Intelligent Optical Gain Block Controller

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Introduction

Optical amplifiers are one of the key components in the metro and long haul optical networks. The EDFAs and Raman amplifiers are the most commonly used for the purpose of optical amplification. Many vendors are offering optical amplifiers that consist of active and passive optical components without electronic control circuitry. Such products are called optical gain blocks. For normal functioning of the optical gain block, an electronic control circuit has to be added.

To illustrate technical challenges facing design of optical gain controllers, we have analyzed the following EDFA products:

- PGE608 30/SC and PGE608 21/SC (Ericsson),
- OA500 and OA1000 (JDS Uniphase),
- 926 EDFA Module (Corning)

All analyzed products provide electrical access to the pump laser(s) and other components if they are present in the gain block assembly. However, the connectors and pin assignments for units from different vendors are not compatible. Corning module requires external PIN diodes for monitoring input and output optical powers. JDS Uniphase, in turn, has incorporated a heater for the erbium fiber. There are other differences as well.

In the case of the Raman amplifiers, we have investigated electrical specifications of the high power laser pumps. The number of pumps and their spectrums are usually the results of system analysis and the particular design needs.

Due to the immense diversity of optical amplifiers, there is no commercially available electronic circuit that could be used to address and solve common technical problems and challenges. In other words, an electronic circuitry that is universal and easily adaptable for different needs is not available to system designers and integrators. Presently, they have to use either their own proprietary amplifier modules or to integrate optical modules into their system.

The Intelligent Optical Gain Block Controller (IOGBC) described in this document fills the evident gap in the current market offering and provides an efficient and flexible solution for the control circuitry of optical amplifiers of various technical ancestry.

1 IOGBC Design Considerations

The major technical considerations taken into account during the design process of the IOGBC are as follows:

- One stage versus multistage. We consider one stage of the optical amplification only if it is possible to measure both optical input and output powers to that stage. Otherwise, for multistage amplifiers, each stage is controlled independently.
- Host system. The goals and parameters of the control are set by the host system. Communication with the host system is accomplished by means of the serial link.
- Autonomous operation. The controller requires minimal intervention from the host system and can operate correctly even in the presence of the minor malfunctions of the host system.
- Interface universality. Standard notation and commonly used physical units are used for the exchange of information. ASCII set of characters is used for the encoding. Reported parameters are in their final version i.e. “ready to be displayed” format and with no need for any additional computations.
- Standards-based design. The GR-1312-ILR telecommunication standard (Bellcore) is used as reference for the design. The controller will monitor all optical amplifier signals as required by this standard .

The circuit operates in one of three basic modes:

- Constant Gain Mode - the input output optical powers ratio is maintained constant
- Constant Power Mode – the optical output power is maintained at the desire level
- Constant Current Mode - regardless of the input and output powers, the laser pump operates at constant current or can be shut down to prevent ASE generation.

1.1 IOGBC Accuracy and Speed of Operation

For the monitoring purposes 12 bits resolution is used. To increase the accuracy, whenever possible we are using ratio metric method for the measurements.

The data acquisition system is used exclusively for passive monitoring only and there is no feedback loops (controls) based on digital data. Target values for such parameters as the laser temperature, laser current, amplifier gain, and amplifier output power are set digitally. However, they serve only as the reference values for the analog circuitry.

In the case when amplifier is shut down, the IOGBC can constantly monitor input for the presence of the input signal and it can enable amplifier to the default state without the need for the host system intervention. This feature facilitates the local immediate control actions. The host system can enable or disable this feature. By default this feature is TBD.

The output power and the gain of the amplifier are set according to the linear scale. The host system has to change logarithmic units to linear.

When operating either in constant power or constant gain mode it may not be possible to achieve set goals of the regulation. Such situation is flagged (signaled) to the host system although; it is possible to take default action locally without the need for the host system intervention.

The speed of the analog circuit is directly related to the ability of the amplifier to maintain its parameters when the level of the input power changes. In other words, the question is to what extend amplifier suppresses transient generation?

The IOGBC design provides for time constant in the range of 10μs to 20μs. It means that the new steady state is reached 20μs to 50μs after the input changes. This particular speed of the circuit has been chosen for the following reasons:

- Some vendors are using the pilot tone modulation for the wavelength identification. This small AM modulation is superimposed on the communication traffic. It uses a frequency in the hundreds of kHz range. We do not want to compensate for these power changes or cause any unwanted inter modulation between different wavelengths.
- It is possible to have the time constant in a single μs or even a sub-μs region but the laser current driver will start to exhibit fast ringing of 20% to 50 % of overshoot in laser current amplitude lasting few tens of ns. This in turn, will create additional transients. This ringing is caused by the parasitic components in the circuit.
- Finally, it can also be advantageous to broaden laser spectrum to prevent some nonlinear effects in the fiber. This can be accomplished by adding a small AC component to the laser driving current. This AC component can also interact with the control circuit.

