# Bringing Together Headend Consolidation and High-Speed Data Traffic in HFC Architecture Design

Dr. Timothy Brophy, Dr. Robert Howald, Curt Smith
General Instrument Corporation
Transmission Network Systems

*The move toward headend consolidation, coupled with the evolution of the traditional CATV HFC network into a two-way interactive data communications platform, has led to an investigation of optimal architectures. The goals of such architectures are clear. They must meet current needs of multiplexed analog and digital systems and provide a straightforward and cost-effective migration. As a utopian objective, it should provide the ability to handle the maximum capacity anticipated, as two-way interactive services continue to expand in the longer term.*

*This latter aim, commonly referred to as "future-proofing," is much more difficult to pin down. The highly variable nature of potential service offerings, and the inability to predict the likelihood of their acceptance makes achieving this goal challenging. However, it is commonly accepted that increased use of optics and the efficient use of the RF bandwidth are the enabling network technologies to assure these goals are met. In this paper, we will discuss today's freshest technologies, DWDM and frequency stacking.*

*As a result of the need for more bandwidth in both upstream and downstream paths, optical and RF technologies have advanced. Today, DWDM systems are being deployed to provide segmentation and increased bandwidth. Additionally multiplexing in the RF domain is also being used in the upstream passband to increase bandwidth efficiency. From a network planning perspective, both DWDM and frequency stacking are excellent tools for "future-proofing" a network. The focus of this paper will be the combination of these technologies. Questions to be answered are:*

*Will it work?*
*How does it help my network?*
*How does it compare with other options?*

## INTRODUCTION

In a typical CATV plant today, downstream content occupies the 50-870 MHz frequency partition of the network. Return path, or upstream, signals are relegated to the 5-42 MHz frequencies. Given the asymmetrical nature of the frequency bands used it is very likely that the upstream traffic will be the first to be constrained. In this paper we will address the combining of two technologies to provide increased capacity in the upstream network. Both technologies involve multiplexing, optical multiplexing using dense wave division multiplexing (DWDM) and RF multiplexing using frequency stacking. As we will see, the combination of these technologies can increase the efficiency of the return path. But first, let's start with an introduction to DWDM and frequency stacking and their uses.

## DWDM 101

CATV systems have evolved from their earliest days of delivering standard off-air channels to remote areas plagued with poor reception. In those early systems, a single headend with a large master antenna received the channels for distribution over coaxial cables and through many RF amplifiers to customers. In the late 1980s and through the 1990s, fiber optic transmission became a reality for the MSO (multi–system operators) of cable television. In a typical system, the optical fiber replaced the trunk section of the RF transmission plant and improved signal quality by virtue of avoiding the degradation of the multiple amplifier cascade. Since the system was almost exclusively designed for one-way transmission (from signal source—the CATV headend—to home), the architecture evolved into the fiber-fed, tree and branch network dominant today. [1]

Return path implementations, which were often installed due to franchise requirements, were lightly loaded and used primarily for communications with set top converters. With the advent of cable modems and the promise of IP telephony over cable, a robust return path will be required. This will be driven by higher use rates as the network evolves into much more symmetric architectures. The implication is not only for the build out of the return path, but also the ability to segment the forward signal to address individual subscribers. Further, total network traffic is kept to manageable levels by logically segmenting the signals to address individual users at the headend. The driving motivation behind the use of DWDM in CATV is the increase in bi-directional capacity without the use of additional fiber. [2] This includes delivery of independent signals to various end users, and the cost-effective collection of return signals from those users. These independent signals, or targeted services, include internet data streams, telephony, requests for and delivery of video-on-demand, near-video-on-demand, and analog channels reserved by franchise requirements for public, education, and government use.

In the CATV world today, DWDM systems are used exclusively in the 1550 nm optical window. As in the telephony world, the erbium doped fiber amplifiers (EDFA) are the enabling technology that makes this wavelength window attractive. The wavelengths that comprise the ITU grid [3] are actually a set of predefined frequencies currently spaced at 100 GHz, from which wavelengths can be derived. The wavelength spacing is approximately 0.8 nm, and the range of wavelengths covers the EDFA band, from about 1530 to 1570 nm. Not all the wavelengths need to be used in any given system and commercial products are available at 100, 200, and 400 GHz spacings, with a variety of individual product offerings. In the system to be discussed later, the spacing chosen is 200 GHz, and it is this closeness of wavelengths that make the system "dense." This is to distinguish them from some existing CATV systems, which use a combination of 1310 nm and 1550 nm wavelengths in a WDM arrangement. As described earlier, the signals traditionally sent to subscribers were analog channels, to ensure compatibility with television tuners. In CATV jargon, the signals sent over DWDM transmitters are digital. They are actually QAM signals, where a digital bit stream is encoded onto an analog subcarrier. Frequently in the literature, the terms QAM, digital, targeted services, or DWDM signals are used interchangeably.

## DWDM Components

*Transmitters*

The laser sources for DWDM systems are housed in a headend transmitter, which provides the bias, temperature, and monitoring controls as well as the means of modulating the sources with the RF content. That RF content is either the analog broadcast television signals or the targeted services QAM signal. The modulation techniques are either external (using the modified balanced-bridge Mach-Zehnder interferometer) or direct (using the driving current control of the laser directly).

Directly modulated transmitters have the advantages of low cost and simplicity of design. Their operating wavelength (as for the sources in external modulators) is well controlled by their bias current and operational temperature through standard feedback loops. It is also possible to purchase highly linear sources that need no predistortion to yield the system performance required. Launch powers are available up to about 12 dBm. The most significant disadvantage is the chirping of the laser due to the modulating current.

