Chapter 2
Laser Technology

The development of lasers has been an exciting chapter in the history of science and engineering. It has produced a new device with potential for applications in an extraordinary variety of fields. Einstein developed the concept of stimulated emission on theoretical grounds. Stimulated emission is the phenomenon that is utilized in lasers. Stimulated emission produces amplification of light so that buildup of high-intensity light in the laser can occur. Einstein described the fundamental nature of the stimulated emission process theoretically.

This characterization of stimulated emission did not lead immediately to the laser. Additional preliminary work on optical spectroscopy was done in the 1930s. Most of the atomic and molecular energy levels that are used in lasers were studied and investigated during those decades.

2.1 Basic Principles

The word laser is an acronym for light amplification by stimulated emission of radiation, although common usage today is to use the word as a noun—laser—rather than as an acronym—LASER.

A laser is a device that creates and amplifies a narrow, intense beam of coherent light.

Atoms emit radiation. We see it every day when the "excited" neon atoms in a neon sign emit light. Normally, they radiate their light in random directions at random times. The result is incoherent light—a technical term for what you would consider a jumble of photons going in all directions.

The trick in generating coherent light—of a single or just a few frequencies going in one precise direction—is to find the right atoms with the right internal storage mechanisms and create an environment in which they can all cooperate—to give up their light at the right time and all in the same direction.

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In a laser, the atoms or molecules of a crystal, such as ruby or garnet—or of a gas, liquid, or other substance—are excited in what is called the *laser cavity* so that more of them are at higher energy levels than are at lower energy levels. Reflective surfaces at both ends of the cavity permit energy to reflect back and forth, building up in each passage.

Only three basic components are necessary for laser action: a lasing medium, a pumping system that supplies energy to the lasing medium, and a resonant optional cavity. Lenses, mirrors, shutters, saturable absorbers, and other accessories may be added to the system to obtain more power, shorter pulses, or special beam shapes.

2.2 Overall Theme

This report deals with the effects of directed energy weapons, treating such diverse types of weaponry in particular laser and in our case airborne laser (ABL). Although when we talk about directed energy weapon, we can consider such weapon as particle beams, microwaves [1], and even bullets as part of directed energy weapon (DEW) system. In order to understand these weapons and their effects, it is necessary first to develop a common framework for their analysis, and in our particular case, we expand our concentration on just laser as DEW in particular ABL under the scope of this project and related issues of laser range safety tool (LRST).

It is a thesis of this report that all laser weapons (continuous or pulse) may be understood as devices which deposit energy in targets and that the energy which must be deposited to achieve a given level of damage is relatively intensive to the type of laser weapon employed, type of engagement environment, dual time on target, and type of targets these weapons are engaged.

Of course, energy cannot be deposited in a target unless it has first delivered there. Therefore, an important element in understanding laser weapons is knowledge of how they deliver (or "propagate") their energy. Some loss of energy is invariably associated with this propagation, whether it is the atmospheric effect such as a known phenomenon as thermal blooming [1] or delivery system as well as other related technical and obstacle issues. A laser weapon must therefore produce more energy than needed to damage a target, since some of its energy will be lost in propagation. As a result, weapon design depends upon two factors: first, the anticipated target, which determines the energy required for damage, and, second, the anticipated scenario (range, engagement time, etc.) which determines how much energy should be produced to insure that an adequate amount is delivered in the time available and dual time on target.

2.3 A Word About Units

Since our goal is to reduce the jargon associated with different types of laser weaponry to common units, the choice for these common units is obviously of interest. For the most part, we will use metric units of MKS, where length is in meter, mass is in kilograms, and time is in seconds. In these units, energy is expressed as *joules*.

2.4 Developing Damage Criteria

If we are to determine how much energy a weapon must produce to damage a target, we need to know two things:

1. How much energy it takes to damage a target.
2. What fraction of the energy generated will be lost in propagation to it.

These will be developed in detail for different weapon types in subsequent sections. For the moment, we will consider some of the fundamental issues, which affect damage, and propagation of laser weapon independent of its type (CW or pulse).

2.5 The Energy Required for Damage

In order to be quantitative about the amount of energy necessary for damage, we must first define what we mean by damage. For a military system, this could be anything from an upset in a target's computer (in case of microwave weapon) and preventing it from operating or to total vaporization (in the case of laser weapon). These two extremes are usually referred to as "soft" and "hard" damage or kill, respectively. The study of soft damage clearly is beyond the scope of this project and is much more sensitive to specific details of the target system and its shielding as well as related countermeasure under attack than hard damage. Few good references are published and are available for soft kill or damage study [2].

Without knowing the details of a computer, its circuitry designs, and the hardness of its chips and electronic components, we will not know if it has been upset until we see it in operation, whereas vaporizing it produces immediate feedback on the effectiveness of an attack, and it is the subject of this project. On the other hand, vaporizing a target will require more energy than degrading its performance. We will concentrate in this book on hard or catastrophic damage for two reasons: it avoids target-specific details, which are often classified, and it provides a useful first cut at separating weapon parameters, which will almost certainly result in damage from those for which the likelihood of damage is questionable or for which more detailed analysis is required.

