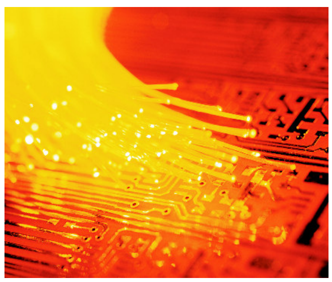
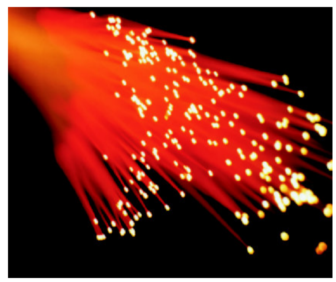
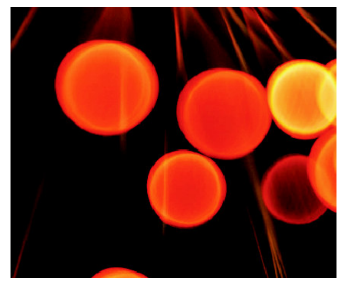
Dispersion Management

White Paper

Fiber Bragg Grating based DCM

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Abstract

This white paper will discuss the underlying technology and cost saving potential provided by Fiber Bragg Grating (FBG) based dispersion compensation.

Unique and enabling FBG features such as low insertion loss, lack of non-linarites and low latency etc will be explained in detail and a comparison between the two dominating technologies, Direct detection and Coherent detection will be made. Important differences between the two technologies in regards to key characteristics and general properties as well as cost efficiency will be discussed.

The dispersion compensators discussed in this paper are commercially available from Proximion AB.

Summary

FBG based chromatic dispersion management provides the telecommunication industry with unparalleled possibilities when it comes to cost and performance network optimization. The increased focus on cost, especially considering 10G, 40G, 100G and future networks, is well served by this unique technology – a conclusion supported by the to date, thousands of units deployed in various networks worldwide.

About Proximion AB

Proximion AB is a world-class provider of optical modules and sub-systems based on Fiber Bragg Grating (FBG) technology. By combining these unique optical devices with the truly innovative skills of our team, Proximion contributes to our customers' and partners' success in a variety of markets.

Applications

The inherent characteristics of the Fiber Bragg Grating based DCM makes it suitable for a variety of applications and a detailed description of all of them is beyond the scope of this white paper. Below follows some of the currently most interesting applications within the Optical network segment.

Coherent Networks

It has been repeatedly said in media and on the official stand that the coherent networks would not need optical dispersion compensation. In theory it holds true but there are numerous application areas where the combination with optical dispersion compensation turns out to be the optimal solution. This is valid both from an economical perspective as well as from a technical.

When the system designer tries to reduce the amount of non-linear effects, such as usage of larger effective fiber area, it often comes with an increase in chromatic dispersion. For LH and ULH networks it becomes a necessity to add optical dispersion compensation as a complement to the DSP. Proximion offer a wide range of suitable products for dispersion handling in coherent networks. The DCM-CB provides up to 2,400 ps/nm continuous compensation over the entire C-band while the DCM-HDC offer a state-of-the-art 10,000 ps/nm over 7 nm bandwidth which is a common structure in Submarine links.

There are three important key benefits offered by the use of optical compensation in coherent networks: Reduced Power Consumption, Reduced Latency and Reduced Complexity

Reduced Power consumption

Coherent detectors are power hungry and the use of FBG based DCMs may ease this burden significantly. The most optimal solution is to use a continuous grating designed to cover a sub band, i.e. 4 nm, combined with very high dispersion i.e. as 10,000 ps/nm.

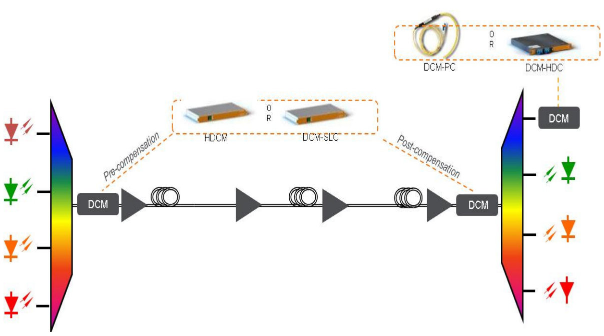

Figure 1 – Post, Pre or Band specific dispersion compensation utilizing FBG-DCMs in Submarine links

In ULH links with 150,000 ps/nm the insertion loss will be as low as 50 dB, a fraction of any competing DCM or DCF.