1.2 IOGBC Efficiency

It can be expected that the unit will operate in ambient temperature of up to 50ºC. The TEC circuit consumes the majority of energy. To drive the TEC of the laser, our design uses a high efficiency PWM circuit resulting in the overall efficiency of 90% to 94%.

The laser current source works in the linear mode and its efficiency is determined mainly by voltage difference between the laser diode voltage drop and the supply voltage. For the high current lasers, this voltage difference is measured and supply voltage is adjusted by a high efficiency PWM local converter. The other parts, including the micro-controller are low power and have no practical impact on the total power consumption or efficiency.

The mechanical dimensions are determined by the size and number of components. Our design uses very small surface mount parts (mainly 0603 size for passive components). The dimensions of some components are directly depending on the laser and its TEC parameters.

Parts of the circuit that are of no interest to a particular application can be eliminated altogether thus reducing the size and cost of IOGBC module. This is simply the issue of the trade offs between desired functionalities and the size/cost factors.

The IOGBC design requires one voltage (+5Vdc) power supply. The other voltages that are required are generated and controlled locally. In the case when the other voltages are available externally, further reductions in size and cost are possible.

1.3 IOGBC Cost Factors

The fundamental principle underlying the IOGBC design is to meet all stringent performance requirements. Only the off the shelf good quality electronic components are used. The vast majority of components have the second source thus lowering the overall cost substantially. One exception is the new IC (AMC7820) from Texas Instruments. Usage of this particular IC in one of the circuits increases the overall IOGBC performance.

The optical parts in the IOGBC design, as in all other opto-electronic devices, are the most expensive. For example, the Corning unit requires external monitoring PIN diodes that are more expensive than the rest of the electronics.

The cost of the circuit is not limited to the cost of components and other cost components that need to be considered are: development of low-level software and unit calibration, both labor intensive.

Many electrical parameters depend on the values of optical parameters that in turn can vary by a factor of ten. For example, the measurement of the input optical power depends on the value of optical splitter and PIN diode responsiveness. If the unit is not calibrated, the accuracy of the relevant measurements can be lower than expected.

Other parameters that are not directly used by the controller, have to be measured and stored as well. For example, changing the gain of the amplifier significantly alters its noise figure and leads to a signal to noise degradation. From the system point of view it may be desired for the host to have access to this information.

If there is more then one stage of amplification then, every stage of optical amplification is controlled by IOGBC independently. Very often the Gain Flattening Filters (GFF) or Variable Optical Attenuators (VOA) are inserted between different stages of optical amplification. A separate control circuit has to be used if the optical amplifier contains either the GFF or VOA. Control of these devices belongs to the outside of the IOGBC design and problems related to the gain flatness of the amplifier have to be considered at the system level. The gain, as a function of the wavelength characteristic, changes if a particular amplification stage operates in its linear or close to saturation mode. This gain information can be made available to the system if proper measurements are done during calibration.

2 Single Stage Optical Amplification Control Circuit.

The following describes the operation of a single stage optical amplification control circuit. Figure 1 below shows the general block diagram of the amplifier.

