External Light Modulators

Ferroelectric light valves, modulated mirror arrays, piezoelectric shutters, Kerr cells, Pockels cells, Bragg cells and liquid crystals are all light modulators. They can be used to intensity modulate light being emitted by an external source as it passes through them or reflects off them. The light can originate from incandescent lamps, CW xenon gas arc lamps, light from a gas laser or even focused sunlight. Although usually very expensive, some of the devices can be used to produce powerful modulated light signals at high pulse rates.

Liquid crystal modulators are perhaps the slowest of the group. Most can't be driven much faster than about 100 flashes per second. Ferroelectric light valves and piezoelectric shutters are a little faster and can be pushed to perhaps 10,000 flashes per second. Kerr cells, Bragg cells and Pockel cells, on the other hand, are known to be very fast. However, they work best when used with laser light at a specific wavelength and at narrow angles. Some of these devices can modulate the light from a laser at rates beyond 100 million pulses per second. But, most of these devices are very expensive, are complicated and are therefore impractical for the average experimenter.

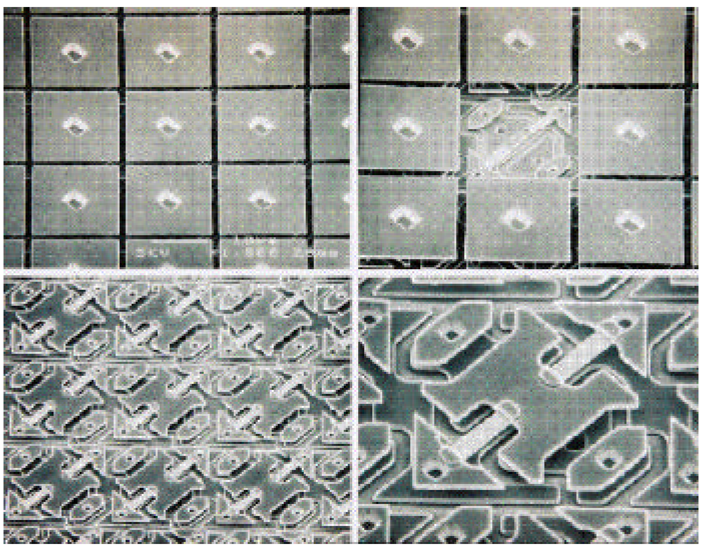


Figure 3j

A new device developed by Texas Instruments (***Figure 3j***) has some interesting possibilities. The technology was originally developed for flat panel computer and TV displays, but the techniques might be useful for optical communications. TI's process fabricates a large array of very small mirrors that can be moved using a voltage difference between the mirror and an area behind the mirror. Like tiny fans, each mirror would wave back and forth in response to the drive voltage. Because the mirrors are very small, the modulation rates might be pushed to perhaps 100,000 activations per second. If the mirrors were used to reflect light from an intense light emitter, a nice source of modulated light could be produced.

as much as 1000 watts of light with a narrow divergence. Such a transmitter would certainly have some long-range possibilities. However, most xenon discharge lamps are more useful for low speed and long-range applications, requiring very powerful light pulses. Many years ago, I constructed a demonstration telemetry system that launched very powerful light pulses at a low data rate that had a useable range of 50 miles. (See discussion on long-range telemetry transmitters using xenon flash sources.)

Nitrogen Gas (air) Sparks

For very powerful and very short light pulse applications, a simple electrical spark in air can be used. Some simple systems use two closely spaced (0.5mm) electrodes (usually made of tungsten) in open air. With sufficient voltage, the air between the electrodes can be made to ionize briefly, forming a small spark. Some gas barbecue grill igniters that use piezoelectric crystals to produce the needed high voltage, can be modified to produce useful sparks for some experiments. Commercially made nitrogen spark sources claim to generate light flashes that pack about 100,000 watts of light power into short 5 nanosecond pulses.

