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## Introduction to BER testing of WDM systems

Application note 1299



Wavelength division multiplexing (WDM) is a new and exciting technology for migrating the core optical transmission network to higher bandwidths. The ability to transfer multiple optical carriers over the same span of fiber promises almost unlimited bandwidth.

However, the ultimate test for any transmission medium is its bit error ratio (BER) performance.

## How WDM overlays onto the network

If a network hotspot produces capacity shortfall problems, network operators can now opt to deploy a WDM system to quickly expand capacity on existing fiber links. For example, WDM equipment has already been deployed to multiply the capacity of existing STM-16/ OC-48 links—by combining and carrying up to 16 STM-16/OC-48 signals along the existing fiber path<sup>†</sup>. At the same time, upgrading of the existing STM-16/OC-48 line terminal mux to WDM operation is also readily achieved, providing increased bandwidth while retaining existing tributary access and connections. The operation of a WDM system can best be explained by looking at the sub-system level.



Figure 1. Simplified WDM system configuration.

- † Schemes are proposed carrying up to 32 STM-16/OC-48 signals.
- Currently, ITU-T draft recomment dations O.mcs specify 43 WDM wavelengths.

Laser sources and remodulators The transmitter of a WDM system produces laser signals at specific wavelengths and with a nominal spectral line spacing between them (Figure 2). Frequency separation is carried out using laser sources of specific frequencies, or using parallel 1550 nm laser sources with a remodulator to obtain the required frequencies. Laser sources are usually distributed feedback (DFB) lasers, typically working in the range 1530 to 1565 nm<sup>‡</sup>. They offer good stability and a narrow spectral width which is a prerequisite for dense-WDM (DWDM), where the spectral line spacing can be as narrow as 0.8 nm.

If the WDM system is deployed within existing STM-16/OC-48 fiber links then the remodulator also accepts the existing 1550 nm signal and remodulates it to the chosen WDM wavelength, ready for the wavelength multiplexing process.

#### **Optical multiplexer**

The multiplexer (mux) couples together different wavelengths then combines them for transmission into a single mode fibermaintaining the wavelength integrity of each optical carrier.

#### Fiber path and EDFAs

If an optical link is short, the transmission path will consist of nothing more than optical fiber. If the path is longer, say 50 to 100 km, then erbium doped fiber amplifiers (EDFAs) are used for pre- and postamplification. Where longer links are deployed, over 100 km, then EDFAs are also used as intermediate amplifiers.

#### **Optical demultiplexer and wavelength** selection

The receive side employs a demultiplexer (demux) or decoupler to distribute the optical signal to the wavelength selectors. These devices define the optical bandwidth to recover the original tributary and remove unwanted components.

## Impairments affecting WDM system performance

This application note focuses on the requirement for BER testing a WDM system. There are several potential sources of impairments associated with WDM components and optical fiber links. The main impairments that affect BER performance are listed below.

## Amplifier spontaneous emissions from EDFAs

An accumulation of naturally occurring emissions that may cause a reduction in overall signal-to-noise ratio.

#### **Gain flatness of EDFAs**

A measure of how flat the optical spectrum remains after passing through the amplifier. Ideally all wavelengths in the WDM signal are amplified equally. Nonlinearity needs to be compensated for, because ultimately it could lead to channel failure.

#### Gain competition in EDFAs

This is associated with the allocation of power to channels. Each EDFA has a defined amount of optical power available for amplifying incoming signals. Increasing the bandwidth of the amplifier adds more channels but leads to an overall reduction of power in existing channels.

#### Intrinsic and timing jitter

Jitter is the phase variation of a signal from its correct position in time. It can accumulate in a transmission network, leading to errors. The remodulation stage of a WDM system employs a clock recovery and re-clocking stage which can contribute to jitter on an incoming signal.

#### Dispersion

The characteristics of a fiber can cause wavelengths to propagate at different velocities through the fiber. This leads to pulse broadening and, ultimately, pulse merging which results in errors on the receiver detection circuit.

**Crosstalk between adjacent channels** This is the interaction between adjacent channels in a WDM line signal. Because of the closeness of channel spacing, the contents of one channel can cause interference in an adjacent channel, introducing errors at the receiver after demultiplexing and channel selection.

#### Four wave mixing

This occurs if components of existing optical signals combine to produce a new optical signal at a new wavelength.

## Simulated Brillouin scattering and Raman scattering

A description of the interaction between the optical signal and acoustic waves in the fiber, and between the optical signal and the fiber.

As any of these impairments could adversely affect the future fail-safe operation of the network, they need to be evaluated properly and corrected when implementing a WDM system design. For parametric measurements such as power level and optical spectrum checks use a wavelength meter and an optical spectrum analyzer.

For information on diagnosing individual WDM impairments, refer to the DWDM Components Test Guide 5965-3124E.

# **Evaluating BER** performance

Conclusive testing of BER performance (and other impairments) in a WDM system requires the duplication, as close as possible, of an in-service situation. Loading up the tributaries of a WDM system with dynamic, uncorrelated test signals gives a good simulation of live traffic. A typical test setup requires multiple 2.4 Gb/s optical sources of network quality, using DFB lasers or equivalent. Testing also requires wavelengths from the ITU-T WDM grid in order to mimic or test beyond system designs. An OC-48/STM-16 BER analyzer with SONET/SDH frame structures will simulate the traffic of a real network, and if it offers a modular, scaleable transmit/receive measurement capability would be ideal for WDM system testing.



#### 1. Tributary-side BER testing

Once assembled, WDM systems are usually 'soak tested'. That is, an endto-end BER test is performed across all tributaries of the WDM system. Each tributary test is typically 3–4 hours duration due to the low residual BER levels of WDM systems.

Soak testing can be approached in a number of ways.

