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LASER COMMUNICATION SYSTEMS

Over the last year or two it seems that a growing number of Amateurs have been building laser communication systems. This is probably the result of two factors. First, the availability of surplus lasers is increasing while the cost is decreasing. Second, many of the VHF/UHF/Microwave contests now award extra points for laser contacts. Last fall at the Mid-Atlantic States VHF Conference I gave a talk on laser communications which seemed to generate a lot of interest, so I thought I'd cover laser communication systems in my first few columns. Understanding how to build and operate such systems requires knowledge of three factors: laser transmitters, laser receivers, and atmospheric effects on laser propagation. While a number of complex heterodyne laser communication techniques are possible, they are out of the realm of Amateur operation, so I'll deal only with simple direct detection systems here. This month I'll discuss the laser transmitter end of the link.

I think a little historical background would be useful. In 1917 Einstein postulated — as part of his theory of blackbody radiation — that when an atom in an excited state was hit by a quantum of radiation, it could be induced to emit radiation with the same frequency, phase, and direction as the incident quantum. The original incoming quantum of radiation isn't absorbed and amplification has been achieved because one radiation quantum has now become two. This process is known as the stimulated emission of radiation. The first practical use of this process came in the invention of a microwave amplifier in the early 1950s. This device was the MASER, which stands for Microwave Amplification by Stimulated Emission of Radiation. Later, the same principle was applied to optical frequencies and the optical maser was developed. This is now called the LASER, and stands for Light Amplification by Stimulated Emission of Radiation. Most lasers are used as light sources rather than amplifiers by using positive feedback (more on this later).

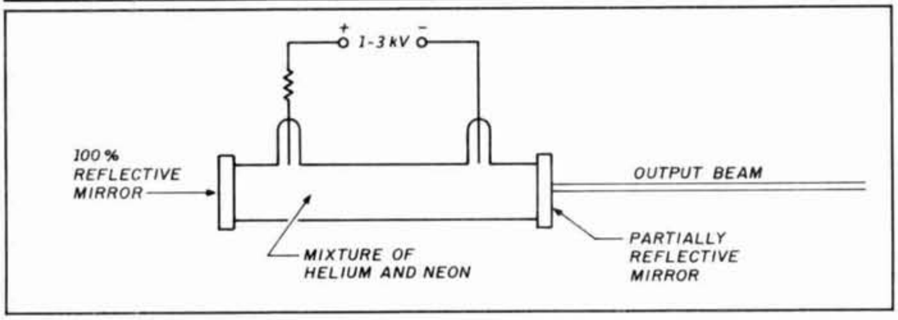
The many different types of laser are usually classified by the nature of the lasing medium. This medium can be a gas, liquid, or solid. The lasers which show up on the surplus market are almost always gas lasers. A mixture of helium and neon make up the lasing material. They are known as helium-neon or He-Ne lasers. Semiconductor lasers also show up from time to time, but they are generally less useful for DX communications purposes, so I won't deal with them here. The basic construction of a typical He-Ne laser is shown in **Figure 1**. A hollow glass or ceramic tube is closed off at each end by mirrors and filled with a mixture of helium and neon. One of the mirrors is 100 percent reflective; the other is only partly reflective, allowing some light to pass through. An electrical discharge is then set up in the tube, exciting some of the neon atoms. A few of these atoms emit light quanta through a process known as spontaneous emission. These light quanta can then collide with other excited atoms, causing stimulated emission (the amplification process) in the same direction as the incident quantum. Because there are mirrors at the ends of the laser tube, light quanta are reflected back and forth along the tube making many collisions with excited atoms in the process. This further amplifies the light and sustains the emission process through positive feedback. A small amount of light leaks out through the partially reflective mirror; this is the output laser beam. The wavelength of the output light is determined by the composition of the gas in a laser and the design of the tube and end mirrors. He-Ne lasers are normally designed to emit red light at a wavelength of 632.8 nm, but they can be designed to emit green light or even infrared radiation at lower efficiency. Other gas lasers, like the helium-cadmium (He-Cd) and argon (Ar), emit light mainly in the blue and blue-green regions of the spectrum. Note that the nature of the light output by a laser is usually characterized by its wavelength. A number of units are commonly used. They are:

Nanometers = 10^{-9} meters
Angstroms = 10^{-10} meters
Microns = 10^{-6} meters

The frequency of the output beam is rarely, if ever, used. Thus the red beam from a He-Ne laser can be characterized as one of the following, all of which are equivalent:

632.8 nm (nanometers)
6328 Å (angstroms)
0.6328 μ (microns)

FIGURE 1



Simple He-Ne Laser.