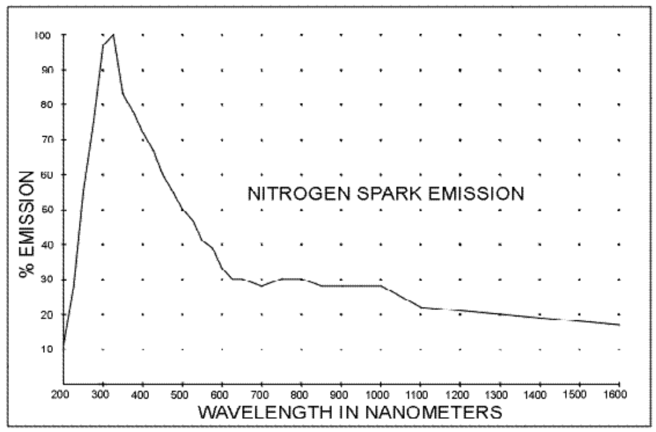


Figure 3i

The nitrogen (air) arc emits a broad spectrum of light with large peaks in the visible blue and invisible ultraviolet (see ***Figure 3i***.) Such a spectrum is not ideal when used with silicon detectors. But the small emission areas of the sparks allow simple lenses or mirrors to be used to form very tight divergence angles. But, the air ionization (sparking) can be become very unstable at high pulse rates, without using specially made discharge tubes and drive circuits. Therefore, the sparks are best used for powerful, very short pulse applications that demand only low pulse rates. Optical radar, electronic distance measurements, air turbulence monitors and wind shear analysis are some possible uses for such a light source. You shouldn't be fooled by the seemingly dim appearance of these light emitters. To our human eyes the tiny flashes may not seem very bright, but to a fast detector they can be very powerful. However, to take advantage of these unique pulses, a fast light detector and an equally fast amplifier must be used. Since few experiments have been conducted with these unique light sources, it is a great area for the experimenter to see what can be done.

Other Gas Discharge Sources

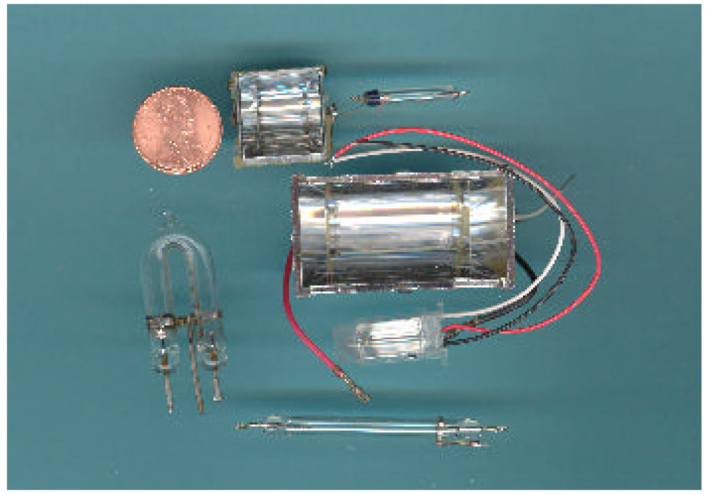
Glass discharge tubes filled with Cesium, Krypton or Rubidium will all produce lots of infrared light. Krypton behaves much like Xenon and has a very similar emission output. Cesium and Rubidium are both semi-liquids at room temperatures and can be operated under high or low pressures in a discharge lamp. Such lamps might be constructed in a similar manner to the more common yellow color sodium vapor street lamp. Cesium, in particular, appears to be a good candidate for some experimentation in developing some powerful light sources with high peak power outputs. Since kilowatt size sodium vapor street lamps are being manufactured, perhaps similar lamps using cesium could be made. Such lamps might be able to produce multi-kilowatts of modulated infrared light using pulse methods.

very powerful light sources that might be able to launch tens of thousands of watts of light, pulsed at rates exceeding tens of millions of light pulses per second. Although the typical experimenter may not be interested in such light power levels it does raise some interesting possibilities for use in city wide optical communications.

Gas Discharge Sources

Xenon Gas Discharge Tubes

The most common form of this class of light source is the electronic camera flash. These devices are some of the most intense light sources available to the experimenter and have many interesting applications. The discharge lamps are typically made from a glass tube with a metal electrode installed at each end. They are filled with xenon gas at about one atmosphere of pressure (14psi). The gas inside the tube can be made to glow with very high intensity when an electrical current is passed through it.



Xenon Lamps

As illustrated in ***Figure 3h***, the xenon arc emits light over a broad spectrum with some large peaks in the near infrared range. The electrical to optical conversion is fairly good. A typical camera flash can produce about 2,000 watts of light from about 10,000 watts of electrical power (20% efficiency). Some specially made discharge tubes can generate flashes that exceed one million watts of light power. As in fluorescent lamps, the minimum flash duration is somewhat dependent on the length of the discharge tube. A typical camera flash tube has an electrode gap of about 15mm (0.6") and will usually produce a flash, which lasts about one millisecond. The energy used to produce the short flash comes from discharging a special capacitor, charged to several hundred volts. By decreasing the size of the capacitor (say to 6 microfarads) and increasing the voltage (say to 300 volts) the camera flash tube can be made to produce flashes as short as 20 microseconds. Shorter discharge flashes are only possible by using specially made discharge tubes with very narrow electrode gaps (0.5mm). These narrow gap lamps can produce flashes as short as one half microsecond. However, the physics of the xenon gas arc prevents flashes much shorter.

