Designing Fiber Optic Systems

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Everyone knows that fiber optics can carry a huge amount of data. There are more benefits to using fiber optics in broadcast applications than you might realize. This article describes how to design a system to link two facilities with multiple video, audio and data channels in both directions.

Fiber Optics

Fiber optics has many advantages over copper. You can build much longer point to point links using fiber than is possible with conventional wire cables, the bandwidth is much wider, it is lighter and it occupies less space. By careful adoption of the available tools, you can also multiplex many signals of different types onto a single fiber link. The link can even be bi-directional.

Lasers and LEDS

Electrical to optical video converters generally have a BNC coaxial cable connector at the input and a fiber optic connector on the output. In order to get the digital bits down the fiber optic cable, a light emitting device is used, onto which the digital signal is modulated. Either a laser or an LED (Light Emitting Diode) is used for this purpose. Lasers are more expensive, but they have significant advantages over LEDs. Lasers concentrate the light into a narrow beam at a unique wavelength. This narrow beam can travel much further than the diverging light emitted from an LED. Even if distances are short, the additional signal strength offered by lasers gives the system designer many more options to employ patch panels, splitters and other devices. Multiple signals can also be carried over a single fiber by using lasers of different wavelengths. This is not possible with LEDs.

Single-mode and multi-mode

Fiber optic cable is available in single-mode and multi-mode types (Fig 1). Multi-mode cable has a larger core diameter (50um or 62.5um) than single-mode fiber (9um core diameter). When light travels down multi-mode fiber it is reflected at different angles as it propagates down the transmission path. These multiple reflections cause the light to spread out in time as it propagates down the fiber, making it more difficult for the receiver to recover the data. Single-mode fiber being much narrower, confines the optical signal to a straighter path with fewer reflections. As a result, optical signal dispersion is significantly reduced, which translates into a cleaner signal. Longer transmission lengths can therefore be achieved with single mode cable. It is also a bonus that single-mode fiber can now be purchased for the same or less than multi-mode fiber.

Single-mode and multi-mode cable should not be mixed in the same system. However, if really necessary, it is possible to use multi-mode fiber downstream of single-mode fiber, as the larger diameter multi-mode fiber will collect most of the light emitted from the single mode fiber. You can never use single mode fiber, or any single-mode components such as CWDM devices, downstream of multi-mode fiber.

Fiber Optic Characteristics

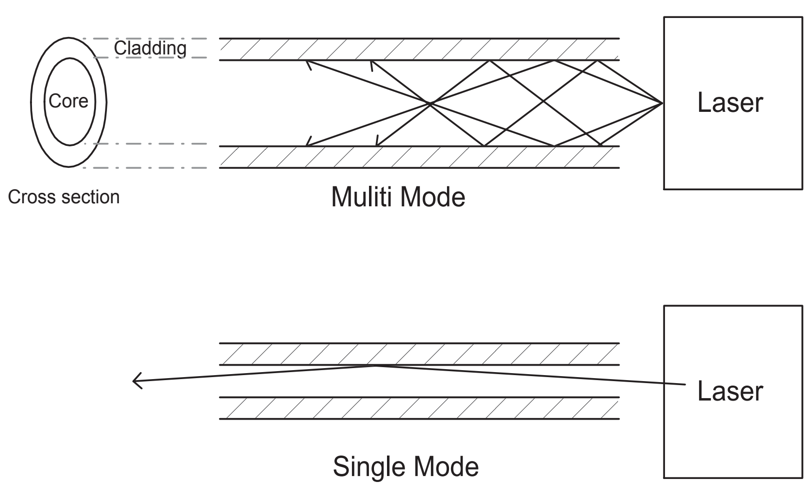

Fig. 1 Multi-Mode and Single Mode

The standard fiber optic cables in use today, have attenuation characteristics similar to those in Fig. 2. As can be seen, the minimum attenuation occurs at wavelengths around 1310nm and 1550nm. Laser manufacturers have consequently designed a wide range of lasers for these specific wavelengths, where attenuation is less than 0.4dB per km.

