Compact WDM Analyzer using OPM

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***Abstract*— Compact WDM Analyzer is an important tool used in high capacity optical transmission system. This paper reviews OPM applications and techniques, while examining the role of OPM as an enabling technology for advances in high-speed and optically switched networks, in particular, OSNR monitoring.The proposed OPM technique is based on RF spectrum analysis and is used for simultaneous and independent monitoring of powerand BER in 40Gbit/s multi-channel systems.The requirements for optical performance monitoring in all-optical networks is also presented in this paper. Investigations show that current monitoring technologies are not sufficient for the optically switched networks and that several performance monitoring operations need to be moved down to the physical layer. The monitoringis generally used for the purpose of determining the 'health' of the signal in the optical domain.**

***Keywords**: Optical communication systems, optical networks, performance monitoring,optical performance monitoring (OPM).*

I. INTRODUCTION

The explosive expansion of telecommunications and computer communications, especially in the area ofthe Internet has created a dramatic increase in the volume of worldwide data traffic that has placed anincreasing demand for communication networks providing increased bandwidth. To meet this demand,fiber optic networks and dense wavelength-division-multiplexing (DWDM) communications systemshave been developed to provide high-capacity transmission of multi-carrier signals over a single opticalfiber. In accordance with DWDM technology, a plurality of superimposed concurrent signals istransmitted on a single fiber, each signal having a different wavelength [1]. In WDM networks, opticaltransmitters and receivers are tuned to transmit and receive on a specific wavelength.

Multimedia services have been the main drivers in the deployment of higher capacity optical networks. Recently, access optical networks have been exposed to substantial challenges with exponentially increasing per-user bandwidth demand and ever-increasing backbone capacity. Although access technologies, such as digital subscriber line (DSL) and cable modem (CM), offer affordable solutions for residential data users, they pose fundamental distance and bandwidth limitations. It is expected that the next-generation optical networks will be able to support various emerging broadband applications as well as emulate many kinds of legacy services over the same infrastructure, with minimal engineering investment. Two main factors have emerged to satisfy this new demand. The first factor has been to increase the data channel bit-rate. With the explosive growth [1] demand for capacity in optical networks, high bit-rate fiber transmission has recently become an essential part of state-of-the-artcommunications. Modern optical networks are no primarily based on 2.5Gbit/s and 10Gbit/s channels. 40Gbit/s channels have begun to be implemented in new product offerings, while 100Gbit/s and even 160Gbit/s bit-rates are being tested in various labs. The second factor has been the use of wavelength division multiplexing (WDM) which has dramatically increased the network capacity. This technology allows the transport of hundreds of gigabits of data on a single
fiber for distances over thousands of kilo meters, without the need of optical-to-electrical-to-optical (O-E-O) conversion.The system manufacturers would then design and integratethe OPM function into the optical network. Some related to the measurements of a single performance parameter, such as that of the bit-error-rate (BER), the Q factor or the optical signal-to-noise ratio (OSNR). OPM takes several early field trials used OPM methods for control of transmission [2], [3]. The broad definition of physical layer monitoring for the purpose of determining the 'health' of the signal in the optical domain. Current performance monitoring, based on digital signals, relies on synchronous digital hierarchy/synchronous optical networking (SDH/SONET) line terminal elements to determine the BER or loss of signal from power measurements.

Other degradations that may affect the signal-to-noise ratio (SNR) are calculated in advance by measuring the characteristics of the optical components (such as the optical amplifier noise figure). However, these simple monitoring techniques are inadequate in the case of dynamic networks. Traditionally, the primary application of performance monitoring was to certify service level agreements between the network operators and their clients. In a dynamic network, the desired applications have evolved to signal diagnosis for impairment compensation and fault management. An Compact WDM Analyzer device, deployed at each link, would allow for the physical layer fault management by identifying discontinuities in parameters such asOSNR whereas the diagnosis of impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD) would provide a mechanism to trigger alarms or provide feedback for active dispersion compensation [1]. Future dynamic networks will require dynamic compensators that are controlled using feedback from a performance monitoring system. In such networks, each channel is dynamically added and dropped,

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and has a different transport history which may include different paths and different opticalelements, in addition to changes in environment such as temperature. This prevents network management based on statically mapped network elements and fiber properties, and drives the need for dynamic OPM and compensation.

