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High Power Laser in Intercepting the 'Flash'

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Abstract—With the advance in coherent beam combining, high power laser is no longer a scientific fiction. Laser is strong and has light speed, making it suitable to intercept hypersonic missile by means of suitable fast autonomous lens system. Hypersonic missile is a deathly hallow due to its changing locus along its flight. It escapes radar detection by low-level flying, that poses a great challenge to defence system. Pinpointing spherical section device with surrounding ring of solar cells, light- and motion-sensitive detectors fixes the target in short time. Leverage with damping of spherical section lens system is faster than the moving object because 180° angle motion with covers all the possible position of distant object. The pendulum movement with inertia can further predict the immediate next position of the flying object. The rate of change of illuminance is zero when the target is right above or below the device-carrying fighter aircraft. With the advance in unmanned aircraft, we can approach closer and ignite the target.

Keywords—hypersonic missile; plano-convex lens; spherical section; illuminance; IR radiation; Tiled Aperture; Filled Aperture; Mixed Aperture coherent beam combing laser; light-sensitive detecting device; motion-sensitive detecting device.

I. INTRODUCTION

Recent advance in coherent beam combing laser reduces the issue of scattering and minimises the energy loss to the surroundings. Coherence, rather than increase in frequency, is a necessity to add up the power of two or more lasers.

Laser ignition of the flying object is easier in space than within the Earth's atmosphere where energy loss is inevitable, unless the firing distance is reduced. The laser can be carried by unmanned flying vehicles so as to get near the hypersonic missile.

To tackle erratic, unpredictable hypersonic missile, high speed laser beam together with the aiming device using plano- convex lens surrounded by a peripheral ring of solar cells is mentioned in the paper 'Can you hit what you see?' This design place the plano-surface normal to the infrared (IR) radiating object, such that the peripheral ring of solar cells receive the same amount of IR. The device divides the 3-dimensional movement into left-right and up-down motions, resulting in longer reaction time.

If the plano-convex lens is replaced by a spherical section and the detector-firing couple is changed to rely on the rate of change of illuminance, the real 3-dimentional space is within the detection and firing scope.

It is interesting to note that the IR radiation is maximal but the rate of change of illuminance is zero when the missile is flying directly over or under the fighter, according to the Lambert's cosine law. The irradiation is increasing when the missile is approaching and is decreasing when the missile is away from the aiming device. We can set the laser is fired when the rate of change of illuminance is approaching to zero, either positive to negative or negative to positive.

A leverage is set up with one end being the lens system, and the other end being the coherent laser beam device. As there are friction over the movable part and the air resistance, a damped pendulum motion of the aiming device results. Once the target is within the set range, pulsed laser firing will start and will not be interrupted by the pendulum motion as it occurs in milliseconds. The target will be fixed in few seconds. At that time, the laser will continuously firing until the target explode.

The new device is more versatile. It can be set up at fixed (on the ground) or movable (carried by the fighter) positions. If two lasers, each with an aiming device, at two different or random positions, they will converge at and hit the target. The set-up will not be affected by the orientation of the target and fighter, or the longitude and altitude. It depends only on the rate of change of IR illuminance and the motion of target as sensed by the light-sensitive and motion-sensitive detecting device.

II. POWER OF LASER IS INCREASED BY FOCUSING, ULTRA-PURE CRYSTAL FOR CONVERGENCE AND COHERENT BEAM COMBINING

A. *Constraints to Power Scaling of Laser*

Power scaling of single-mode fiber lasers has confronted certain constraints like nonlinear effects (NLE), thermal issues, optical damage, and pump power limitations. These, in turn, are due to the following effects:

1. Stimulated Raman scattering is a nonlinear effect in which energy is coupled from an optical pump beam to longer wavelengths via vibrational modes or thermal phonons of the molecules in the glass medium.

2. Stimulated Brillouin scattering: Energy is transferred from an optical pump beam to longer wavelengths through interaction with the glass medium. Acoustic phonons are involved with small frequency shift (11 GHz) and very small bandwidth (50 MHz).

3. Self-phase modulation is a nonlinear optical effect of light–matter interaction. An ultrashort pulse of light, when travelling in a medium, will induce a varying refractive index of the medium due to the optical Kerr effect.

4. Self-focusing can be induced by a permanent refractive index change resulting from a multi-pulse exposure. This effect has been observed in glasses which increase the refractive index during an exposure to ultraviolet laser radiation. Accumulated self-focusing develops as a wave guiding, rather than a lensing effect.

5. Four-wave mixing is an intermodulation phenomenon in nonlinear optics, whereby interactions between two or three wavelengths produce two or one new wavelengths. The efficiency of the process is strongly affected by phase matching conditions.

6. Transverse mode instability: the quality and stability of the beam emitted by a fiber laser system are suddenly reduced once that a certain average power (100 W to kWs) has been reached, depending of the fiber laser system. It is a thermally-induced non-linear effect observed in an optical fiber.