Chirping (FM efficiency) converts amplitude changes into frequency changes, which broadens the linewidth in a time varying fashion. The chirp, when combined with fiber dispersion, can lead to degradation in even order distortions measured at the receiver. Recall that standard single mode fiber has comparatively large dispersion of ~17 ps/nm/km in the 1550 window. This second order distortion effect (a form of a multi-channel system non-linearity called composite second order, or CSO) is worse at high subcarrier frequencies. This limits the maximum operational frequency of the transmitter. Further, the time-varying line broadening is also detrimental due to interaction with the passive components. When the broadened line encounters a non-flat area in the multiplexer or demultiplexer, the instantaneous amplitude change is itself a source of non-linear distortion. Finally, if the linearity performance of the transmitter is limited, intermodulation distortions will occur, falling at the sum and difference frequencies of the RF content. If the loading on the transmitter is wider than 50 MHz, these IM distortions will fall into the band of the downstream analog channels.

With external modulators, the advantages are attributable to the unmodified characteristic of the laser source. The narrow linewidth is desirable so that interaction with the width or shape of the passband in the multiplexer or demultiplexer is minimized. Too narrow a linewidth can lead to fiber non-linearities, which are discussed below. Given this, a means to broaden the linewidth is required. Another desirable property is the low chirp of the source. Since the total line broadening of the link is length dependent, the low chirp characteristic leads to longer fiber links being attainable before being limited by second order distortions. On the down side, externally modulated transmitters are generally more expensive than their directly modulated counterparts, and will always need some correction to improve their intrinsically poor linearity, which results from the sinusoidal transfer function of the modulator.

*Receivers*

Receivers for use in DWDM systems are not distinguished from their existing analog components. Typical receivers use an InGaAs photodetector that is transformer coupled to an RF preamplifier. The photodetector has adequate energy gap so that both 1310 and 1550 nm are received for conversion into current.

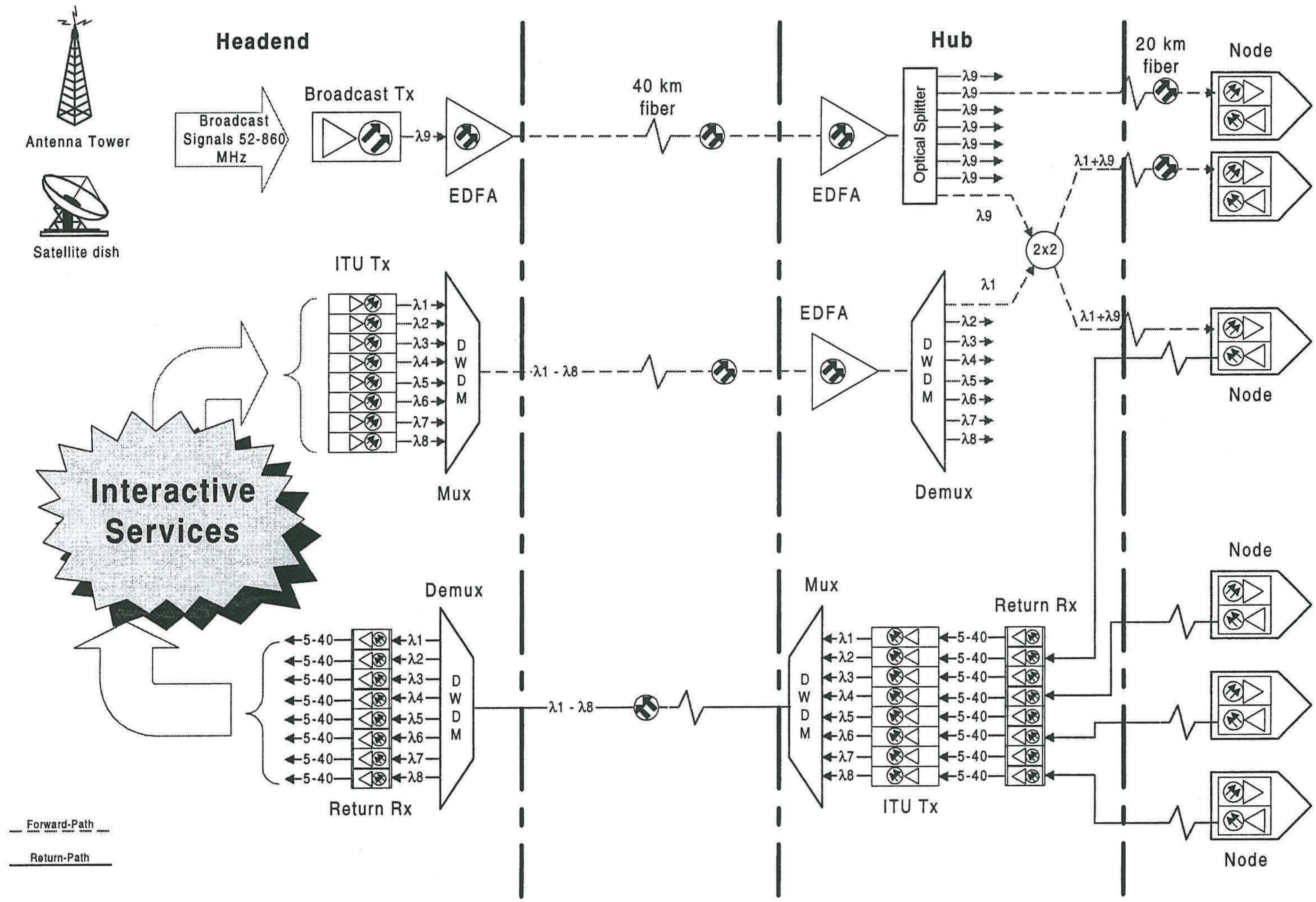


**Figure 1: Generic DWDM network**

*Passives*

Passive components in the DWDM system include optical attenuators to assure uniform power at the individual nodes and proper relative level of the targeted services delivery (TSD) wavelengths compared to the analog. In addition, there are fused fiber couplers used to combine the analog with the TSD wavelengths at the OTN location for subsequent distribution to the node. Most importantly, however are the multiplexer and demultiplexer components. These are used to combine the various ITU grid wavelengths through a low loss coupler and carry them on a single fiber and subsequently separate those wavelengths to place them onto individual fibers. There are four competing technologies that are available to create these components. They are fused biconic taper (FBT) couplers [4], fiber Bragg grating (FBG) couplers, (both of which are configured as fiber Mach-Zehnder interferometers), silicon array waveguide grating (AWG) couplers [5], and thin film interference filters (TFF).

