Transponder for Coarse Wavelength Division Multiplexing (CWDM) Optical Communication Systems

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Resumo **– Neste artigo é feita a descrição de um transponder óptico bidireccional implementado no âmbito do projecto SIRAC para um sistema óptimo com múltiplos comprimentos de onda espaçados (CWDM). As várias opções tomadas são detalhamento discutidas. É ainda analisada a possível extensão do transponder para sistemas densos com múltiplos comprimentos de onda (DWDM).**

Abstract **– In this paper a CWDM bi-directional optical transponder is described. This transponder was built in the framework of the project SIRAC. The design options followed are detailed discussed. This paper also discusses the possible extension of the transponder to Dense Wavelength Division Multiplexing (DWDM) systems.**

Index Terms **— Optical Transponder, CWDM Systems, DWDM Systems, FEC.**

I. INTRODUCTION

The optical communication systems had an enormous evolution in the last decade. The velocity of the transmitters has grown up to the gigabit rates. The reach of the systems was largely increased by the use of optical amplification. The systems went to single channel to multi-channels, allowing an aggregate capacity of the order of terabit rates.

The very large spectral window of optical fibers makes possible the multiplexing of several wavelengths channels in one single fiber (WDM-Wavelength Division Multiplex), each channel supporting transparently different protocols. This technology was rapidly improved and resulted in two different spectrum dispositions accordingly to the capabilities of the equipment used for transmission and detection, namely: CWDM - Coarse WDM and DWDM - Dense WDM. These two technologies were standardized by the ITU-T in 2002 [1, 2].

DWDM channel allocation is very dense with the possibility of having 150 channels in the spectral window ranging from the 1490nm to 1610nm, taking advantage of the optical transparency window provided by the erbium doped based amplifiers. However, this extremely dense channel allocation puts huge demands in several optical components, mainly in the spectral purity and stability of lasers sources and in the stability and suppression range of optical filters.

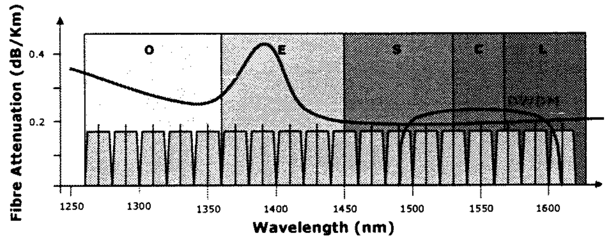

Fig .1 – Comparison of the CWDM and DWDM channel allocation. The CWDM channels are allocated between 1260nm and 1620nm. The DWDM channels are placed around 1550nm. A typical spectrum of fiber intrinsic attenuation is superposed in the graphic.

Due to advances in the fiber manufacturing process, mainly in the purification process regarding the hydroxide ion, the peak of absorption visible in the E band, see figure 1, is almost suppressed in recent fibers. Besides that other optical amplification mechanisms, mainly Raman amplification, have been developed in order to provide gain in all optical bands. Furthermore, fibers have reached the metro market, where distances are small and optical amplification is not needed. Additionally, there is still a great deal of dark fibers in the field that the operators want to make profitable. Having this in mind the CWDM standard was created to take advantageous of a higher separation between optical channels. The CWDM channel allocation has channel spacing of 20nm, whereas DWDM has channel spacing of 100GHz (~0.8nm). This less complex variation of WDM promises a cost-effective way to deliver bandwidth. Continuing technology advances combined with recent strides made in standards organizations, have led to a growing interest in CWDM.

This paper describes the implementation of an optical transponder for CWDM systems.

II. THE TRANSPONDER

The transponder is a module that does the interface between the electrical equipment, typically a SDH or Gigabit Ethernet card, and the optical line system.

According with the etymology **Transmitter-Responder,** a transponder is a device that transmits a specific signal in response to a given input signal that may or may not be of the same physical nature.

In this application the device implements the interface between the client and the optical line, see figure 2. It converts a signal intended to be transmitted in short-distance paths (SR - Short Reach), typically between local equipments, and a signal intended to be transmitted in long-distance paths (LR - Long Reach), typically between remote equipments [3]. Therefore, the projected transponder has two bi-directional optical interfaces, a short reach and a long reach optical interface. The SR interface connects with the SR interface of the electrical equipment. The LR interface connects through the optical line with the counterpart transponder in the other side of the line. The LR interface meets the CWDM standard requirements. The major differences between the SR and LR optical signal, besides the central wavelength, is the spectral purity. Typically the SR signal is generated using an inexpensive multimode laser, and the LR signal is generated by a single-mode laser.

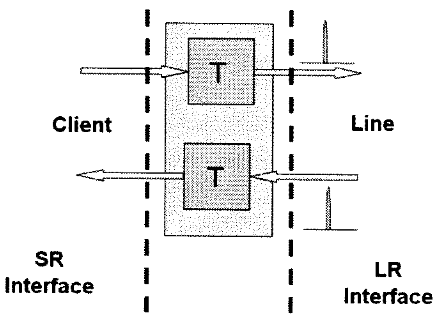

Fig. 2 – A bi-directional transponder.

