEYING (DPSK)

Submarine systems require every fraction of a dB to be squeezed from the line budget. The choice of terminal modulation format is critical in achieving the maximum reduction of the linear and non-linear impairments accumulated over the transmission fibre. In recent years, DPSK format transponders have replaced the more traditional RZ transponders at the top end of the optical performance market, bringing a benefit of ~3dB in OSNR sensitivity compared to On Off Keying (OOK) techniques used in Intensity Modulated (IM) systems. This increase in performance comes at a price however, there is an increased complexity and cost of the components and transponder which must be more than compensated for with the performance improvement.

In IM systems, the digital signal is represented by the power level of the optical signal. The digital signal can also be represented by the phase of the optical signal, so-called phase-shift keying (PSK). Until fairly recently, the optical phase of the laser signal was not sufficiently stable to allow industrialisable PSK based systems. Advances in laser stability and the development of actively stabilized receivers now mean that it is possible to practically realize PSK systems. Differential PSK (DPSK), where the phase of the preceding bit is used as a relative phase reference, is the most often used format.

3.1. DPSK Transponder implementation

In a DPSK transmitter, shown in Figure 1, the data signal is encoded as either a '0' or a 'π' phase shift between adjacent bits. An electrical NRZ signal is encoded by the DPSK encoder (essentially a NOR gate and then an XOR combination with a one-bit delay) to produce a DPSK electrical signal. This signal is then used to drive an electro-optic phase modulator to produce an NRZ optical signal. A digital '1' is seen as a π phase change between the consecutive bits in the optical signal, a '0' is represented by no phase change between consecutive bits. To produce the final RZ-DPSK output, the signal is modulated by a second intensity modulator clocked at the data rate. The DPSK-RZ transmitted eye diagram is shown in Figure 2.

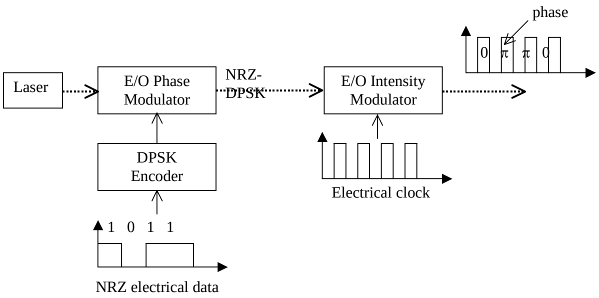
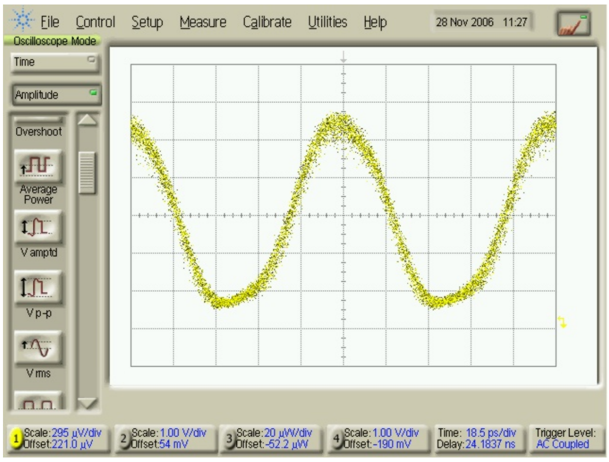


Figure 1: RZ-DPSK Transmitter

To decode the DPSK signal at the receive end, a Mach-Zehnder Delay Interferometer (MZDI) is used as shown in Figure 2. The MZDI correlates each bit against the previous bit by interference with a 1 bit delay. The complementary outputs of the MZDI are used to produce a balanced receiver which can yield a 3dB OSNR sensitivity improvement. The two complementary outputs are input to two photodiodes and the two resulting electrical signals are combined to double the signal level. In an ideal case, this doubling of signal level results in a 3dB improvement over conventional OOK systems.



Scale: 295 µV/div Offset: 221.0 µV
Scale: 1.00 V/div Offset: 54 mV
Scale: 20 µW/div Offset: -52.2 µW
Scale: 1.00 V/div Offset: -190 mV
Time: 18.5 ps/div Delay: 24.1837 ns
Trigger Level: AC Coupled

