Lasers and Amateur Radio

By Maureen Thompson,* KA1DYZ

What do you think of when you hear the word laser? Killer satellites placed within the Earth's atmosphere destroying each other? Comic book space traveller Buck Rogers zapping the enemy, or Star Wars? Though these things are not reality in today's world, the progress of laser technology may soon develop systems such as these.

Amateur Radio operators experimenting with new technology are communicating in popular modes other than CW and voice. AMTOR, packet radio, RTTY and other computer-assisted communication are coming of age. Microwave records are still being created since its invention prior to the 1940's. What about laser communication? You might think its ultimate use is for military operation, industrial processes, or medical surgery, but what about Amateur Radio? What potential do lasers hold for this mode of communication?

The August 1984 issue of QEX featured Geoff Krauss, WA2GFP's, VHF+ Technology column. In Geoff's text, he mentioned laser contacts established during Amateur Radio contests. The data led me to investigate this area further. To understand laser technology, it is wise to look into its operation and what makes it work. Let's take a look at what type of laser would best suit Amateur Radio operation, and its basics.

The Birth of a New Technology

The first experiment involving laser technology began with Albert Einstein and Danish physicist Niels Bohr during the period of 1913 to 1917. They had discovered, through their individual laboratory research, that electrons exposed to external energy sources are raised to higher energy levels momentarily. When the energized electrons fall back to their original energy state, energy in the form of light or electromagnetism is released. It was also noted that electrons of the same material emit light of the same wavelength (like a "pump"). Ruby crystals are more easily pumped than other materials.

Laser is an acronym for "light amplification by stimulated emission of radiation." It is a human-made generator of coherent (monochromatic) light. This means that it is composed of a single wavelength or pure color, and has corresponding points on the wavefront that are in phase. It is an ideal wave whose spatial and time properties are clearly defined and predictable. Noncoherent light on the other hand, consists of random and discontinuous phases of varying amplitudes, and is made up of many wavelengths and colors. Light-emitting diodes (LEDs), produce incoherent radiation, but have a similar structure to that of the

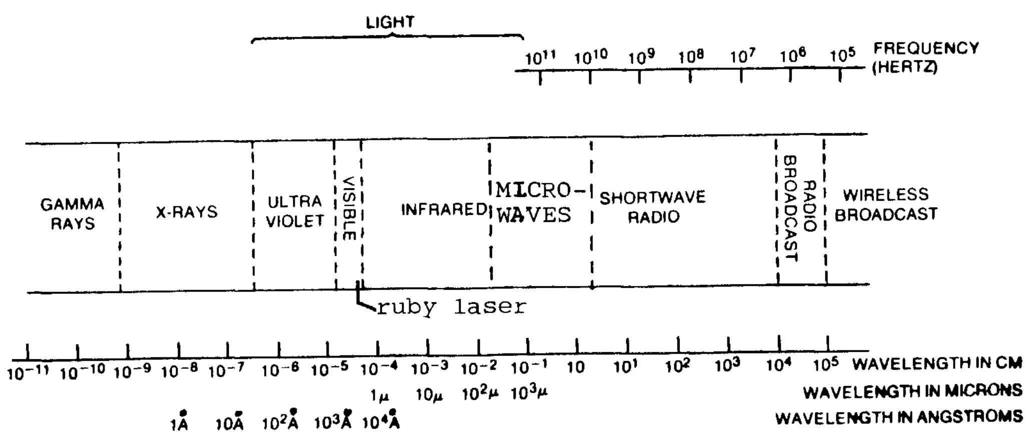

Fig. 1 -- The electromagnetic spectrum. The ruby laser falls within the visible light range. Other lasers producing coherent light span from the microwave region to the part of the spectrum where light is visible.

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semiconductor laser which will be discussed later. Fig. 1 shows the electromagnetic spectrum with the laser placed in its appropriate spot. Coherent radiation, produced by the laser, spans from the microwave region to the part of the spectrum where light is visible.