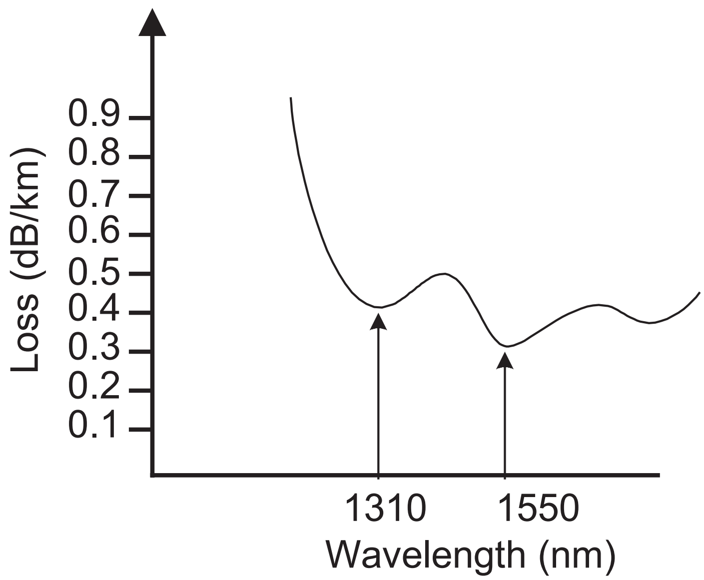

Fig 2. Minimum loss at 1310nm and 1550nm

One signal, one way

A simple one way link is shown in Fig. 3. The electrical to optical converter uses a laser, or perhaps an LED, to transmit the light at 1310nm or 1550nm. The optical to electrical converter at the receiver end, has an optical detector and an electrical re-clocking amplifier. The output typically appears on a co-axial BNC connector.

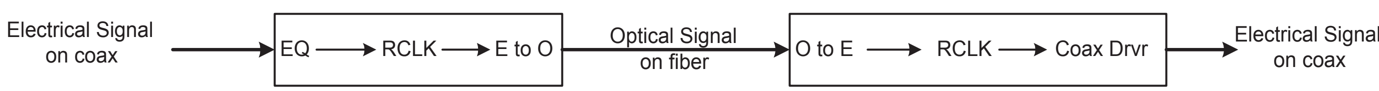

Fig 3. Simple one way fiber link

Doubling up

By employing Wave Division Multiplexing (WDM) two signals at two different wavelengths of 1310nm and 1550nm, can be conveniently carried on the same fiber. See Fig. 4. The first WDM combines the two signals while a second WDM at the other end of the link, separates the two wavelengths again. More on WDM later.