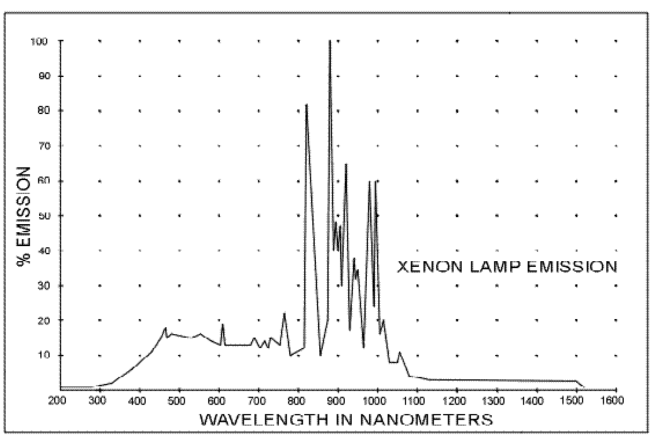


Figure 3h

Flash rates up to 10,000 per second are possible with the short gap lamps, but the typical camera flash tube can't be pulsed much faster than about 100 flashes per second. Since some special high speed lamps can dissipate up to 75 watts of average power, it is possible to design an optical voice information transmitter which could launch

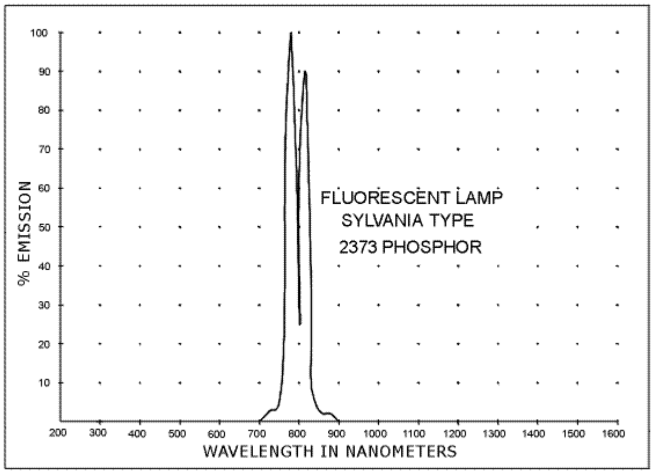


Figure 3g

up to about 10,000 pulses per second, but some miniature 2" tubes can be driven up to 200,000 pulses per second. The main factor that ultimately limits the modulation speed is the response time of the phosphor used inside the lamp. Most visible phosphors will not allow pulsing much faster than about 500,000 pulses per second. The visible light emitted by the typical "cool white" lamp is also not ideal when used with a silicon photodiode. However, some special infrared light emitting phosphors could be used to increase the relative power output from a fluorescent lamp, which may also produce faster response times. (see ***Figure 3g.***)

If a conventional "cool white" lamp is used, a 2:1 power penalty will be paid due to the broad spectrum of visible light being emitted (see ***Figure 3f***.) This results since the visible light does not appear as bright to a silicon light detector as IR light (see section on light detectors). Also, light detectors with built-in visible filters should **not** be used, since they would not be sensitive to the large amount of visible light emitted by the lamps. Although the average fluorescent lamp is not an ideal light source, the relative low cost and the large emitting surface area make it ideal for communications applications requiring light to be broadcasted over a wide area. Experiments indicate that about 20 watts of light can be launched from some small 9-watt lamps at voice frequency pulse rates (10,000/sec). Such power levels would require about 100 IR LEDs to duplicate. But, the large surface emitting areas of fluorescent lamps makes them impractical for long-range applications, since the light could not be easily collected and directed into a tight beam. (For additional information see section on fluorescent lamp transmitter/receiver circuits.)

Cathode Ray Tubes (CRT)