As a simple example of the kind of energies necessary to achieve damage, let us first consider what it takes to vaporize a given target using laser techniques employed in effects of high-power laser radiation [3] or effect of laser radiation on absorbing condensed matter [4].

2.6 The Laser Beam

The laser beam has many unique qualities, which can be manipulated in many ways by the use of different accessories that are added to the basic laser. The beam is characterized by its collimation, coherence, monochromaticity, speed, and intensity [5]. The laser beam is the source of light that can have all the above properties, while the other source of light may possess these properties but not all at the same time.

Collimation in a laser can be very high, which means that the radiation emitted by most lasers is confined to a very narrow beam, which slowly diverges as the beam moves away from the laser source, a phenomena that is known as diffraction.

Diffraction refers to the spreading, or divergence, of light which emerges from an aperture of given diameter, as shown in Fig. 2.1 [6].

In this figure, a beam of light of essentially infinite beam width is passed through an aperture of diameter D. Calculating the beam divergence or diffraction is a matter of elementary geometry analysis, and it can be shown that the angle of divergence θ is related to D and the wavelength, λ, of the beam by relationship $\theta \approx \lambda/D$. The divergence of the beam is normally a small enough angle so that the approximation holds that the sine and tangent of the divergence angle have the same value, with the angle itself expressed in milliradians (a milliradian divergence would mean that a beam would be 1 yard wide at 1000 yards range, 2 yards wide at 2000 yards, and so forth) [5]. Due to nature of wave light, it is impossible to make a laser weapon that is 100 % collimated beam and has no divergence at all (see

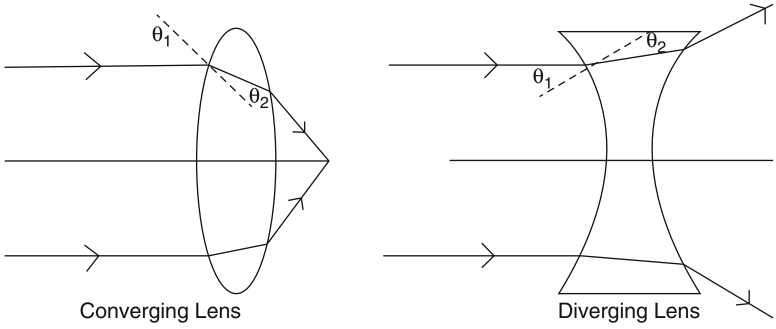

Fig. 2.1 Converging and diverging lenses (Figure has been adapted from Figure 3.13 in Eugene Hecht and Alfred Zajac, Optics, Addison-Wesley, 1976)

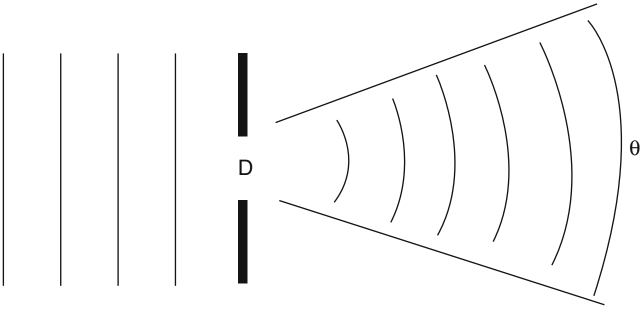

Fig. 2.2 Diffraction of light passing through an aperture

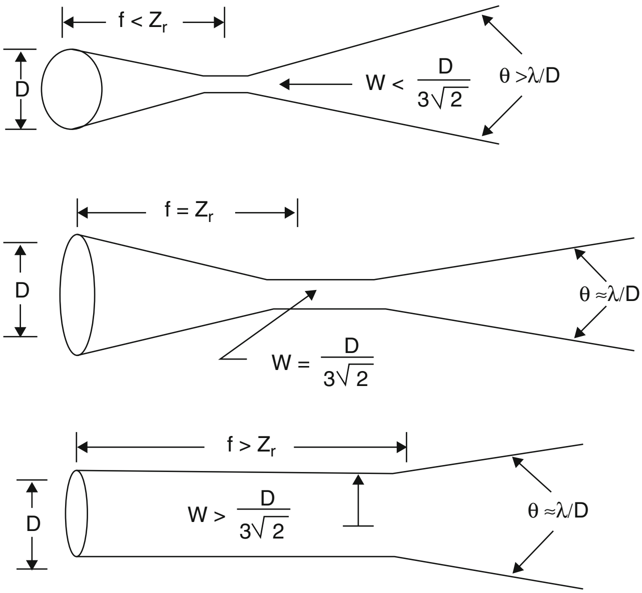

Fig. 2.3 Focusing of a beam of light and the Rayleigh range

Fig. 2.2). However, the angle of divergence of a laser beam can be forced to be as small as possible by usage of a converging lens that is placed in path of the beam. Such approach reduces the effect of divergence to achieve a longer effective beam as illustrated in Fig. 2.3.