- 1. Using a single transmit/receive optical source with optical switches to test each tributary in turn.
- 2. Using an optical splitter on the transmit output of an optical source to load up all inputs of the WDM mux, then using an optical switch at the output for measuring BER on each receive tributary in turn.
- 3. Using mulitple transmit/receive optical sources to allow all inputs of the mux to be loaded and to allow simultaneous BER measurement on all receive tributaries.

**Approach 1** may be sufficient for a functional test of a proven design, but testing each tributary in turn is inefficient. This approach often results in a trade-off on the amount of time spent measuring each tributary—in order to reduce overall test time. Simply expressed, we can say that . . .

Overall test time = number of WDM channels  $\times$  BER test time per channel

A further limitation is that loading each tributary in turn may not produce or detect the impairments described in the previous section. Any BER estimate from this approach may therefore be unreliable. If there is any instability in the system design then this approach is not recommended.



**Approach 2** may also result in a trade-off in test time, but removes the need for optical switching on the transmit side and allows all tributaries to be loaded. Most of the WDM impairments will emerge in this configuration. However, as the tributary test signals are identical, this approach is less likely to highlight crosstalk problems. In general, this BER estimate will be a good approximation.

**Approach 3** offers the best solution, in terms of both test time and thoroughness of test. Having independent optical sources means that the test signals are uncorrelated across the WDM tributary inputs. The multiple receive capability allows tributary BER measurements to be made in parallel, reducing overall test time significantly and providing a more accurate means of identifying problem tributaries by cross correlation of BER performance.

Figure 4. A modular, scaleable transmit/receive measurement capability is ideal for WDM system testing.



Multiport configuration and parallel measurements allow easy cross-correlation of test results.

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#### 2. In-service BER testing

Accessing tributaries for test when the WDM system is carrying live traffic is impractical. Some network monitoring capability may be built into the WDM but it is yet unclear how comprehensive and informative this capability will become. In any case, because of system aging, inservice testing a WDM system requires measurements of both BER performance and optical parameters.

The present strategy for maintaining the performance of a WDM system relies on examination of the optical spectrum of the WDM signal to ensure optical wavelength and power levels are within established limits. These tests are completed using a waveform multimeter and perhaps an optical spectrum analyzer (OSA) for higher resolution measurements. These measurements are a good indication of system performance but not an absolute, quantifiable measure. This can only be achieved with a BER measurement and the challenge is how to access a channel within a WDM line signal to make BER testing possible.

Using an OSA with a monochromator allows individual tributaries to be isolated and dropped to a BER analyzer. The analyzer can then perform in-service B1 parity error measurements on the live signal. So BER performance can be checked for any change in channel performance detected by parametric testing.



Periodically checking in-service BER performance could be used as a vital pro-active measure, highlighting any degradation in quality of service (QoS) before it impacts the service user. Further, for long term monitoring, a maintenance strategy could specify that a WDM channel be allocated as a test channel. This test channel could be 'hard-wired' by the OSA to the BER analyzer, then be monitored continuously as a measure of overall system performance. This would achieve a time-stamped record of QoS with no impact on throughput of traffic. The test channel could be allocated from any one of the channels carried in the WDM system and could be switched periodically across the output stream to check for non-linearities in system performance.

For more information on creating a tunable SONET/SDH BERT for WDM line testing, refer to product note 5965-2741E.

#### 3. BER testing and jitter

In SONET/SDH networks, jitter is a serious threat to quality of service. Controlling intrinsic jitter levels is a priority, and conformance testing of a SONET/SDH network usually includes some BER testing combined with jitter analysis. Later, when a network is operational, the level of jitter is monitored to ensure it remains inside ITU-T recommended levels. Because WDM is being overlaid onto the SONET/SDH infrastructure, it too must meet the current jitter requirements. The two key jitter measurements are jitter transfer and jitter tolerance.

#### Jitter transfer

This is a measure of jitter gain across any element or section of the network.

Jitter transfer (dB) = 20 log (Jitter out / Jitter in)

It is important to measure jitter transfer across a WDM system to ensure that there is no jitter contribution from the clock recovery stages present in the remodulators. Using a jitter analyzer with low intrinsic jitter performance is the most accurate method to measure the jitter contribution in a WDM system. Typically a test signal (as jitter free as possible) is applied to the input stage of the WDM remodulators and the jitter is measured on the output tributary of the demultiplexer.

#### Jitter tolerance

This a measure of BER performance versus applied jitter. A jitter tolerance measurement is used to verify an interface can withstand defined jitter levels and perform error free. Typically the test signal is applied to the input stage of the WDM remodulators with defined levels of jitter at different frequencies, and the BER performance is measured on the output tributary of the demultiplexer. The jitter tolerance measurement masks have been defined by the ITU-T, and having a test set with these masks built-in makes measurements faster and simpler.

Having a jitter analyzer that displays the results in decibels (dB) will allow a quick comparison with the ITU-T jitter standards.

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For more information on jitter measurement techniques, refer to Application Note 1267 "Frequency-agile jitter measurement system" (5963-5353E).





### HP 75000 Series 90

modular telecom analyzer A scaleable electrical/optical transmit and receive tester for SONET, SDH and WDM systems. Use for loading system inputs, and for BER and jitter measurements to SONET/SDH standards.

STM-16/OC-48 test set Comprehensive testing at 2.488 Gb/s, including BER and jitter analysis to SONET/SDH standards.

optical spectrum analyzer In addition to optical sources, this analyzer can characterize optical-to-optical devices such as couplers, filters, isolators, switches and WDM muxes.

#### HP 86120B

multi-wavelength meter For 700 nm to 1650 nm. Offers fast measurement of wavelength, amplitude, drift and signal-to-noise ratios of up to 100 discrete laser lines.

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