CRTs work somewhat like fluorescent lamps, since they too use fluorescence emission techniques. Electrons, emitted from a heated cathode end of the cathode ray vacuum tube, are accelerated toward the anode end by the force of a high voltage applied between the cathode and anode electrodes. Before hitting the anode screen, the electrons are forced to pass through a phosphor painted onto the inside of the screen. In response to the high-speed electrons, the phosphor emits light at various wavelengths. A voltage applied to a special metal grid near the tube's cathode end is used to modulate the electron beam and can thus produce a modulation in the emitted light. This principle is used in most computer and TV screens. Since the electron beam can be modulated at very high rates, the light source modulation rate is limited only by the response time of the phosphor used. Depending on the type of phosphor, the electrical to optical efficiency can be as high as 10%. Some specially made cathode ray tubes produce powerful broad (unfocused) electron beams that illuminate the entire front screen of the CRT instead of a small dot. Such tubes can yield powerful light sources, with large flat emitting areas. A variation on the usual television type CRT design positions a curved phosphor screen at the back of the vacuum tube and places the cathode electrode at the front or side of a clear glass screen (some portable Sony TVs use such CRTs). This technique increases the overall efficiency, since it allows the light from the phosphor to exit from the same side as the electron source. With the aid of external cooling, such techniques could create audio information over a range of only a few miles. The modulation technique was to vary the gas arc current that then produced a light intensity modulation. However, the extra cost and relative low power that resulted usually did not warrant the trouble. A properly designed system using a single LED will usually out perform any short-range helium-neon laser communications system at a fraction of the cost.

Although too expensive for the experimenter, some gas lasers have been used by the military for many years. In particular, carbon dioxide lasers, that emit long infrared wavelengths (10,000 nanometers), have been used in some military targeting systems. The long infrared wavelength can penetrate smoke and fog better than visible or near IR lasers. Also, the Navy has been experimenting with some blue-green laser light to attempt to provide communications to submarines deep under water. But, overall gas lasers fall short of the ideal for practical through-the-air communications.

Fluorescent Light Sources

Fluorescent Lamps

Fluorescent lamps work on the principle of "fluorescence" and because of their low cost have many through-the-air applications. An electrical current passed through a mercury vapor inside a glass tube causes the gas discharge to emit ultraviolet "UV" light. The UV light causes a mixture of phosphors, painted on the inside wall of the tube, to glow at a number of visible light wavelengths (see ***Figure 3f***.) The electrical to optical conversion efficiency of these light sources is fairly good, with about 3 watts of electricity required to produce about 1 watt of light. A cathode electrode at each end of the lamp that is heated by the discharge current, aids in maintaining the discharge efficiency, by providing rich electron sources. By turning on and off the electrical discharge current, the light being emitted by the phosphor, can be modulated. Also, by driving the tubes with higher than normal currents and at low duty cycles, a fluorescent lamp can be forced to produce powerful light pulses. However, like the pulse techniques used with LEDs, the fluorescent lamp pulsing techniques must use short pulse widths to avoid destruction of the lamp.

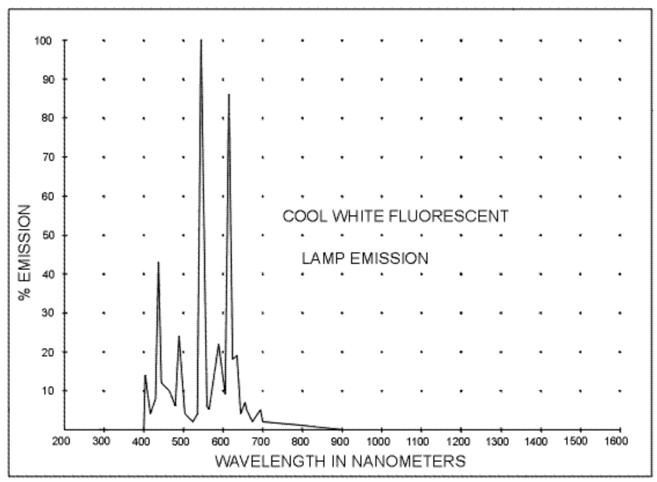


Figure 3f

To modulate a fluorescent lamp to transmit useful information, the negative resistance characteristic of the mercury vapor discharge within the lamp must be dealt with. This requires the drive circuit to limit the current through the tube. The two heated cathode electrodes of most lamps also require the use of alternating polarity current pulses to avoid premature tube darkening. The typical household fluorescent lighting uses an inductive ballast method to limit the lamp current. Although such a method is efficient, the inductive current limiting scheme slows the rise and fall times of the discharge current through the tube and thus produces longer then desired light pulses. To achieve a short light pulse emission, a resistive current limiting scheme seems to work better. In addition, there seems to be a relationship between tube length and the maximum modulation rate. Long tubes do not respond as fast as shorter tubes. As an example, a typical 48" 40 watt lamp can be modulated

Surface Emitting Lasers (VCSEL)

These devices are just now beginning to appear in some catalogs. Many companies have been experimenting with these latest semiconductor devices since about 1988. Their small size and high efficiency make them very suitable for some applications. They are mostly used in optical fiber communications. Instead of being grown as single chip emitters, these devices are fabricated into large arrays of very small individual laser sources sharing a common substrate. Since the individual laser diode emitters can be as small as one micron (1/10,000cm) as many as 100 million separate devices could be placed into a 1cm X 1cm area.

