Optical tunable dispersion compensation aids 40G

By Martin Guy, Yves Painchaud, and Carl Paquet

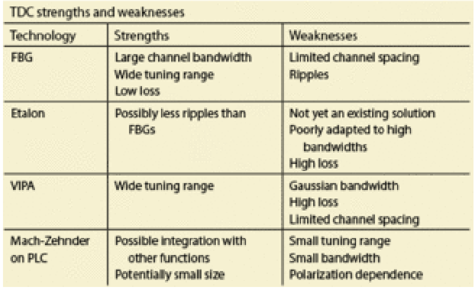
Over the last 2 years, we have seen a number of public announcements regarding commercial deployments of 40-Gbit/sec systems in Europe and the US. Most Tier 1 carriers are currently looking at 40 Gbits/sec, and even higher speeds such as 100 Gbits/sec are being considered. The most notable of these deployments is the recent public announcement by AT&T of a massive 40-Gbit/sec build-out in key routes between 31 cities throughout AT&T's U.S. backbone network, with initial deployments by the end of the first quarter of this year.[1] The trend toward 40-Gbit/sec deployment will most likely speed up in the coming years with the increasing availability of routers with 40-Gbit/sec optical interfaces combined with a huge increase in data traffic (up to 100% year-over-year for some carriers) driven by new services such as triple play (including IPTV), file sharing, etc.

One of the most important challenges for successful operation of these 40-Gbit/sec systems is the cost-efficient management of chromatic dispersion. In fact, dispersion tolerance of systems operating at 40 Gbits/sec decreases dramatically compared to systems at 10 Gbits/sec and is typically around 100 psec/nm. The very small dispersion tolerance at 40 Gbits/sec makes the use of a tunable dispersion compensator (TDC) a prerequisite, since even a small perturbation along the fiber link (for example, temperature variation) can make the system perform out of specification.

An introduction to TDC

It is now well recognized by system and transponder designers that an optical tunable compensator is a key component in fulfilling the challenging requirements of dispersion management at 40 Gbits/sec. Although electronic dispersion compensation at 40 Gbits/sec is also a potential option, this technology is still at the R&D level and will take many years before reaching the level of maturity and performance necessary for commercial deployments.

Different competing optical TDC technologies are presently available, such as fiber Bragg gratings (FBGs), virtually imaged phase array (VIPA), etalons, and Mach-Zehnder interferometers on planar lightwave circuits.[2] Performance tradeoffs among these technologies are highlighted in the table.



TDC strengths and weaknesses

Technology	Strengths	Weaknesses
FBG	Large channel bandwidth Wide tuning range Low loss	Limited channel spacing Ripples
Etalon	Possibly less ripples than FBGs	Not yet an existing solution Poorly adapted to high bandwidths High loss
VIPA	Wide tuning range	Gaussian bandwidth High loss Limited channel spacing
Mach-Zehnder on PLC	Possible integration with other functions Potentially small size	Small tuning range Small bandwidth Polarization dependence

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Among the technologies presented in the table, TDC based on multichannel FBGs is the leading technology for 40-Gbit/sec applications. Combining multichannel FBGs with a thermal gradient platform (with or without integrated control electronics) provides a compact and easily controllable device that can be integrated on a line card or in a transponder (see TDC picture in Figure 1). It also provides very low insertion loss, which is critical for 40-Gbit/sec systems given the 6-dB optical signal-to-noise ratio (OSNR) penalty compared to 10-Gbit/sec systems.

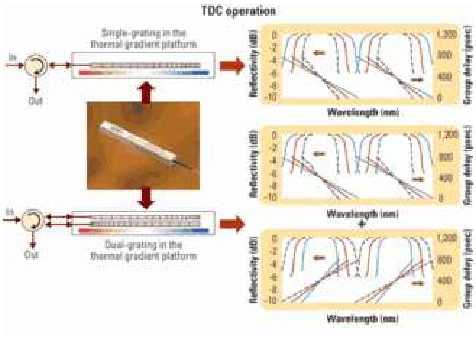

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Figure 1. Thermally controlled optical TDCs can use a single-grating (top) or a dual-grating (bottom) configuration in the thermal-gradient platform. The picture showing the TDC (without integrated control electronics) illustrates that the same thermal gradient platform can be used for both the single- and dual-grating configurations.

A wide dispersion tuning range over large channel bandwidth makes the use of this technology suitable with the new modulation formats being considered at 40 Gbits/sec such as duobinary and differential phase-shift keying. Finally, it is worth mentioning that the multichannel FBGs used in the TDC are based on a mature, reliable, and cost-effective technology that has been widely deployed for years in the field for static dispersion compensation that replaces dispersion-compensating fibers.

In operation, the chromatic dispersion of an FBG can be changed by imposing a thermal gradient along its fiber length.[3] Assuming a thermal gradient of either sign can be applied, the dispersion can be increased or decreased with respect to the non-thermally adjusted state. This is illustrated in the top of Figure 1 for an FBG (two channels are shown in this figure) having a negative dispersion, the dispersion being defined as the slope of the group delay versus wavelength.