Each of these technologies has some advantages and disadvantages relative to the others, and it is not always possible to determine which characteristics are most critical without also considering the system level interactions. Essentially, comparative evaluation comes down to cost, potential for high volume manufacture, degree of operational temperature stability (is active thermal control required?) and operational performance parameters, such as passband flatness and width, and adjacent channel isolation capability.

## DWDM Applications

*Downstream (Forward Path) Narrowcast Overlay With Optical Insertion*

A schematic of a generic architecture for a DWDM overlay of a standard CATV distribution system is shown in figure 1. The analog transmitter is an externally modulated source, comprising a 1550 nm DFB laser coupled to a Mach-Zehnder interferometer made in a lithium niobate substrate. The output is optically amplified to a saturated level of about 17 dBm, transmitted through 40 km of standard (non-dispersion shifted) single-mode fiber (SMF) to an Optical Transition Node (OTN) location, amplified again and split into a number of outputs that matches the number of targeted-services wavelengths. After splitting, the analog signal is combined with the QAM wavelengths in an analog/digital coupler and that combination is again split to serve the number of nodes for which the given wavelength is targeted. The nodes are the optical-to-electrical conversion points for transmission of CATV signals. In our generic system, those nodes are 20 km away from the OTN and are connected using standard SMF. Note that there may be multiple nodes targeted per wavelength, especially in the early deployment stages when subscriber take rates are low corresponding to a low bandwidth requirement per node.

The DWDM sources are also externally modulated transmitters in the example system, but directly modulated sources may also be used. Eight wavelengths are shown in the figure and are combined into a single fiber in a multiplexer. The standard SMF is 40 km long, and is distinct from the fiber carrying the analog signal, but may be in the same cable. After the 40 km, at the OTN location, the combined wavelengths are amplified and then demultiplexed into separate fibers. Each targeted services

