OPERATING PERSPECTIVES ON THE 1550 nm WAVELENGTH

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ABSTRACT

Since 1991, cable television operators have been weighing the relative merits of a new transmission window, the 1550 nanometer (nm) wavelength, versus operating at 1310 nm, where much of the industry's recent transmission efforts have been concentrated.

In conjunction with this, the feasibility of erbium-doped fiber-optic amplifiers (EDFAs) operating at 1550 nm also have been the topic of much discussion. The high output power and minimal distortions of these devices makes them ideal for amplitude modulation (AM) video distribution. As passive optical components, such as low loss, high port count (ie. 1x4, 1x8, and 1x16) splitters and optical amplifiers become commercially available in high volumes, the economic implications of their deployment in cable TV system rebuilds can be compelling.

Fiber-optic amplifiers can reduce the costs of an optical link and allow deeper penetration of fiber into the system. Due to the inherently lower attenuation of optical fiber at 1550 nm, nearly 40 percent lower relative to 1310 nm, amplifiers can permit longer fiber runs and increased sharing of transmitters via optical splitting. In addition, because the 1310 nm operating window is not currently utilized in an optical amplifier based system, operators can design their systems to deliver broadcast signals at 1550 nm today with the ability to offer narrowcast services at 1310 nm or other wavelengths in the future.

This paper will discuss the status of passive optical component technologies for splitters and the status of EDFAs. In addition, it will present the current state-of-the-art performance for some of these devices and scenarios for their cost-effective deployment in future applications.

BACKGROUND ON ARCHITECTURE EVOLUTION

Prior to 1988, most of the optical fiber used by the cable TV industry was installed for use in super-trunk applications. These applications called for better performance and reliability than could be delivered by coaxial cable or microwave transmission links.

The transmission technology of choice was frequency modulation (FM) over single-mode fiber. With the introduction of very linear, narrow linewidth, distributed feedback lasers (DFB) in early 1989, amplitude modulated (AM) fiber systems were developed and commercialized.

AM fiber-optic equipment is desired by cable TV operators because it is fully compatible with their current standard broadcast format and can be used economically in cable TV plants to upgrade system bandwidth and increase system reliability. However, AM video systems require much higher carrier to noise performance than FM and digital systems, and thus limit the amount of available optical power for link budgets.

Historically, most traditional coax-based cable TV system architectures were designed in a tree and branch configuration to deliver one-way, broadcast video signals. Cable TV designers and operators have constantly sought to get as much power as possible through their networks to the home. Therefore, a cable system's design goal is to maximize the power (RF or optical) presented to the cable plant while inducing the minimum amount of noise and distortion at the lowest cost per subscriber. This design goal typically is achieved by minimizing equipment costs and maximizing the revenue per watt of delivered power (by the laser source or RF equivalent).

Most AM fiber systems today operate at 1310 nm and are limited to distances of less than 25-30 kilometers (km). A major impetus for operating at 1550 nm is to take advantage of optical fiber's lower attenuation at 1550 nm. This could extend the maximum transmission distance of a system out to 40 or 50 km. In addition, optical amplifiers, which operate at 1550 nm, could enable more receivers to be shared by a common laser transmitter, thus potentially reducing the overall system cost.

Corning envisions two applications as appropriate for 1550 nm AM video technology in the near term.

First, initial 1550 nm AM systems are likely to be used for trunking applications, where longer distances can be achieved than with current 1310 nm AM systems. For these applications, it may be appropriate to install optical amplifiers with single-mode dispersion-shifted fiber to reduce significantly the effects of dispersion at 1550 nm.

Dispersion is a key performance parameter affecting current and future capabilities of fiber-based AM video cable TV systems.

In analog transmission, dispersion causes a slightly distorted waveform to become significantly distorted more rapidly. The nature of an AM video signal makes it very susceptible to distortions created by laser chirp. This phenomenon occurs when there is a shift of laser ouput power to slightly different wavelengths.

Because AM cable TV systems rely on DFB lasers with very narrow linewidths, a small amount of laser chirp can significantly distort the ouput video signal. The presence of dispersion enhances this effect and shows up as second order harmonics (or "beats") and is commonly referred to as composite second order (CSO).

