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Testing of WDM Systems

The Latest Developments

WDM (Wavelength Division Multiplexing) systems are no longer considered to be an emerging technology. Instead they are firmly entrenched in the fiber-optic industry, and service providers the world over have deployed these systems. It seems that systems keep getting bigger, faster, and better, almost on a daily basis.

At last count, in January 2000, DWDM (Dense Wavelength Division Multiplexing) technology could send 160 carrier wavelengths on a single fiber, with each carrier moving information at the rate of 40 Gbit/s. As dense WDM evolves, system designers, installers, and operators are going to expect much more from their test equipment.

FROM H. TYRON BOOKER, XAVIER LEE, STEPHANE VIGOT, MARTIN ENG

DWDM technology has created a need for new test procedures and equipment. Moving several different wavelength carriers on a single fiber means that a third dimension has been added to testing requirements: the spectral dimension. Test instruments must now be able to measure various parameters as a function of wavelength, in addition to time and power. As with conventional technology such as time division multiplexing (TDM), DWDM equipment manufacturers and operators will still have to test the network at the component and system levels, including the fiber itself.

System Building Blocks

As shown in figure 1, the optical layer is made up of various components or building blocks: transmitters and receivers, DWDM multiplexers and demultiplexers, dispersion compensation devices, optical amplifiers, optical add/drop multiplexers, and the optical fiber itself. Each has to meet certain minimum performance expectations as detailed in its technical specifications, and each plays a critical role in the overall performance at the system level. For example, slight crosstalk at the multiplexer level may well have been negligible during factory tests, but it can have a major impact on the quality of transmission when this building block is combined with others.

Not everyone needs to perform the same level of detailed testing. Equipment manufacturers and component suppliers must qualify their product specifications according to ITU and Bellcore standards. However, end users of these systems, such as service providers, may only be required to test their fiber plant for chromatic dispersion or polarization mode dispersion (PMD) impairments. Listed below are some of the testing requirements for a variety of building blocks.

Transmitters and Receivers

The specific transmitter wavelengths for DWDM systems follow the ITU standard wavelength grid. Wavelength meters should be used to characterize the wavelength accuracy and long-term stability of the output from DWDM transmitters. Laser linewidths can also be measured with a very high-resolution wavelength meter. Provisionable transmitter output power levels should be verified with optical power meters, while optical spectrum analyzers (OSA) can be used to measure the sidemode suppression ratio. Optical return loss (ORL) from connectors should be measured using ORL meters.

By using a programmable variable optical attenuator (pVOA) and a bit-error rate (BER) test set, parameters such as receiver sensitivity, input power range, signal degradation, and loss of signal (LOS) thresholds can be verified.

DWDM Multiplexers and Demultiplexers

Multiplexers and demultiplexers are actually sophisticated multipassband filters. They combine and separate multiple wavelengths into and from a single fiber in an optical link. As such, the spectral shape and filtering characteristics are key parameters to be tested. In particular, center wavelength, bandwidth, insertion loss, and ripple or flatness of each individual passband should be characterized. High isolation between worst-case adjacent and neighboring channels should