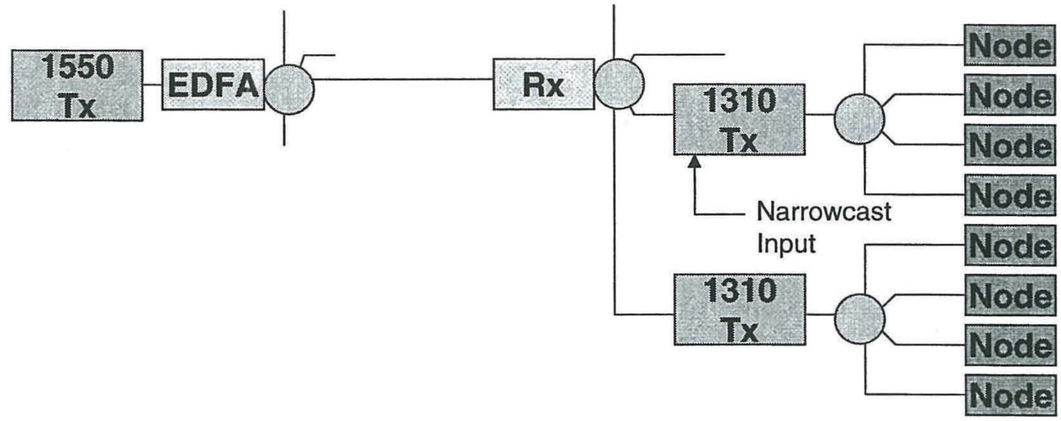


**Figure 2: Dual-hop optical architecture**

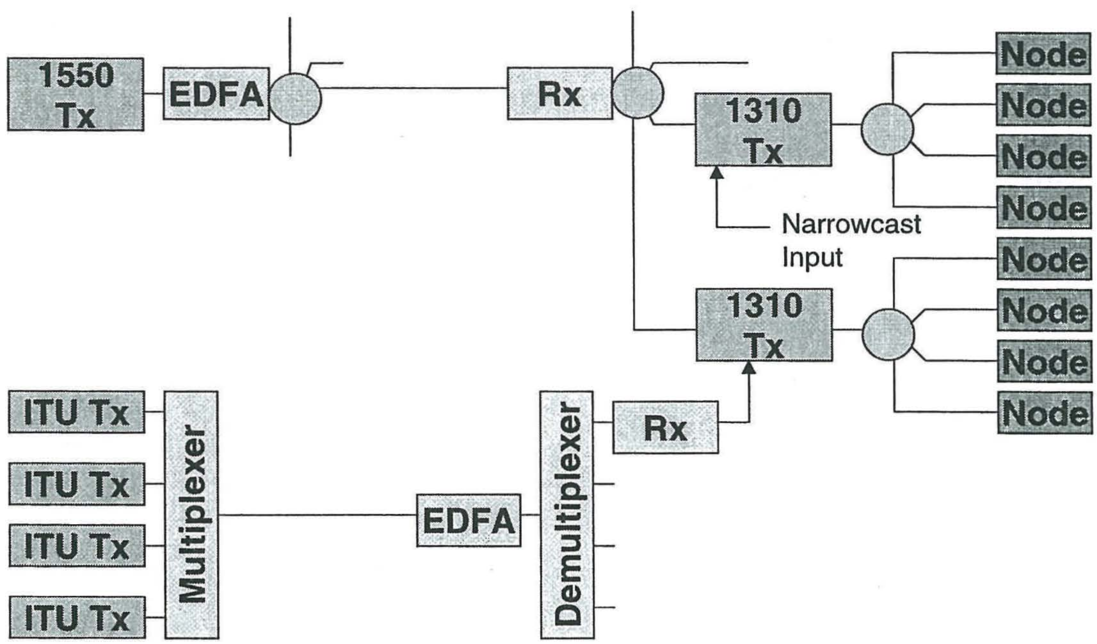


**Figure 3: Narrowcast overlay with RF insertion**

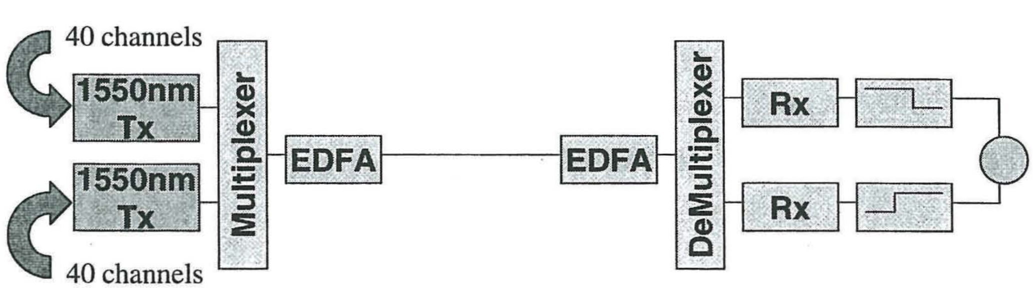


**Figure 4: Split-band application using a single fiber**

wavelength is combined with one of the split analog signal outputs and distributed to nodes through a single fiber carrying both the analog and digital signal. The fiber node contains a receiver that detects both the analog and QAM signals for distribution through the RF plant beyond the node.

*Upstream (Return Path) Transport*

In keeping with the drive towards a more symmetric network, the upstream or return path mirrors that of the downstream. The exception to this mirroring occurs not so much in the single fiber of the DWDM system, but in the portion of the return from the node to OTN. The return path is managed as a two-hop process. In the illustrated system, a temperature compensated 1310 nm laser (typically a DFB) is in the node. The RF signals from homes served by this node (1000-1200 subscribers) are collected and time division multiplexed before driving this laser. That optical output is sent over the 20 km link to the OTN, where it is detected and amplified by a receiver before directly modulating an ITU grid laser. That laser is one of several which combine the entire return path into a DWDM set for transmission over the 40 km back to the headend and for subsequent processing. Each of the DWDM wavelengths may handle the return traffic from multiple nodes using a combination of time, frequency, or code division multiplexing.

*Downstream (Forward Path) Narrowcast Overlay With RF Insertion*

The network solution shown in Figure 1 assumes that the optical network remains in the 1550nm window from the headend to the node. What if the existing system utilizes a re-transmission scheme at the hub/OTN. It is a goal to preserve as much of this infrastructure as possible. Fortunately DWDM can still be used to provide the narrowcast overlay.

For the purpose of discussion, we will assume that the network is configured as shown in Figure 2. This generic network uses 1550 nm technology from the headend to the hub. At the hub, the signals are returned to RF and then routed to 1310 nm lasers for distribution to the nodes. We will also assume that these 1310 nm lasers have a second RF input port for narrowcasting.

To implement the narrowcast overlay the arrangement is very similar to the approach in Figure 1. This arrangement is shown in Figure 3. Signals are placed in the proper RF spectrum and routed to the ITU grid transmitters in the headend. Outputs from the transmitters are multiplexed and transported to the hub. At the hub, the optical multiplex may need to be optically amplified to overcome demultiplexer losses. At this point the approach becomes different. Instead of combining the demultiplexed optical signal with the broadcast, the individual wavelengths are routed to receivers. Outputs of the receivers are then passband filtered, and then routed to the proper 1310 nm transmitter. Combined at RF, both analog and QAM signals drive the laser. At the node a single detector converts these signals to RF for distribution into the plant.

*Downstream (Forward Path) Application to Improve Super-trunk Performance*

In this application DWDM is used to reduce the quantity of optical amplifiers and fiber required while still maintaining the performance improvements associated with a split-band super-trunk configuration. Figure 4 illustrates this application.

