

A Tutorial Introduction to Optical Modulation Techniques

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This tutorial is intended to be a “first lesson” for readers who have little experience with the inner workings of optical technology

This article introduces the subject of optical modulation, the process of applying information to a light wave. Those light waves may be sent through a

transparent medium as a laser beam, or contained within a fiber optic cable.

The conversion from high frequency/high speed electrical signals into light can occur in two general ways—applied directly to the power source of the lightwave emitter (e.g. photodiode), or indirectly, by manipulating the light beam.

Simple Schemes

Simple optical laboratory experiments often involve voice transmission or low rate digital information, such as Morse Code. It is easy to apply the modulation for either via control of the current to a laser diode or LED. On-off keying and amplitude modulation (AM) are accomplished in the same manner as a radio transmitter, using a series pass transistor in the DC feed to the transmitting device.

For these simple signals, indirect light beam modulation may also be accomplished, using mechanical shutters or a voice-coil driven mirror. These electro-mechanical devices are, of course, limited to low frequencies and useful only in the most simplistic applications.

Some very early light-beam communications and remote control equipment used techniques similar to those just described, mainly to demonstrate the viability of lightwave technology. But soon, high frequency modulators were developed, using both direct and indirect modulation methods.

Direct Modulation

Digital signals consist of logical 1s and 0s, which readily corresponds to electrical ON and OFF states, or to two discrete voltage (or current) levels. The typical optical communications light source is a laser diode, which is easily modulated by controlling its current.

Several factors limit the upper frequency at which a laser diode can be modulated. These include the time constants (frequency response) of the driving circuitry, the physics of the diode itself, and the characteristics of the transmission medium, which is typically an optical fiber.

Microwave design and layout techniques have been used to assure performance of driving circuitry well into the GHz range, removing this as a major limitation. Optical fibers have a certain amount of dispersion, which introduces uncertainty at the detector, related mainly to transmission distance. This uncertainty is worse at high data rates—integration can help resolve the uncertainty, and there is less intergration time with the shorter high-speed pulses.

Ultimately, direct modulation is limited by the characteristics of the diode itself. A full turn-on/turn-off cycle represents a significant electrical and thermal stress, which can result in a frequency shift (chirp), transients (ringing), as well as reduced operational lifetime of the laser diode.

One method of dealing with these effects is to apply a modulated “radio signal” to the diode. The current swing is reduced, which improves reliability, and the bandwidth is greatly increased because the diode’s drift and transient responses are reduced. But this technique also greatly reduces the signal-to-

noise ratio, which reduces the range, and it requires more complex driver and detector circuitry.

Indirect Modulation

Modulation of a continuous light beam removes the laser diode-related problems at the cost of greater complexity. It also eliminates the signal-to-noise problems of applying a modulated subcarrier. The stable light source allows maximum transmission distance for a given amount of dispersion in the fiber.

Established methods include delivering the data to electrically modulated crystalline materials such as lithium niobate. These devices can rapidly switch the light beam between a direct signal path, or split the beam into two paths with 180-degree phase shift, which cancel when recombined. This provides electrically controlled on-off transitions that do not affect the light source.

The other common method uses electro-absorption (EA) modulators, usually a semiconductor material that can be switched between transmissive and opaque states to provide the on-off transitions. Materials used in these modulators can be conveniently integrated with the laser diode. As with direct modulation, the driving circuitry uses microwave design and layout to couple high speed data streams to the modulating devices.

The latest methods of achieving indirect modulation

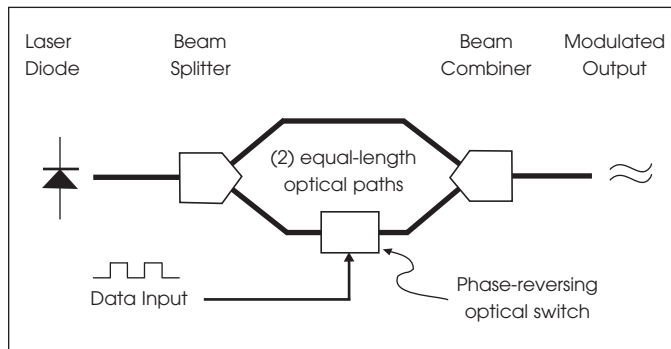


Figure 1 · Functional diagram of an optical modulator.

are fully integrated onto a single substrate. The latest developments in solid state optical switching are faster than EA, so switched optical paths are used, integrated onto the same substrate, with optical paths typically using transparent versions of the same material. Figure 1 is a block diagram of such an optical modulator, which can be further integrated with a detector onto a microprocessor or other device, as on-chip optical interface.

This tutorial only begins to discuss optical modulators. Readers are encouraged to find additional information using the many references available in books, as well as application notes from optical device manufacturers.