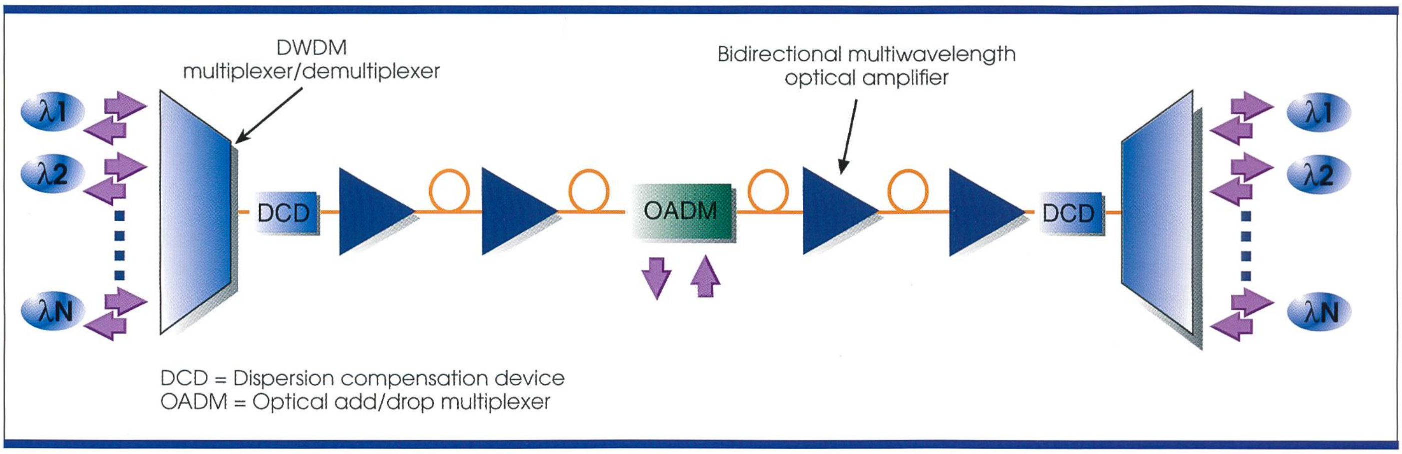

Fig. 1. DWDM optically amplified system.

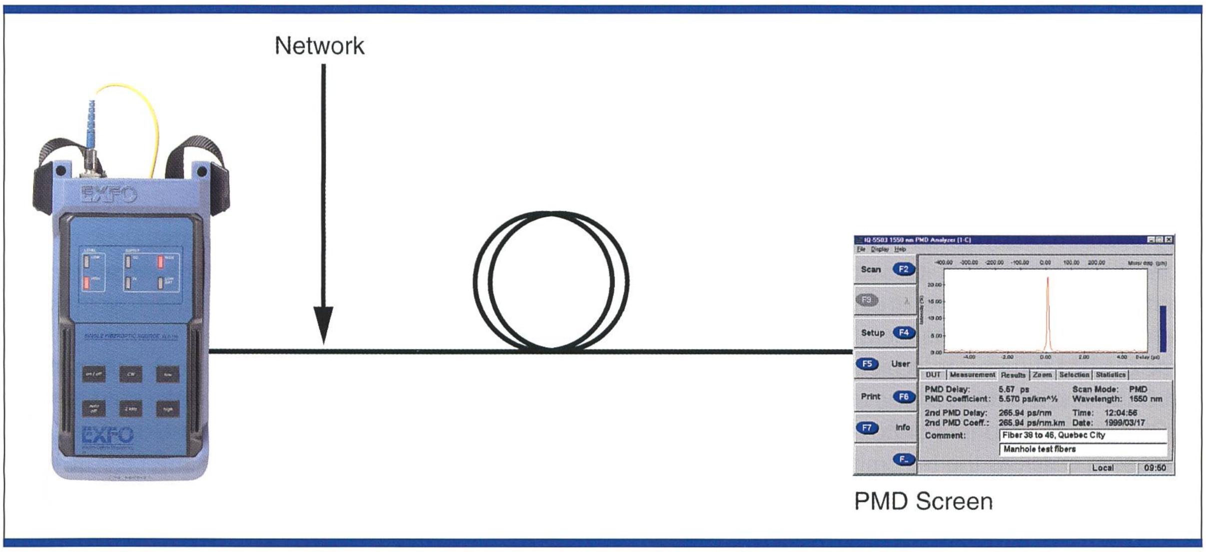

Fig. 2.
Testing PMD.

be measured to ensure that crosstalk is negligible. Insertion loss uniformity among channels should be verified to test the channel differential loss or device ripple. If the multiplexers/demultiplexers have upgrade ports to accommodate future capacity growth, similar tests should be performed on the upgrade passband. All these measurements can be performed using an OSA. High-density multiplexers and demultiplexers usually contain many connector ports, which increase the potential of obtaining a source of high reflection; therefore, ORL measurements on all connectors are essential. Polarization dependent loss (PDL) as a function of wavelength can be verified using a combination of a tunable laser, polarization controller, and a PDL meter or detector. Although PMD is expected to be quite small in these devices, it can adversely affect high bit rate systems and must be measured.