In standard split-band super-trunk applications two fibers would be required to

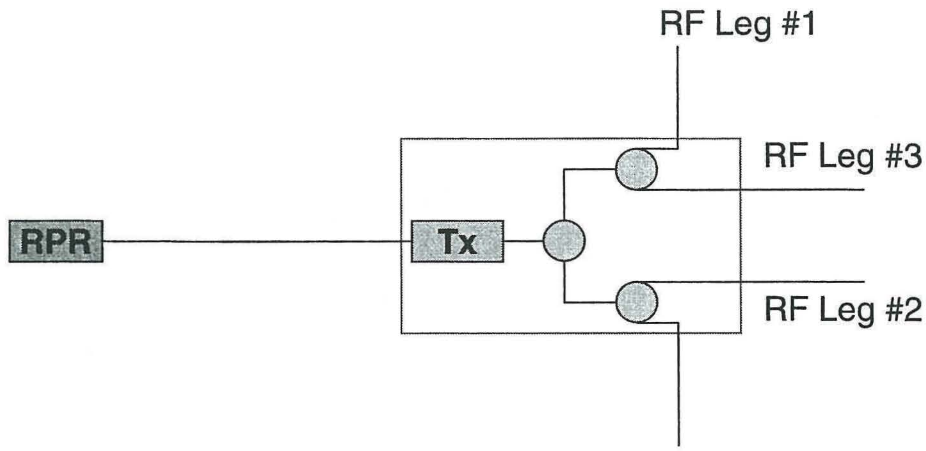


**Figure 5: Typical node configuration**

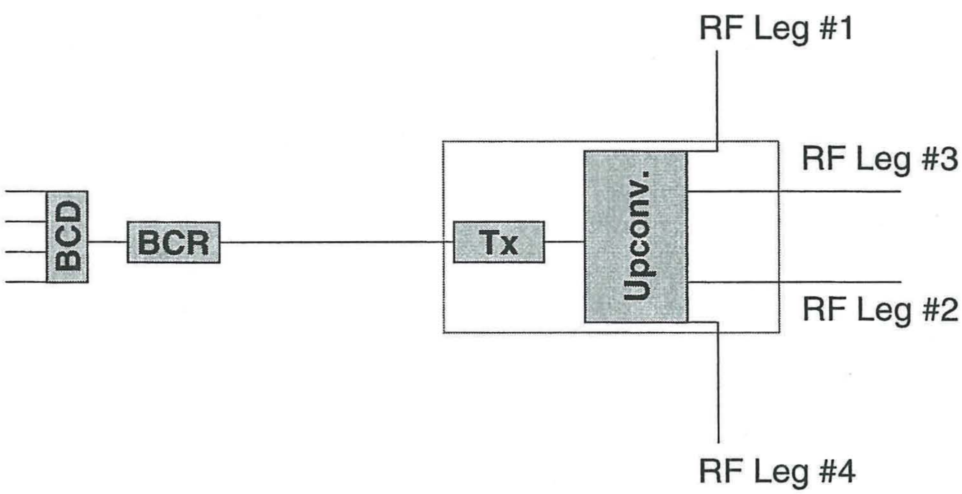


**Figure 6: FSS block diagram**

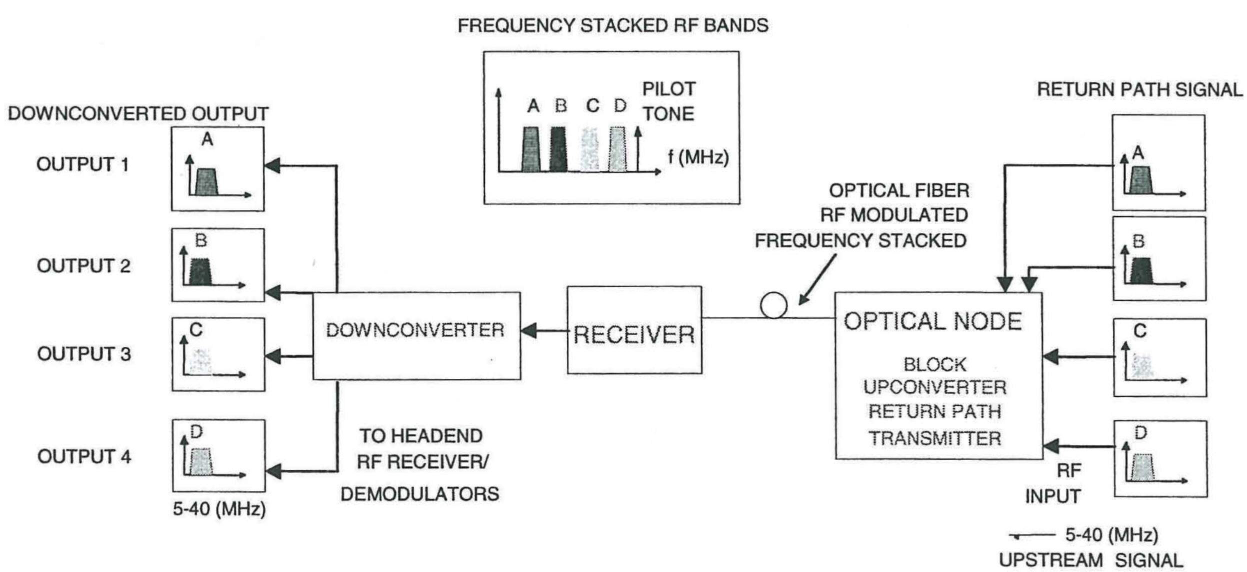


**Figure 7: FSS spectrum allocation**

transport the signal from the headend to the hub. In instances where there are multiple amplification points in the network it would require two identical sets of this equipment. By using DWDM to optically multiplex these signals a significant savings can be achieved. By using only one fiber the quantities of optical amplifiers is reduced to half.

## FREQUENCY STACKING 101

In frequency stacking systems the 5-40 MHz return passband is block upconverted or shifted to another frequency passband. This may be done in a hub environment or, as we will discuss here, in the field located node. The main advantage of the implementation of a frequency stacking system (FSS) is the expansion of the return bandwidth per home passed. This allows for larger node sizes, which in turn reduces the overall system costs.[6]

If we look at "typical" node configuration, shown in Figure 5, all the users served by the node share the return path spectrum. If this were a 1200 home passed node, each home passed would have approximately 29 KHz of guaranteed simultaneous bandwidth. This assumes that the entire 35 MHz is available, and we can dynamically allocate the bandwidth. As Figure 5 illustrates each of the coaxial busses are RF combined into one stream.

Adding more transmitters combined with segmenting the RF paths within the node may increase bandwidth. This approach has disadvantages. Beyond adding one additional return transmitter in the node, which only doubles capacity, fiber availability issues may become the limiting factor. To achieve the same level of bandwidth per home passed as FSS three additional transmitters and fibers would be required.

An FSS approach utilizes upconversion in the node to create four passbands for the return. In this approach each leg now has its own 35 MHz of space. The four passbands are RF stacked and sent to the return laser. Figures 6 and 7 illustrate this arrangement.

### FSS Components

As Figures 6 and 7 illustrate there are four major components associated with a FSS system. These components would be common in function regardless of whether the application is hub or node based. Each of these components is briefly discussed below.

*Upconverter*

Frequency stacking begins with the upconverter. This device, simply put, takes multiple return passbands and shifts them to other independent passbands in the spectrum. The conversion process maintains the information that resides in the original passband. In the implementation shown in Figures 6 and 7, each of the RF legs are upconverted to different passbands within the 50 – 400 MHz passband. A pilot carrier serves two key functions. First, it compensatesfor the range of link loss introduced by the optical network. Second, it is used by the downconverter to phaselock to the upconverter thus eliminating frequency offsets.

