



Choosing the Best Optical Transmitter Technology for Next-Generation Access Networks



Overview

Cable operators continuously face the challenge of meeting ever-increasing access network capacity requirements for new high definition (HD) channels, on-demand services and high-speed data. In many cases, to provide this additional capacity will typically require the cable operator to reduce the number of homes per serving area.

Splitting the initial serving area can be accomplished by segmenting existing optical nodes or by adding a new satellite node to an existing node location. The new serving area requires a separate fiber feed. In systems where dark fiber is available, providing the feed to the segmented node may be relatively straightforward.

However, dark fiber is a precious commodity reserved for new revenue streams such as business services customers, and in some cases no dark fiber is even available. Where dark fiber is not physically available, pulling new fiber into an existing serving area remains the single highest expense for any plant capacity expansion project.

To avoid using any dark fibers, 1550 wavelength-division multiplexing (WDM) technology provides a cost-effective means to increase the utilization of the existing headend-to-node video delivery fiber and thereby deliver multiple services to both residential and commercial customers located in the same serving area. However, until recently, 1550 WDM solutions required a compromise in signal performance (composite second order/composite third order (CSO/CTB) distortion, reach (optical link budget) or both.

Improved 1550 WDM optics using electro-absorption technology now make it possible to create simpler, more economical single-fiber solutions for transporting multiple full-spectrum hybrid fiber coax (HFC) streams consisting of broadcast, narrowcast and unicast content for each specific node, without compromising performance.

This paper describes the current C-band access technologies and the techniques employed for creating dense WDM (DWDM) systems, and it describes the performance and cost tradeoffs between the various technologies that are available today.

1. Multi-wavelength Narrowcast Spectrum Solutions for Traditional HFC Networks—The Special Case of DWDM Broadcast / Narrowcast Overlays

The majority of cable access plant fiber links are 40 km or less. But in lower population density areas or systems that have purposely reduced the number of network hub locations, fiber link spans can extend up to 100 km or more.

In these situations as well as in systems that are extremely fiber poor, a 1550 nm broadcast transmitter can be combined with as many as 40 narrowcast quadrature amplitude modulation (QAM)-only 1550 nm narrowcast transmitters (each on a separate C-band ITU wavelength) feeding an optical amplifier, to provide a one fiber/low-fiber count system capable of reaching a large number of distant serving areas. At each service area, the broadcast wavelength and one narrowcast wavelength can be optically fed into a single-node receiver.

This single-receiver implementation reduces the cost and complexity at the node (one optical receiver instead of two receivers) and has contributed to making the DWDM broadcast / narrowcast overlay network design a very cost-effective solution for long-reach applications, but with one significant limitation.

The number of narrowcast channels on each narrowcast transmitter must be limited so that the additive composite intermodulation noise (CIN) impact of the narrowcast channel load is kept relatively low. Until recently, and to achieve acceptable performance, most narrowcast 1550 nm transmitters have been limited to a few (typically 6 - 8) narrowcast QAM channels.

The growth of on-demand, IP video and targeted services is raising narrowcast channel capacity requirements, and this demand will continue to grow dramatically over the next few years. Most experts agree that future networks will need to support a minimum of 64 narrowcast channels and as many as 128 narrowcast channels.

While recent QAM transmitter designs have taken advantage of new, lower-chirp distributed feedback (DFB) lasers to allow higher narrowcast channel loading, as systems increase their narrowcast capacity and move toward unicast, these DWDM systems may not be capable of supporting the total bandwidth demand, especially if they retain any analog video channels. Therefore, as operators plan major increases in narrowcast transmitter channel loading, they still need to consider the cost and performance limitations that narrowcast/broadcast transmitter overlays impose on long-reach networks.

In HFC networks, analog video channels are the most sensitive to noise and distortion impairments, and therefore create a limitation on the number of narrowcast channels that can be supported in a DWDM overlay system.