Dispersion Compensation Devices
Using a dispersion compensator to apply an equal but reversed dispersion on an optical pulse travelling through the fiber will counter pulse broadening due to chromatic dispersion. Currently, two types of dispersion compensating devices (DCD) are commercially available: dispersion compensating fiber (DCF) and dispersion compensating grating (DCG). In the case of the DCG, the delay ripple and insertion loss ripple over the working bandwidth should be characterized. Chromatic dispersion analyzers should be used to measure the dispersion of these devices over the relevant bandwidth. Insertion loss and PDL over the bandwidth should also be measured. PMD analyzers can be used to verify the mean differential group delay (DGD). ORL must also be tested.

Optical Amplifier (EDFA)
The natural gain spectrum of EDFAs is not uniform, with a peak around the 1530 to 1535 nm region. Most commercially available optical amplifiers used in long-haul telecommunication systems have gain-flattening filters built into the EDFA construction. Amplifier gain must be characterized as a function of wavelength; the amplifier's spectral gain flatness should be evaluated, and its gain equalization must be ensured for balanced, uniform spectral amplification. This is especially important in optical links with cascaded amplifiers. Characterizing the spectral content of the noise from the EDFA or amplified spontaneous emission (ASE) is also necessary to quantify the optical signal-to-noise ratio (OSNR). A series of tests should be conducted to characterize the gain and noise figure (NF) across the working bandwidth. A series of gain and NF curves at several probe wavelengths can be obtained at varying gain levels for a reference wavelength. From these series of curves, we can determine the amplifier NF, gain ripple, and tilt across the working bandwidth at varying gain levels. OSAs with built-in EDFA programs can be used to analyze the spectral responses to determine these parameters. Since some of the components in the EDFA may be sensitive to polarization or may exhibit birefringence, PDL/PDG (polarization dependent loss/gain) and PMD can be measured. ORL must be measured, and so must the optical amplifier's performance sensitivity to back reflections. This can be tested with a back reflection reference meter.

Optical Add/Drop Multiplexers, OADM
OADMs employ different types of filtering technologies: dielectric filters, acousto-optic filters, fiber Bragg grating filters, arrayed waveguide grating (AWG) filters, etc. No matter which filtering technology is used, the principle function of the OADM is to add and drop specific wavelengths without interfering with the remaining wavelengths that pass through the filter. Therefore, there are three paths that have to be verified: the in-out (pass-through) path, the in-drop (drop) path, and the add-out (add) path. For each of these paths, the passband insertion loss and ripple, channel isolation, ORL, and PDL should be measured.

Fiber
Before deploying a DWDM system in the field, the operator must first characterize certain parameters in the fiber plant to assess which system configuration and technology can be handled by that particular fiber network. As line rates increase, the effects of chromatic dispersion and PMD on the quality of transmission, due to distortion and dispersion induced non-linear effects, also increase. Chromatic dispersion analyzers should be used to measure the total dispersion in the fiber link and to understand how much dispersion compensation will be required. PMD analyzers should be used to measure the DGD. Span loss and fiber lengths can be characterized using OTDRs.

The Entire System

At the system level, with all the building block components working together in the optical link, end-to-end optical testing should be performed. The net dispersion between the transmitter and receiver for all the wavelengths, including OADM wavelengths, should be characterized to ensure that it is within specified levels. Optical power and OSNR at the receiver site should be measured. In some DWDM systems, to achieve balanced OSNR levels among all the channels, an OSA can be used to monitor the changes in OSNR as the transmitters are varied.

From a vendor's perspective, testing the optically amplified system's transmission performance is key to verifying the optical link budgets, after a system has been set up and optimized. Beginning at the operating condition of the system, the optical link should be stressed to the point at which the maximum permissible BER occurs, for example a BER of 10-12. The optical links can be stressed by adding supplementary attenuation to the link, or by adding noise to the system, hence reducing OSNR, to determine the noise margin. The penalty due to adding distortion to the system should also be characterized. The noise margin should then take into account allowances for aging, temperature variation, transmitter/receiver compatibility, and it should correct for worst case possible ripple and noise figure, power fluctuations, and link distortions due to non-linear effects. Based on the net margin and initial average span loss used in the operating condition, the guaranteed end-of-life (EOL) span loss can be determined.