*Transmitter*

The transmitter used in this application is not a standard, band-limited, return path transmitter. In his implementation, a forward path transmitter designed to operate in the 50-400 MHz passband is used to

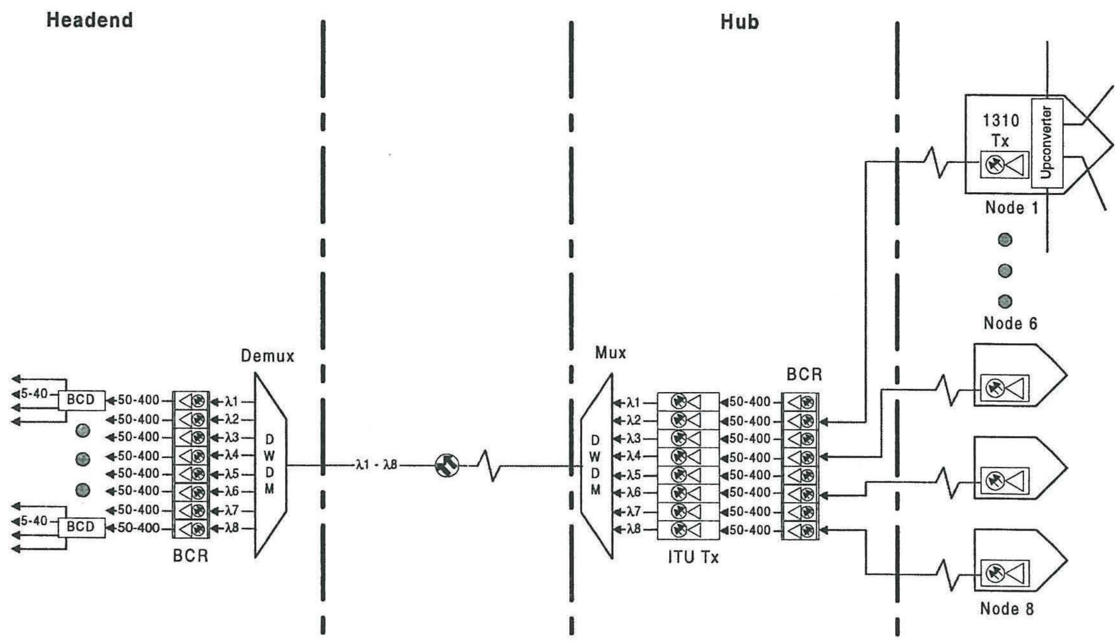


Figure 8: DWDM/FSS configuration 1

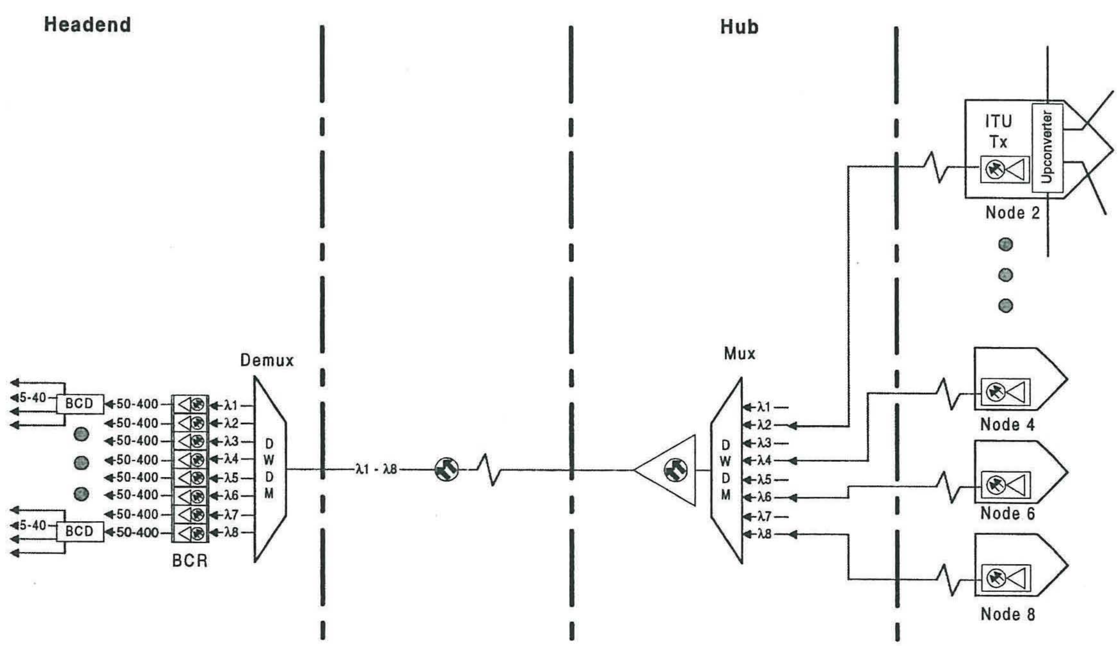


Figure 9: DWDM/FSS configuration 2

transport the upconverted signal. A DFB laser is chosen to provide optimum performance and reach.

*Receiver*

The FSS receiver (BCR) is also different than the normal return path receiver (RPR). Again chosen for the forward path, the receiver provides the composite RF output. Contained within this passband are the four upconverted bands along with the pilot carrier. To recover the individual bands, a downconversion process is performed.

*Downconverter*

The downcoverter provides the means of returning the upconverted bands to their original 5-40 MHz spectrum. Using the pilot carrier for frequency synchronization, the block downconverter (BCD) reverses the process initiated in the node. This device provides four independent 5-40MHz passbands, one for each of the upconverted bands. These outputs are then fed to the return splitting/combining network and eventually end at the individual service demodulators.

## COMBINING DWDM and FREQUENCY STACKING SYSTEMS

### System Description

Now that we have discussed both DWDM and FSS in some detail let's look at how these two systems complement each other. In our goal to increase bandwidth efficiency, both approaches work together to increase the efficiency of both the return distribution and return transport aspects of the network. Combining both DWDM and FSS technologies it is possible to have thirty-two 5-40 MHz return bands on a single fiber. There are two configurations currently being investigated to combine these two technologies. The difference is the location of the ITU grid transmitters. These configurations are:

1. DWDM transmitters at the hub/OTN
2. DWDM transmitters at the node

In the first configuration the ITU grid DWDM transmitters are located at the hub/OTN. As illustrated in Figure 8, this configuration upconverts the return path signals at the node location. Transmitted back to the hub/OTN via the optical distribution network they are received by the forward path block conversion receiver (BCR). At this point we begin to differ from a standard FSS network. Instead of routing the RF output from the receiver to a downconverter, it is routed to a DWDM transmitter. This transmitter has an output wavelength on the ITU grid. We now have a concentration of four discrete 5-40 MHz passbands on each of these transmitters.

