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WDM hybrid transmission based on CWDM plus DWDM

A hybrid WDM technique based on coarse and dense multiplexing methods combines the major advantages of each regime into one system: low per-channel entry cost for a small CWDM node but with the full channel scalability of a DWDM node.

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CWDM systems are usually considered to be a low-cost alternative to widely used DWDM systems. CWDM technology takes advantage of low-cost uncooled distributed-feedback lasers and economical passive filters. This approach also enables the use of cheaper small-form-factor transceivers. Due to the coarse channel spacing, however, these systems offer a limited number of usable wavelengths leading to a limitation of system capacity.

According to the recent ITU Recommendation G.694.2, "Spectral grids for WDM applications," up to 18 CWDM wavelengths with 20-nm spacing can be used. Eight of these wavelengths lie in a spectral range where the attenuation of typical standard singlemode optical fibre (SSF) is unacceptably high for many applications. As a consequence, CWDM as based on G.694.2 has a generic limit of eight wavelengths over SSF (the channels at 1470, 1490, 1510, 1530, 1550, 1570, 1590, and 1610 nm). So far, whenever a customer's WDM network required higher channel counts, a switch to DWDM technology has been mandatory. The DWDM wavelength grid offers considerably higher numbers of channels (typically 32, 64, 128) at a channel spacing of 200, 100, or even 50 GHz but at significantly higher cost per channel. Customers must evaluate their future traffic evolution to determine whether they prefer to install either a CWDM system with low entry cost and low scalability or a DWDM system with high entry cost and high scalability.

In the following considerations the term DWDM is used for a system with 100-GHz channel spacing. The difference in cost between CWDM and DWDM systems is typically in the range of 20-40%.

Figure 1 shows the above-mentioned widely used CWDM wavelengths with the channel spacing of 20-nm. The additional blue-shifted channels at lower

CWDM vs. DWDM grids

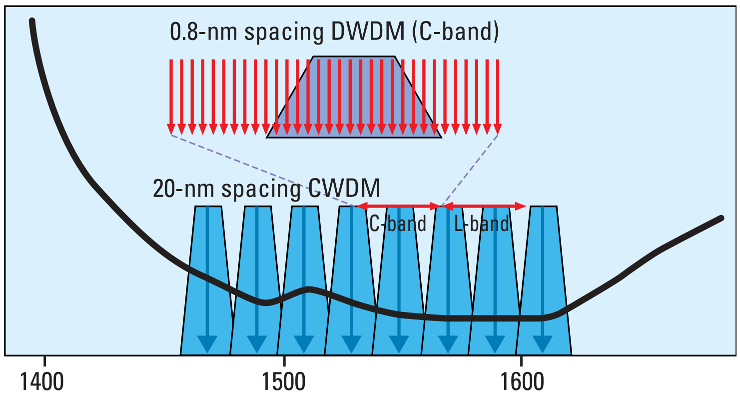

Figure 1. Comparison between CWDM and DWDM wavelength grids. The bold line is the relative optical attenuation of standard singlemode fibre.

wavelengths and additional red-shifted channels at larger wavelengths would underlie significantly increased optical attenuation when being transmitted through SFF. Therefore, the CWDM grid offers a maximum of eight wavelength channels at reasonable transmission performance. In comparison, the DWDM C-band and L-band, while covering an even smaller spectral range, use a smaller spacing between channels. The indicated spacing of about 0.8 nm for two adjacent DWDM channels corresponds to a so-called 100-GHz DWDM grid and covers a total of at least 64 channels—32 channels in the so-called C-band plus 32 channels in the so called L-band (some systems use even more L-band wavelengths).

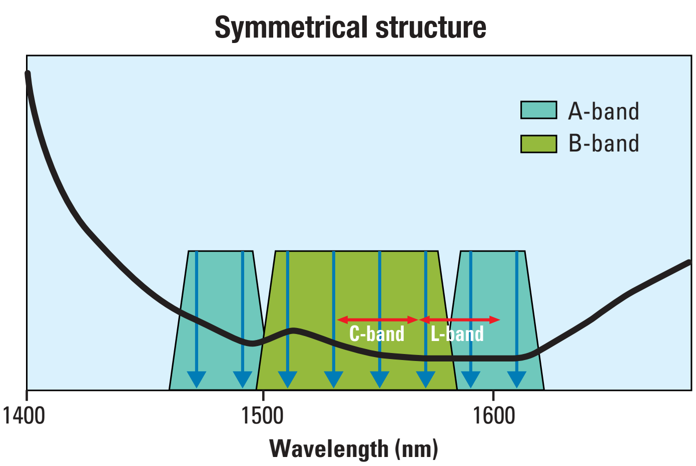

Figure 2. Symmetrical banding structure for a CWDM/DWDM hybrid system. The bold line is the relative optical attenuation of standard singlemode fibre.