Expressed as a frequency these become:

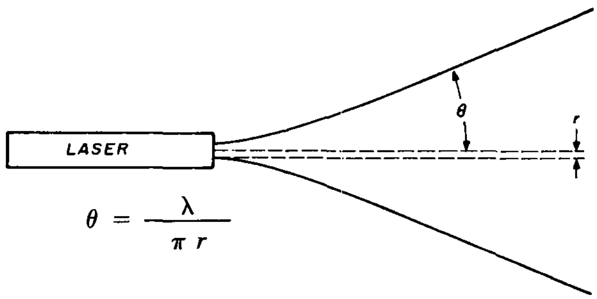
474.35 THz
474,350 GHz
474,350,000 MHz

Most of the He-Ne lasers on the surplus market have a power output of 1 to 5 mW, which is quite adequate for even long range DX contacts. Prices range from $40 to $200 depending on power output and condition.

A laser beam has several properties which distinquish it from other light sources. It consists of light of a single wavelength (or a very narrow wavelength range), in contrast to light from a flashlight which emits light over a very broad wavelength range. For an RF analogy, you might equate the laser with a single frequency crystal-controlled carrier, while the flashlight would be analogous to the output from a noise diode or even a spark transmitter! A second important characteristic of the output beam from a typical gas laser is its very small divergence (beam spreading). Even at a distance of about a mile, the beam from a small He-Ne laser spreads only to a diameter of 5 feet. A third unique feature of laser light is that it is coherent; that is, every light quantum, or photon is emitted in phase. This is very important in certain laser applications, like holography, but isn't a requirement for efficient DX communication.

From the standpoint of DX communication, perhaps the most important feature of the laser is the low beam divergence. The laws of physics indicate that all beams diverge, no matter how perfectly collimated (parallel) they are to start with, as a result of diffraction. The degree of divergence is directly related to the beam diameter — the larger the beam, the lower the divergence. A radio analogy can be found in parabolic antennas. A very large antenna produces a very wide initial beam with a very small beamwidth (divergence), whereas a small antenna produces a small initial beam with a large beamwidth (divergence). You can also look at this as a consequence of diffraction. The same equations govern both the spreading of a laser beam and the beamwidth of a parabolic dish. The geometry of diffraction spreading is shown in **Figure 2**.

FIGURE 2



$$\theta = \frac{\lambda}{\pi r}$$

where θ is the beam divergence in radians. (1 radian ≈ 57.3°)
λ is the wavelength
r is the beam radius
(λ and r are measured in the same units.)
For a He-Ne laser with a 1-mm diameter beam.

$$\theta = \frac{6328 + 10^{-7}}{(\pi) + (0.5)} = 4.03 + 10^{-4} \text{ Radians}$$

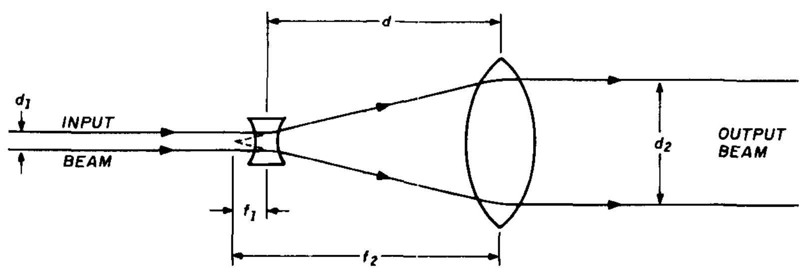
Total beam divergence = 0.806 mR or 0.046°

Diffraction limited beam spreading. Both θ and r are measured at the point at which the beam has an intensity of

$$\frac{1}{\ell}\left(\frac{1}{2.7}\right)$$

the intensity in the beam center (assuming a Gausian beam). θ then corresponds to the 4.3-dB beamwidth of the beam.