Reduced Latency

Complex FEC schemes are used in coherent networks to improve system margins thereby adding latency. This can be cured by the use of FBG based dispersion compensators with virtually zero latency added.

Reduced Complexity

By doing the dispersion compensation in the optical domain it is possible to use a simpler DSP design or to close down the static block of the DSP and at the same time extend reach.

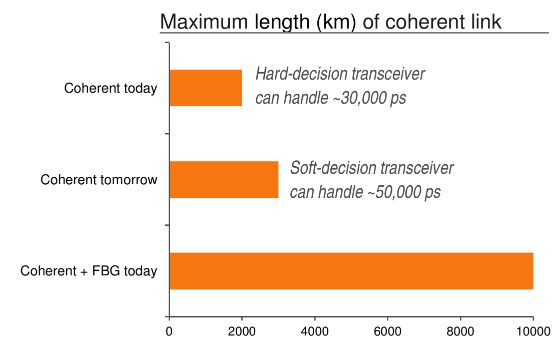

Figure 2 – Extended reach in a coherent system using optical compensation

In summary, by using optical dispersion compensation as a complement to coherent DSP´s the customer will have a future proof system at a lower CAPEX and OPEX.

Direct Detection Networks

Point to point networks

By making good use of the low insertion loss, the equivalent of hundreds of kilometers of single-mode fiber (SMF) dispersion compensation can be concentrated in single nodes. This is especially interesting to achieve cost-effective point-to-point networks, not requiring distributed dispersion compensation.

The low loss and high-power tolerance further provide the network designer with the possibility of placing the compensation either directly after the multiplexer (MUX) on the transmitter side or after the booster. The exact placement of the FBG-DCM will be governed by optical signal-to-noise ratio (OSNR) requirements and/or terminal equipment layout.

In Figure 3 one implementation possibility is illustrated.

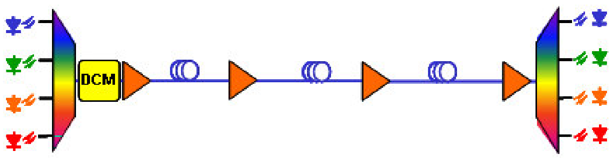

Figure 3 – Point-to-Point optical transport network with pre-booster FBG-DCM placement

Dispersion Distributed networks

Networks requiring distributed dispersion compensation, typically an architecture used when requirement on signal fidelity at each node is vital, normally relies on the use of mid-stage access amplifiers, or node specific DCMs, to accommodate this.

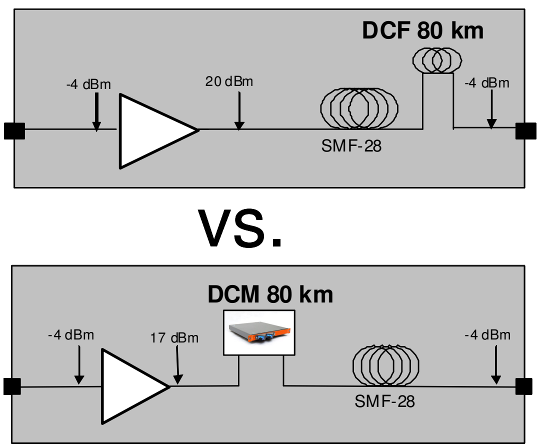

Figure 4 – Cost saving enabled by high loss DCF-DCM to low loss FBG-DCM substitution

By utilizing the low insertion loss of the FBG-DCM, the elimination of mid-stage amplifiers is in some networks, an attractive strategy to pursue. If such a strategy is implemented in a network the amplifier related cost saving per span can be as high as 40%.

Even in networks where MSAs are not used the insertion loss related cost saving could still be significant. By simply utilizing amplifiers with less available output power, as illustrated in Figure 4, the savings on amplifications alone can be in the area of 20% for a standard 80 km span.

In ultra long haul applications, i.e. submarine links, where typically fiber mixing has been the method of choice for dispersion management, aggregated dispersion becomes an issue. It is in general no problem to optimize the optical transport fiber to have a zero dispersion at the center of the transmitted band, however huge amounts of residual dispersion is usually built up at the edges of said band. This dispersion build-up is caused by the difference in dispersion versus wavelength characteristics of the fibers used and increases linearly with the transport distance. The residual slope dispersion can reach values of several thousand ps/nm.