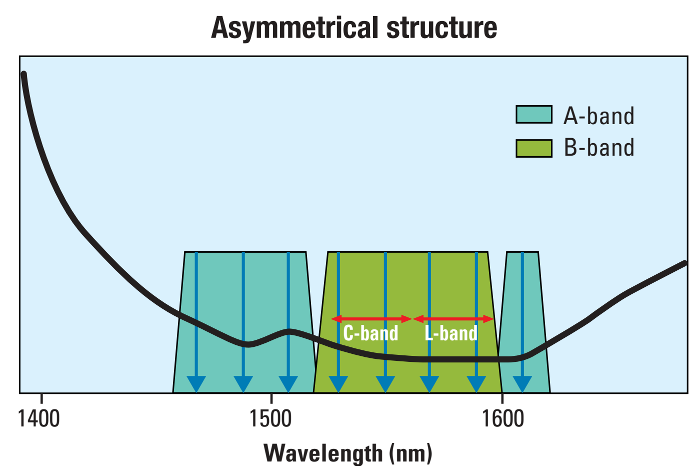

Figure 3. Asymmetrical banding structure for a CWDM/DWDM hybrid system. The bold line is the relative optical attenuation of standard singlemode fibre.

DWDM upgrades of single-stage CWDM systems

Several WDM equipment manufacturers offer a migration between CWDM and DWDM in such a way that when the capacity of the fully loaded single-stage CWDM system needs to be extended, individual CWDM channel ports can be extended by DWDM filters. As indicated in Figure 1, up to eight 100-GHz-spaced DWDM channels fit into a single CWDM channel envelope. Therefore, a single CWDM channel in principle could be exchanged by up to eight DWDM channels. The main drawbacks of this method are that on the one hand side not all the CWDM channels have spectral overlap with corresponding DWDM channels and that on the other hand side about 50% of the DWDM channels cannot be used because they overlap with the guardbands and/or edges of the CWDM filter structure (red arrows). An existing eight-channel CWDM system as indicated in Figure 1 could be subjected to DWDM upgrade steps as shown in Table 1.

The numbers in Table 1 are derived from a simple calculation of spectral overlaps, assuming the appropriate choice of specification for the individual active and passive components. The maximum achievable channel number in this scheme is 32. Note that each upgrade step within such a single-stage CWDM filter structure would cause service interruptions in the transmission system since individual CWDM active components would need to be exchanged during the upgrade for DWDM wavelengths. (Alternatively, there is a CWDM transmission architecture that uses a two-stage filter approach. This approach allows users to upgrade to DWDM wavelengths in service while achieving considerably higher channel scalabilities as compared to the single-stage approach.)

L-banded architectures in CWDM systems

Double-stage-filter architectures based on wavelength bands are commonly used in DWDM systems. The main technical reason for this approach is to achieve high optical isolation between groups of wavelength channels, the so-called channel bands. Isolation is necessary to support bit-error-free transmission of signals in multinode networks that show significant differences in their optical power levels. A further advantage in offering filter modules per wavelength band is an improved system modularity, which lowers capital investments and simplifies wavelength upgrades.

Figure 2 shows the application of this band concept to a CWDM system. In this example, the eight channels are separated into two bands, A and B, each of them covering four CWDM wavelengths (A-band: 1470, 1490, 1590, and 1610 nm; B-band: 1510, 1530, 1550, 1570 nm). The B-band is symmetrically surrounded by the A-band wavelengths. In an actual implementation, the separation into A- and B-band could be realised by a simple passband filter. The specification for the edges of that passband filter would be according to a standard CWDM channel filter. The most important characteristic of the banding scheme

Table 1. Upgrade steps for single-stage CWDM system

	CWDM channels	DWDM channels	Total channels	In-service upgradable
Step 0	1-8	0	1-8	No
Step 1	7	1-8	8-15	No
Step 2	6	9-16	15-22	No
Step 3	5	16-24	21-29	No
Step 4	4	24-28	28-32	No

Table 2. Upgrade steps for L-banded double-stage CWDM system

	CWDM channels	DWDM channels	Total channels	In-service upgradable
Step (a) (Figure 4a)	1-2	0	1-2	No
Step (b) (Figure 4b)	3-4	0	3-4	Yes
Step (c) (Figure 4c)	5-8	0	5-8	No
Step (d) (Figure 4d)	4	1-32	5-36	Yes
Step (e) (Figure 4e)	4	1-64	5-68	Yes

as shown in Figure 2 is that the B-band completely covers the DWDM C-band (red arrows). Therefore, a parallel operation of CWDM A-band and DWDM C-band is possible. In addition, the B-band reuses a set of four CWDM wavelengths that has been widely used in optical networking for many years. It can be said that this symmetrical banding scheme in general supports commercially available passive optical components while allowing for parallel operation of CWDM and standard DWDM C-band.

A similar scheme based on an asymmetrical band structure is shown in Figure 3. The wavelength assignment in this second scheme is A-band: 1470, 1490, 1510, and 1610 nm; B-band: 1530, 1550, 1570, 1590 nm. Due to the full overlap of the B-band with DWDM C- and L-bands, the asymmetric band scheme supports parallel operation of CWDM plus DWDM C- and L-bands, yielding significantly higher system scalability. Whereas the first scheme is based on standard components, the second scheme would be based on customised passive components for band-filter and channel-filter modules.