The laser as we know it today, was developed by Dr. Theodore Maiman at the Hughes Aircraft Company in Culver City, CA on May 14, 1960. Dr. Maiman's laser system consisted of a small ruby rod with both ends smoothly polished. The ends were silvered like a mirror, and one end consisted of a very thin silver layer to enable light escapement. A xenon flashtube was wound around the rod. When the flashtube energized, a large number of photons were generated within microseconds. Photons can be perceived as packets of energy whose characteristics are those of matter as well as electromagnetic radiation travelling at the speed of light. Many of these photons were absorbed by the rod because the tube is wrapped around the ruby rod. The absorbed photons excite the ruby and place the atoms in a high-energy state. As these atoms or molecules expel excessive energy, other photons are generated. At the silvered end, the moving photons are reflected back and forth repeatedly. This is called avalanche action. They strike other atoms and molecules during their activity and create more photons. Radiation strength increases within the ruby because of this. One end is semitransparent and some photons escape in a beam of the same wavelength and diameter of the ruby. This beam is confined to a very narrow frequency characteristic of the ruby material. This single-frequency light is called monochromatic or coherent.

Dr. Maiman's laser system is shown in Fig. 2. This design was suggested by Charles Townes and Arthur Schawlow in their 1958 publication. Their first experiment took place in 1951 and included the use of a "maser." Similar to the laser, the maser consisted of a small metal box containing excited ammonia molecules. With microwaves radiating into the cavity tuned to 24 kHz, a highly coherent beam of high-frequency microwaves was emitted. Prior to this, Gordon Gould wrote his laser ideas in 1957, notarized it and approached the Pentagon for funding. Visions of military "death rays" impounded Gould's notebooks until he won a patent challenge in the late 1970's. In 1968, lasers performed tasks in integrated optics, a discipline that emerged as part of the pursuit to develop optical communications systems (LEDs, electro-optic scanners).

A few years after Dr. Maiman's laser system was widely accepted by research institutes across the country, the first Amateur Radio laser demonstration (one-way) took place. On May 3 and 4, 1963, the Radio Club at Electro-Optical Systems, Inc., of Pasadena transmitted a voice message 118 miles across the California dessert. Using a helium-neon laser and a pair of confocal (having the same focus) mirrors, this event claimed a new

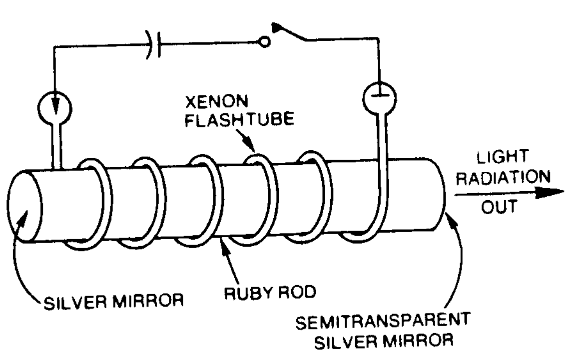

Fig. 2 -- Diagram of the first laser system invented by Dr. Theodore Maiman in 1960.

record for communications on 474,100,000,000 kc.

The laser used in "Operation Red Line" was excited and modulated by a Viking II operating on 28.62 Mc. Measured laser output was 1/8 mW. At the receiving end, a beam was collected through a 12 1/2-inch telescope which fed an S-20 photo-multiplier tube and its associated translation equipment. An audio amplifier was connected to a loudspeaker and a tape recorder.

The first two-way laser QSO took place at the U.S. Air Force Academy in Colorado on February 25, 1971. WA8WEJ/Ø and W4UDS/Ø are credited for establishing point-to-point contact over a 950-foot path on 475 teraHz (Mega-Mega Hertz). Their laser was modified for AM using a power transformer as a modulation transformer. The receiver was an RCA 929 photo tube which sensed the audio variations in light intensity. The audio signal was then amplified and fed into a speaker.

During the 1960's, a laser kit could be purchased for less than $100. Because of this low cost, high school students such as Thomas D. East, WB8LOX, also became involved in experimenting with pulse-frequency modulation (PFM) laser communication systems.

