External Modulators

When data rates were in the low gigabit range and transmission distances were less than 100 km or so, most fiber optictransmitters used directly modulated lasers. However, as data rates and span lengths grew, waveguide chirp, caused by turning a laser on and off, limited data rates. Dispersion problems resulted when the wavelength chirp widened the effective spectral width of the laser. A laser source with no wavelength chirp and a narrow linewidth provide one solution to the problem. This solution took the form of external modulation which allows the laser to be turned on continuously; the modulation is accomplished outside of the laser cavity.

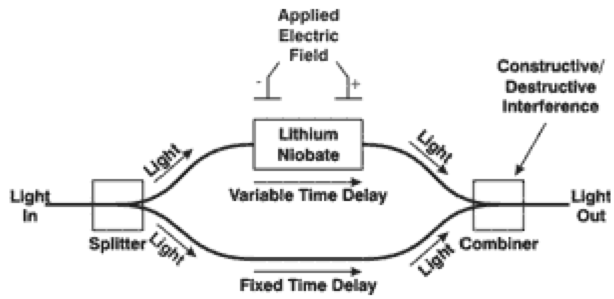
Theory of Operation

An external modulator restrains the light, functioning like an electrically activated shutter. As analog devices, external modulators allow the amount of light passed to vary from some maximum amount (P_{MAX}) to some minimum amount (P_{MIN}). Other key terms related to external modulators include: **Vp**: This is the voltage required to take the response function through ½ cycle or 180°.**Bias Point**: The DC point around which the modulation signal swings. **Insertion Loss**: The amount of loss from the light injected by the laser at the peak of the waveform. This usually amounts to 3-5 dB. Keep in mind that operating at the usual bias point will introduce an additional 3 dB of loss for a total insertion loss of 6 to 8 dB. (See Figure 5 for details.) **P_{MIN}**: The minimum light output from the external modulator. Usually about 5% of the maximum value. **P_{MAX}**: The maximum light output from the external modulator. Usually 3 to 5 dB less than the laser input. **P_{AVG}**: The average light out of the external modulator. Usually 3 dB less than P_{MAX} if driven by a 50% duty cycle waveform.

Lithium Niobate Amplitude and Phase Modulators

The popularity of lithium niobate ($LiNbO_3$) as a material used in external modulators results from its low optical loss and high electro-optic coefficient. This coefficient refers to the electro-optic effect, which occurs in some materials such as lithium niobate, in which the refractive index of the material changes in response to an applied electric field. The refractive index of the material causes light to travel at a speed inversely proportional to the refractive index of the material. Thus, if we could suddenly increase the refractive index of a material, we would slow the light beam down and vice versa. Figure 1 shows the block diagram of a typical external modulator. The input light enters the external modulator via the input fiber. The light is first splits into two fibers using an optical splitter. The top fiber path travels through a length of $LiNbO_3$ crystal. The light in the bottom fiber experiences a fixed delay. After the light travels through the lithium niobate crystal and the fixed length of fiber, an optical combiner merges the two fiber paths. The light travels through identical path legs.

Figure 1 - Typical Lithium Niobate ($LiNbO_3$) Optical Modulator



By applying an electric field to the material, its refractive index changes. We now see that if the time delay through the fixed fiber and the $LiNbO_3$ crystal is equal, the light will be in phase when it reaches the output optical combiner. Due to the nature of light, we see that since the light in both legs are in phase, they will constructively add to form the maximum possible output. The refractive index and the speed of light change as the applied voltage changes. When the speed changes enough to delay the light by half of one wavelength, the light will be out of phase when it reaches the output 3 dB coupler. Now the light will destructivelyform, yielding a minimum possible output. Building a waveguide in the substrate makes the device suitable for use in fiber optic devices. As with optical fiber itself, this is accomplished by introducing dopant materials into the area that will become the waveguide. Doping raises the refractive index of the waveguide relative to the surrounding substrate while maintaining optical transparency. Once accomplished, the waveguide will contain the light by the principles of total internal reflection. If the dimensions of the waveguide remain consistent with the dimensions of the core of a single-mode fiber, about nine microns in diameter, then light will efficiently couple into and out of the waveguide. This basic design proves useful in a fiber optic system. Figure 2 illustrates the simplest type of external modulator, a phase modulator. The phase modulator has a single optical input ofpolarization maintaining (PM) fiber and a single optical output of PM or single-mode (SM) fiber. In a simple phase modulator, two electrodes surround the waveguide. The bottom electrode is grounded while the top electrode is driven by an outside voltage signal. As the voltage on the top electrode changes, the refractive index of the waveguide changes accordingly, alternating the light as the refractive index rises and falls. While this modulates the phase of the light, the output intensity remains unchanged. This modulation overcomes stimulated brilliouin scattering, the easiest fiber nonlinearity to trigger. The SBS threshold can increase by as much as 10 dB because phase modulating the light effectively widens the optical energy.