On the other hand, network operators prefer to have a minimum number of system tests that demonstrate the overall system functionality and the integrity of the signal transmission. The procedure to test and deploy SONET/ SDH single-channel optical transmission systems is well documented. However, emerging technologies such as WDM lack such detailed procedures. Optical component properties and cable characteristics that could safely be neglected in systems using simpler transmission techniques must now be considered. Continuing advances such as add/drop multiplexers are giving rise to wavelength routing over complex networks. Optical cross-connects, though still on the drawing board, offer the potential to change how future telecommunications networks are constructed. As such, an effort is underway to define a set of system-level tests that characterizes end-to-end network functionality such as optical signal transmission, multiplexing, supervision, performance monitoring, and survivability. These tests are categorized as

- Network compatibility
- Transmission performance
- Operations, administration, and maintenance
- Inter-vendor operability
- Architecture interconnections

Network Compatibility

Network compatibility tests ensure that the existing signal is compatible with the fiber interfaces to the WDM network elements (NE) and verify that the electrical power specifications of the WDM NEs are equivalent to the existing network. Some essential field tests measure end-to-end attenuation, optical reflections at the network interfaces, and dispersion when the systems are being turned up. End-to-end attenuation testing at 1310 nm and 1550 nm examines the fiber path for optical discontinuities and determines whether the fiber conforms to system requirements. Testing for reflected power from individual components, such as connectors and fiber joints, determines whether the impact of single and multiple reflections are within specified tolerance requirements. Chromatic and polarization mode dispersion testing

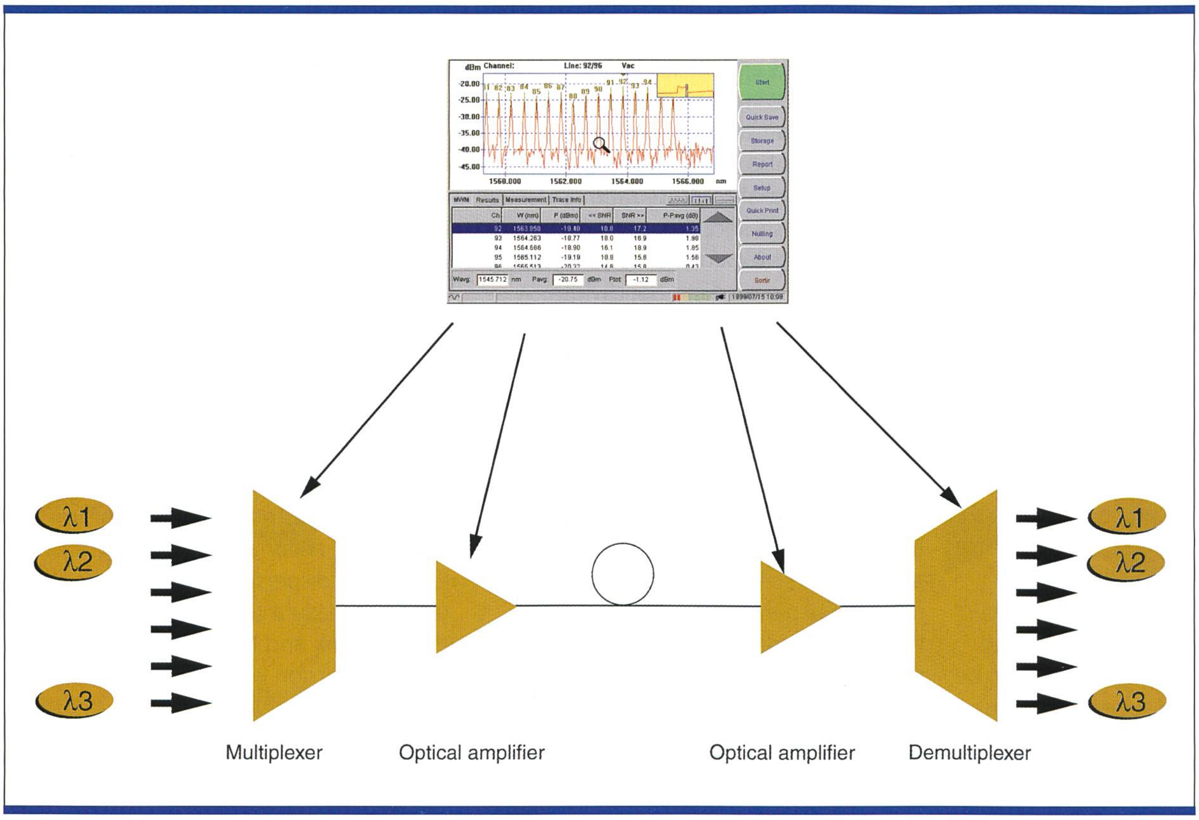

Fig. 3. Testing with a multiwavelength meter.

is not routinely done on newer fiber (unless dispersion compensators are present in the system) since these parameters are generally specified by cable manufacturers. However, these tests should be conducted on older fiber plant being considered for high bit rate (OC-192) transport or whenever fiber distances are great enough to encroach on system dispersion limitations.