New Generation Transponders

Taking advantage of recent advances in high speed digital electronic processing the new generation of optical transponders incorporates a module of inclusion and exclusion of extra digital information for forward error correction (FEC). With these FEC modules is possible to increase the bit-rate and/or extend the optical span without any BER penalty. This is achieve increasing slightly the bit-rate in order to incorporate the redundant information introduce by the FEC coding. For example a Reed Solomon code with 255/238 can improve de BER from $1x10^{-4}$ to $5x10^{-15}$, see table 1 [4].

BER_{input}	BER_{output}
10^{-4}	5×10^{-15}
10^{-5}	6.3×10^{-24}
10^{-6}	6.4×10^{-33}

Table 1 - Theoretical output versus input BER for a Reed Solomon coding with 255/238.

This BER improvement can be swapped by the increase of optical line spans.

III. SYSTEM SPECIFICATIONS

The transponder was specified to meet the standardized data rates specified for Synchronous Digital Hierarchy (SDH).

The information to and from the client (short distance connection) is STM-16 frame format. The CWDM (long distance connection) has information in the STM-16 with FEC encoded frame format.

Each client transmits and receives the information in the 1300nm and 1500nm wavelengths respectively.

The CWDM interface has optical wavelengths defined by the CWDM grid.

IV. TRANSPONDER ARCHITECTURE

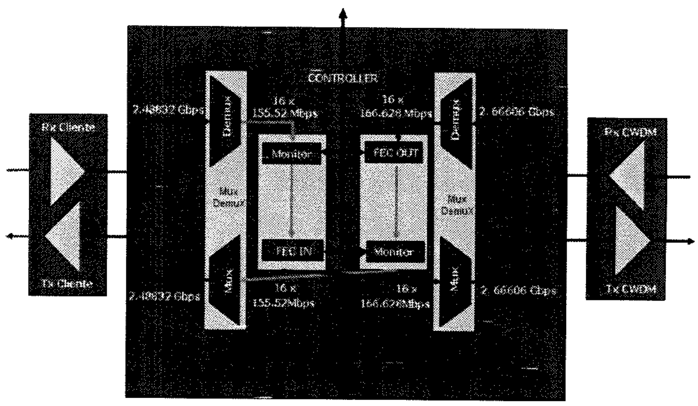

Fig. 3 - Transponder block diagram.

The present technology commercially available and the physical dimensions of the devices had influenced in the final architecture decision, see figure 3.

In this application the Client frames are STM-16 without FEC, with bit-rate equal to 2.48832 Gbps. The CWDM frames are STM-16 with FEC using the Red-Solomon code RS(239,255), with bit-rate equal to 2.66606 Gbps.

The main blocks and corresponding bit-rates are:

- Client transceiver (2.48832 Gbps);
- Line transceiver (2.66606 Gbps);
- Multiplexing-Demultiplexing stages (2.48832 Gbps to 155.52 Mbps, and 2.66606 Gbps to 166.628 Mbps, and vice-versa);
- Monitoring stages (155.52 Mbps and 166.628 Mbps);
- Controller;

The Client and Line interfaces have transceivers to make the electro-optic and optic-electric conversions.

From the Client to the Transponder the received optical data in the client receiver (Rx Client), after being converted to electrical format, is demultiplexed to 16 STM-4 frames in the Mux/Demux block. The bit-rate is equal to 155.52 Mbps. The Encoder/Decoder block introduces FEC in these frames and then they are multiplexed to STM-16 frames with FEC, at 166.628 Mbps bit-rate. The data is then converted to a CWDM optical signal and inject in the line (Tx CWDM) at 2.66606 Gbps.

In the LR interface the optical data is received at 2.66606 Gbps and it is demultiplexed to STM-4 frames with FEC having a bit-rate equal to 166.628 Mbps. After the demultiplexing stage the frames are monitored and the FEC is removed, allowing the multiplexing to STM-16 frames without FEC. These STM-16 frames are converted to optical non-return-to-zero (NRZ) signals and injected in the Client interface (Tx Client) at 2.48832 Gbps.

Client Transceiver

This device has a module that implements the electro-optic conversion at 2.48832 Gbps, being capable to control the average optical power.

The module that implements the optic-electric conversion has a PIN photodiode as the photodetector element being capable to recover the clock from the regenerated data at 2.48832 Gbps bit-rate.

CWDM Transceiver

This block is more complex than the client transceiver and required a separated project for the receiver and transmitter elements.

The optical fiber links in the CWDM network can be very long requiring high sensitivity photodetectors. An avalanche photodetector (APD) was chosen having a sensibility of -33dBm (0.5μW). One problem raised at this stage, the APD requires a high-voltage source power supply. With careful electronic design it was implemented a stable high-voltage source able to generate a voltage range between 30V and 90V [5].