II. OPTICAL PERFORMANCE MONITORING

The technology for transmitting dataover fiber optic networks has dramatically improved andevolved into a mature technology platform that capitalizes onthe immense transport capabilities of the optical fiber.With the enormous increase in the requirements forcommunication bandwidth in recent years, new networktopologies have been deployed that cover almost every stageof transport, starting with the sender of data and ending withthe receiving party. Commonly found network topologiesinclude office, metro, long-haul, ultra long-haul and submarine;all striving to meet the ever increasing demand formore bandwidth [4].

Instead of installing more fiber into the ground, system vendors have looked into the possibility of lighting up existing fiber by adding more communication channels to each fiber. This approach is termed wavelength division multiplexing (WDM) and can be described as separating each channel by aunique color, called a wavelength, of the light beingtransmitted. The technology of modern fiber optic networks allows formore than 100 channels to be simultaneously transmitted ona single fiber, at data rates of up to 10 billion bits per second,per channel over long distances. Each fiber can thusaccommodate up to one million users surfing the Internetvia a high speed cable-TVmodem. The trend to better utilize the fiber's bandwidth has becomeapparent as the number of channels grow, channel spacingbecomes denser, and the communication speeds increase. As show in fig.1. This trend, as well as the development toward transmittingdata over longer distances without restoration of the opticaldata, generates a need for monitoring the optical layer inorder to ensure the quality of transmission.

OPM can be broken down into three layers, as shown in Fig. 2.**The first layer** is transport or WDM channel management layer monitoring, which involves a determination

of the optical domain characteristics essential for transport and channel management at the WDM layer. For example, real time measurements of channel presence, wavelength registration, power levels and the spectral OSNR are transport layer measurements. **The second level** is the optical signal or channel quality layer monitoring, which locks onto a single wavelength and performs signal transition sensitive measurements. Examples of features that can be analyzed in the signal quality layer are the analog eye and eye statistics, *Q*-factor, the electronic SNR, and distortion that occur within the eye due to dispersion and nonlinear effects. **The third level** of OPM involves monitoring the data protocol [5]

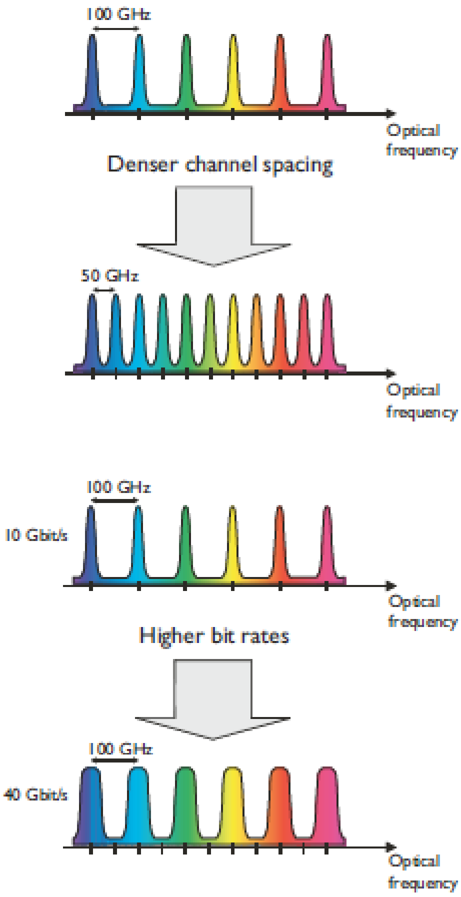

Fig. 1 – The trend in telecommunications is to expand a single fiber's bandwidth by packing channels closer together and increasing the data bit rates.