Using 200 GHz spacing, we can now optically multiplex eight of these transmitters, each with its own different ITU grid wavelength, on a single fiber. **We now have 32 discrete 5-40 MHz passbands (1.12 GHz) on a single fiber.** The signals are now routed to the headend. Depending on the distances involved, and requirements such as redundancy, optical amplifiers may be required to meet the input requirements of the headend receivers.

At the headend the optical signals are demultiplexed into the eight wavelengths. Individual wavelengths are routed to receivers (one for each wavelength). These receivers are the same as those used to receive the frequency-stacked multiplex at the hub/OTN. At this point we complete the FSS system by routing the composite RF signals from the BCRs to the downconverters. The four, 5-40 MHz, RF outputs from the downconverter correspond to the four coaxial legs coming into the field node.

In the second configuration, illustrated by Figure 9, much of the same components are used. DWDM transmitters are now located in the node. Fed by the stacked RF from the upconverter the individual wavelengths are transmitted back to the hub/OTN.

At the OTN, the optical signals are routed directly to multiplexers. Since it is possible to have different optical levels, due to different node to OTN loss budgets, some level of signal equalization may be required. Output from the multiplexer is sent to the headend in the same manner as in configuration 1. The headend components are assembled as in configuration 1 as well.

The key advantage with this approach is the reduced amount of active equipment located within the hub/OTN. As figure 9 illustrates, it is no longer necessary to convert the signal back to RF. This will improve performance, but places the transmitter in a more hostile environment. This temperature stability is one of the technical issues associated with not only this technology combination, but with DWDM itself.

## Technical Issues

### *Maintaining required performance in the return band*

In the return band, the Noise Power Ratio (NPR) test replaces CNR as a discriminating criterion of robust operation. [7, 8] In this test, a marker is placed at the average level of the noise "signal" in the 5 to 40 MHz range, and the system noise floor is measured in the filter notch at 22 MHz. A conservative requirement is for a 40 dB ratio. To provide adequate headroom, the requirement of 40 dB should be met over a dynamic range of signals. In the NPR test, the RF input level is varied over power while measuring the signal level and that of the noise floor. Today's DWDM systems are able to achieve NPR's of roughly 15 dB above a NPR = 40 dB.

Additionally an FSS system can achieve well over 40 dB with a wide dynamic range. The FSS-2000 implementation shown was designed around successfully closing a 32-QAM link budget with margin, thus clearing comfortably the anticipated widespread use of 16-QAM. In the (noise+distortion) link budget sense, a required NPR of 40 dB is conservative. 16-QAM at 1e-8 BER requires 22 dB uncorrected CNR. With digital IMD looking noise-like, it behaves similarly to C/IMD. Losses are incurred from channel impairments (frequency response, interference, impulse noise, clipping, phase noise), HE combining, optical and RF link variation, and modem implementation losses. Link "gain" is achieved via error correction, as well as indirectly through equalization, in the sense that it mitigates frequency response distortions. It is also indirectly achieved in the so-called "hy-phy" approaches that will form the next round of cable modem technology (CDMA, OFDM).

When the two systems are combined, a reasonable goal is still 40 dB NPR. DWDM/FSS implementations as discussed here have about 9 dB of dynamic range for a 40 dB NPR. It is common practice in developing link budgets to ignore the benefits of error correction and frequency response equalization, harsh as that may be. Uncorrected data is an actual functional mode in DOCSIS1.0. However, completely ignoring any such benefits means that the

NPR requirement as specified assumes 18 dB is in reserve for contributions from the set of impairments described above. This provides superior technical performance, but of course must be weighed in terms of dollars for dB as to the need for this much margin. The problem is complicated by the fact that the comfortable amount of headroom necessary will vary among plants, depending on it's susceptibility to high levels of interference. We have found that commonly occurring interference is not typically large enough itself to have a major impact on the probability of clipping.[8]

*Temperature stability of DWDM components*

As mentioned earlier, temperature stability of the DWDM components is achievable. However this stability does have a cost. In the implementation of DWDM networks today the environment in which they are placed are somewhat controlled. Early versions of the equipment were intended for climate controlled facilities, but with the technology maturing they are being placed in less environment-friendly locations. The need for temperature compensation has occurred in two areas relative to current applications. Advances in both DWDM components and cabinet design have allowed these devices to move into more hostile environments.

However, there is still work to be done to move these components into the node. Implementations that place ITU grid transmitters in the node would require these transmitters to be very stable. In addition the amount of multiplexing will continue to increase. With 200 GHz spacing, 8 wavelengths can be multiplexed. If the industry moves to an implementation that places multiple ITU grid transmitters in the node, the need for more multiplexing will rapidly increase. Given that there are alternatives that provide the equivalent bandwidth, the networks may not reach this level. However, our crystal ball is as cloudy as everyone else's.

## Comparative Analysis

*Equipment usage*

If we compare a hypothetical system that has a distance of 40 km between the headend and the OTN and a distance of 20 km from the OTN to node we see large differences in the amount of equipment. There will be 20 nodes fed from the OTN. The goal is to get the return path traffic for these nodes (80 individual 5-40 MHz passbands) back to the headend. The four scenarios that we will investigate are:

1. Standard 1310 return to the OTN and then retransmission utilizing DWDM back to the headend.
2. Standard FSS transport to the OTN and then retransmission utilizing DWDM back to the headend.
3. FSS transmission using ITU lasers in the node and multiplexing/optical amplification in the OTN for transport to the headend
4. Transmission from the node to the OTN using ITU lasers and then multiplexing/optical amplification in the OTN for transport to the headend.