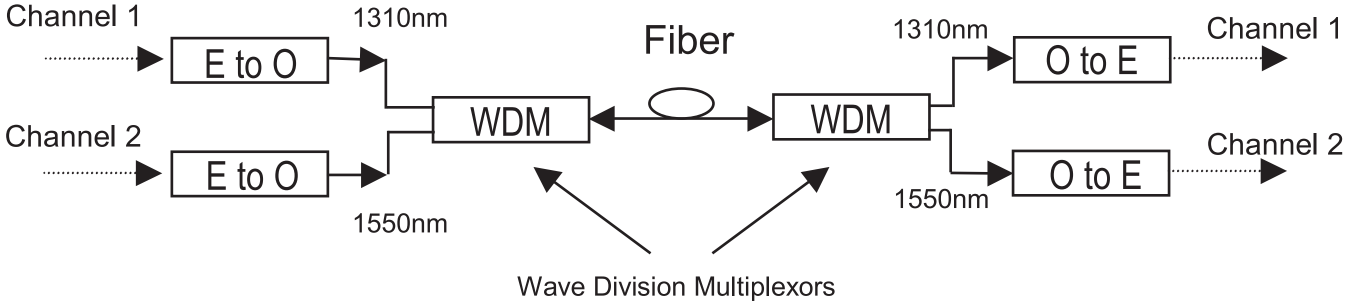

Fig 4. Combining two signals onto one fiber

Going both ways

If we want our fiber link to be bi-directional, we need to employ lasers at both ends. As the lasers will be transmitting towards each other, we need to ensure that they do not affect each other's performance. The best solution is to utilize optical isolators built into each laser, to prevent the light coming from the other end, from affecting the center wavelength stability and performance characteristics of the local transmitting laser. Some laser types, (e.g. DFB lasers) are more susceptible to interference than other laser types (e.g. FP). Laser types will be explained in a later section. Evertz uses built-in optical isolators on any laser type which could be affected by reverse transmission effects or back reflections, in bi-directional fiber links.

A key component in bi-directional fiber links is the combiner device, which combines and separates the bi-directional signals at each end, as shown in Figure 5. These devices route the source light from the lasers directly to the fiber line, without permitting it to get back into the local lasers. Some systems, which are specifically designed for bi-directional applications, may have built-in directional couplers. Note that a bi-directional system should only be built with directional splitters, if the optical path loss is less than 14dB. Otherwise it is possible that the output of the local laser will be reflected back into the local receiver. Evertz publishes tables for bi-directional system, to help the designer choose whether to employ a single fiber, dual fibers or WDM techniques using two or more fibers.

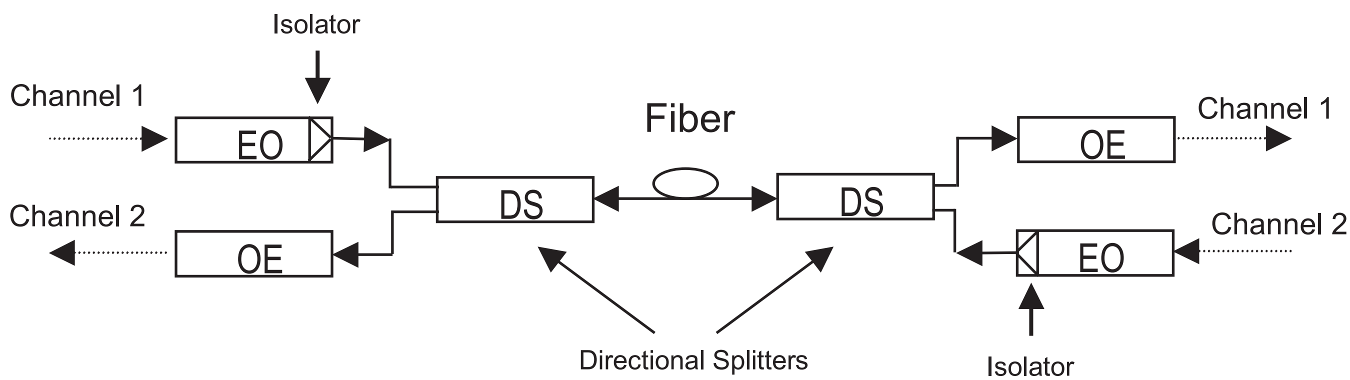

Fig 5. Bi-Directional Video

Digital video and audio

Digital video is often transported over long distances using fiber optics. If audio is embedded in a digital video bit stream, it will be automatically transmitted over a fiber optic link along with the video. This applies to SDI at 270Mb/s and HDSDI at 1.485Gbps.

Time Division Multiplexing

Digital audio can be transmitted in a similar way to digital video. The bit rate used for 48Khz digital audio broadcasting is 3.073Mbs, so by using Time Division Multiplexing (TDM) techniques, multiple audio channels may be transmitter over the same fiber. TDM techniques permit multiplexing of such signals as SDI video and separate ASE audio. This has the advantage that if the video or audio fails, the other signal will be unaffected. Other signals which may be multiplexed using TDM, include data and time code.