Figure 2: RZ-DPSK transmit eye diagram

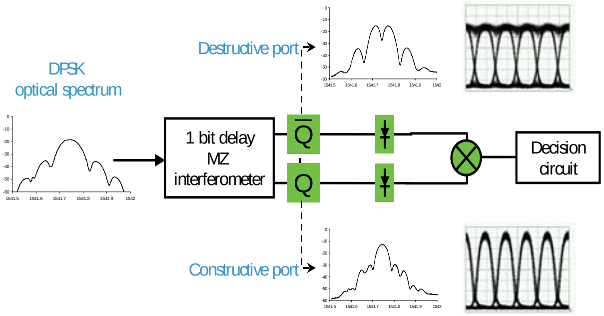


Figure 3: DPSK receiver

3.2. Critical design constraints

DPSK receiver performance is very sensitive to the mismatch between the centre frequency of the MZDI and the frequency of the optical carrier. A detuning can be caused either by a temperature change of the demodulator or a drift of the laser centre wavelength. A detuning of 0.5GHz corresponds to a 1dB penalty at a bit rate of 10Gbit/s. Today, laser specifications will give a tolerance of +/-1.5GHz over the 25 year lifetime of a submarine link. Clearly one of the critical design constraints is to develop a reliable, long term method of ensuring sufficient alignment between transmitter and receiver drift. [4].

3.3. Results

As explained DPSK modulation format associated with a balanced receiver improves the Optical Signal to Noise Ratio (OSNR) sensitivity by nearly 3dB. While a BER of 10-6 is obtained with a OSNR of 12.5 dB/0.1nm with RZ modulation format, a BER of 10-6 is obtained with a 9.5 dB/0.1nm with DPSK. This corresponds to a 3dB BER-OSNR improvement. Measured results on a DPSK transponder are shown in Figure 4.

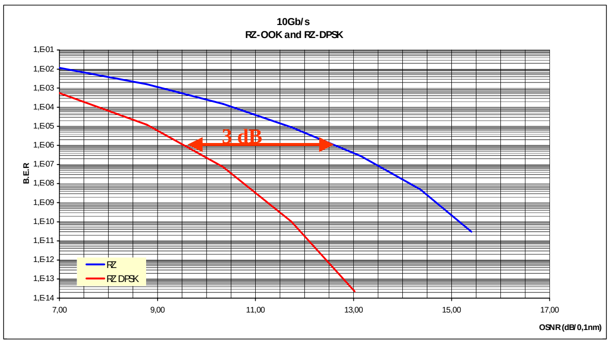


Figure 4: Typical BER-OSNR curves for RZ-OOK and RZ-DPSK modulation format

3.4. System benefit

This 3dB improvement in OSNR sensitivity can roughly be translated into a 15km span length increase. When associated with Dispersion Slope Matched Fibre, this improvement allows to an increase in the repeater span of approximately 30km on a trans-oceanic system [3].

The improvement can also be exploited to increase the capacity of the system by reducing the channel spacing. 33GHz spaced systems can be considered with DPSK transponders, even for the longest transpacific systems. To achieve transponders for this reduced channel spacing, it is necessary only to replace the tuneable laser source fitted to the transponder. This laser is fully tuneable over the available repeater bandwidth, meaning that only one transponder variant is required for each transponder type, greatly reducing the number of spares that have to be held to meet availability requirements.

Results on long systems prove that DPSK format is well suited for high spectral density transmission over transoceanic distances. This format also exhibits a very large tolerance to in-line cumulated dispersion. These two characteristics make DSPK a modulation format which can be used, not only to design cost-optimised new systems, but also to upgrade already installed links. [1] [2] [3].

4. FLEXIBILITY

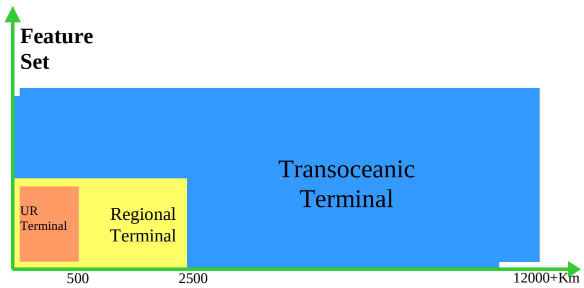


Figure 5: Flexibility in configurations

One of the major advantages that the introduction of a common core platform can bring to the design of the SLTE is undoubtedly flexibility, both in terminal configurations, i.e. in the capacity to adapt to different system requirements in the submarine business (as shown in Figure 5), and in the availability of a number of client interfaces that allows customers to respond to an increasingly diversified traffic demand.

4.1. Flexibility in configurations

A flexible submarine terminal must be able to cope with at least the following six different submarine configurations:

Transoceanic: the highest performance and feature-rich version of the submarine terminal, allowing transmission over all distances up to transpacific spans. It includes the most advanced submarine features like 1+N equipment protection, submerged plant supervision and an additional fully featured submarine line management system. This configuration covers all possible needs in DWDM submarine networks including 33GHz (0.27nm) channel spacing and can theoretically reach 144 channels, although often limited by the submerged equipment bandwidth to a nevertheless respectable figure of 118 channels.

Regional: lower cost than the transoceanic configuration, the regional terminal is perfectly adapted for systems up to 2500 km and up to 32 channels. Certain features, like 1+N equipment protection, are not offered in this configuration in an effort to contain the overall cost of the solutions.