Information, protocol performance monitoring (PPM). This includes digital measurements such as the BER, when used to infer properties of the analog optical signal. There are several methods of implementing OPM in a line system.

i) The non disruptive dedicated monitor: where the signal is tapped on a WDM fiber and the monitor is shared among many wavelengths on a single fiber (either through polling orin parallel);

ii) The disruptive shared monitor: this is the case in which one of multiple optical fibers can be switched to a monitor so the monitor is shared, but the monitoring is disruptive as ittakes the fiber offline. This case can also be used to poll multiple fibers. Non disruptive fiber polling can be implemented by combining i) and ii).

iii) The in-line monitor: the full optical signal is transmitted through the monitor and a nondestructive measurement is performed. This approach is most effective when the signal is demuxed into single channels and is often integratedwith optical regeneration devices

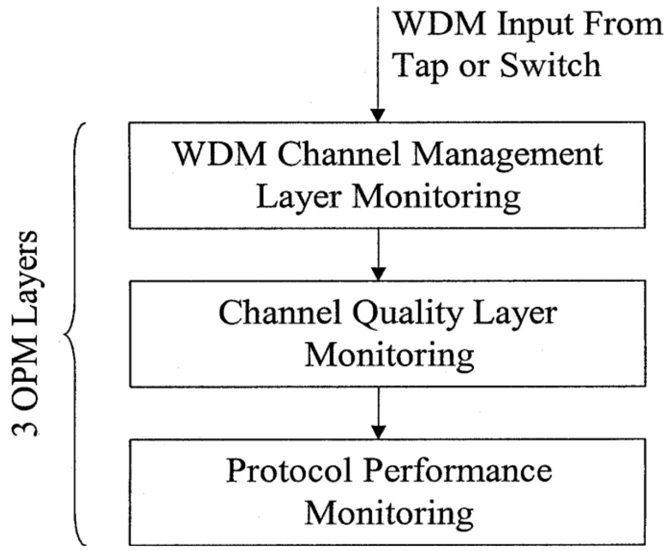

Fig. 2-Three layers of OPM: transport monitoring, Signal quality monitoring, and protocol monitoring.

III. OPTICAL PERFORMANCE MONITORING TECHNIQUES.

A major challenge in submarine systemshas been to locate amplifier failures. Several techniques weredeveloped including low-frequency modulation of the amplifierpump lasers for supervisory signaling, loop-back methods, and tone modulation [6]–[7]. In terrestrial WDM systems, particularlywith the use of optical add-drop multiplexers, there hasbeen interest in measurements of the optical spectrum for managing. As seen, the network-monitoring device is a crucial optical element for modern optical network systems with DWDM technology. It is the surveillance device in optical layer by providing information about the optical power level, channel wavelength, and optical signal-to-noise ratio (OSNR) of each individual channel. It also serves as a feedback device for controlling certain functions of the optical networks.

A) What is an OPM?

OPM is certainly a new class of devices in fiber-optic products. It is difficult to give it a general definition. Structurally, an OPM consists of a spectral element, a detection unit, and an electronicprocessing unit. The spectral element separates the wavelength components of the multiplexed signalcontaining a plurality of wavelengths. The detection unit is usually a detector array and is used to convertthe optical signal to electric signal for further processing by the electronics circuit. Functionally, an OPM should be capable of providing real-time measurements of the wavelengths, powers, and OSNR ofall DWDM channels. From these measurements, we will know: 1) channel central wavelengths, 2) centralwavelength shifts with respect to the ITU grid, 3) channel powers, 4) channel power distribution, 5)presence of channels, and 6) OSNR of each channel. Several types of the OPM devices are available in the market, each of which addresses differentfunctions and different purposes. The OPM emphasizes the information (power) at given channels,rather than monitoring wavelength and its variation. OPMs commonly use Demux-type components as itsspectral elements. Since a Demux-type component, such as AWG, gives a set of fixed discrete channelswith a pre-defined frequency interval (channel spacing), such OCMs can only provide powermeasurements at the wavelength positions corresponding to the DWDM channels. It is obvious that themeasurements will be biased when there is thermal-wavelength drift of the spectral element. It seems thatOPM can provide more network information than OCM since an OPM not only measures power andOSNR, but also monitors wavelength and its variation. However, as more and more such networkmonitoring devices are employed, the difference between OCM and OPM is evolving to be ambiguous.And some customers prefer to use the name of OCMs while the others would like to use the term ofOPMs.In order to avoid the confusion in using network-monitoring devices, we suggest a more general name forthis class of products: *Optical Performance Monitor* (OPM).