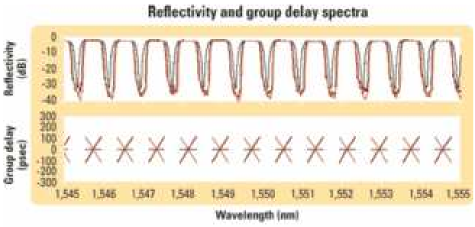

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Figure 2. This figure shows the reflectivity and 100-pm-smoothed group delay spectra of a 51-channel 100-GHz-spacing TDC shown over 10 nm. The spectra are shown when the dispersion is adjusted to −600, 0, and +600 psec/nm.

As the dispersion is tuned, the channel passband also changes as can be seen in Figure 1. For most applications, there is a need for a device that provides a symmetric tuning range around 0 psec/nm. This is accomplished by imposing the same temperature gradient on two FBGs having dispersions of opposite signs as illustrated in the bottom of Figure 1. When these two FBGs are connected to a four-port optical circulator, their overall dispersion is the sum of the FBGs' individual dispersion.

For 40-Gbit/sec systems, adjustment of the residual chromatic dispersion using a TDC is performed at the receiver end either in an open or a closed-loop configuration. Although a per-channel adjustment of the residual chromatic dispersion is performed, the colorless operation of the TDC is still a strong requirement for inventory purposes. For this reason, it is advantageous to have a single TDC that can cover the full C-band and/or L-band. In the case of the TDC based on FBGs, this means that the gratings incorporated in the thermal-gradient platform must have a multichannel character.

To manufacture multichannel FBGs cost-effectively, a conventional phase mask approach in which the multichannel character is encoded in a complex phase mask element is used.[4] It has been shown recently that fixed multichannel FBGs fabricated using this manufacturing approach are now suitable for in-line long-haul applications for distances up to 2,000 km.[5]

Signals at 40 Gbits/sec with a traditional modulation format such as non-return to zero-on/off keying may require components having clear passbands up to 80 GHz. For such a large bandwidth, the channel spacing is limited to 200 GHz and the tuning range to around ±400 psec/nm for a dual-grating configuration. In this case, two different part numbers would be required to cover any channel on a 100-GHz grid. When 100-GHz channel spacing is a strong requirement, a TDC can be designed as long as the channel bandwidth can be proportionally reduced. A bandwidth of 40 GHz can be acceptable for 40-Gbit/sec systems that use specific narrowband modulation formats such as duobinary.

A 51-channel 100-GHz spacing TDC with a −1-dB bandwidth larger than 40 GHz and a tuning range from −600 to +600 psec/nm is presented in Figure 2. The phase ripple standard deviation was found to be 0.059 rad in average (smoothed group delay ripple [GDR] was found to be less than 6.4 psec peak-to-peak for all channels), thus fulfilling the requirements for 40-Gbit/sec systems.

TDC design tradeoffs

As can be seen from the 100- and 200-GHz channel spacing TDC designs, there are some tradeoffs between dispersion tuning range, operation bandwidth, and channel spacing. The length of the thermal platform imposes a maximum FBG length, which in turn limits the achievable delay. This delay is directly related to the dispersion and channel passband, the dispersion being obtained by the ratio of the group delay and the channel passband.

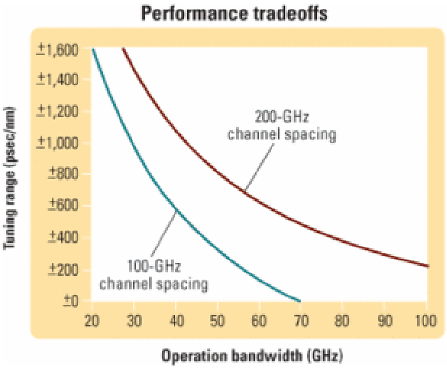

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Figure 3. Performance tradeoffs among

> *operational bandwidth, tuning range, and channel spacing for a dual-grating TDC need to be managed to match the device to the system requirements.*

There exists also a limitation on the channel spacing, which should be large enough to avoid interference between channels when dispersion tuning is performed. In particular, the channel passband, limited by the highest absolute dispersion, is limited to about 50% of the channel spacing.

Figure 3 gives an indication of these tradeoffs for the particular case of a commercially available dual-grating TDC. The use of longer FBGs would allow an increase in the operational bandwidth and/or the tuning range of the device. The dual-FBG configuration presented in Figure 3 assumes that the two FBGs are similar (but in opposite directions in the tuning platform), thus providing a symmetric tuning range around the zero dispersion value. In the dual-grating configuration, different FBG designs could be used if, for example, an asymmetric tuning range around the zero dispersion value would be required.

In this article, it has been shown that thermally controlled multichannel FBGs are particularly well suited for tunable residual dispersion compensation at 40 Gbits/sec, making them the technology leader for this application. Through recent and continuous performance improvements, FBG-based TDCs now meet the performance requirements of system designers very well, making this device a critical element for future massive deployments of 40-Gbit/sec systems.

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