Maintaining a basic tier of analog video channels has long provided cable operators with an advantage over telco and satellite competitors when subscribers weigh the cost of service to multiple TVs in the home. While operators continue to reclaim a number of analog channels, many intend to preserve this competitive barrier by preserving a smaller (approximately 20 – 40 channel) analog video tier in their program maps.

For truly long reach links, a broadcast / narrowcast overlay architecture is still a fiber efficient and cost-effective solution. Narrowcast loading can be increased significantly over current levels to meet near-term requirements with only a minor impact to operational performance. However, heavily loading the QAM transmitter with a full bandwidth load of channels will have consequences that will impact the end-of-line performance, unless considerable configuration changes to the network are implemented. This technical limitation is explained as follows:

In overlay architectures, noise generated by the erbium-doped fiber amplifier (EDFA) combines with second order composite intermodulation noise (CIN2) generated by the narrowcast QAM transmitter in addition to dispersive CIN resulting from the interaction of the laser chirp and the fiber chromatic dispersion. As the number of narrowcast channels increases comparatively to the number of broadcast channels, the optical modulation index (OMI) level of each QAM channel is reduced and the broadcast

channel to narrowcast channel optical power ratio must be reduced proportionally to maintain the appropriate RF derate at the node receiver.

This degrades the composite carrier-to-noise ratios of both the broadcast and narrowcast channels, thus diminishing the assumed improvement of going to a more digital network. To counter this effect, a second optical receiver and RF filtering for both receivers could be added to every node, which would significantly reduce the composite carrier-to-noise impairments to the broadcast channels. However this raises the cost and complexity at every optical node.

2. Multi-wavelength, Full-spectrum Solutions for Traditional HFC Networks

As discussed in the previous section, combining narrowcast and broadcast optical signals in a single receiver creates a number of technical challenges. It also creates additional wiring complexity in the headend or hub. Full-spectrum transmission is more desirable if it is cost effective and provides acceptable performance.

Today in most HFC access networks, to optically transmit the full spectrum of analog plus QAM channels to the node, a single 1310 transmitter is employed. To save dark fiber, a more ideal solution would be a family of full-spectrum DWDM transmitters. In the last few years, O-Band (1291 – 1371 nm) multi-wavelength CWDM solutions such as Motorola's GX2-LC1000 ECWDM system have been successfully deployed, but the higher fiber losses and lack of optical amplification possibilities in the 1310 nm range limit the usable reach for a four wavelength CWDM system to typically 25 km.

More recently, considerable development has taken place to create C-Band (1530 – 1560 nm) downstream transmitters capable of analog video performance at a cost comparable to a 1310 nm system. However, there are a number of obstacles inherent in transporting 1550 nm analog signals over highly dispersive single-mode fiber. Therefore, a number of different technology solutions have been introduced into the market. However, some of these are not without significant compromises, which are explained below.

Directly Modulated QAM Transmitters

Full-spectrum capable 1550 nm QAM transmitters such as Motorola's GX2-DM1000 employ directly modulated DFB lasers. DFB lasers targeted for cable TV applications have very good linearity characteristics. Due to the impacts of DFB laser chirp, DFB lasers are limited in the distance that they can carry a large number of video carriers (versus power limited). Thus, they are primarily limited to digital (QAM) carriers. The explanation of this is as follows:

Laser chirp is an instantaneous change in wavelength of the laser as it is directly modulated. Chirp is very analogous to frequency modulation. (A common method used to quantify laser chirp is a measurement of the FM efficiency as the laser is modulated.) Laser chirp can interact with fiber dispersion to generate second order distortion products that impact the performance of the link. In the same manner, chirp can interact with the optical gain tilt or ripple within the passband of a passive filter such as a mux or demux to produce second order distortion.

Most recently, manufacturers are improving the performance of this class of optical transmitter by including RF pre-distortion correction circuits. Using electronic dispersion compensation can reduce but not eliminate some of the degradation effects of transmitter chirp in the fiber.

A single QAM transmitter on a dedicated fiber (no DWDM) is capable of transporting RF-modulated signals to a reach of approximately 100 km depending on the laser chirp characteristics and the effectiveness of the internal dispersion compensation circuitry.