Some solutions exist today for this effect. Equipment manufacturers can electrically or optically compensate their 1550 nm AM systems for the effects of dispersion, enabling successful operation at 1550 nm on standard single-mode fiber. Another alternative could be to design channel loading per fiber by octave, thus eliminating the effects of CSO distortions that are enhanced by dispersion.

The second 1550 nm AM system application offers deeper fiber penetration at a lower overall cost per subscriber by employing optical amplifiers. In this case, optical amplifiers would generate high ouput power levels, allowing the laser transmitter to be shared among several optical receivers.

This cost sharing allows for greater penetration of fiber closer to the home and reduces the total installed fiber cost. When optical amplifiers are installed in the headend, then compensation techniques can be used to minimize CSO distortions.

When 1550 nm AM video systems with optical amplifiers are deployed eventually in the field as part of fiber-to-the-subscriber systems, the effects of dispersion on CSO may be minimal, since the maximum fiber lengths would likely be reduced to less than two kilometers (km).

Because this application holds the promise of significant economic benefits for operators, a more detailed examination of two enabling component technologies for 1550 nm -- planar ion exchange couplers and optical amplifiers -- is warranted.

COMPONENT TECHNOLOGIES

Planar Ion Exchange Coupler Technology

In addition to offering system cost savings potential, the planar ion exchange technology for fabricating passive optical components also offers performance benefits. This approach is a radical departure from more traditional coupler technologies.

The ability to create higher port count 1xN (ie. 1x4, 1x8, or 1x16) splitters by other methods, commonly referred to as fused biconic taper, usually is achieved by splicing several fused 1x2 devices together to create a unit with the desired number of ouput ports. However, the planar ion exchange coupler fabrication process begins with an optical substrate glass rather than optical fibers (Fig. 1).

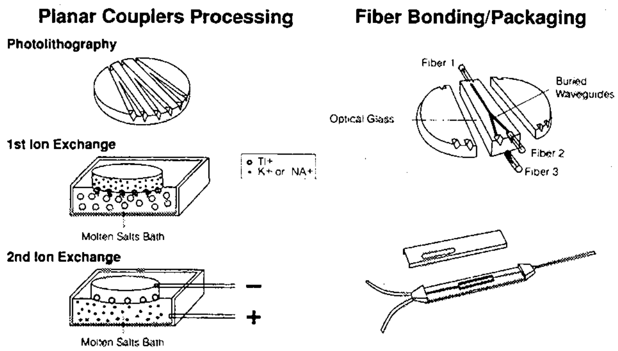

Fig. 1. Planar Ion Exchange Technology

Using photolithography, the pattern of an optical circuit is imposed on the surface of the optical substrate material. Two chemical ion exchange processes then are used to actually create a waveguide structure in the glass substrate itself. Following these steps, the processed substrate wafer, which consists of numerous individual components, is cut into discrete devices or chips. A precision automated technique for mechanically attaching the input and output fibers to each optical chip is used and the resultant coupler then is packaged.

With this technology, it is possible to make low loss, dual window wideband splitters in 1x2, 1x4, 1x8, and, most recently demonstrated, 1x16 configurations (Fig. 2). These devices are extremely small relative to cascaded devices using fused coupler. As an example, a planar 1x8 is approximately 1/250th the size of a cascaded fused 1x8 (Fig. 3).