Previous methods used where DCF fiber employed to compensate for the negative dispersion and bundles of SMF fibers used to compensate for the positive ditto. Using the Proximion DCM-SLC for full band slope compensation or the DCM-PC for sub band or single channel compensation provides a significantly more cost effective and space saving solution.

Single Channel Applications

FBG based dispersion has been used for many years to address the specific requirements for single channel applications, such as TDM based SONET/SDH systems.

The DCMs used in these systems has usually been in the form of athermal packaged channelized gratings. However, quite recently, a novel packaging technique has made it possible for these single channel FBG-DCMs to be offered integrated in patch cords.

This new packaging technique enables the use of wider continuous gratings rather than narrow channelized ones. The freedom in grating design and unique form factor offered by this solution makes this a very suitable solution not only for 10G systems but also for 40G/100G systems using wider modulation formats.

The utilization of a wide continuous grating further removes the necessity of costly thermal stabilization of the FBG hence a smaller and more cost effective component can be realized.

Figure 5 – FBG and circulator incorporated in a patch cord

FBG based Dispersion Compensating Technology

Chromatic dispersion, i.e. temporal distortion (spreading or smearing) of short optical pulses as they traverse optical fibers, is a fundamental problem in optical transport. The distortions of the signal will, if not properly compensated for, lead to inter-symbol interference which eventually results in data loss and/or traffic interruption.

The introduction of Coherent detection has greatly changed the landscape of dispersion management. Using the calculation power in the DSP compared to the traditional DCF bundles provides significant space and cost saving opportunities while also increasing capacity. As said above, the FBG based DCM offers benefits to both the future and the traditional systems.

Typically, DCFs have a dispersion coefficient four to eight times that of standard single mode fiber. However, this level of dispersion is achieved by reducing the diameter of the fiber core, which in turn increases the fiber transmission loss as well as limits the levels of optical power that can effectively be transmitted through the fiber without inducing other distortions, so called "non-linear" effects which can be especially harmful in Coherent networks..

Chromatic dispersion compensation using highly efficient reflective Fiber Bragg Gratings is significantly different from DCF compensation and proves to have, as later will be described, some obvious benefits with regard to addressing both the technical as well as the cost-related issues of current and future dispersion compensation.

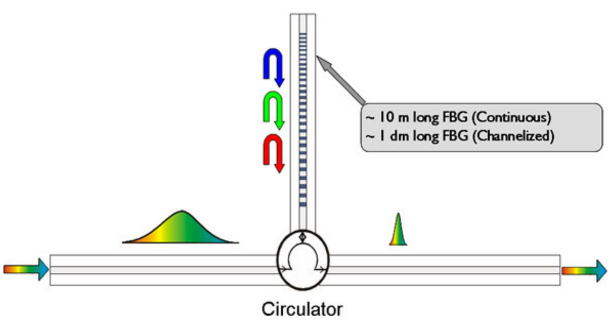

Figure 6 – FBG based dispersion compensation principle

Dispersion compensation utilizing FBGs is based on the introduction of wavelength-specific time delays through the use of a precisely chirped FBG. By combining such an FBG with a standard optical circulator a highly effective Dispersion Compensation Module (DCM) can be realized.

A graphical illustration of the FBG based dispersion compensating principle is shown in Figure 6.

FBG-DCMs are devised by basically assembling an optical circulator and a chirped FBG. The basic principle is to achieve the compression of a dispersion broadened pulse by letting the "fast" wavelengths of the pulse be reflected further away in the FBG than the "slow" wavelengths that are reflected closer to the circulator.

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, or grid specific, compensation whereas the continuous type provides, in much the same manner as a DCF, continuous compensation throughout the C-band, hence providing total channel plan independency.

Important to realize is the lack of channel partitioning of the bandwidth in the continuous type of FBG-DCM. The device operates truly continuously over the whole C-band. One additional benefit of having a continuous FBG is that no temperature control is required for the component, as there is no need to prevent the DCM operating bandwidth to glide out of the ITU channel. Furthermore, for standard fibers, the derivative of the group delay, i.e. the dispersion, is essentially the same regardless if the grating shifts in wavelength with temperature hence the FBG-DCM is a totally passive optical component with no active components.

Optical Characteristics

Insertion Loss

The most obvious and commonly known advantage relating to FGB based Dispersion Compensation Modules (FBG-DCMs) is the low insertion loss (IL). Typically, a 120 km FBG-DCM has an insertion loss in the range of 2-4 dB dependent on type while a DCF equivalent represent an IL of approximately 10 dB or even higher. For ULH this becomes even more beneficial with a total insertion loss of less than 50 dB in a 150,000 ps/nm system using DCM-HDC from Proximion.