Transmission Performance

Transmission performance tests measure transmitter/transponder and receiver performance, optical amplifier performance, error performance, and the effects that accumulate through WDM network elements. The laser wavelengths may vary because of factory variations, thermal shifts, or frequency broadening. When a spectrally broadened signal propagates through a dispersive medium such as conventional fiber, degraded error performance can result. The number of wavelengths available to a WDM system is limited by crosstalk, component drift, fiber non-linearity, and cascaded filter alignment tolerances. Because of the use of optical amplifiers to compensate for component and transmission losses, the impact of noise accumulation and cross-gain saturation needs to be carefully controlled to minimize signal power variations in the amplifier. The transmission performance tests verify end-to-end optical system performance. Channel wavelength, channel drift, optical signal-to-noise ratio, channel spacing, channel isolation, insertion loss, amplifier noise and gain flatness, bit error rate, jitter, and transmission delay are all critical measurements.

Operations, Administration, and Maintenance

Operations, administration, and maintenance tests confirm the capability of performing network operations and management functions, communicating with management systems and other NEs, monitoring end-to-end performance of a connection, and isolating faults of a replaceable or repairable entity.

When maintaining a WDM system, the operator ensures the optical carriers remain within specifications, that the wavelengths remain stable, and that the power does not fluctuate more than the system can tolerate. These tests make use of data communications (optical supervisory) channel(s) that enable communication between the WDM NEs (NE/NE), and the operation systems and network elements (OS/NE). Information that must follow a particular connection is transmitted via the embedded data communications channel (DCC), local area networks (LAN), or optical supervisory channel (OSC). Alarm surveillance and performance monitoring are tested. Key provisionable features and parameters are validated as locally provisionable at the craft interface or remotely from an OS interface. System administration and security functions must be verified. These tests ensure that the operations communication functions meet the needs of individual architectures and allow the network operator to discover and control the state of the network.

As on any kind of system, back reflection is still of concern. Performance monitoring detects the light reflected back that could cause parasitic interference effects and lead to power fluctuations, phase noise, and pulse distortion. If the reflections are particularly strong, they may induce instability in the transmitting laser.

Inter-Vendor Operability

Inter-vendor operability tests substantiate that WDM systems work with other vendors' transport technology equipment. To date, optical translators have been incorporated to provide an interface between various vendors' equipment. To avoid using optical translators, the physical properties of the optical signal and the content (e.g., wavelength, line rate, coding format) at the network interface must be standardized. Standards are required to ensure open specifications enabling vendor interoperability. The ITU and other standards bodies are actively defining standards for optical interfaces, architectures, and management. These interoperability tests verify transport of client layer signals across multivendor equipment.

Architecture

Architecture interconnection tests corroborate the functionality and survivability of network interconnections. Current WDM systems have been designed primarily for point-to-point connectivity over long distances, and optical network survivability is provided almost exclusively at the electronic layer by SONET. These systems are being augmented by systems that allow static wavelength add/drop and soon by dynamically reconfigurable add/drop systems. High performance switches and routers will be capable of routing wavelengths over complex networks. Optical cross-connects and other advanced optical technologies will support topologies that are more flexible. Restoration architectures based on self-healing rings, diverse routing, or mesh-based distributed algorithms are receiving considerable attention. Service protection, an essential aspect of the architecture, is tested for network reliability, survivability, and service consistency.

The Future of WDM Testing

As WDM technology evolves, operators are going to find themselves approaching the full capacity of their fiber-optic networks. System designers can choose how to make their systems more powerful. Some might increase the number of carriers by expanding the operating WDM window and/or by reducing the channel spacing, Others might choose to increase the data rate of each carrier. In either case, testing needs are going to evolve as fast as the technology. Testing procedures will have to keep up.

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