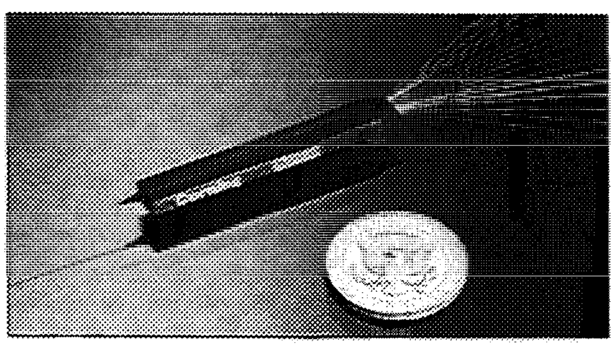

Fig. 2. Miniature 1x16

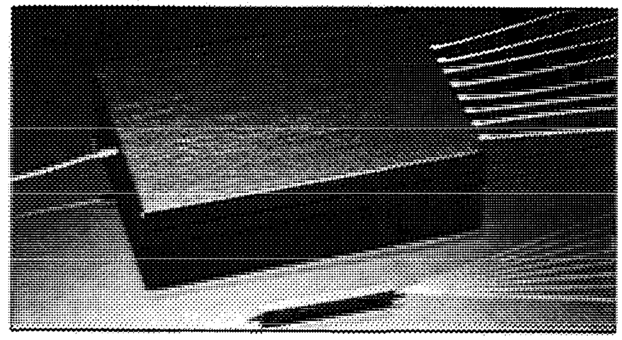

Fig. 3. Size Comparison of Planar and Fused Biconic Taper Couplers

Many new developments in coupler design have been achieved over the past two years through advancements in Corning's planar fabrication technology. Improvements in optical circuit design and waveguide fabrication have resulted in planar couplers with enhanced wide-band achromatic optical performance. Double window 1x4s and 1x8s (1310 nm and 1550 nm) have been achieved with very low insertion losses (Figs. 4, 5).

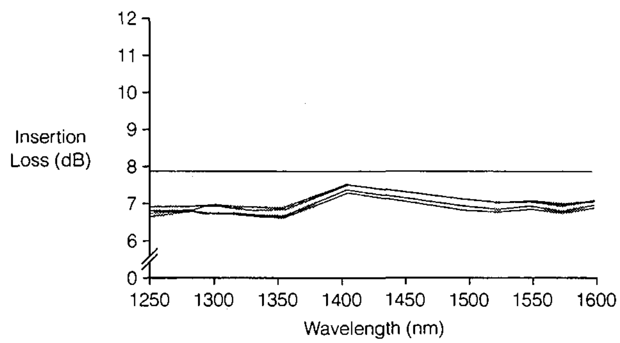

Fig. 4. Typical Insertion Loss - Corning Single-Mode 1x4 Tree Coupler

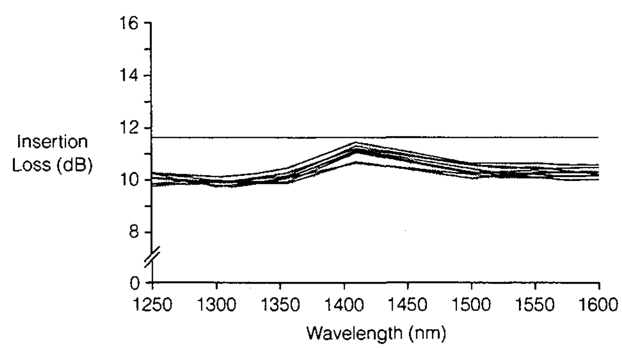

Fig. 5. Typical Insertion Loss - Corning Single-Mode 1x8 Tree Coupler

For 1x4 couplers, typical insertion losses have been measured at 6.8 dB for 1310 nm and 7.0 dB for 1550 nm. In addition, 1x8 couplers have been fabricated with optical losses of 10.3 dB for 1310 nm and 10.9 dB for 1550 nm.

These planar devices have typical port-to-port uniformity of about 0.3 dB for 1x4s and 0.7 dB for 1x8s (Figs. 6, 7).