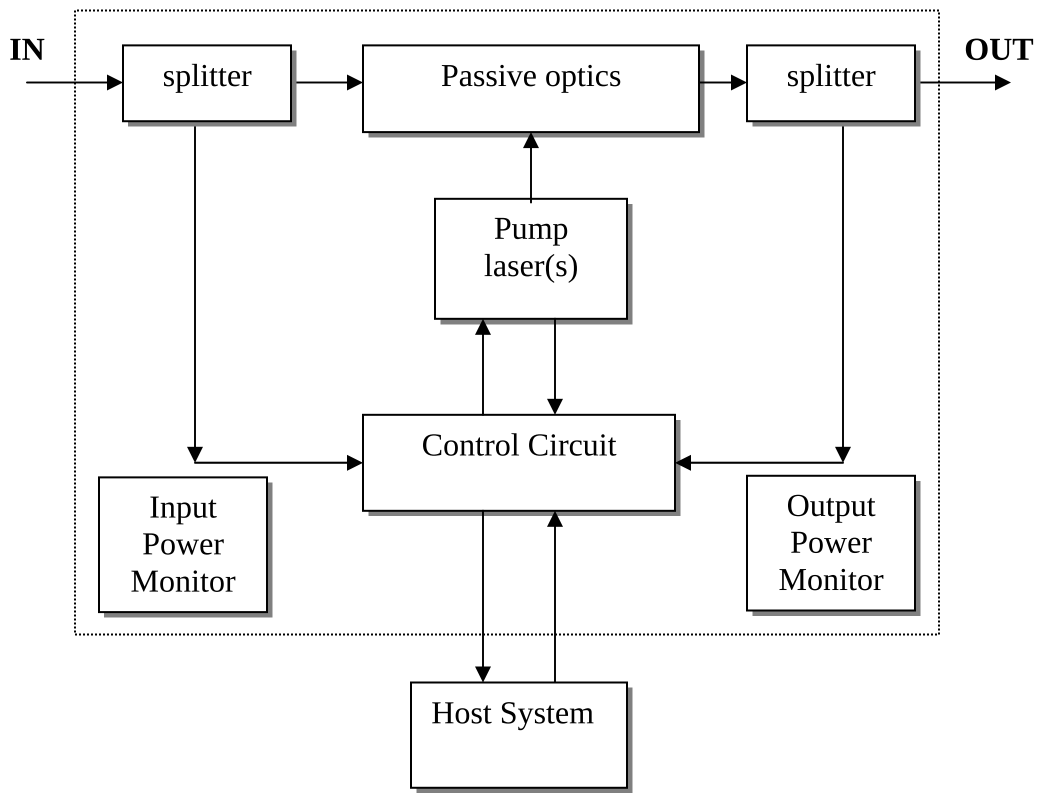

Figure 1. The general block diagram of the amplifier

The Control Circuit drives the Pump laser (s) and its Thermo Electric Cooler (TEC). The control algorithms and goals are set by the Host System. The communication between the Host and Control Circuit uses the RS232 link and one of the following interface standards:

- SPI
- I^2C

The RS232 link is used primarily to download and modify the flash memory content of the local controller. It is also used for the calibration and debugging purposes. A craft interface to the module also can use the RS232 link.

2.1 Electrical Parameters

The following are the maximum values the IOGBC can support in the present design:

Supply voltage VCC	+5VDC +/-10%
Supply current ICC	5A max
Max TEC voltage	VCC -0.5V
Max TEC current	+/-3A
Max laser current	1.5A
Max laser voltage drop	3V
Max monitor PIN diode power	4mW (+6dBm)

It is possible to set the operating limits at lower values. Such decrease can lead to a smaller size of the circuit and therefore should be considered when a small volume of space is critical. (See description of the demo board later in this document)

2.2 Modes of Operation

The IOGBC unit operates in one of three modes.

2.2.1 Constant Current Mode.

Constant current is forced through laser pump regardless of the level of other signals.

2.2.2 Constant Power Mode.

Laser pump current will be set in such a way that optical output power is constant and will not depend on optical input power.

2.2.3 Constant Gain Mode.

The Control Circuit adjusts laser current so that gain of the system will be equal to the target value.

There are physical limitations when the amplifier is placed in one of these modes. It is not possible, for example, to exceed saturation power of the amplifier. As the consequence, it will not be possible to achieve certain level of settings.

The inability to maintain some settings is signaled (flagged) to the Host System that can decide what action to take if any. For example, based on the actual input signal power, the Host System can decide to place the amplifier in the constant laser current mode, or it can shut down the Pump Laser to prevent generation of the ASE. The IOGBC provides the host system with all necessary information to decide on the control action.

The IOGBC design provides one hardware control signal (SHD) which can be used to overwrite all hardware and software settings, and to shutdown the laser pump. This signal is under full control of the Host System and is provided for emergency like situations. Once the SHD is set, the Pump Lasers are disabled and cannot be activated until the SHD is re-set (cleared). However, it is still possible for the Host System to communicate with the local controller and a special soft start procedure can be used to turn the Pump Laser on.

The laser driver forces DC current trough the pump laser. This current is limited and this limitation is preset by manufacturing. The value of this limit depends of the laser diode parameters. Changing the value of option resistor can modify this limitation.

The IOGBC design includes limiter just before the laser driver and after all closed loops of regulation. Thus, the laser current will never exceed the limit, including any fault conditions.

Additionally to the DC component, a small AC current can be added to the laser. The frequency of this signal is 1MHz. The amplitude of modulation is 6% of the main DC current. The purpose of this AC modulation is to broaden the laser spectrum and to prevent high power nonlinear effects in the fiber. Similarly to the current limitation, the frequency and depth of modulation can be changed by using different resistors.

The maximum limit for the voltage/current of the TEC element is set by the appropriate voltage divider.

The temperature controller uses a PID type of compensation circuit and well stabilizes the laser temperature.