Operation of the System

The laser operates on the principle of stimulated emission. Imagine two levels of electrons; the upper level which is mostly unoccupied by electrons, and the lower or ground level that normally consists of many. When an electron is in the upper level, a light wave of the same wavelength corresponding to the energy difference strikes the electron in the excited state. The light stimulates the electron to transfer down to the lower level and emit a photon. This photon is emitted in the same direction, and its associated wave is in the same phase as that of the incident photon. This is shown in Fig. 3.

"Pumping" is an expression used to describe the process of exciting laser material, or raising electrons to an excited state. It can be done optically using a lamp, by electric discharge, chemical reaction, or semiconductor laser (inject electrons into an upper energy level by means of an electric current).

Laser systems that we are familiar with is the Fabry-Perot Optical Resonator. This type of cavity provides optical feedback and consists of two parallel mirrors. The rear mirror fully reflects while the front partly reflects and partly transmits at the laser wavelength. The light reflected from the front and rear mirrors serves as positive feedback to sustain oscillation. The light transmitted through the front mirror acts as the laser output.

Laser action is started by spontaneously emitted light from excited atoms or molecules.

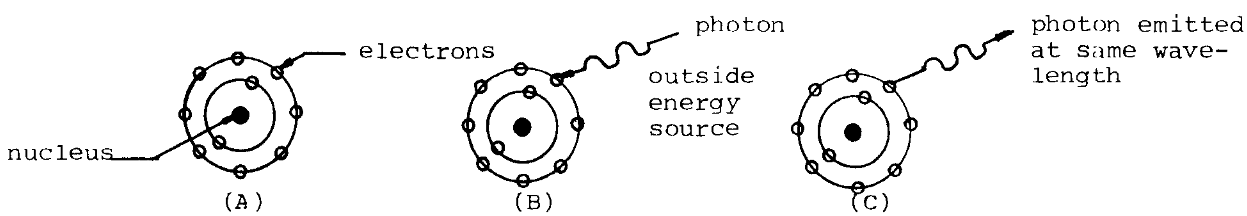

Fig. 3 -- Fig. A shows an atom with electrons orbiting its nucleus. When an outside energy source strikes the atom, a photon is absorbed, sending the atom into an excited state. (Fig. B) When a photon at the same frequency is released, the atom is allowed to return to a low-energy level (Fig. C) until another photon strikes. This process goes on continuously, amplifying energy buildup until a coherent light beam is produced.

The two mirrors form an optical cavity that can be tuned by varying the spacing of the mirrors. The laser can operate only at wavelengths for which a standing-wave pattern can be set up in the cavity (the length of the cavity is an integral number of half wavelengths). Mirrors may be separate or deposited on its end faces.

Population inversion is necessary to initiate and sustain laser action. Let's look at our two levels again. When the upper level has a greater collection of electrons in an excited state than the lower one, a population inversion is said to exist. This supports lasing since a travelling wave of the proper frequency can stimulate downward transitions and the associated energy can be amplified.

Spectral mode means the multiplicity of radiation patterns permitted within the cavity. Spacing of the mirrors determines the longitudinal (or axial) modes. This mode structure oversees the spectral characteristics of the laser (coherence length and spectral bandwidth). Transverse modes (set crosswise), vary not only in wavelength, but also in field strength in the plane perpendicular to the cavity axis. It determines the spatial characteristics (beam divergence and beam energy distribution).

Mode control or selection is achieved by varying the mirror curvatures, restricting the beam by apertures in the cavity, using resonant reflectors that reflect only a narrow band of wavelengths, and using Q-switching techniques. Q switching (Q spoiling) is a means of obtaining all the energy in a single spike of very high peak power. These spikes result because the inverted population is being alternately built up and depleted. Lowering the Q of the optical cavity means the laser cannot oscillate, and a large inverted population builds up. When the cavity Q is restored, a single "giant pulse" is generated. This method is useful in communication.