In the case of DCFs the insertion loss originates from the attenuation in the fiber itself due to the reduction in core diameter needed to achieve sufficient dispersion compensation. This will result in a linear increase of the insertion loss with span length, i.e. the amount of dispersion to be compensated for.

The FBG case is fundamentally different compared to that of a DCF as the length of the fiber gratings used is very short, hence having only a fraction of the total loss. In fact, the IL of an FBG-DCM is mainly governed by the optical components used in the design, e.g. circulator(s) and in some cases tilt filters.

This lack of linear compensation length behavior, i.e. span length independence, is of course a huge cost saver when it comes to compensation of longer spans, since it directly reduces the amount of amplification needed to sustain sufficient optical signal strength. The typical IL characteristics of DCF and FBG based dispersion compensation is illustrated in Figure 7.

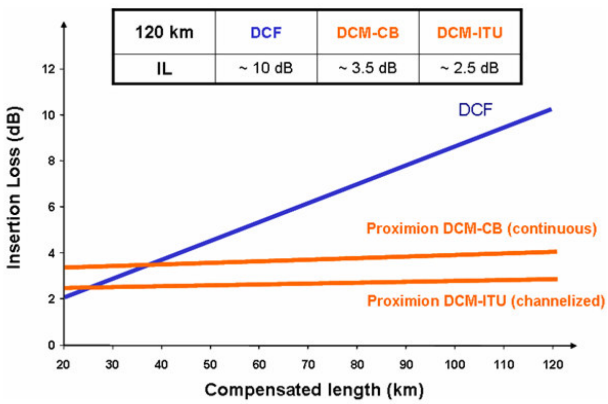

Figure 7 – Insertion Loss comparison between DCF-DCM and FBG-DCM

Latency

Latency arises in both Coherent and Direct Detection networks. The main contribution in the Coherent network comes from the calculations made to compensate for fiber impairments and the FEC. In the Direct Detection system a large portion of the addressable latency comes from the DCF spools FBG based DCMs have virtually zero latency and can thus greatly improve latency figures in both Coherent as well as Direct Detection links.

DCMs with low latency are absolute essential in systems designed for high frequency trading. It is also commonly known that latency is an issue in Storage Area Networks (SAN) and other applications relying on massive package transfer due to the negative impact on effective throughput and/or reach. Low latency is also a key enabler for the novel cost efficient and high performance amplifier designs currently emerging.

Power management and non-linearities

The ability to tolerate high optical powers without suffering from penalties caused by non-linear effects is also one prominent characteristic separating the FBG-DCM from the DCF-DCM. While a DCF will display non-linearity effects at rather low optical powers, typically limiting the power to -2 dBm per channel, the FBG-DCM will not introduce such effects even at the highest power levels present throughout any traditional optical network. The Coherent systems are especially sensitive to non-linearities and the FBG based DCM can thus offer a cost effective cure.

General Properties

Dispersion Matching

DCF-based compensation typically displays a high degree of wavelength-dependent residual dispersion due to manufacturing and design issues leading to batch-to-batch variations and inadequate slope matching. This behavior is especially noticeable for DCFs targeting non-zero dispersion-shifted fiber (NZ-DSF), e.g. LEAF fiber compensation, but also exists to some extent for standard single-mode fiber (SMF) optimized DCFs.

In the case of FBG based dispersion compensation the story is quite different. By utilizing advanced fiber exposure techniques the chirp of the FBG can be tailor made. This ability to tailor the compensation behavior of the FBG, to fit virtually any dispersion and dispersion slope characteristic is one of many advantages of FBG technology.

A comparison between a typical DCF and FBG compensation of NZ-DSF is illustrated in Figure 8.

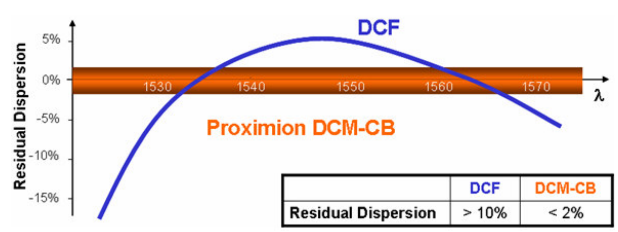

Figure 8 – Typical residual dispersion for DCF-DCM versus FBG-DCM for a NZ-DS Fiber

Proximion standard products are designed to fit the most commonly deployed standard G.652 or G.655 fibers, i.e. SMF-28 and LEAF, Figure 5.