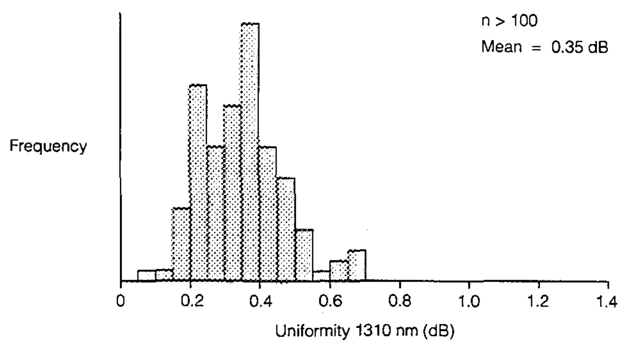

Fig. 6. Uniformity at 1310 nm,
1x4 Double Window Splitter

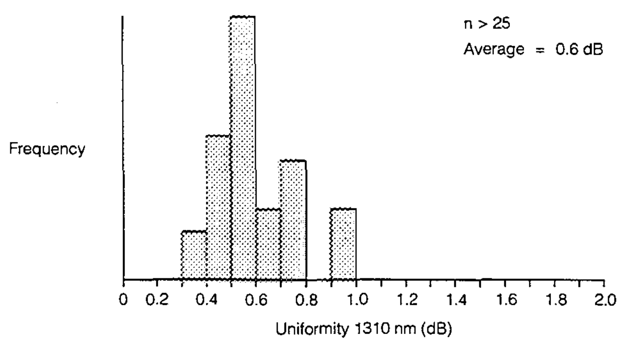

Fig. 7. Uniformity at 1310 nm,
1x8 Double Window Splitter

Planar 1x16 couplers are now in development. Corning's planar technology preserves optical performance and reduces size through passive integration of multiple Y-junctions (Fig. 8). For these developmental products, low insertion losses, on the order of 14 dB and port-to-port uniformity of 1.5 dB, have been achieved (Fig. 9).

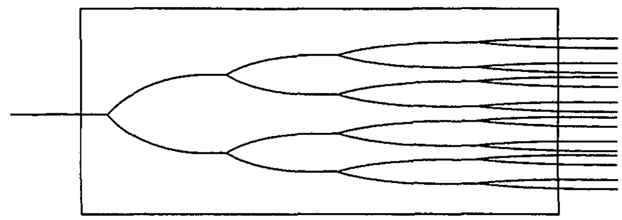

Fig. 8. 1x16 Splitter

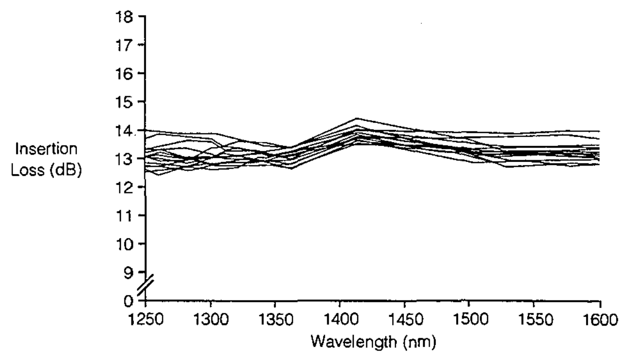

Fig. 9. Typical Insertion Loss - Developmental
1x16 Corning™ Single-Mode Splitter

Erbium-Doped Fiber Amplifier Technology

This second fiber-optic component technology, when combined with the planar coupler technology previously discussed, presents the greatest opportunity for overall system cost reduction and future upgradeability. The EDFA represents a synthesis of optical components that could have a significant impact on the way cable TV systems are designed.

Although the majority of AM video systems currently operate at 1310 nm, the increased availability of linear DFB lasers operating at 1550 nm, make EDFA technology an attractive alternative for cable operators looking to install optical fiber cost-effectively.

EDFA Components

An EDFA consists of several distinct elements that can be better understood from a functional standpoint if viewed in block diagram form (Fig. 10). These include: environmental protection, status monitoring, back-up power, and gain control. These functions are absolutely necessary to achieve a fully useful and functional amplifier that will survive in the outside plant environment. While much of this functionality relates to the operation and internal control of the device, particular attention should be given to the element containing the source of the optical gain.