FIGURE 3

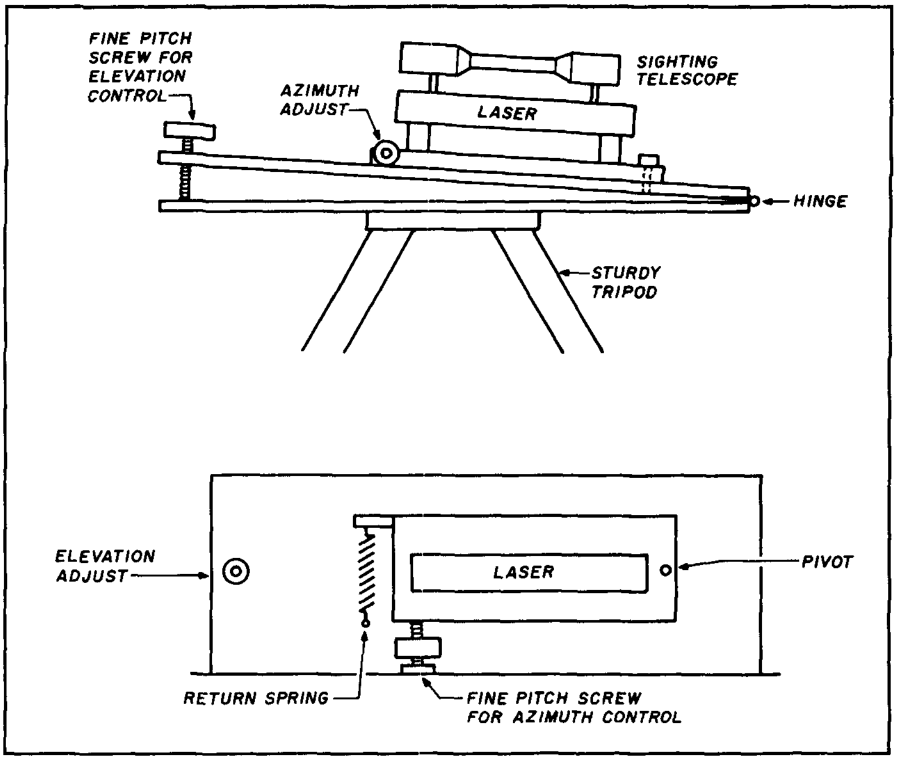


f1 = (negative) focal length of diverging lens (input)
f2 = (positive) focal length of converging lens (output)
Beam expansion = f1/f2
Lens separation = d = f2 − f1
With an input lens of focal length (−) 1 cm
and an output lens of focal length 4 cm:
The beam will expand by 4×.
The lens separation will be 3 cm.

Laser beam expander.

Increasing the beam diameter of a laser is analogous to using a higher gain antenna. Optically this is accomplished by means of a beam expander, as shown in **Figure 3**. This is akin to a Gallilean telescope used in reverse; that is, the beam enters through the eyepiece and exits through the objective. While such a decrease in beam divergence may be desirable for DX communication, it is not without significant problems. Most small He-Ne lasers have an intrinsic beam divergence of about 1 milliradian (1/20 degree). This means that the laser must be pointed at a distant receiving station with an accuracy of better than 1/20 degree. If the beam is expanded five times, the beam divergence drops by a factor of 5, and the required pointing accuracy becomes 1/100 degree. Obtaining such a pointing accuracy isn't an easy task. It requires a very solid mounting system and a capability for very fine positional adjustment, not only in azimuth but also in elevation. You can achieve this by using a system like the one shown in **Figure 4**. You can also try adding a sighting telescope as an alignment aid.

FIGURE 4



Azimuth-elevation mount for laser. Note: The greater the pivot-azimuth screw and hinge-elevation screw distances, and the finer the screw pitches, the better the fine adjustment capability. Never point laser at any person, animal, or vehicle.

In order to transmit information via a laser beam, you must achieve some form of beam modulation. Mechanically interrupting the beam is the simplest, cheapest, and most efficient modulation scheme. At reasonable CW speeds you can do this using a solenoid operated shutter. This would correspond to A1A emission using the WARC '79 scheme. Alternatively, you can modulate the beam at an audio frequency by passing the beam through a rapidly rotating wheel with slots cut in it (try the blades of a fan). This modulated beam can be keyed on and off mechanically. This is modulated CW (MCW), or A2A modulation, under the WARC '79 designation. The advantage of using MCW is that it lets you use a simpler receiver system which I'll describe later.

If you want analog (voice) or high speed digital modulation, there are a couple of ways you can accomplish it. The preferred method is to use an acousto-optic modulator. This device is made up of a special type of crystal which is acoustically modulated at a very high frequency (several MHz) by the application of an RF field. The process is similar to the piezo-electric effect exhibited by quartz crystals. This acoustic modulation sets up standing pressure and density fluctuation in the crystal which can diffract a laser beam passing through it. As a result, a single input beam is diffracted into two (or more) output beams. The relative intensity of the power in the beams is a function of the RF modulating power. When the RF power is modulated, the output beams are amplitude modulated. While this method is capable of efficient and rapid analog or digital modulation (with bandwidths in excess of 1 MHz), its disadvantages are high cost (new acousto-optic modulators are $500++) and the complexity of the drive electronics. Surplus equipment (from laser printers or FAX machines) containing acousto-optic modulators is sometimes available on the surplus market for $50 to $100.

A second method of amplitude modulation involves modulating the high voltage supply to the laser. This isn't very efficient because the maximum amplitude variation in the output laser beam is about 15 percent (typically it's much lower), but it can be done inexpensively. The reason for the low modulation amplitude lies in the discharge process in the laser tube. It operates somewhat like a common neon bulb. A certain voltage is required to "strike" the discharge, but if the voltage is too high, the resultant high current will destroy the tube. Because the tube voltage must be held within quite tight limits, the resultant power output doesn't change greatly. The voltage modulation can be achieved by connecting one side of a well-insulated transformer in the lead carrying the high voltage to the laser tube. The other side of the transformer is then connected to an audio modulation source. You may need to experiment to find the optimum conditions for maximum laser modulation amplitude; some lasers may be more amenable to this type of modulation than others. Typical modulation levels will be on the order of a few percent.

There are numerous other modulation methods. These include: reflecting the laser beam from a small mirror attached to a loudspeaker, using transmission type liquid crystal displays (LCDs) as a shutter, and various kinds of magneto-optic and electro-optic devices (Kerr cells and Pockels cells). Though all of these methods can be made to work, they will generally be less convenient and less efficient than