The following values are measured, monitored and made available to the Host Controller:

1. Optical Input Power two stages of amplification
2. Optical Output Power
3. Laser Diode Current
4. Laser Diode Optical Power (Back Facet Monitor)
5. Temperature of the Laser Subassembly (*)
6. TEC Current
7. Voltage Margin for Laser Current Source. (**)
8. Ambient Temperature. (***)

(*) Resistance of the thermistor is measured and reported.

(**) This value can be used internally to adjust power supply voltage of the laser current source. It is measured and used only for high power lasers (laser current exceeding 1A)

(***) Ambient temperature is measured indirectly and is approximated from micro-controller chip temperature measurement.

All measurements are based on 12 bits accuracy. The only exception is the TEC current measurement, which has 11bits and sign accuracy. This 12/11 bits accuracy of the system is real and special temperature compensation correction is applied to the results of measurements.

2.3 Software

The SCPI (Standard Commands for Programmable Instruments) is an ASCII-based instrument command language for test and measurement systems. The IOBGC design uses the syntax and structure of this language for the communication with the Host Processor. This approach simplifies and makes programming and maintenance of the whole system much easier.

The Programmers Guide lists all commands that are available and provides examples of programs written in BASIC and C languages. Those examples illustrate how the Host System can interact with the local controller.

The Programmers Guide also lists all commands that are available for communicating with the local controller. The system will respond to all of the commands by either sending back an appropriate relevant value or confirmation.

With the RS232 link it is possible to send and receive information using any of the terminal software that is commonly available on PC. For example, the laser current is reported as ASCII string "IL= ddddE-d A", and d has value of (0,..9).

Optionally, if the customer preference is to interface with the IOGBC using communication standard other than SCPI, a simple replacement of the relevant software module is available. It should be noted however, that the vocabulary and volume of information transferred to/from the Optical Gain Block does not justify the use of a parallel bus. The proposed RS 232 interface rated at 38400bps, or SPI interface with 2MHz clockor I^2C link are fully adequate and the most cost effective.

3 IOGBC Demo Board

The IOGBC demo board consists of three circuits:

1. High power laser driver A
2. High power laser driver B
3. Practical implementation for the two stages EDFA

3.1 High Power Laser Driver A

In high power laser driver A the laser current can be as high as 1.5A. The maximum TEC current is 3A. The circuit is intended to be a Raman pump driver. The modulation of the laser current is set to 6% and its frequency is 1MHz.

The circuit has both input and output power monitors. In case of counter propagating Raman amplifier it will not be possible to measure the input power. It is however possible to measure the output power and place the amplifier in the constant power or constant laser current mode.

For the co-propagating Raman amplifier, the constant laser current mode is the preferred mode of operation.

The circuit can also be used for 1480nm or 980nm pumps. The resistor setting limits can be changed to set these values according to the laser and TEC specifications.

3.2 High Power Laser Driver B

For the high power laser driver B the laser current can be as high as 1.5A. The maximum TEC current is 3A. The circuit has the same functionality as previous plus the extra feature.

The current limit is set to its hardware maximum and can be lowered by software to any desired value. This feature can be used in the situation as described below.

The maximum laser pump current is, for example, 500mA and it is specified for the end of life condition. It is most likely that during the initial calibration the gain block requires only a fraction of this current to achieve desired performance. However, during periodic self-calibration procedures, the setting of the current limit can be modified to satisfy the system requirements.

There are also few others measurements available in the high power laser driver B.

3.3 Two Stages EDFA Implementation

The third circuit is the practical implementation for the two stages EDFA.

The demo IOGBC unit is designed with two stages driving circuit to control Corning 926 EDFA module.

The specification of this module includes a power booster and indicates that its primary mode of operation is constant output power mode.

The maximum TEC current is ~1.5A and the maximum laser current is 400mA for the first stage and 800mA for the second. It was possible to reduce size of the coils in the TEC controller. A constant voltage of 3.3V was used to supply laser drivers. There are four optical power monitors (PIN diodes).

Each stage of the EDFA is controlled independently. One interface to the host (PC in this case) is used to control both stages. The other simplifications are:

- No AC modulation added to the laser current,
- No possibilities to place amplifier in constant gain mode,
- Only the first amplifier has double stages optical input power sensing.

The circuit size is about 3”x3” with components mounted only on one side.

The design monitors both the output power of the first stage and the input power of the second stage. These powers generally can be different. This happens, for example, if the gain-flattening filter is inserted between two stages.

Communication with the demo boards can be accomplished by sending and receiving ASCII strings according to the programming guide. A simple program with a GUI interface to simplify this process is also provided.

One of the functions of the PC program is the calibration of the OFA. Many parameters have to be known to the control circuit to correctly evaluate measured data.

Before attempting to control optical amplifier, the control circuit will issue a prompt to enter or measure some parameters. Normally, these parameters will be stored in EEPROM/FLASH memory during the calibration procedure.