IV. BLOCK DIAGRAM OF COMPACT WDM ANALYZER USING OPM.

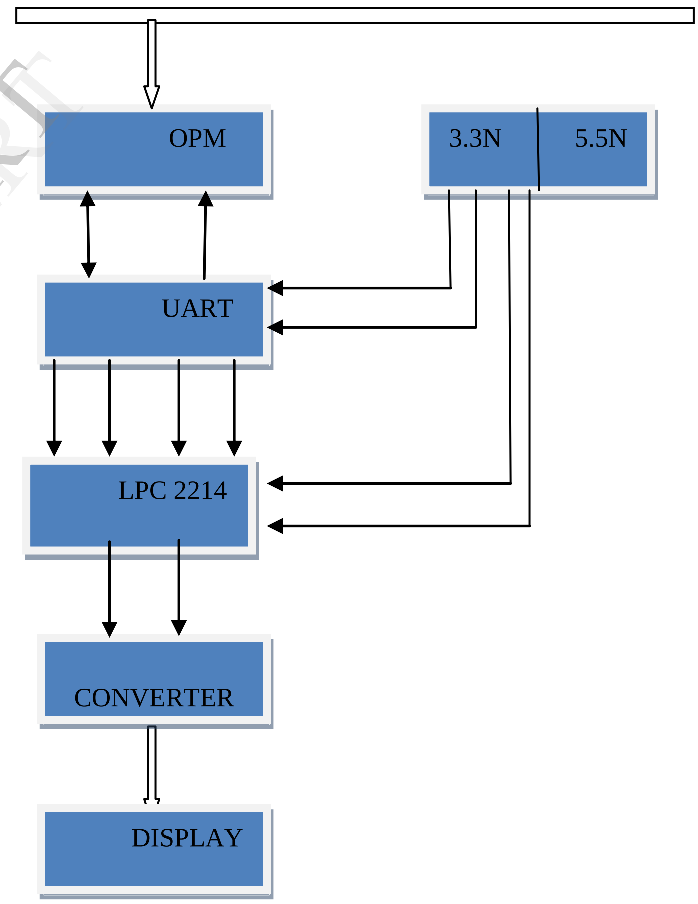

Fig.3- Block Diagramof Compact WDM Analyzer.

A) ADVANCED OPM

Advanced optical performance monitoring techniques are sensitive to the SNR of the optical signals. In general These techniques can either be analog or digital. Digital techniques use high-speed logic to process digital information encoded on the optical waveform. Measurements on the digital signal are used to infer the characteristics of the optical signal. Digital methods have the strongest correlation with the BER, but are usually less effective at isolating the effects of individual impairments. Analog measurement techniques treat the optical signal as an analog waveform and attempt to measure specific characteristics of this waveform. These measurements are typically protocol independent and can be subdivided further into either time domain methods or spectral methods. Time domain monitoring includes eye diagram measurements and auto- or cross-correlation measurements. Spectral methods must be broken down into optical spectrum and amplitude power spectrum (also referred to as the electrical or RF spectrum) measurements. The optical spectrum is conveniently measured using highly sensitive optical techniques and can provide optical noise information. Unfortunately, the connection between the optical spectrum and the signal quality is not particularly strong. The amplitude power spectrum is a better measure of signal quality because it measures the spectrum of the signal that is encoded on the optical carrier (assuming intensity on-off keying modulation). Noise and distortion on the amplitude power spectrum will usually directly translate to impairments on the signal. Many monitoring techniques based upon the amplitude power spectrum are facilitated by the use of spectral tones. These narrowband monitor signals are superimposed on the data signal and used as monitoring probes. The most common low-frequency technique involves placing an RF sinusoidal modulation on the optical signal at the transmitter. Because the tone is at a single, low frequency it is easy to generate and process using conventional electronics. Each WDM channel is assigned a different RF frequency tone. The average power in these tones will be proportional to the average optical power in the channel. Thus, the aggregate WDM optical signal on the line can be detected and the tones of all the channels will appear in the RF power spectrum in much the same way they would appear in the optical spectrum. Furthermore, the noise between the tones will be proportional to the optical noise, except in the cases mentioned later. The clear advantage here is that an image of the optical spectrum is encoded on the electrical (or RF power) spectrum for convenient monitoring [8], [5].