B. High Power Laser

The above systems work only if there is a high power laser. Mixed aperture coherent beam combination, by changing the absolute phases of input lasers to adjust the power weights of diffraction orders, is most promising. The power/ energy performance can be increased up to 10^6 rad/s.

C. Ways to increase the laser power

1. Focusing

X-ray laser power density can be raised to 100-fold by using four ultraprecise mirrors. A beam size of 30 nanometer height and 55 nanometer width can achieve an intensity density of 10^{20}W/cm^2. The point is fully coherent lasers. This SPring-8 Angstrom Compact Free Electron Laser (SACLA) is now located at Harima in Hyogo Prefecture

2. Convergence by ultra-pure crystal

Laser power is increased tremendously at the confluent point on passing through diamond. This collaborative power-transfer effect is due to Raman scattering—the inelastic scattering of photons by ultra-pure diamond with both energy exchange and a change in the light's direction. In addition, diamond can quickly disperse heat to prevent damage to itself.

3. Coherent Beam Combining

Coherent Beam Combining solves the above problems by combining multiple laser amplifiers, which are seeded by a common source, into a single high-power beam. The lasers are in the same phase with preserved spatial and spectral properties, so the parallel amplifiers act as a single laser. This can be achieved by using tiled aperture, filled aperture, or mixed-aperture geometries.

•In Tiled Aperture, laser beams are next to each other, and side-by-side in an array, with the largest array filling factor (the minimum gap between individual laser beams). The laser beams interfere in the far-field by wave propagation or by lens converging.

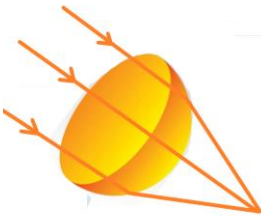
•In Filled Aperture technique, laser beams are efficiently combined on the near-field by beam splitter, diffractive optics, and mirror. 10.4 kW coherently fiber laser system with 96% combining efficiency can be achieved.

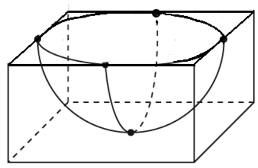
•Mixed aperture Coherent Beam Combining is based on micro-lens arrays (MLAs) to split and combine lasers . Spatial light modulator (SLM) shifts the phase of lasers to control the power weights of diffraction orders. Input beam can be splitted into 25 beams, and then coherently reunited into a single laser with 90% combining efficiency at the charge-coupled device (*CCD*).

III. Basic Principle of the Detector-Firing Coupling

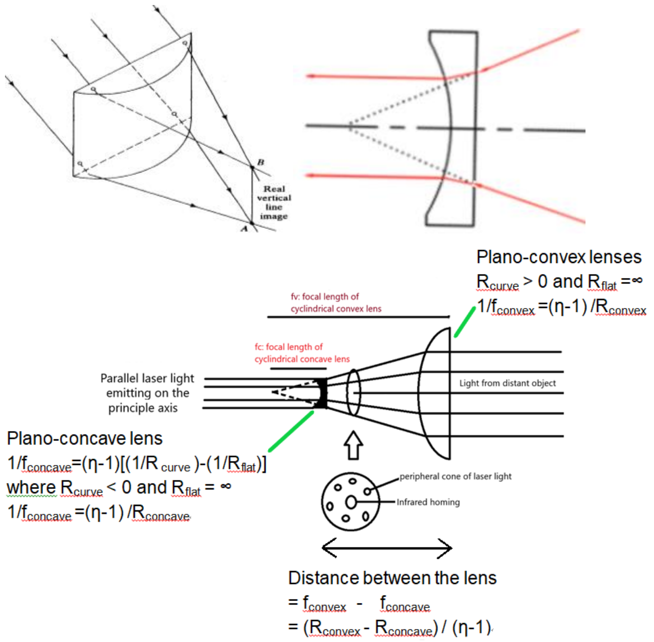
By means of lens system, the distant object will form a point image in a spherical section and a line image in cylindrical plano-convex lens. Parallel lasers will pass through the same route of incident light to ignite the missile. The underlying principle is based on the Lens Maker's formula: $1/f = (\eta-1)\ (1/R_{curve} - 1/R_{flat})$, where f is the focal length of the lens, η is refractive index relative to the medium, R_{curve} and R_{flat} represent the radii of curvature of the curved and flat surfaces.

Section of sphere will converts the distant object to a one-point image. And the hollow sphere in glass cube will provide a gliding curved surface for the system.





To understand the basic principle, the original design using cylindrical plano-convex lens is described below. It converts the distant object to a one-line image. It works with a plano-convex lens to converts back to parallel light rays, that is detected and responded by the system. Pendulum motion of system is coupled with right-left motion using a linear actuator. These make the system to move in a 3-D manner.