Figure 2 - Simple Phase Modulator

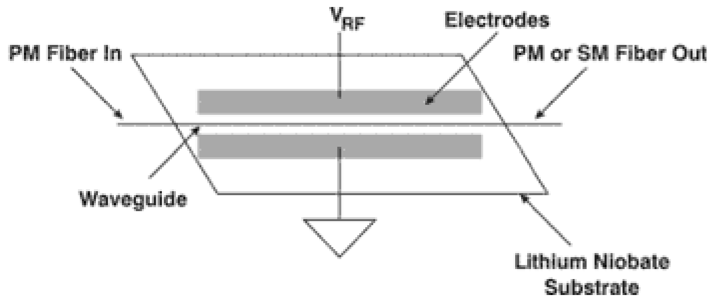
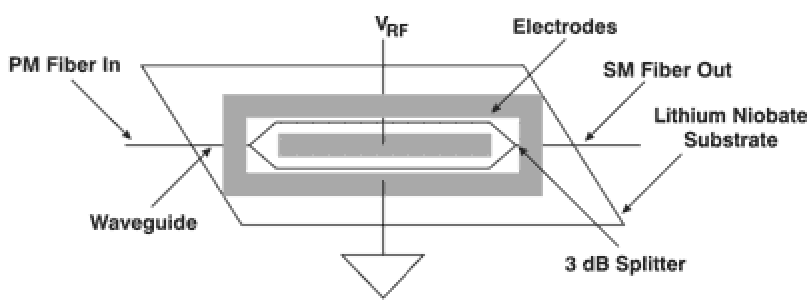


Figure 3 shows a more internally complex device. It has the same input and output fiber setup as the simple phase modulator. However, after the light enters the lithium niobate waveguide, it optically splits into two paths using a fiber optic coupler designed into the substrate. These two paths travel for a distance and then recombine using another fiber optic coupler. If the light waves are in phase, they will add constructively to produce a large output on the output leg. If they are out of phase, destructive interference yields little or no output. The two paths of light travel through sets of electrodes arranged so that they have opposite effects on the two paths. By applying an external voltage, the refractive index of one path will rise while the refractive index of the other path falls. This causes the output optical amplitude to vary as the light from the two paths moves from constructive addition to destructive interference.

Figure 3 - Single Output Intensity Modulator



A third type of external modulator, illustrated in Figure 4, resembles the modulator shown in Figure 3. However, in this case, a 3 dB coupler forms at the output, giving two output fibers rather than one. The light amplitude of the two output legs will move opposite of each other. When the light level of one leg increases, the light level of the other leg decreases. The dual output modulator, which provides two out of phase outputs works best in analog drive situations.

Figure 4 - Dual Output Intensity Modulator

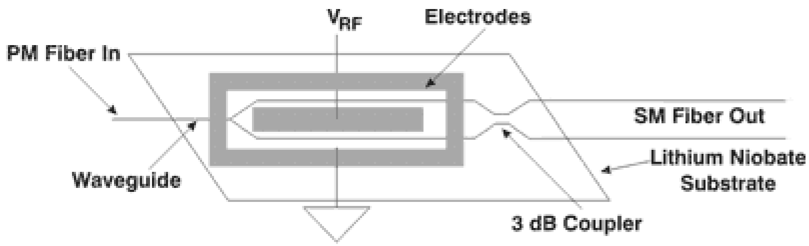
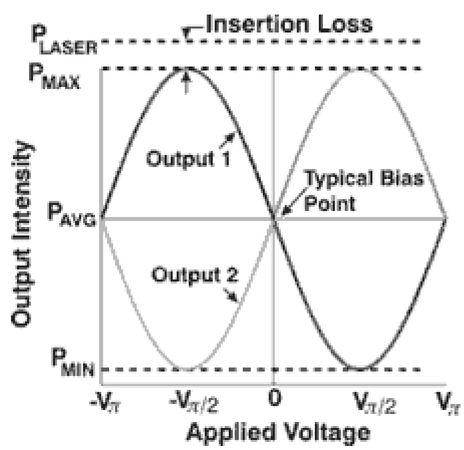


Figure 5 shows the typical raised sine function response of the dual output intensity modulator. The modulator operates around zero Volts bias. At zero Volts bias, the output intensity of both output legs is equal. As the applied voltage increases slightly, the intensity of output 2 increases, while the intensity of output 1 decreases. This continues until the voltage reaches $V_{p/2}$. At that point, the intensity of output 2 will be at a maximum and the intensity of output 1 will be at a minimum. This sine function response repeats as the applied voltage increases or decreases. Usually, modulator designers exploit the response nearest zero Volts bias.

Figure 5 - Dual Output External Modulator Response



Digital Operation

In the simple applications, an external modulator transmits a digital data stream, toggling the drive voltage between $-V_{p/2}$ and $V_{p/2}$. This causes the output intensity to swing from maximum to minimum utilizing maximum modulation depth.

Analog Operation

External modulators may also be used to transmit analog signals. This modulation scheme may require extensive stabilization and linearization. Stabilizing the bias point at exactly the 50% point minimizes that second-order distortion. However, a third-orderdistortion remains. A small drive signal may yield a response that does not require linearization. CATV applications require predistortion of the signal to remove the effects of third-order distortion when sending 80 or 110 channels.

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