B) LPC 2214

The LPC2114/2124/2212/2214 are based on a 16/32 bit ARM7TDMI-STM CPU with real-time emulation and embedded trace support, together with 128/256 kilobytes (kB) of embedded high speed flash memory. A 128-bit wide internal memory interface and a unique accelerator architecture enable 32-bit code execution at maximum clock rate. For critical code size applications, the alternative 16-bit Thumb Mode reduces code by more than 30% with minimal performance penalty. With their compact 64 and 144 pin packages, low power consumption, various 32-bit timers, combination of 4-channel 10-bit ADC or 8-channel 10-bit ADC (64 and 144 pin packages respectively), and up to 9 external interrupt pins these microcontrollers are particularly suitable for industrial control, medical systems, access control and point-of-sale. Number of available GPIOs goes up to 46 in 64 pin package. In 144 pin packages number of available GPIOs tops 76 (with external memory in use) through 112 (single-chip application). Being equipped wide range of serial communications interfaces, they are also very well suited for communication gateways, protocol converters and embedded soft modems as well as many other general-purpose applications[10].

C) WORKING OF COMPACT WDM ANALYZER

The basic operating block diagram of an Compact WDM Analyzer is schematically shown in Figure4. Figure 3. A fractional portion (e.g., 2%) of lightpower is tapped from the mainstreamoptical signal for the monitoring purposewhile keeping the properties of the maintraffic unchanged. Since the tappedsignal will not be added back to themainstream data, there are no effects onthe properties of the transmitted data and OPM provides a non-invasivemeasurement. The weak signal tappedfrom the networks is then directed to thespectral element, from which thechannelized wavelength components areseparated in space. These spatiallydispersed signals are detected by a OPM this signal is transmitted in LPC 2214 for interfacing by UART and from this, the light signals are converted into electric ones. The electric outputs aretransmitted to the electronic circuitry for processing and output, from which power, wavelength, andOSNR are obtained [4].

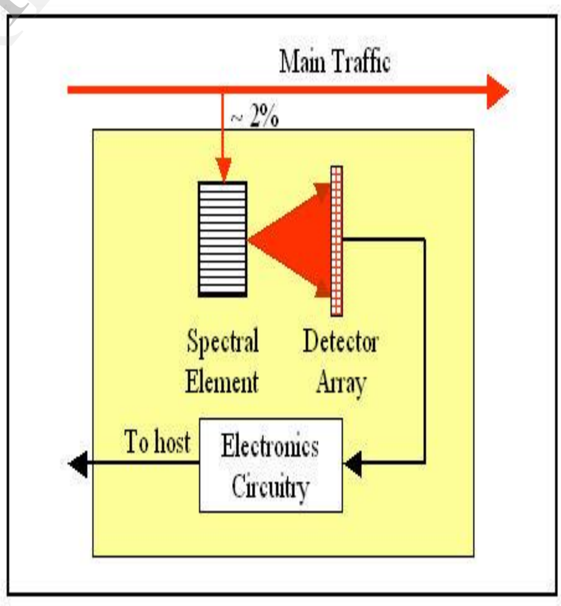

Fig - 4. Schematic diagram of operation of an OPM.