However, when multiple transmitters are combined in a multi-wavelength system launched into a single fiber, the resulting fiber induced crosstalk will significantly reduce the maximum reach depending on the channel loading, wavelength spacing and optical launch power. In a four-wavelength system (200 GHz spacing) with full-spectrum QAM-only loading to 1 GHz, the typical link reach will be limited to roughly 50 or 60 km.

LiNbO3 Mach Zender Externally Modulated Transmitters

Combining a continuous wavelength (CW) DFB laser with an external LiNbO3 Mach Zender (MZ) or phase modulator dramatically reduces the level of transmitter chirp. External modulator (ExMod) transmitters such as the GX2-EM1000 have been available for many years and are primarily used as broadcast transmitters in long-link or fiber-starved broadcast / narrowcast overlay HFC applications.

ExMods are also the primary transmitter technology for RF-over-glass (RfOG) and passive optical network (PON) RF overlay architectures.

ExMod technology transmitter designs are much more complex than a directly modulated laser because they require both a CW laser and an external modulator. Also, depending on its performance specifications, the MZ modulator can be a relatively high-price component, which in combination with the CW laser makes this transmitter design more costly than traditional directly modulated transmitters.

To reduce the cost of ExMod-based transmitter designs, some vendors have reduced the performance specification for the external modulator. This presents challenges to the operator in meeting system end-of-line performance. These vendors have compensated by reducing the long-reach capability of the transmitter but maintaining the same analog-plus-QAM performance for a typical-reach HFC multi-wavelength system, thus limiting the effective reach of their solutions.

Other vendors have developed transmitter designs that optically combine the output of several lasers into a single modulator. A significant drawback to this approach is the difficulty of making sure that every laser is matched to each other and all are aligned to the modulator operating point in order to achieve acceptable performance.

Multiple lasers also translate to a lower mean time between failure (MTBF) ratio and uncertainty regarding the long-term stability of four independent laser sources. From a network standpoint, a significant concern is the issue of a single point of failure. In a single box employing multi-wavelength transmitters, any failure will require the replacement of the entire box, taking down multiple serving area links.

Electro-Absorption Transmitters

Recently, a cost effective C-Band multi-wavelength solution that overcomes the limitations of other C-Band solutions has been achieved by employing electro absorption (EA) technology. This solution is based on highly proven integrated laser/EA modulator designs already extensively deployed in 10 GB digital metro enterprise links.

Until recently, EA-based modulators were quite expensive. However with the widespread adoption of 10 GB in the metro, the cost of these optics has become quite reasonable. The only challenge that remained was to create a laser EA modulator design optimized for HFC network applications.

The EA laser is an integrated package consisting of an integrated DFB laser die combined with an EA modulator chip on a common substrate. Compared to a DFB laser, an EA modulated laser exhibits near zero chirp. Compared to a LiNbO3 Mach Zender external modulator, an EA modulator has far less optical loss and therefore requires a lower-power laser for the same optical output. Therefore, a transmitter based on an EA design eliminates much of the complex correction circuitry that these other technologies require.