Analog video and audio

Although it is possible to modulate a laser beam with an analog signal, these days it is expedient to use digital techniques. Modern fiber transmitters for analog audio and composite analog video, usually convert these signals to digital, before transmitting them. TDM solutions can again be employed to multiplex analog audio and video signals onto the same fiber and even multiple video and audio signals onto the same fiber.

Other signal types

In addition to digital and analog video and audio, broadcasters have a need to transmit an ever growing variety of signal types. These include time code, RS-232/422/485 remote control, intercom, L band and IF band satellite signals, DS3, T1, Ethernet for computer networks and so on. These can all be accommodated on a single fiber by employing the appropriate multiplexing devices.

WDM, CWDM and DWDM

We previously mentioned the use of WDM for combining two signals. Coarse Wave Division Multiplexing (CWDM) extends the number of feeds which may be carried. This is achieved by broadening the bands used in the 1310 and 1550nm areas of the spectrum. As can be seen in Fig. 6, wavelengths used in the 1550 attenuation trough, can range from 1470 to 1610nm. A similar group of wavelengths can be used around the 1310nm trough and by combining these two groups, up to 16 channels can be multiplexed onto one fiber. CWDM wavelengths are 20nm wide and are fairly easily created. To further increase the number of channels carried, DWDM (Dense Wave Division Multiplexors) can be employed. DWDM wavelengths are typically only 1.6nm wide and require much more sophisticated technology to maintain the assigned wavelengths.

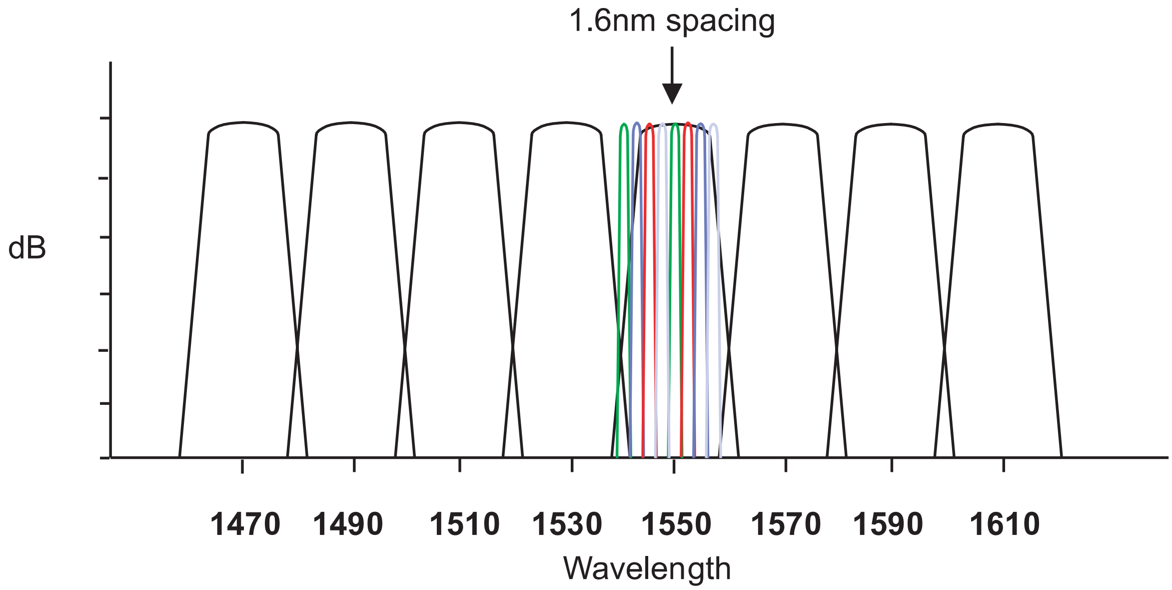

Fig 6. CWDM and DWDM

Putting it all together

There are many different solutions to the problems of getting different signal types from one place to another. The ideal solution will depend upon the distance between the two locations, whether the fiber is owned or leased, if the audio is embedded or separate and a variety of other factors. There are modules available to convert most signals types from copper to fiber and to multiplex different signal types together. The challenge is to find the most economical solution.