D) OSNR MONITORING

The optical signal-to-noise ratio (OSNR) of a channel is defined as an absolute ratio of the cleanoptical signal power ***P***(signal) at a channel wavelength to noise power ***P***(noise), measured in units of dB,i.e.,In practice, an approximation of ***P***(signal) = ***P***(mixed) - ***P***(noise) is used since the clean optical signal isnot obtainable, where ***P***(mixed) is the total power measured at the corresponding channel wavelength.The implementation of OSNR measurement involves an embedded algorithm; readers can referdocuments such as TIA/EIA-526-

19. OPMs can measure OSNRs for allchannels at the same time. **Figure 8** is a snapshot of the OSNR measurement for a 100 GHz 40 channel OPM, whose values are around 30 dB.

$$\mathrm{OSNR} = 10 \times \log_{10}\left[\frac{P(\text{signal})}{P(\text{noise})}\right]$$

Perhaps the most direct method for implementing advanced optical performance monitoring is to perform OSNR monitoring. Often signal (average) power monitoring is required for gain equalization and other network functions. free-space and MEMS diffractive optics, and dielectric thin film filters. Several techniques have been developed that do not directly measure the optical spectrum or focus on wavelength monitoring [10]–[9]. Modulation tone techniques have also been used as a low-cost alternative to spectral measurements. In principle, these same techniques that measure signal power can also be used to obtainthe optical noise power, which is extracted from the power level adjacent to the channel. Other OSNR monitoring techniques have been developed that measure the noise power within the individual channel optical bandwidth. The challenge in this case is to discriminate between the noise and the signal. In principle, an optical signal will have a well-defined polarization, whereas optical noise will be unpolarized. Therefore, the polarization extinction ratio is a measure of the optical SNR. Unfortunately.

E) Q-FACTOR/BER:

The preferred parameter to use for fault management is the BER. Indeed this is precisely the parameter used in electronic networks. Since it is the same metric that is used at each network end-terminal for QoS, it is sensitive to the same impairments that affect the QoS. In fault localization, one hopes to identify the location of the cause of the BER degradation. In order to implement this in optical networks today, one would effectively need to terminate the optical line with a transponder (O/E/O) on every channel and thus remove all of the advantages of optical networking. An alternative solution is to use polling. Instead of an entire bank of transponders, in this case only the receive side of a single transponder is used and a tunable optical filter sequentially polls each WDM channel and even multiple fibers in a repeater. In order for this approach to be nonintrusive, the monitor either must work off of a 1–2% optical tap or it must be placed at a location in which a larger tap might be tolerated such as mid-stage in an optical amplifier. If a large tap loss is required, an optical preamplifier can be used to overcome this loss. In fact, a 20 dB tap loss is similar to the loss on a single span and therefore the combination of optical tap andfilter/preamp front end is roughly equivalent to terminating the line one span farther down and conducting performance monitoring on the full signal.

V. OPM APPLICATIONS

In this section, a survey of OPM applications is listed to help you to understand who need the OPMsand where the OCPMs are employed. In the modern communications networks, OPM has nearlybecome a standard part and appears at many key physical positions. In general, the OCPM acts as awindow on the DWDM networks by giving the management and control systems a true picture of thehealth of the optical signal. Specifically,

1. Real-time optical performance monitoring ofDWDM networks.
2. Tracking channel power, wavelength, and OSNR.
3. Monitoring channel inventory in DWDM networks.
4. Channel presence and detection for optical protection systems.
5. Fault detection and isolation in DWDM systems
6. Optical add/drop monitoring and diagnostics
7. Remote gain equalization of DWDM systems based on optical power or OSNR.
8. Transmission laser wavelength locking.
9. Real-time system error warning and alarming.
10. Optical cross connect channel quality monitoring.

VI. RESULTS AND DISCUSSION

Figure 5 shows a representative spectrum detected by the Advance OPM. The input signal contains 40 channels with 100 GHz channel spacing. Displayed is the processed power spectrum.Channel powers, power distribution and central wavelengths are clearly identified. In anothermeasurement, the ability to detect channel power and channel presence is

demonstrated. Themeasurement result is shown in Figure. As seen, both the present and absent channels can be correctlydetected. The yellow dots are the raw sampled data and the green lines are the processed results,Figure 6. Processed power spectrum detected AdvanceOPM First 25 Channels,Figure 7. Processed power spectrum detected AdvanceOPM First 40 Channels