The output efficiency (electrical power to light power) has been reported to be about 40%, with each tiny device emitting about 0.003 watts. Although each device may emit only a small amount of light, when used as an array, 100 million such devices could launch some 100,000 watts of IR light from about 200,000 watts of electricity. Of course, cooling such a powerful array would be a real challenge, if not impossible. But, perhaps smaller arrays could be placed into common semiconductor packages for easy mounting and cooling. Maybe a 0.1-watt device would be placed into inexpensive LED style packages. Other devices may be mounted in better heat conducting metal packages to allow perhaps 100 watts of light to be emitted. Since their maximum modulation rates have been measured in the multi-billion pulses per second rate, surface-emitting lasers would be ideal for many future through-the-air communications applications. They would especially be useful in broadcasting optical information over a citywide area, where very powerful high-speed light sources are needed. A 10,000-watt source, emitting light in a specially shaped 360-degree pattern, might be able to transmit information over an area covering some 500 square miles. Such a broadcasting system might be used to transmit library type information from large centralized databases.

Externally Excited Solid State Lasers

Some of the very first lasers made were the Ruby and YAG lasers. Most of these lasers are excited externally using large xenon flash tubes that are positioned around the central glass laser rod. A small portion of the light from the xenon flash excites the specially positioned rod material, forming short coherent light pulses. Although these lasers are capable of emitting very power light pulses, with very narrow divergence angles, they are generally much too expensive and too complicated for the average experimenter. They would therefore find very limited use in earth-bound optical communications. However, some scientists believe that the extremely powerful light pulses that these devices are capable of producing, might be useful in transmitting information into very deep space. Since some pulsed lasers have been reported to launch light pulses approaching one terawatt (1000 billion watts), low speed communications might be possible to a range of several light years (one light year = 6 trillion miles). Such a feat would be very difficult to accomplish with microwave techniques.

Gas Lasers

Helium-neon, carbon dioxide and argon are the more common types of gas lasers. The light emitted from a gas arc, inside a glass tube, is bounced back and forth through the excited gas using specially fabricated mirrors. A portion of the light is allowed to escape through one of the mirrors and emerges as very monochromatic (one wavelength) and highly coherent (same phase) light. Such lasers have narrow divergence angles (typically less than 0.1 degrees) but have very low conversion efficiencies (much less than 0.1%). They are also expensive and bulky that makes them impractical for most optical communications applications. Some published designs that did provide experimental optical communications using helium-neon lasers were designed to transmit voice

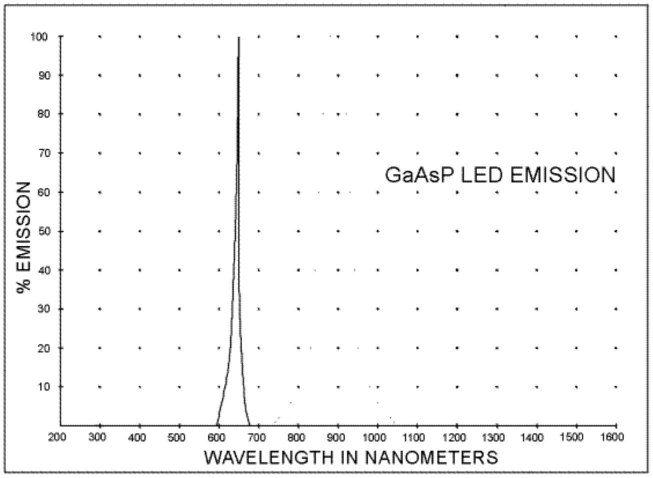


Figure 3d-1

addition, since their emitting spot sizes are very small, they can also be focused into very tight beams using rather small lenses. In addition, since their spectral widths are very narrow the matching light detector circuit can use an optical band pass filter to reduce the noise levels associated with ambient light (see receiver circuit section). For low speed and long distance applications, the GaAs laser should be considered. However, they do have some disadvantages. They typically cost much more than a GaAlAs LED (up to $75). They have shorter lifetimes (may only last a few hundred hours) and are sensitive to temperature. Therefore, they require a carefully designed transmitter circuit that can switch 20 or more amps at high speeds and can compensate for changes in operating temperature.

GaAlAs (CW) Lasers

These are the latest in infrared light emitting semiconductor devices and are rapidly maturing. The first wide spread application for these devices was in audio compact disk players and CD-ROM computer disk drives. They are also being used in some computer laser printers, bar code readers and FAX machines. They have very small emitting areas, can produce peak power levels in excess of 0.2 watts and have narrow spectral bandwidths (see ***Figure 3e***.) The most important improvement over other light sources is that they can be modulated at frequencies measured in gigahertz.