Loss budget

Although this topic has been saved to last, loss budget is actually the first thing to consider, as it is an essential requirement that the signals get from point A to point B and still retain a healthy margin of signal strength. It is best to start with a simple calculation of the laser power at the source, minus the anticipated losses in the fiber (calculated from published specifications for the fiber being used). The remaining signal power can then be compared with the sensitivity of the receiver to see how much margin is available. Here's an example:

Laser power:	-7.5dBm
Fiber attenuation:	0.4dB per kilometer
Fiber length:	20Km
Receiver sensitivity:	-29dBm
Connector loss:	0.5dB
Number of connectors:	2

The loss in the fiber cable is 20 x 0.4 = 8dB. We need to add an allowance for connector loss and there are 2 connectors. At 0.5dB loss per connector, this adds 1dB to our loss budget. The power level at the input to the receiver is therefore -7.5dBm -8dB -1dB = -16.5dBm.

The receiver sensitivity is -29dBm, so the margin is 29-16.5 = 12.5dB. Typically we would like to leave a 3dB safety margin, so in this case we still have 8.5dB of margin to play with. The margin decides how many other products could be added. These might be multiplexors, splitters, patch panels, etc and by looking up the insertion loss of each of these devices, we can easily determine if they can be employed in our system. If the loss budget is exceeded, we might need to choose a more powerful laser option.

Deeper Stuff
After we have made a rough calculation of the loss budget to determine the available power margin, we can decide if further calculations are warranted. If margins are minimal and we are using high frequencies as in HDTV, we will want to consider other factors which might affect the performance of the overall fiber system Here's a look at the most important variables.

Laser Types
There are two basic types of lasers; Fabry-Perot (FP) and Distributed Feedback (DFB) and both types are available for 1310nm and 1550nm. We need to choose which type best suites our needs.

Fabry-Perot lasers are the simplest and the least expensive, but the wavelengths of light they emit contain too many side bands for the most critical applications. The spread in wavelengths is measured as Full Width Half Max (FWHM), as shown in Fig 7. An FP laser might typically have an FWHM of around 4nm. Evertz uses 1310nm FP lasers for lower data rate and shorter distances, as they are the most economical.

DFB lasers were developed to satisfy the need for narrow, precise wavelengths as illustrated. Typically a DFB laser might have an FWHM of 0.2nm. These lasers employ a filtering system, which reflects (feeds back) light of only one specific wavelength into the cavity where the light amplification is taking place. The light is evenly distributed throughout the cavity; hence the name Distributed Feedback laser. DFB lasers are used for the more demanding applications and always for CWDM applications.