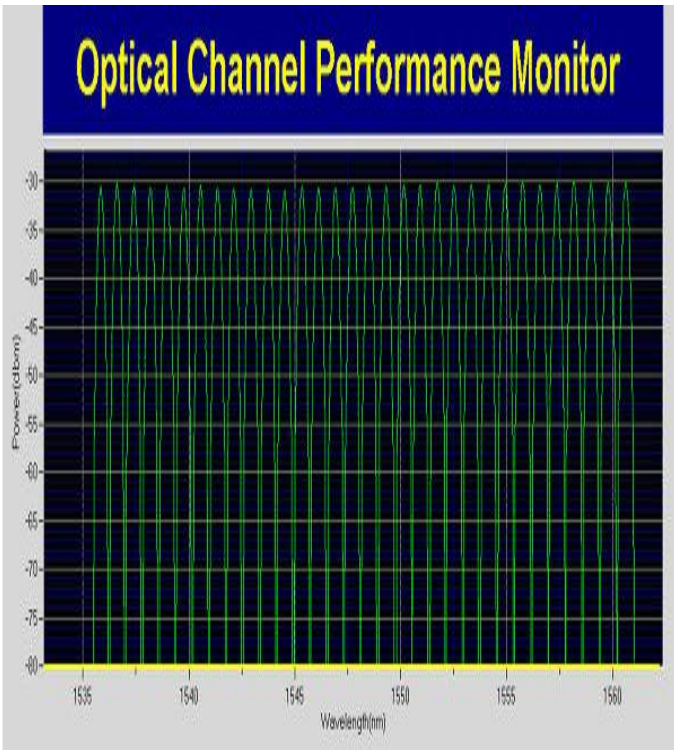

Fig- 5. Processed power spectrum detected AdvanceOPM

OPM provides 50 & 100 GHz, single-band and dual-band optical channel performance monitors. The single-band OPM covers wavelength range in either C-band or L-band. The dual-band OPM monitorsoptical performance over the wavelength range of C+L-bands. The channel spacing, 50 or 100 GHz, isspecified for the customer's OSNR applications, not for the OCPM itself since the device responses to thecontinuous spectral band. So we often specify the response bands, C- and/or L-band. For example, in asingle C- or L-band, the device can handle up to 40 DWDM channels for 100 GHz application and 80DWDM channels for 50 GHz applications. For a dual-band OCPM, the device supports up to 80 DWDMchannels for 100 GHz application and 160 DWDM channels for 50 GHz applications.

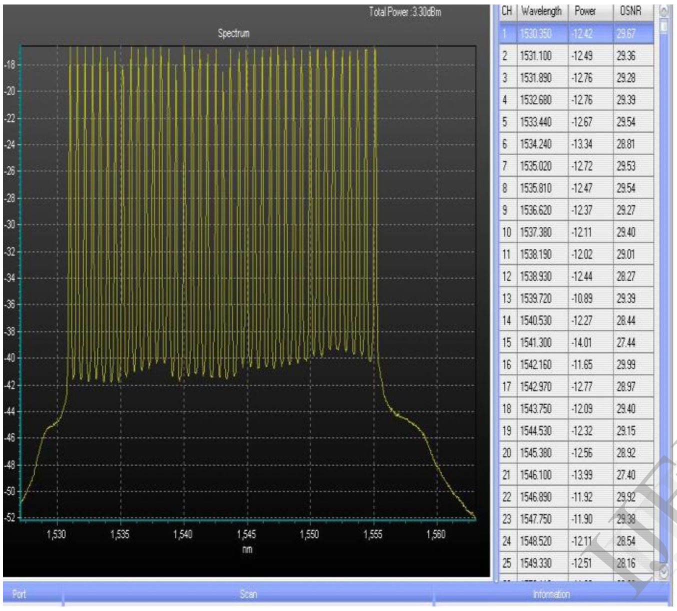

Fig-6. Processed power spectrum detected AdvanceOPM First 25 channels.