Un-Repeatered terminal: a specific configuration, designed for Unrepeatered systems. It must be possible to complement this terminal configurations with external Raman pumps up to 3rd order, boosters and amplifier to extend the reach to up to 500Km.

Line Supervision Equipment: a sub-system devoted to the supervision of submerged equipment. Can be deployed in association with other terminals: a typical usage to this sub-systems is in scientific and off-shore network projects.

Dark Fibre Monitoring Equipment: another sub-system of a submarine terminal allowing the supervision of dark fibres and relevant submerged equipment. This configurations has to be easy to use and small sized.

All these configurations, although apparently so different, share the same core platform and basic software and can utilise the same high reliability common parts with duplicated pump line amplifiers and boosters: all of them can be managed by the same equipment management system.

4.2. Flexibility in client interfaces

Several new types of client interfaces have recently appeared in the submarine business and are now available on the most advanced submarine terminals.

In addition to the traditional 9.95Gb/s STM-64/OC-192 SDH interface UNI, capable of transporting also the

10Gb Ethernet WAN signals, a fully compliant ITU-T G709 NNI 10.7 Gb/s interface is now often requested.

Internet traffic can also be transported by the 10GEthernet LAN interfaces (10.31Gb/s input) of the terminal, compliant with IEEE802.3.

Transporting low level Ethernet traffic becomes possible via a new 8x1Gb Ethernet LAN concentrator. The realisation of this board is shown in Figure 6.

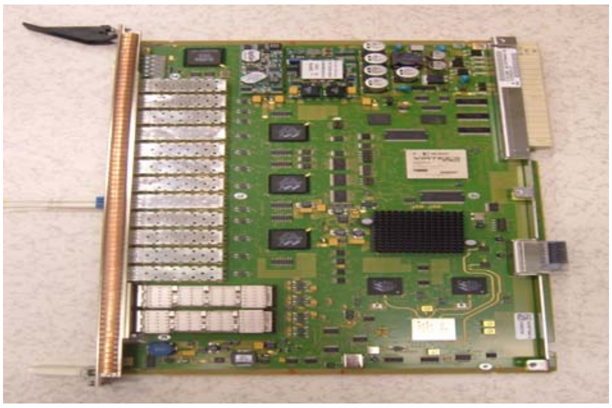


Figure 6: 8 x 1Gb Ethernet concentrator unit

A 4x2.5 Gb/s concentrator with I16.2 or S16.1 B&W interfaces, often requested for restoration of existing 2.5 Gb/s systems, completes the list of currently available submarine client interfaces.

All these units, transponders and concentrators, are now tuneable on the entire C band, offering a remarkable degree of flexibility in operations and sparing.

In addition, the new generation of transponders lies on a newly designed universal transponder platform providing 10G client interfaces, S64.2b, VSR or 10GE, via pluggable XFP modules: a further step in flexibility that allows a more efficient management of the traffic and of the station spare units. The choice of 10G B&W interface becomes plug-and-play for any bit rate and optical module, the same feature that the existing 2.5G concentrators already provide.

For systems with low installed channel count, dummy channels are necessary to load the line: these dummy channel units are now tuneable on the C band as a signal laser continuously tunable over the range 1529-1569nm with a stability of ±12pm has been incorporated into Automatic Loading Channel unit. This provides a cost benefit to customers with the reduction in the number of spare loading channel units required, and also greatly implifies operational management with a single code to manage for all systems and all stations.

5. CONCLUSION

We have shown how the new generation of terminal equipment can keep pace with the latest market requirements; on one hand with increased performance allowing to optimize system cost and/or system capacity, and on the other hand, to provide terminal cost reduction with flexible, application-specific configurations and selectable client interfaces.

The submarine terminal of tomorrow is likely to continue with this approach of building flexibility on top of an established stable platform. As 40Gbit/s transponders become common place in terrestrial networks, their transfer to submarine systems could be rapid as there is little change required in the remainder of the terminal. A second major step in the medium term is likely to be to increase the power and capability of the terminal management system, providing faster reaction and access time and radically enhanced, more intelligent auto-diagnostic tools.

6. REFERENCES

[1]: “8370 km with 22 dB spans ULH transmission of 185*10.709 RZ DPSK channels” - G. Vareille et al - OFC 2003

[2]: “42x42.7 GB/s RZ-DPSK transmission over a 4820 km long NZDSF deployed line using C-band only EDFAs” – L. Becouarn et al – OFC 2004

[3]: “124*10 Gbits/s RZ-DPSK transmission over 12380 km without channelized chromatic dispersion management” – L. Du Mouza – OFC 2007

[4]: “Investigation on stabilised DPSK receiver at 10 Gb/s with a 5111 km long transmission” – L. Becouarn – ECOC 2005.