These lenses serve as an apparatus to bend the laser beam inward, focusing it to a spot of radius *W*. The width of the focal spot depends upon the focal length, *f*, of lens. For shorter length of *f*, the beam focuses to smaller spot and will diverge rapidly beyond that spot, and for longer, *f*, the light diverges as it leaves the source of the light at the aperture.

The best optimum focal length at which beam has the best optimum collimation for greatest distance is known as the *Rayleigh range*, Z_r. The beam radius at the

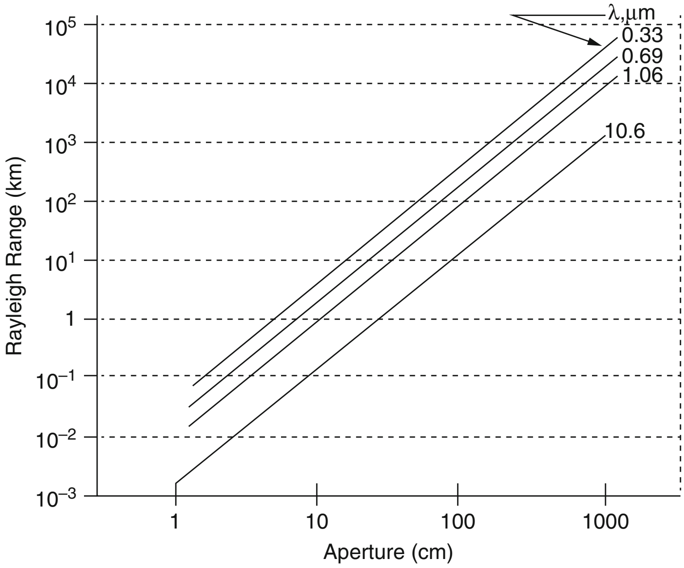

Fig. 2.4 Rayleigh range vs. aperture and laser wavelength

Rayleigh range is $W = D/3\sqrt{2}$, and the Rayleigh range is given by $Z_r = \pi W^2/\lambda$. Therefore, in practical application, laser light can be used as a collimated beam over a distance of about twice the Rayleigh range or about D^2/λ, where D is the aperture from which the light emerges from the weapon and λ the wavelength of the light. If the laser designer wants this laser beam to be focused as much as possible on small spot at long distances, the reciprocal relationship between divergence and the size of the output optics is used (see Fig. 2.4). When a beam with a very small divergence is required, large lenses must be used on the output of laser aperture. Beyond this distance, divergence and diffraction at an angle of about λ/D must be taken into account in evaluating the energy density on target. With ordinary lenses, the focal spot may not be smaller than a few times the wavelength of light. For most military purpose, this is certainly more than sufficient. In some high-energy laser (HEL) weapon systems, a concave mirror is used to focus as much energy on the target as possible.

Note: Propagation within Rayleigh range is known as "near-field" propagation and a greater distance as "far-field" propagation.

Laser can operate in the continuous-wave (CW) or the pulsed mode. The mode of operation depends on whether the pump energy is CW or pulsed. A CW mode laser emits light steadily as long as it is turned on. A pulsed mode laser can have either one single pulse or repeated pulses, possibly on a regular basis in a train. The pulse repetition frequency (PRF) is the number of pulses a laser produces in a given time. The duration of the pulse (or pulse width) and the PRF may vary immensely between different lasers. Lasers are available with a PRF as high as several hundreds of thousands or millions of pulses per second. In a visible beam band, the human eye will not see such a pulsation, and the beam will appear to be CW [5].

One of the most important factors to a designer and user of laser weapons is the energy level delivered by laser beam. Energy is the power emitted by a laser within a given time. The following equation can be used to calculate the intensity of the beam:

$$E = P \cdot t$$

where E is the energy in joules, P is power in watts, and t is time in seconds. The energy of repetitively pulsed lasers is calculated using the average power level emitted over a standard interval, which is usually 1 s.

A high-energy laser weapon designed to down aircraft, missile from several miles away may have several megawatts of power, while a low-energy helium–neon laser such as is used in a lecture hall pointer or a supermarket scanner usually has only a milliwatt or less of average CW power, although the CW power of a helium–neon laser can be as much as 50 mW [5].

2.7 Summary

Present-day laser technology is very extensive and diversified, and, within certain limits, it allows for many civilian as well as military applications. Military staff, defense researcher institutes, and defense industries are constantly looking for new laser concept that are suitable for military application and that will fulfill the very tough but realistic battlefield requirements. Many new military laser systems will most certainly be designed to back up their military needs. Thus, if and when realistic battlefield laser weapons concepts pass through the research and development phase, there will be a strong laser industry already in existence to mass-produce these weapons [5].

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