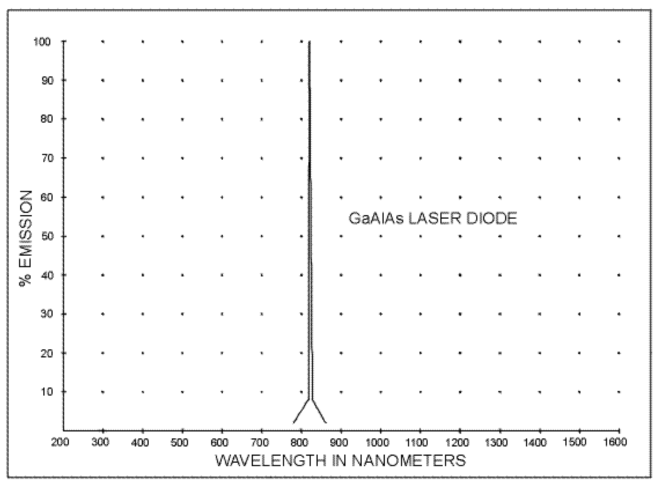


Figure 3e

However, as in any new technology they are still rather expensive. Low power units that emit less than 0.01 watts of 880nm infrared light, sell for about $20.00. Some of the more powerful devices can cost as much as $20,000 each. Although the use of a laser in a communications system might give a project a high tech sound, a much cheaper IR LED will almost always out-perform a low power laser (typical LED will be able to emit 10 times more light at 1/10 the cost) in low to medium speed applications. But, when very high-speed modulation rates (up to 1 billion pulses per second) are needed, these devices would be a good choice.

Although expensive now, these devices should come down in price over the next few years. They will also most likely be available at higher power levels too. But, until then, their advantages do not justify their expense and the more useful high power units are beyond the reach of practical experimental designs. I suggest using these devices only when necessary.

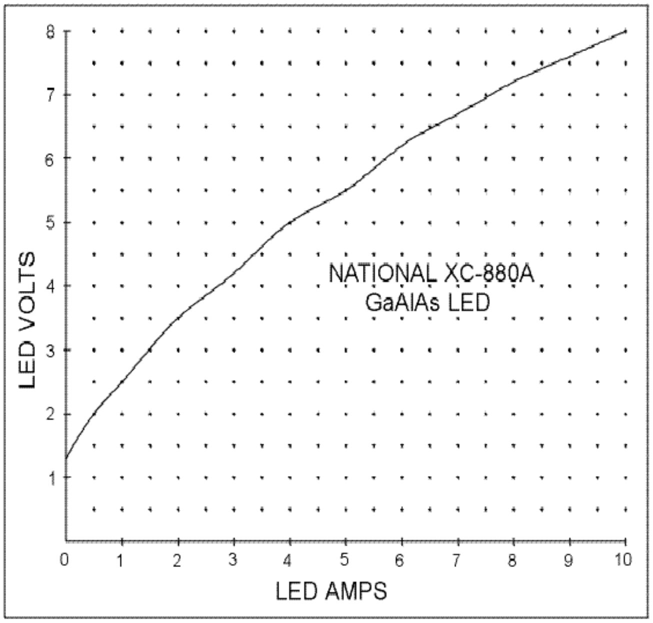


Figure 3c

GaAsP Visible Red LEDs

Although not as efficient as the infrared devices some visible red LEDs (***Figure 3d-1***)are now available, that might find limited use in some short range through-the-air applications. Some so called "super bright" LEDs boast high light output. However, even the brightest components will still produce only 1/3 as much light as a quality infrared part.

Also, since their light is a visible red color, an automatic 2:1 penalty will be paid when the devices are used with a standard silicon detector that has a weaker response to red light. The visible red LEDs are generally faster (up to 2 million pulses per second) than IR components and can therefore be used for medium speed applications. Also, since their light is visible, they are much easier to align than invisible IR devices, especially when the devices are used with lenses.

Solid State Semiconductor Lasers

GaAs (Hetrojunction) Lasers

These devices have been around since the 1960s and can produce very powerful light pulses. Some devices are able to launch light pulses in excess of 20 watts, which is some 200 times more powerful than a typical GaAlAs LED. But, these devices can only be driven with duty cycles, less than 0.1% (off time must be 1000 times longer than on time). Also, their maximum pulse width must be kept short (typically less than 200 nanoseconds) even under low pulse rate applications. However, despite their limitations these devices can be used in some voice transmitter systems if some careful circuit designs are used.