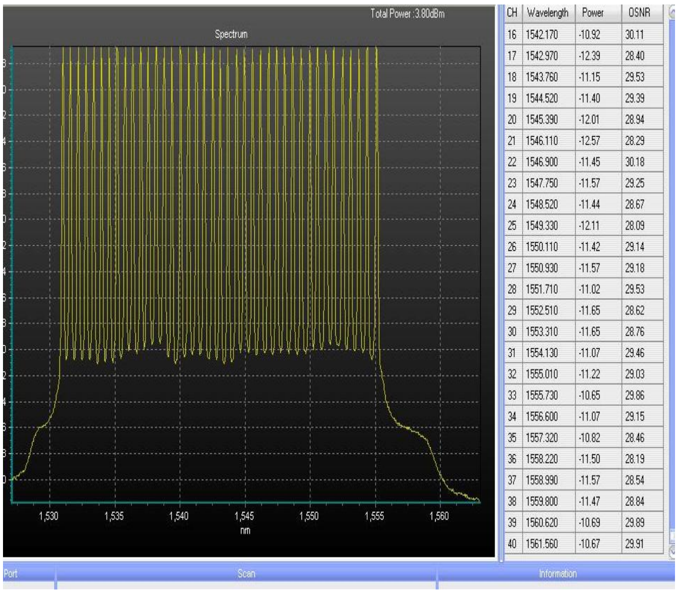

Fig-7. Processed power spectrum detected Advance OPM First 40 Channels

Table I gives atypical specification for a single-band 100 GHz

Parameters	Specifications	Unit
Wavelength Range	1528 - 1570 (C-Band) or 1570 - 1605 (L-Band)	nm
Channel Number	40	-
Channel Spacing	100 (ITU Grid)	GHz
Absolute Wavelength Accuracy	± 20	pm
Relative Wavelength Accuracy	20	pm
Dynamic Range	60	dB
Channel Input Power Range	- 50 to -20 (or customer specify)	dBm
Channel Absolute Power Accuracy	± 0.5	dB
Channel Relative Power Accuracy	0.5	dB
Channel Power Repeatability	± 0.2	dB
Power Resolution	0.1	dB
Polarization Dependent Loss	< 0.3	dB
Noise Floor	- 80	dBm
OSNR	30	dB
OSNR Accuracy	± 1.5	dB
Response Time	< 20	ms
Spectral Engine	Proprietary stigmatic spectrograph	-
Detector	256-element InGaAs detector array	-
Input Voltage	3 to 5 (DC)	V
Power Consumption	< 2	W
Operating Temperature	- 5 to 65	°C
Storage Temperature	- 40 to 85	°C
Electronics Interface	RS232/Parallel/USB	-
Dimension	68 (W) × 96 (L) × 15.8 (H)	mm
Weight	< 250	g

Table I : Typical specification for a single-band 100 GHz

VII. CONCLUSION

The value of OPM increases with increasing transparency. Networksare evolving in ways that make higher levels of OPM desirableif not required. Numerous technologies have been developed toaddress this OPM need. The challenge going forward will beto apply these techniques with the right balance between monitoringcoverage, sensitivity, and cost.A novel approach of optically down-converting a high-frequency in-band data tone to anintermediate frequency of 10kHz has been developed in the course of this work. It has beenshown analytically and verified experimentally that the BER/Power parameters can bedetermined. Whereas the OSNR is obtained from an amplitudemeasurement of the IF tone, in conjunction with the average power.

VIII. FUTURE WORK

We have shown that the initial implementationto provide for multi-channel chromatic dispersion monitoring. This initialimplementation evolved to the final proposed OPM technique that had the ability tosimultaneously and independently monitor multiple channels and multiple.These added features have come at the expense of increasing theacquisition time to 100ms. Depending on the dynamically reconfigurable networks, fasterOPM techniques may be required. We foresee that an improvement on the acquisition timecan be achieved by optically down-converting the in-band tone toward a higher intermediatefrequency (IF). For example, using a 1MHz IF instead of 10 kHz (as done in this thesis) couldpotentially improve the acquisition time by a factor of 100.

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