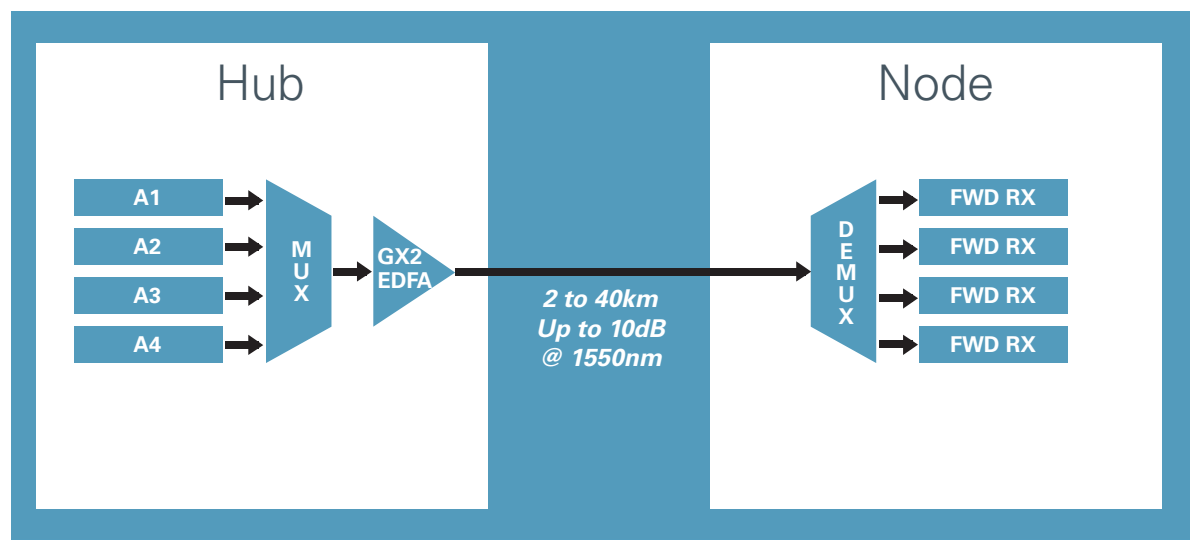
Motorola has performed significant research to create an EA-based laser package optimized for HFC network applications. As a result of this

effort, Motorola has developed the GX2-EA1000 electro-absorption transmitter, whose design and application is very similar to a directly modulated laser transmitter.

The GX2-EA1000 is a 1 GHz full spectrum, analog plus QAM, multi-wavelength transmitter covering the entire ITU standard DWDM wavelength grid. Its low-chirp performance minimizes fiber-induced distortion and allows the use of a wide range of optical passives. The EA1000 can replace existing QAM-only transmitters, providing increased full-band loading capability while reducing chirp-induced performance degradation. As a result, it provides a simple, more cost-effective and flexible solution for meeting the future bandwidth requirements of cable operators.

The GX2-EA1000 allows the operator to employ a multi-wavelength DWDM 1550 nm solution that addresses and eliminates restrictions on narrowcast channels, distance limitations based on chirp and the complexities of multi-transmitter solutions. The design of the GX2-EA1000 allows it to fit in a single wide-module housing compatible with the Motorola GX2 platform.

The EA1000 design also offers a low-cost, high launch power transmitter solution for RFoG and PON RF overlay deployments.



Summary

Next-generation access networks will require fiber deeper architectures providing increased downstream and upstream capacity per subscriber serving area. The cost of pulling new fiber into an existing brown field system is a major hurdle in preparing these legacy networks for future bandwidth services. The following table summarizes the pluses and minuses of each technology.

Based on new advances in electro-absorption transmitter technology, the improvements in multi-wavelength C-Band laser transmitter design cost and analog linearity now make it possible to design a fiber deep serving area at a lower cost while receiving higher performance and greater reliability—and avoiding the expense of pulling new fiber from the headend or hub.

The DWDM wavelength capability of these transmitters allows operators to segment legacy networks while combining HFC with commercial services customers on the same plant fiber.

The Motorola GX2-EA1000 multi-wavelength transmitter is designed to facilitate the next-generation multi services network by providing a low-cost, scalable solution for cable operators as they push fiber deeper into their networks.

For more information about choosing the best optical transmitter technology for next-generation access networks, visit www.motorola.com or contact your Motorola Account Representative.

C-Band Technology				
	Broadcast - Narrowcast Overlay	DFB Laser w/ Correction Circuitry	Low Cost LiNbO3 ExMod	Electro - Absorption Modulator
Distance Limited By Laser Chirp	NOT LIMITED	LIMITED	NOT LIMITED	NOT LIMITED
Requires Complex Non-Linearity Correction	OPTICAL/RF FEEDBACK	PREDISTORTION	OPTICAL/RF FEEDBACK	PREDISTORTION
Relative Cost of Solution	HIGH COST	LOW COST	MODERATE	LOW COST
Relative Performance	EXCELLENT	MODERATE	MODERATE	EXCELLENT



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