Gas Lasers

There are four basic categories of lasers. They are: gas, solid-state optically pumped, liquid dye and semiconductor. I will go through each of them quickly, but the one Amateur Radio communications is concerned with is the gas laser. The helium-neon laser is a popular device in this category and produces a continuous wave (CW) beam in the red and near infrared region of the electromagnetic spectrum. For applications such as data transmission, it is necessary to have sources of continuous light beams. This is accomplished in liquid and gas lasers. It also has the broadest spectral coverage and offers variety. The laser medium, the material used as the rod in the cavity, may be very pure, a single-component gas or a mixture. It can also be a permanent gas, or vaporized solid or liquid. The active species in the gas laser may be a neutral atom, an ionized atom, or a molecule (including excimers, "stable" molecules only in an excited state).

Operating pressures range from a fraction of a torr to atmospheric pressure, with operating temperature from $-196^{\circ}$to 1600°C. Excitation methods include electric discharges (glow, arc, pulse, RF, dc), chemical reactions, supersonic expansion of heated gases (gas dynamic), and optical pumping. Average output power of useful gas lasers range from a few microwatts to tens of kilowatts (10 orders of magnitudes). Peak power ranges are from a fraction of a watt to 100 MW. Range of output wavelengths extend from 0.16 to 774 µm at discrete wavelengths.

Most gas-laser materials have different wavelengths. The neon atom has more than 100, the argon ion more than 30. By rotating a prism or diffraction grating in the optical cavity, it can be operated with a multiwavelength output or one transition at a time.

Most gas lasers are excited by electric discharges. This method is performed with two electrodes protruding into the laser tube. Electrons accelerated by the electric field transfer energy to the gas atoms and molecules by collisions. These collisions may excite the upper laser level directly. Indirect excitation is also possible by cascading from higher-energy levels of the same atom (or molecule) or resonant-energy transfer from one atom (or molecule) to another by collision. Radio frequencies of about 20 to 30 kHz are used and the electrodes are wound around the discharge tube.

Typical configuration of these lasers has the gas contained in a glass tube with an electrode near either end. The ends are sealed by windows mounted at Brewster's angle (Hutchinson, Technical Correspondence, May 1983, p. 43) to minimize reflections at the windows (for one plane of polarization). An optical cavity is formed by two mirrors (usually both are concave), at least one of which is partially transmitting. When an electric discharge is produced in the tube between the electrodes, the gas atoms or molecules are excited and laser action begins.

In laser terminology we refer to a laser transition by its wavelength in micrometers (µm) or nanometers (nm), and discuss the structure of the transition in terms of frequency. Oscillation can occur at discrete frequencies (cavity modes) at frequency spacing of f = frequency; c = velocity of light, and L = separation of cavity mirrors. The formula for this is: $\Delta f = c/2L$

Depending on the nature of the laser medium and geometry of the optical cavity, oscillation may occur at a number of different modes, within the line width of the transition. Typical widths of the Helium Neon (HeNe) common-gas laser are:

(HeNe)	λ, µm	line width, MHz
	0.6328	1,700
	1.15	920
	3.39	310

Single-axial-mode oscillation is generally achieved by reducing L so that only one axial mode lies within the line width of the laser transition. A stable optical cavity is required for both frequency and amplifier stability.

The HeNe exhibits low-power (few milliwatts) visible (CW), with over 35 gas-laser species commercially available. Continuous wave lasers are mostly manufactured with helium and neon gases and are electrically stimulated. It contains a power supply that delivers high voltage to a tube filled with the gas(es). Mirrors, one partially transparent, are located at opposite ends of the tube. As long as there is power, a coherent light beam is produced by the electrons of the gas(es). Circulating liquids in lieu of gases, are suitable for lasing in a continuous wave laser. Chemical lasers are now being developed and require no external source of power.

Other Laser Systems

The solid-state optically pumped laser category spans the visible to near infrared region. Its output frequency is limited to a few sharp closely spaced lines. The wavelength of these lines depends on the active ion in the laser. This is the only laser class that can be Q-switched or cavity-dumped. The electronic transitions are pumped either by flash lamps or by semiconductor diodes. Their size is equivalent to that of a sliver of glass. It can be continuous wave or pulsed at microsecond durations with a peak of about 10 watts of power.

