White Paper
Chromatic Disperson Compensation: Extending Your Reach

Introduction

Chromatic dispersion of short optical pulses traversing optical fibers is a fundamental problem when it comes to optical transport. Signal distortion, if not properly compensated, will lead to inter-symbol interference that may result in data loss or traffic interruption. This paper will describe the technologies used to compensate for chromatic dispersion and how to implement reliable optical connections between equipment nodes that could extend more than 100km apart.

Optical Dispersion

Dispersion, by definition, is the separation or light by refraction into individual components of different wavelengths. Dispersion results in most materials because a material's index of refraction depends on the wavelength of the light passing through it. Therefore, different wavelengths entering a fiber optic cable will fan out into different paths within it. This phenomenon is called chromatic dispersion.

Chromatic dispersion is due to an inherent property of silica fiber. The speed of a light wave is dependent on the refractive index of the medium within which it is propagating. The refractive index varies with wavelength. Therefore, different wavelength channels will travel at slightly different speeds within the fiber. A pulse of light from a laser has some spectral width, hence each of its wavelength components will travel at slightly different speeds within the fiber. This results in a spreading of the transmission pulse as it travels through the fiber thus distorting the light.

Dispersion Compensation Techniques

A common method of controlling dispersion is the use of Dispersion Compensating Modules (DCM) placed at periodic intervals. DCMs are usually one of two.

The first type uses a Dispersion Compensating Fiber (DCF). This is simply a spool of a special type of fiber that has a very large negative dispersion. Typically, DCF dispersion can be in the range -80 ps/(nm x km). By example, a 20km length of DCF can compensate for the dispersion in a 100km length of fiber.

One drawback of this technology is that the DCF by design has a high insertion loss. This, combined with the fact that the length of the DCF is proportional to the length of the transport fiber, leads to high insertion loss and bulky terminal components. The result is higher cost.

The second type of DCM is a Fiber Bragg Grating (FBG) type. By utilizing the unique properties of the FBG, insertion loss issues can effectively be addressed. FGB provides a cost-effective alternative to the incumbent DCF technology.

Dispersion compensation utilizing FBG is based on the introduction of wavelength-specific time delays through the use of chirped FBG. By combining a FBG with a standard optical circulator, a highly effective dispersion compensation module (DCM) can be achieved.

Accurate control over the FBG chirp is the key for precise dispersion compensation. By utilizing state of the art direct-write FBG manufacturing techniques, dispersion characteristics can be made to precisely mimic the dispersion properties of the fiber span.

Two main types of FBG-based dispersion compensators are commercially available today: multi-channel (or channelized) and continuous.

The channelized version provides channel spacing specific compensation. The continuous type provides continuous compensation throughout the C or L band.

Therefore, the continuous type offers total channel plan independence, an important feature when considering higher bit rates, dense channel spacing, and upgradability.

Fiber Bragg Grating vs. Dispersion Compensating Fibers

Insertion loss is a major cost driver for optical networks and the biggest drawback for utilizing DCFs for dispersion compensation is the amount of insertion loss they add. Insertion loss also drives the requirements for the number of erbium-doped fiber amplifiers (EDFAs) needed. However, EDFAs actually add wavelength-dependent dispersion, negatively affecting system performance as theirnumbers increase.

FBG-DCM diminishes the insertion loss obstacle as it has less than half the insertion loss as DCF. Another benefit of the FBG-DCM is its resilience to withstand high optical power. In contrast to DCFs, which display nonlinearity issues at moderate optical power levels, the FBG-DCM can tolerate the highest optical power found in optical networks without inducing nonlinearity effects.

Accurate dispersion compensation becomes more stringent when increasing the bit rate. Typically, the chromatic dispersion for a 10G transmission line is above 100 ps/nm. But when considering optical transport at 40G, this tolerance typically falls well below 100 ps/nm.

DCM for Higher Rate Systems

To overcome the severe dispersion requirements for high bit rate transport, a number of strategies were developed. One method is to increase dispersion tolerance is to move away from simple digital encoding formats and start employing more dispersion tolerant formats such as differential quadrature phase-shift keying (DQPSK).

DQPSK is used in many 40G networks. DQPSK format transmits 2 encoded bits per symbol and hence the symbol rate is half the bit rate with somewhat reduced complexity of the system. DQPSK is tolerant to chromatic dispersion, polarization-mode dispersion, and has a high spectral efficiency, and thus can be used in long haul transmission. The configuration of a DQPSK system is less complex when compared with a QPSK system, but requires a larger size and higher power consumption of the optical transceivers.

For long haul 100G, the industry is adopting dual-polarization quadrature PSK (DP-QPSK) modulation with a coherent receiver. DP-QPSK uses two independent optical signals of exactly the same frequency, but with dual polarization, reducing symbol rate by a factor of two. The QPSK modulation allows a further factor of two reduction in symbol rate.

Furthermore, utilizing new modulation schemes will increase the tolerance to chromatic dispersion. As a result, system vendors and operators are turning to tunable dispersion compensators (T-DCMs) for future systems.

T-DCMs allow operators to basically use 10G design rules for 40G networks since it has the potential to increase the dispersion tolerance tenfold. As such, the original 10G link can remain largely intact. In addition, the T-DCM will also handle time-varying dispersion changes induced by normal temperature variations along the fiber.

FBG-based technology has proven very suitable for T-DCM. FBG-based adaptive dispersion compensation is readily available and tunable FBGs are being considered as the technology of choice in numerous 40G and 100G optical systems.

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