CWDM/DWDM modular configurations

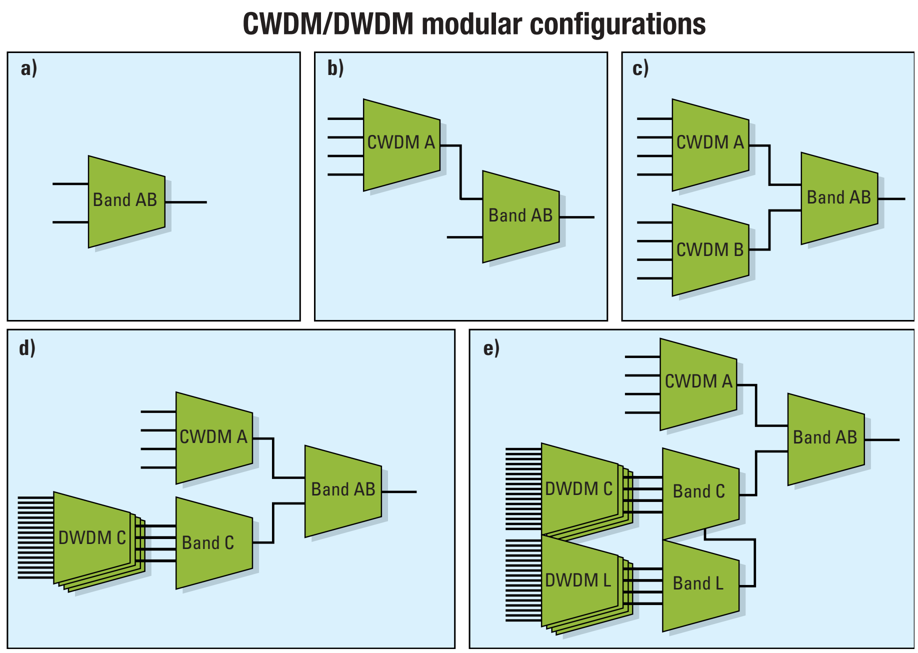

Figure 4. Modular configurations of CWDM/DWDM hybrid systems (single lines stand for optical-fibre pairs): (a) two-channel CWDM, (b) four-channel CWDM, (c) fully loaded eight-channel CWDM, (d) CWDM plus DWDM C-band, and (e) CWDM plus DWDM C- and L-band.

DWDM upgrades of double-stage CWDM systems

The introduction of a second filter stage in the CWDM system significantly enhances the overall configuration flexibility. Figure 4 shows possible system-upgrade steps for WDM terminals. The pure CWDM configurations refer to Figure 4a, 4b, and 4c. In Figure 4a, the CWDM band filter itself operates as a standalone filter, which resembles a two-channel WDM system with the two wavelengths matching any of the above-mentioned numbers for the A- and B-band, respectively. Since this basic configuration is a single-stage architecture, subsequent migration steps would require a service interruption due to the insertion of second-stage filter modules.

Nevertheless, because of the use of the TDM function in most types of modern WDM channel modules, even a simple two-channel WDM terminal may support 4, 8, 16, or more applications depending on the TDM port density of the system. Figure 4b and 4c shows the straightforward CWDM upgrade in two steps of four channels each. This four-channel granularity of the channel-filter modules in comparison to eight-channel modules reduces up-front investments during the upgrade steps. Figure 4d and 4e shows CWDM/DWDM hybrid systems where ports A and B of the passband filter connect to the CWDM and DWDM part of the system, respectively. Typically, the DWDM part itself consists of DWDM band filter plus DWDM channel filter (i.e., another two filter stages). Whereas the configuration in Figure 4e requires the asymmetrical passband-filter characteristic, the structure in Figure 4d could use either asymmetrical or symmetrical banding.

According to Figure 4, there are two main system upgrade paths possible: Upgrades within a pure CWDM system following configurations (a), (b), and (c) and upgrades to a CWDM/DWDM hybrid system following (a), (b), (d), and, as a further extension option, (e).

Table 2 summarises the corresponding channel scalabilities for the various configurations—steps (a), (b), (d), and (e) offer a migration path up to the maximum hybrid system capacity of 68 wavelength channels. To achieve upgrades without any connection disruptions (service interruptions), single-stage operation, according to step (a), should be avoided. An upgrade from step (c) to (d) and (e) would require an exchange of B-band CWDM channels. Therefore, (a) and (c) do not allow for further in-service upgrades.

Double-stage advantages

The presented double-stage filter concept for CWDM systems offers two main advantages compared to standard single-stage systems:

- Improved filter granularity that lowers up-front investments during upgrade steps due to dedicated low-cost configurations for two-, four- and eight-channel CWDM systems.
- In-service upgrade path to CWDM/DWDM hybrid systems that support the full DWDM channel grid according to the ITU Recommendations for DWDM wavelengths. LWE

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