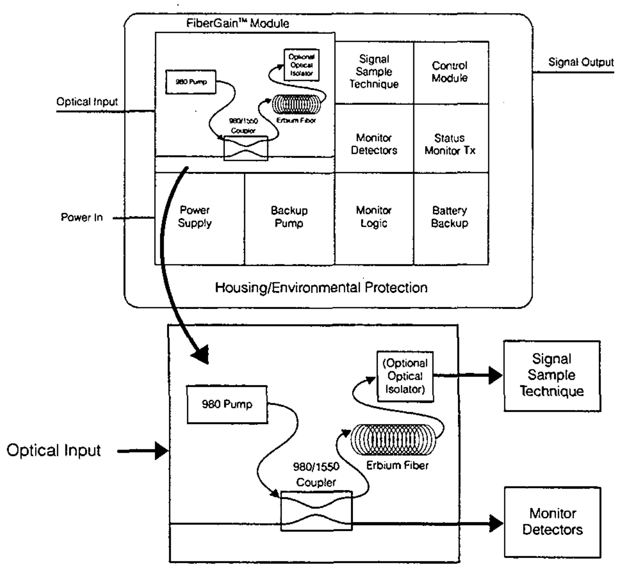

Fig. 10. Erbium-Doped Fiber-Optic Amplifier Schematic

In 1991, Corning introduced its FiberGain™ Module, an optical gain element that consists of one or two 980 nm pump laser(s), one or two wavelength division multiplexer (WDM) coupler(s), and approximately 20 meters of erbium-doped single-mode fiber (Fig. 11). The WDM coupler serves the purpose of combining the input optical signal (1550 nm) and the pump signal (980 nm) into the erbium-doped single-mode fiber where the conversion of pump power light to amplified signal light occurs.

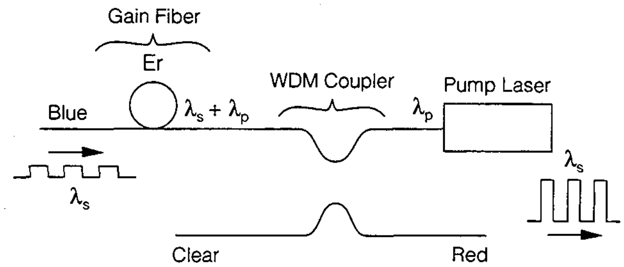

Fig. 11. Fiber-Optic Gain Block

In actual operation, the optical signal would enter the optical gain block (Fig. 12) on an input leg of the WDM coupler. Pump light from the diode laser is delivered on the other WDM input. The input and pump signal is then coupled into the erbium fiber and the input signal undergoes between 15 to 30 dB gain. Saturated ouput power levels as high as 12 to 15 dBm are possible.

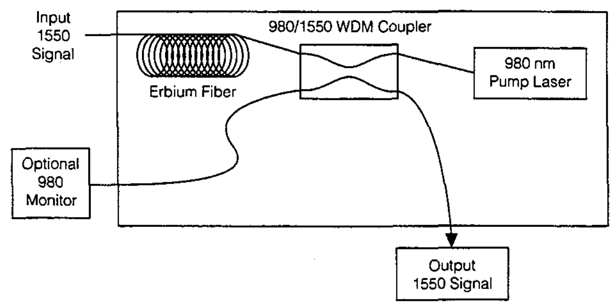

Fig. 12. Corning FiberGain™ Module

PLANAR COUPLER AND EDFA APPLICATIONS

The most likely applications for the EDFA being considered by cable TV operators are for AM supertrunking and shared distribution. In these approaches, the amplifier is configured as a power amplifier where the laser transmitter's output is immediately boosted and transmitted over long distances or split along multiple paths to serve many nodes.

With 1310 nm AM technology being deployed successfully today, cable operators may ask why they should consider the 1550 nm window. With the development and commercialization of optical amplifiers and passive splitters, the ability to share costly transmitters is greatly enhanced. This will not only permit operators to reduce the initial cost of their optical links, but also allow them to extend fiber's reach further into their systems. In addition, the lower attenuation of optical fiber at 1550 nm, nearly 40 percent lower than the 1310 nm window, will allow operators to lengthen their fiber runs and increase the amount of optical splitting.

In order to take the maximum advantage of the optical fiber and these new optical components technologies, operators will want to consider deploying the EDFA and passive splitters in architectures that vary dramatically from the traditional tree-and-branch. One such approach is the cable TV star architecture (Fig. 13). While the specific details of the actual implementation may vary from system to system, there are two key attributes worth considering.