The transmitter was implemented with a CWDM laser and a laser driver.

Multiplexing / Demultiplexing Blocks

This block was implemented with a Mux/Demux device that is able to work with different bit-rates including the previously stated ones. These devices could work with the following signals STM-1, STM-4, STM-16 and GBE (Gigabit Ethernet) with or without FEC.

Monitoring Block

This block is one of the most important in this project, being responsible for the removal of FEC and improvement of the BER. It is also able to work with different bit-rates and different FEC schemes. Table 2 shows the possible FEC modes of the block monitoring device.

Table. 2 – FEC possible modes for the block monitoring.

Error Correcting Capability	RS Code	Bit-rate Multiplying factor
8 bytes per 255-byte block	255/238	15/14
7 bytes per 255-byte block	255/240	17/16
6 bytes per 255-byte block	255/242	255/242
5 bytes per 255-byte block	255/244	255/244
4 bytes per 255-byte block	255/246	85/82
3 bytes per 255-byte block	255/248	255/248

The chosen mode was the error correcting capability of 8 bytes per 255-byte block, the highest available in this chipset.

The device is also able to access specific bytes of the SDH header frame, monitor them and give information to user about their state. It has also the capability of changing the headers when operating in conjugation with a microprocessor or a Field Programmable Gate Array (FPGA).

Controller Block

This block is responsible for the control and monitoring of all the other devices of the transponder.

In this implementation a FPGA was used as the controller of the devices.

It controls:

- The laser driver
- The APD source;
- Selects the Mux/Demux and clock and data recovery bit-rates;
- Selects the FEC mode;
- Monitor registers from the FEC monitoring chipset;
- Optionally changes specific bytes of the SDH frames;
- Initializes the devices;
- Output to the user the state of the two chipsets present in the transponder.

V. IMPLEMENTATION

The layout of the printed circuit board (PCB) had in consideration several factors:

- High-speed transmission lines are needed requiring microwave techniques to implement the impedance adaptation;
- Separated grounds for the different devices are crucial to minimize noise, cross-talk and current rings;
- Electromagnetic interference minimizing required isolation through the introduction of plane layers and not mixing the different logic family devices in the same area;
- Physical dimensions of the components have taken an important role in their respective placement.

VI. ADAPTATION TO DWDM

The adaptation of the presented transponder to DWDM systems deserve some attention and needs to take into account some important aspects.

A - Optical Spectrum

It can be seen from Fig. 1 that the optical spacing of CWDM channels is much broader when compared with DWDM channels. This requires a better spectral purity and stability of the laser source.

B - Power Supply

Power supply requirements for a DWDM laser are much higher compared to a CWDM laser. This difference of power consumption is manly because a DWDM requires a very thigh temperature control. Temperature control in these devices is made through the aid of a temperature sensor and an integrated cooler in the same package. In the DWDM grid the 100GHz spacing between channels is equivalent to 0.8nm and it is required a temperature drift less than 0.08nm/ºC. The CWDM 20nm spacing between channels is large enough to allow the central wavelength of the laser to drift without causing any interference in neighboring channels, even under modulation. It is important to have in mind that a DFB (distributed feedback) laser with a cooling circuit requires 5W of power supply and without cooling only demands 0.5W.

C - Hardware Complexity

The laser drive circuit becomes simpler in the CWDM version because it is not necessary an electronic circuit to control the temperature.

D - Physical Dimensions

The physical dimensions of a CWDM laser are smaller compared to a DWDM laser as they do not include the cooler element (a Peltier device). Eventually it can include a thermistor to obtain quantitative information about the temperature and a photodetector for average optical power monitoring.

It is important to refer that optical power monitoring allows the control of the laser bias point and counteract semiconductor aging.

VII. CONCLUSIONS AND DISCUSSION

The main goals of developing a transponder for CWDM systems were achieved. Expertise in different areas as optical communications, high-speed digital and analog electronic was required.

One of the design requirements was the implementation of the transponder in only one PCB card making it attractive for commercial purposes.

To finalize a DWDM transponder has a more complex, costly and bigger implementation compared to a CWDM one.

VIII. ACKNOWLEDGMENTS

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REFERENCES

[1] ITU-T G.694.2 (2002) "Spectral grids for WDM applications: CWDM wavelength grid"

[2] ITU-T G.694.1 (2002) "Spectral grids for WDM applications: DWDM frequency grid"

[3] *Optical Networks: A Practical Perspective*, Rajiv Ramaswami & Kumar Sivarajan, Morgan Kaufmann Publishers, 1998

[4] ITU-T G.975 (2000) "Forward error correction for submarine systems"

[5] MAXIM, APP 1085, "Choosing The MAX1932 External Inductor, Diode, Current Sense Resistor, and Output Filter Capacitors for Worst Case Conditions", 2002 http://www.maxim-ic.com/appnotes.cfm/appnote_number/1805/ ln/en

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