For traditional optical transport the majority of the dispersion compensation used is negative but some special applications rely on positive dispersion compensation as well. In the FBG case, positive dispersion can easily be produced, since it basically just involves the reversal of the grating chirp.

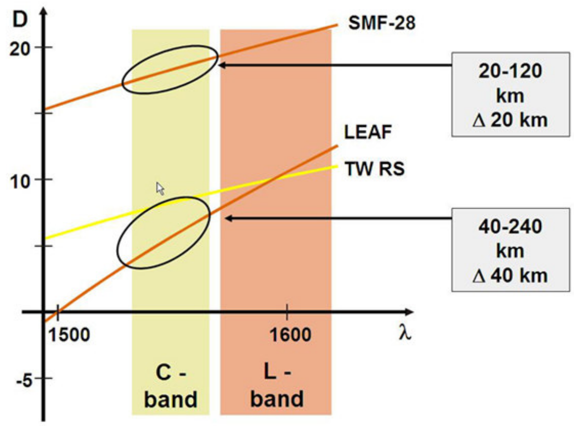

Figure 9 – Standard DCM-CB fiber types and typical span length granularity

Form Factor

The form factor of terminal equipment is also an important property to take into account when designing optical transport networks. This becomes even more important in the Metro and Access networks where space is a precious factor. Using bundles of DCF, typical in the excess of 10 kilometers each, can not be considered to be an effective use of terminal space. The extremely short fiber used in FBG designs enable an immense space saving hence resulting in substantial OPEX and CAPEX related savings.

FBG Technology and Manufacturing

A fiber Bragg grating can, in its simplest context, be seen as an optical filter where a part of the incident light is either being transmitted or reflected. Since the grating is written in the actual core of the fiber it interacts with the light being transmitted.

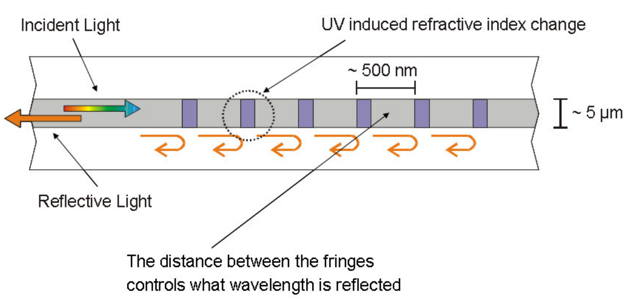

Figure 10 – A view of the ultraviolet fringe pattern induced in the core of the fiber. The distance between the fringes controls what wavelength is reflected, e.g. 500 nm would typically reflect wavelengths close to 1500 nm.

A grating is generated by exposing the core, typically no more than 5 µm in diameter (i.e. a tenth of the diameter of a normal human body-hair) of a specially prepared optical fiber to a fringe pattern of ultraviolet light. The ultraviolet light will locally induce a change in the refractive index of the core. A change in refractive index, even a small change, will be seen as a tiny mirror by the light trying to pass through the grating, and a small portion will be reflected.

By generating many of these local mirrors in sequence at well defined distances, an optically resonant cavity is produced. By tuning the distance and amplitude between the mirror elements, the filter characteristics (e.g. the wavelengths and amount of reflected light) can also be tuned.

Proximion's versatile and proprietary grating writing technology utilizes a two-beam interferometer, as shown in Figure 12, to create a fringe pattern of ultraviolet light used for inducing the change of refractive index to the core of the fiber. A highly accurate motion controller can sequentially add up these fringe patterns with nanometer precision over long distances.

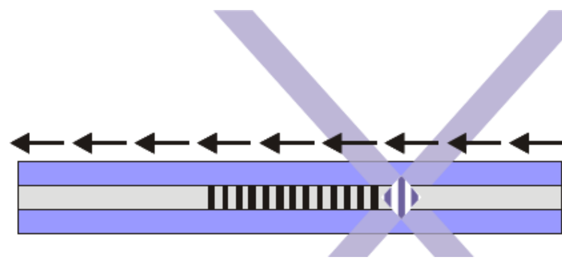

Figure 11 - Two ultraviolet laser beams interfere, resulting in a fringe pattern. By accurately controlling the motion of the fiber many successive fringe patterns can be added into very long gratings

By actively controlling the period of the fringe pattern basically any type of FBG can be generated. Grating characteristics such as wavelength range, reflection and dispersion compensation characteristics are easily controlled via the exposure SW.

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Doc no: 101006-F

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