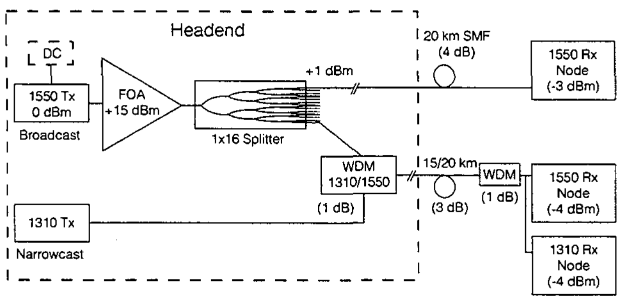

Fig. 13. Cable TV Star Architecture, Using An Optical Amplifier

First, because all splitting is performed in the headend, this architecture will permit operators to maintain home run fibers to and from their receive nodes. Second, while the 1550 nm window is used to deliver AM video, the 1310 nm window remains available to support a host of upgrade possibilities, including narrowcasting, digitally compressed pay-per-view, or video on demand.

To understand the tangible benefits of this cable TV star architecture, it's useful to explore the example shown in figure 13 in greater detail. In this approach, a 1550 nm DFB with an output power of approximately 0 dBm (1 mW) is shown with some form of dispersion compensation (DC). This compensation could be either electronic pre-distortion of the laser transmitter or optical dispersion compensation placed after the transmitter. A key aspect to note is the relatively low output required from the transmitter.

By contrast, 1310 nm DFB systems require almost twice the output power due to higher loss at 1310 nm. Because the EDFA can provide such high output power with very little added distortion and noise, it is possible that lower output 1550 nm devices in volume, may be available at lower prices than 1310 nm devices in the future. The next element of this architecture is an EDFA with a +15 dBm (32 mW) output power.

The output of the amplifier is input to a monolithic 1x16 splitter with a total insertion loss of 14 dB. The resulting output power on the 16 splitter output ports would thus be +1 dBm. Assuming a receiver sensitivity at the 1550 nm receive nodes of -3 dBm to -4 dBm gives an optical budget of 4 dB to 5 dB. At 1550 nm, this equates to link distance of 15 to 20 kilometers (km).

ECONOMIC BENEFITS ANALYSIS

To understand how the previously discussed cable TV star architecture example offers operators the economic impetus to deploy these 1550 nm technologies, it's useful to review the following rough economic analysis comparing the deployment of a star architecture at the 1310 nm and 1550 nm windows.

Using the link length of 15 km will provide an equalization factor with which to make an "apples to apples" comparison of the 1310 nm and 1550 nm approaches. The optical loss of 15 km of single-mode fiber at 1310 nm is about 5.5 dB. Again assuming a -3 dBm receive sensitivity, one would need a 1310 nm DFB with an output of a 9 dBm (8 mW) with no splitting in order to meet the optical budget for just one link.

A comparison of the prices for this 1310 nm and 1550 nm transmission equipment alone tells the story (Fig. 14). Assuming the small volume pricing for a 1550 nm DFB with 0-5 dBm output is $17,000, an EDFA with +15 dBm output power is $40,000, and a 1x16 splitter with 14 dB insertion loss is $2,500, the total equipment cost is $59,500. Dividing this total by the number of nodes served (16) gives a cost per link of roughly $3,700.

- 1550 nm assumptions
  - 1550 nm DFB: 0-5 dBm output power ($17,000)
  - Double pumped EDFA: +15 dBM output power ($40,000)
  - 1x16 splitter: 14 dB insertion loss ($2,500)

  Cost per link ~ $3,700
- 1310 nm assumptions
  - 1310 nm DFB: +9 dBm output power ($10,000)

  Cost per link ~ $10,000

Fig. 14. Cable TV Star Architecture Economics

For the 1310 nm case, the analysis is straightforward since splitting is not possible. In large volumes, one might assume $10,000 for the 9 dBm transmitter. For discussion purposes, large volumes must be assumed since transmitters capable of this kind of high output power are the exception, not the rule. Thus, the capital outlay for the 1310 nm equipment is nearly three times that of the 1550 nm technology.

While not exhaustive, this analysis does provide an example of how these 1550 nm technologies can permit operators to create low cost, upgradeable, fiber-optic distribution networks today.

Clearly, with higher volumes, the component technologies described above will only continue to further enhance the cost-effectiveness of cable TV star architectures.

In addition, the continued development of such products as planar ion exchange splitters, and fiber-optic amplifiers, which are available today, also will continue to allow for the refinement of advanced system architectures and services that will permit cable operators to bring fiber ever closer to the customer's home.