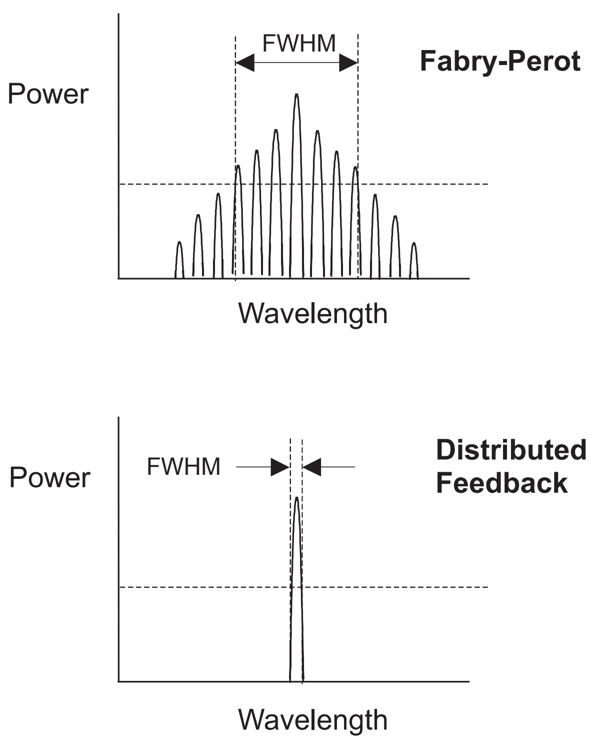

Fig 7. FP and DFB linewidths

Chromatic Dispersion
Different wavelengths of light will travel at slightly different speeds in optical fiber, due to the variation of refractive index with wavelength. Therefore two pulses carried on two different wavelengths, will arrive at the destination at two different times. The time difference is very small and measured in picoseconds, but it can pose problems for Fabry-Perot lasers. A pulse transmitted on an FP laser will suffer dispersion as it travels down the fiber optic cable because the different wavelengths will be traveling at different speeds. Fig. 8 shows how a square pulse of light becomes attenuated and deteriorates into a classical "eye pattern" as it propagates down the fiber and is affected by attenuation and dispersion. (Note that there is a difference between the fixed displacement in time caused by dispersion and the low frequency and high frequency shifting in time caused by jitter. However, the challenge presented to the optical receiver for recovery of the data, is similar).

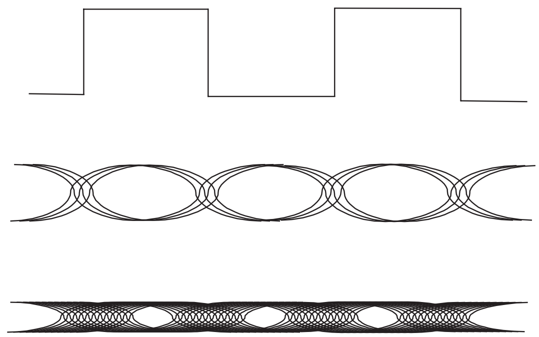

Fig. 8 Typical Eye Pattern

For products operating at frequencies up to 270Mbs, chromatic dispersion is not a significant factor. But for frequencies over 1Gb/s and particularly if margins are slim, we need to consider the affects of dispersion.

Dispersion becomes critical when the time difference between the arriving signals is a significant percentage of the period of the clock rate being used, because at some point, the optical receiver will not be able to distinguish between one bit and the next one.The bit rate for HDTV is 1.485Gb/s, so 1 bit is transmitted in 673ps (the period of one bit). The maximum allowable jitter in HDTV, as defined in SMPTE292M, is 0.2u.i. where u.i. is the period of 1 bit. (In practice, 0.2u.i. is not easy to achieve without incurringa high price penalty, and many of today’s HDTV devices exceed these gitter specs).

In fiber optics we tend to use 0.3u.i as the maximum tolerable dispersion and the maximum permissible "Dispersion Jitter" for HDTV can be calculated at 0.3u.i. x 673 = 201.9ps. The same calculation for SDTV reveals 1,110ps.

FWHM for FP lasers is typically 4nm and for DFB lasers it is typically 0.2nm.
(Actually values for the fiber type being employed should be checked).

Chromatic Dispersion (CD) at a particular operating wavelength, is measured in ps/nm.km. For standard Corning SMF-28 optical fiber this is around 2 for 1310nm and 17 for 1550nm (Fig 9).

$$CD = ps/nm.Km$$
or
$$Km = ps/CD.nm$$

The following table uses the above formula and the above values to derive maximum distances in km attributable to Chromatic Dispersion. (Note that these distances are theoretical values for dispersion only. Other characteristics, such as the fiber attenuation, will generally have more influence as limiting factors and many of the distances quoted will never be attainable).