In each of these scenarios the amount of return segmentation/efficiency will be kept equal. We will use a 2000 home passed node with the return segmented into four 500 home nodes within the node. This same segmentation can also be accomplished by implementing four 500 home passed nodes. This would require more fibers in the downstream direction.

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Standard 1310 nm transmitters in the node | 80 | - | - | - |
| Standard FSS transmitters in the node | - | 20 | - | - |
| ITU grid FSS transmitters in the node | - | - | 20 | - |
| ITU grid transmitters in the node | - | - | - | 80 |
| Qty of return fibers from node to OTN | 80 | 20 | 20 | 80 |
| Return path receivers at the OTN | 80 | - | - | - |
| FSS receivers at the OTN | - | 20 | - | - |
| ITU grid transmitters at the OTN | 80 | 20 | - | - |
| 8-wavelength muliplexers at the OTN | 10 | 2.5 | 2.5 | 10 |
| EDFA optical amplifiers at the OTN | - | - | 3 | 10 |
| Qty of return fibers from OTN to headend | 10 | 3 | 3 | 10 |
| 8-wavelength demultiplexers at the headend | 10 | 2.5 | 2.5 | 10 |
| Return path receivers at the headend | 80 | - | - | 80 |
| FSS receivers at the headend | - | 20 | 20 | - |
| Downconverters at the headend | - | 20 | 20 | - |

**Table 1: Estimated equipment required for transport from node to headend**

*System costing*

As we start to compare the system costs of these four approaches let us examine the fiber savings first. We will assume that the fibers will be in the same sheath. This will allow us to disregard the installation labor of the fiber cable, as it will be the same for each scenario. However, splicing costs for the different amounts of fiber in each approach will be different. We are not including these costs. To make the math easier, we will further assume that the fiber cable costs $0.01 per fiber strand per foot. So a 12-fiber cable that is 10' long would cost $1.20.

Looking at the fiber involved from the node to the OTN, Table 1 shows that the scenarios employing a FSS configuration use one-fourth as many fibers. For the 80 return passbands we want to transport, the non-FSS scenarios use 60 more fibers. At a 20 km distance from the node to OTN, this equates to a 60-fiber cable that is 20 km long. Translating this in monetary amounts with our assumed fiber price results in $39,360 in additional fiber expense in this segment. If we examine the savings in the headend to OTN link we find an additional $9,184 of fiber costs associated with the non-FSS approaches.

Today, the FSS and DWDM equipment is generally more costly than the standard DFB products used in the return path today. Will this eliminate the fiber savings? If we take scenario 1 as our baseline, how we would do it without FSS, we can compare the system costs. Providing the same level of service, a budgetary costing estimate for the equipment only is summarized in Table 2.

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Return path equipment(includes node, OTN, & headend electronics) | $766,000 | $379,060 | $274,000 | $560,000 |
| Percentage difference from baseline (Scenario 1) | baseline | (50.5%) | (64.2%) | (26.9%) |

**Table 2: Equipment cost comparison**

As Table 2 illustrates the DWDM and FSS combinations are less costly than scenarios 1 and 4. Although the FSS components are more costly, the reduced volume greatly offsets this increased unit cost. It should be noted that costs associated with DWDM components that reside in the node (scenarios 3 and 4) are estimates. The technical hurdles of placing this type of equipment in the harsh environment of the node are not fully developed, in a cost-effective solution, at this time.

## CONCLUSIONS

1) These two technologies (FSS and DWDM) are complementary and not mutually exclusive in their implementation. In fact the implementation of this hybrid may reduce system costs extensively.
2) This architecture hybrid can provide adequate NPR performance for the traffic on the return path.
3) This hybrid is very well suited to implementation into existing systems that may have fiber limitations in both the headend-to-OTN and OTN-to-node optical segments.

## REFERENCES


1. For a good historical perspective on the development of CATV architectures through 1990 see Walter S. Ciciora, "An Introduction to Cable Television in the United States," IEEE LCS magazine, February, 1990, pp. 19-25. Other papers in that issue are also relevant. For an up-to-date version of architectures and issues, see Walter S. Ciciora's book An Introduction to Cable Television. It is available at the CableLabs home page at www.cablelabs.com.
2. Oleh J. Sniezko, Video and Data Transmission in the Evolving HFC Network, invited talk, Optical Fiber Communications Conference, 1998.
3. International Telecommunication Union, T study group 15 (Transport, Network, Systems and Equipment); work is not yet completed.
4. Francois Gonthier, "Fused couplers increase system design options," Laser Focus World, June 1998, pp. 83-88.
5. C. Dragone, C. A. Edwards, and R. C. Kistler, "Integrated optics N x N multiplexer on silicon," IEEE Photonics Technology Letters, vol.3, pp. 896-899, 1991.
6. For more information on frequency stacking see Robert Howald, Michael Aviles, and Frank McMahon "Increasing HFC Capacity: Design and Field Test of Return Path Frequency Stacking," 1998 NCTA Technical Papers, Atlanta, GA pp 203-216.
7. Oleh J. Sniezko and T. Werner, "Return path active components test methods and performance comparison," 1997 Conference on Emerging Technologies, Nashville, TN Exton, PA: SCTE, pp. 263-294.
8. Donald Raskin and Dean Stoneback, *Broadband Return Systems for Hybrid Fiber/Coax Cable TV Networks*, Prentice Hall PTR, Upper Saddle River, NJ, 1998, p. 171.


## Acknowledgements


The authors would like to thank Michael Aviles and Mike Short, TNS System Engineering staff, whose efforts were critical in the completion of this paper


## Contact Information


Timothy Brophy, Ph.D.
General Instrument
Transmission Network Systems
101 Tournament Dr.
Horsham, PA. 19044

800-523-6678
tbrophy@gi.com

Robert Howald, Ph.D.
General Instrument
Transmission Network Systems
101 Tournament Dr.
Horsham, PA. 19044

800-523-6678
rhowald@gi.com

Curt Smith
General Instrument
Transmission Network Systems
101 Tournament Dr.
Horsham, PA. 19044

800-523-6678
cusmith@gi.com