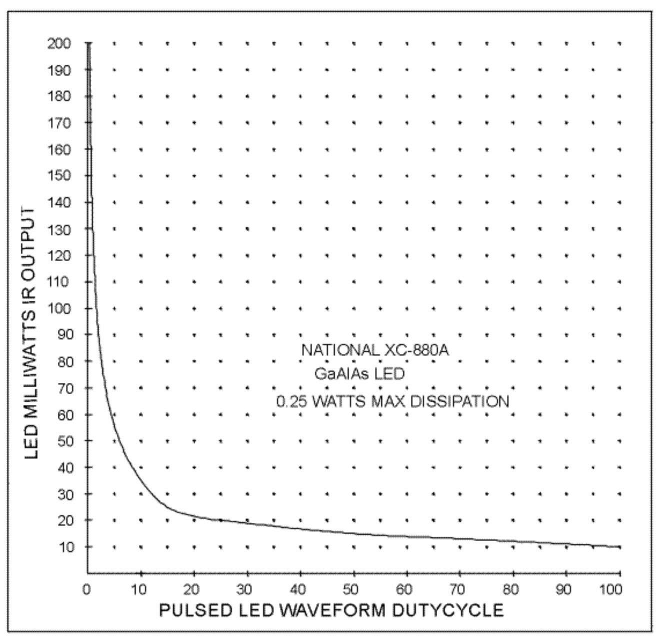


Figure 3d

As in most semiconductor lasers, the GaAs laser does require a minimum current level (typically 10 to 20 amps) before it begins emitting useable light. Such high operating currents demand more complicated drive circuits. Despite a 10:1 sensitivity reduction, caused by the rather narrow emitted pulses (see receiver circuit discussion), the more powerful light pulses available from GaAs lasers can increase the useful range of a communications system by a factor of about 3, over a typical transmitter using a single LED. In

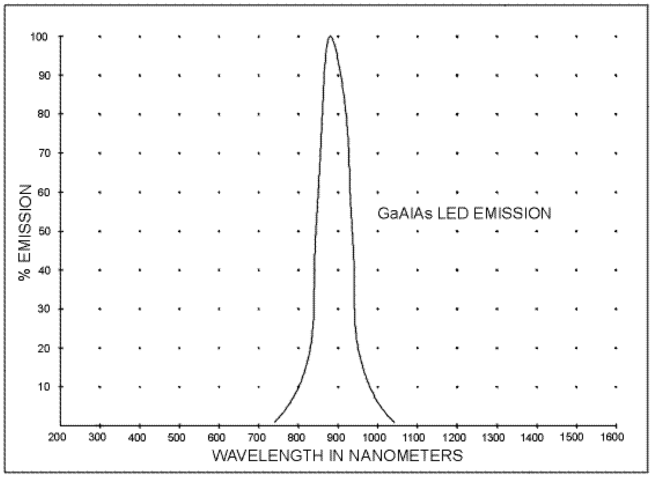


Figure 3a

pulses as short as 100 nanoseconds but most devices require at least 900 nanoseconds. At a current level of about 6 amps a quality device can emit about 0.15 watts of infrared light. However, at higher current levels their efficiency is generally poor, dropping to less than 0.5% (See ***Figures 3a, 3b, 3c and 3d***.) Many resemble the commonly used visible LEDs and will typically be packaged in molded plastic assemblies that have small 3/16" lenses at the end. The position of the actual LED chip within the package will determine the divergence (spreading out) of the exiting light. The typical T-1 3/4 style device will have a half angle divergence ranging from 15 to 40 degrees. They are low cost, medium speed (up to 1 million pulses per second) sources, with long operating lifetimes (typically greater than 100,000 hours).

They are a good choice for short and medium distance control links and general communications applications. When used with a large lens, a single device can be used for a communications system with a multi-mile range. Multi-device arrays can also be constructed to transmit information over wider areas or longer distances. They generally cost between $0.30 to $2.00 each and are available from many manufacturers.