	Fabry-Perot		**DFB**	
	1310	**1550**	**1310**	**1550**
HDTV	25km	3km	500km	58km
SDTV	137km	32km	2,750km	323km

Table 1. Theoretical chromatic dispersion limits - other factors will generally be far more restrictive

Dispersion Characteristics of Optical Fiber

The amount of chromatic dispersion experienced in optical fiber is dependent on the wavelength of the light being transmitted. This can be seen in Fig 9.

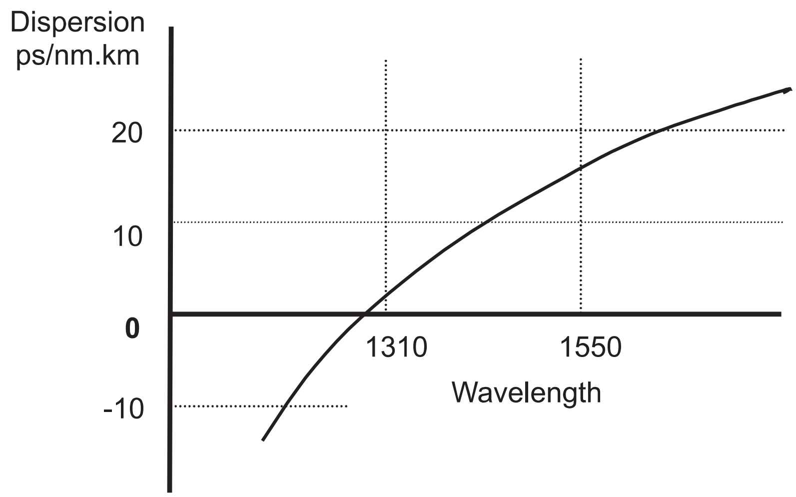

Fig 9. Chromatic Dispersion Slope for Standard Single Mode Fiber

These characteristics lead to the development of Dispersion Shifted Fiber (DSF), where the point of zero dispersion is shifted to the more useful 1550nm wavelength. However, this type of fiber has been shown to be unsuitable for DWDM installations, because the amount of chromatic dispersion is small enough to allow different wavelengths to mix and form a new wavelength. Another type of fiber, Non Zero Dispersion Shifted Fiber (NZ-DSF), was introduced to solve this problem by ensuring that the dispersion is not exactly zero in the 1550nm region.

Imperfect symmetry in fiber optic cables, can also gives rise to a phenomenon known as Polarization Mode Dispersion (PMD), but this has little affect at frequencies below 10Gb/s and will not be considered here.

For distances of less than 50km, the Standard SMF-28 or equivalent Single-Mode fiber is quite adequate and is recommended for broadcast use. Dispersion is generally not an issue for short distance broadcast applications.

Optical Return Loss

A small amount of light is reflected at any fiber optic cable interface and this is known as Optical Return Loss (ORL). The more connectors we have in a system, the more losses we will encounter due to optical return loss. (If a connector is left disconnected, much of the light will be reflected back to the transmitter and a 14.7dB return loss can be expected). ORL is important in bi-directional systems using a single fiber because of the need to keep the sending signal out of the local receiver. To help keep reflections below the minimum sensitivity of the receiver, Evertz limits the transmission power of lasers used in single fiber bi-directional systems. The penalty is shorter distance hops, as defined in the specifications.

If many fiber patch cords are needed in a system, it is sometimes expedient to employ Angle Polished Connectors (APC) to minimize the ORL. The optical ends to these connectors are angled at 8^{o}, such that any reflected light is deflected into the cladding and not back to the source. (i.e. 8^{o} from a line perpendicular to the direction of the fiber). Angle polished connectors with SC fittings, are generally colored green instead of the more usual blue.

Summary

1. Use Standard Single-Mode fiber optic cable wherever possible.
2. Calculate your preliminary loss budget to determine if you have enough power margin with the chosen components. Choose alternative components if signal strength is marginal.
3. If using Fabry-Perot lasers, or HDTV signals, check the chromatic dispersion table.
4. If you are using bi-directional signals on one fiber, optical return loss will be important, so consult the tables to determine the optimum choice of components.