Optically-pumped organic-dye lasers extends in wavelength from 0.4 to 1 µm. The major distinction within this category is its continued tunability over the entire visible spectrum. Because of their broadband spectral output, these lasers can generate subpicosecond pulses when mode-locked. Primary use is in spectroscopy and photochemistry.

Semiconductor or injection lasers are pumped by the injection of excess electrons and holes into a thin semiconductor layer. Radiation is produced when the excess carriers recombine, producing photon energies equal to the band-gap energy. Lead-salt laser diodes operate from 4 to 30 µm, continuously tunable either by varying the drive current or temperature. This form of laser is also used primarily for spectroscopy and must be cooled to 77 K during operation. Semiconductor lasers possess narrow emission bands and a change in temperature varies the output wavelength. They are distinguished by small size and require a low voltage dc power supply.

Fiber-optic communications is potentially the broadest application for semiconductor lasers and LEDs. Research is currently directed toward emitters in the 1.1- to 1.4-µm range. Here, fibers exhibit the lowest loss and dispersion. Selection of the emitter, LED, or laser depends upon required information bandwidth and the fiber length. Key factors considered are fiber attenuation, pulse broadending, and coupling efficiency. First and last factors determine diode power and radiance. Pulse broadending dictates the broadest acceptable spectral bandwidth, assuming fiber dispersion is the limiting factor. Long-distance applications prefers the laser because of its narrow spectral bandwidth (0.16 to 2.0 nm) and high radiance. Short distance lower data-rate applications, the LED may be preferred because of its reduced temperature stability and simpler construction.

Carbon dioxide lasers are continuous wave devices and are most efficient and powerful. Their beams radiate at a wavelength of 10.6 microns, making them invisible to the human eye. This type provides high wattage and heat. Fifteen thousand watts of coherent light can melt almost anything (within the range of this laser).

Conclusion

From the above data, you will agree that the laser holds a great potential as a communications mode. If you are involved in Amateur Radio laser activity (out of the laboratory), keep in mind that eye protection is mandatory and the goggles chosen should be "tuned" to the laser frequency in use! In every book I referenced, this important rule was stressed. There is currently an argument concerning the energy density of collimated (beam) light incident on the cornea (and retina) that will produce eye damage. If you have any questions of the energy levels involved, contact the proper sources for the facts.

The intensity of laser light can reach levels of over 1,000 MW/cm2. A beam of such intensity can cut through and vaporize materials. A laser currently being developed for atomic fusion applications has a temperature of about 100 million degrees and can supply 40 trillion watts of power on target to an atom.

What role does the laser play in the world familiar to us? Thousands of lasers in medical use perform tasks such as cauterizing wounds and destroying cancerous cells. The focused beam exhibits a high energy concentration — as high as the surface of the sun in spots a few thousandths of an inch in diameter. From a short distance away, however, the beam is no stronger than that from a standard light bulb.

The distance to the moon was measured to an accuracy of less than five feet when Apollo 11 carried a special mirror reflector on their journey. The use of microminiature solid-state laser arrays in the computer memory area, in conjunction with light-sensitive materials, can store and retrieve up to a billion bits of data from an area measuring one centimeter square (0.2 in^2). This is a density increase of nearly ten thousand times that of the modern computer memory.

Holography, invented by Dennis Gabor in 1949, is being developed as a medium for data storage in computers. The manufacture of IC chips is assisted by laser beams 300 millionths of a meter wide in the photographic processes, providing precision necessary for the scale of the work.

For the time being, laser communications are limited. Turbulence in the atmosphere limits the amount of information that can be transmitted. One method of eliminating this problem is to confine the beam to a pipe. This might not be practical for the average radio operator, however.

I could cite more examples of lasers in use today, but it would fill many pages. If you are involved in laser communications, drop me a line. I would be happy to hear about your project and share your experiences with others. Though much has been written on laser systems and how they operate, little can be found in the Amateur Radio journals. How many experimenters are dabbling in the world of lasers and employing those applications toward Amateur Radio?

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