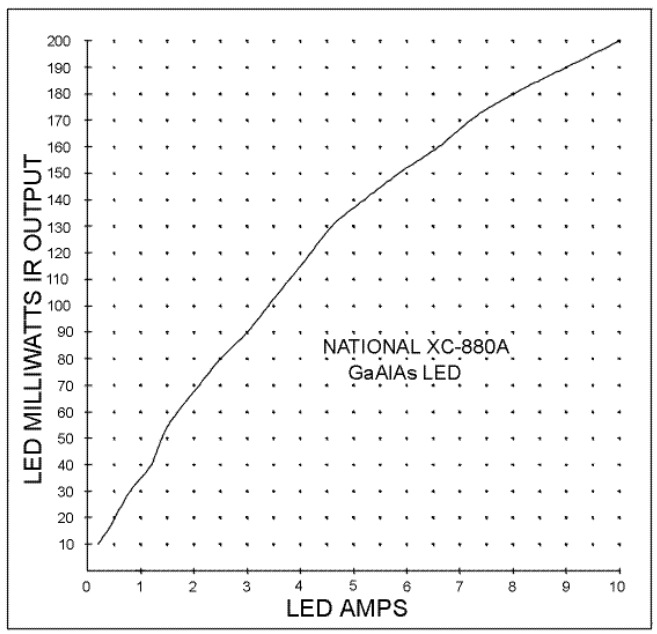


Figure 3b

GaAs IR LED

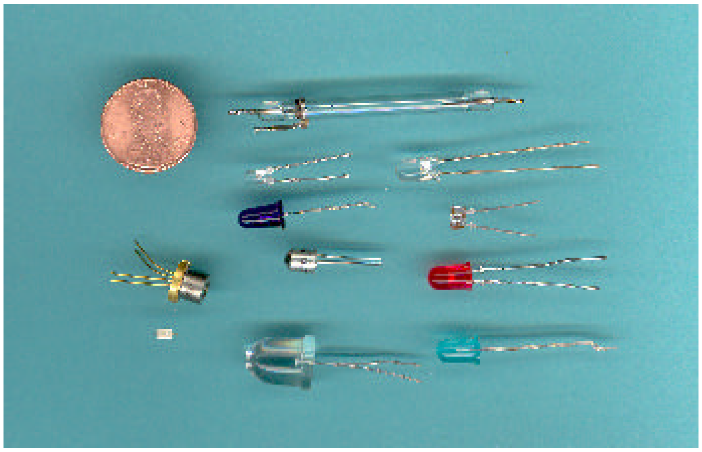
These devices are the older and less efficient cousin to the GaAlAs devices. They come in all styles and shapes. The more useful devices have smaller emitting surfaces than GaAlAs LED's, permitting narrow divergence angles with small lenses. Also, the small emitting areas make them very useful for fiber optic applications. Some commercial devices have miniature lenses cemented directly to the semiconductor chip to produce a small exiting light angle (divergence angle). In conjunction with a small lens (typically 0.5") such devices can launch light with a narrow divergence angle (0.5 degrees). The most important feature of the GaAs LED is its speed. They are generally 10 times faster than GaAlAs LED's but many only produce 1/6 as much light. They are often picked when medium speed transmission over short distances is required. Their price is typically a little more than the GaAlAs LED's, even though they use an older technology. They will cost between $2.00 to $25.00.

Chapter Three
LIGHT EMITTERS

Introduction to Light Emitters

Unlike the limited number of useable light detectors, there is a wide variety of light emitters that you can use for optical through-the-air communications. Your communications system will depend much more on the type of light source used than on the light detector. You should choose the light source based on the type of information that needs to be transmitted and the distance you wish cover to reach the optical receiver. In all cases the light source **must** be modulated (usually turned on and off or varied in intensity) to transmit information.

The modulation rate will determine the maximum rate information can be transmitted. You may have to make some tradeoffs between the modulation rates needed, the distance to be covered and the amount of money you wish to spend.



Samples of Emitters

Many light sources listed below are useful for low to medium speed modulation rates and can have ranges up to several miles. A few others are ideal for low speed telemetry transmission that can reach beyond 50 miles. If you need high speed information transmission, there are only a few choices, and those tend to be expensive. But, as the technology improves the prices should come down. I have also described some of the latest devices that may become available to the experimenter in a few years, but only demonstration devices exist today.

Light Emitting Diodes (LEDS)

For most through-the-air communications applications the infrared light emitting diode (IRLED) is the most common choice. Although visible light emitting devices do exist, the infrared parts are generally chosen for their higher efficiency and more favorable wavelength, especially when used with silicon photodiode light detectors.

GaAlAs IR LED

GaAlAs (gallium, aluminum arsenic) infrared LEDs are the most widely used modulated IR light sources. They have moderate electrical to optical efficiencies, (at low currents 4%), and produce light that matches the common silicon PIN detector response curve (900nm). Most devices can be pulsed at high current levels, as long as the average power does not exceed the manufacturer's maximum power dissipation specification (typically 0.25 watts). Some devices can be pulsed up to 10 amps, if the duty cycle (ratio of on time to the time between pulses) is less than 0.2% (0.002:1 ratio). Some of the faster devices have response times that allow them to be driven with current