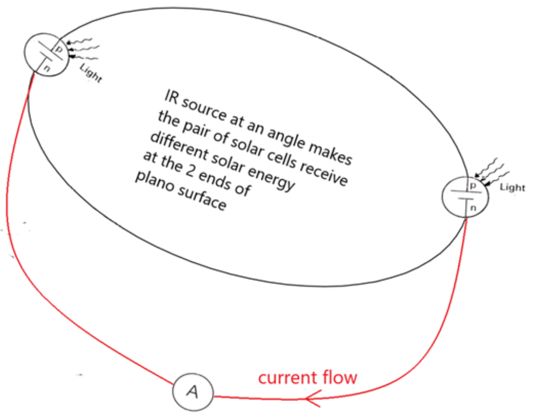


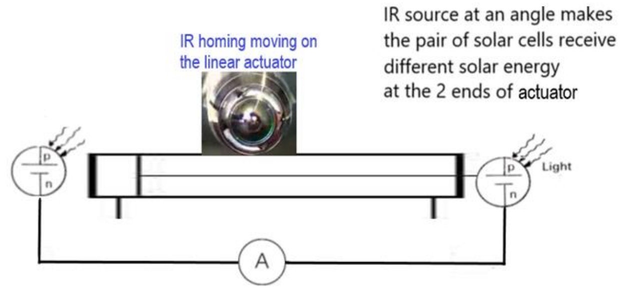
IV. How the peripheral circumferential detectors works?

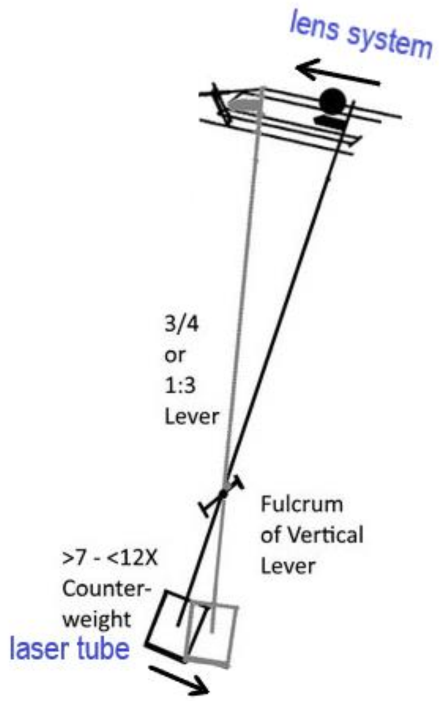
In the spherical section lens system, the pair of light and motion sensitive detectors will receive different light and motion intensity. The different electronic signal on the opposite sides will make the spherical section glides on its curve surface smoothly like the 'human's eye' or 'ball and socket joint'.

In the cylindrical plano-convex lens system, the pair of opposite solar cells will receive different IR intensity. So a current flows causing the plano convex lens to rotate until the opposite solar cells have equal electrical potential. At that time, the plano surface will be normal to the incident light. The horizontal motion of the lens system works by the same principle with solar cells at two ends of actuator. It moves just like a 'Robot'.

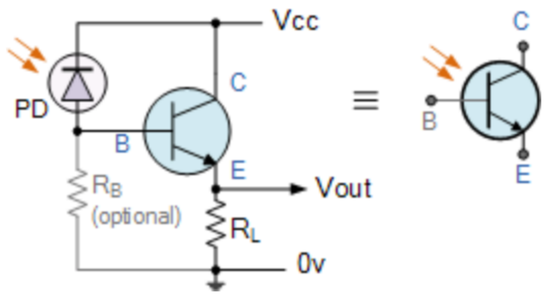
In the original design, the peripheral solar cell detectors around cylindrical plano-convex , the corresponding linear actuator, and the lever system is shown below:



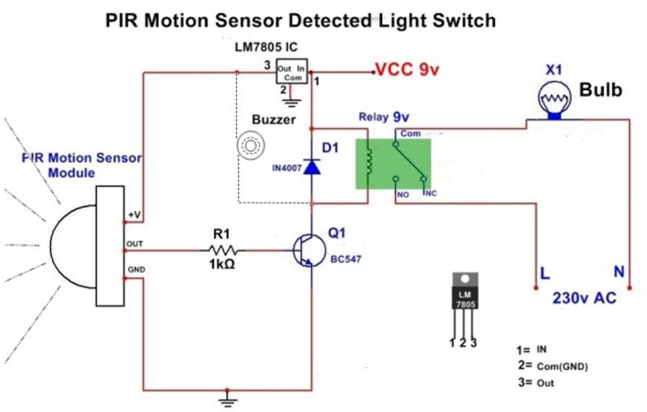




In the new design, peripheral light-sensitive and motion-sensitive detectors around spherical section are used together to reduce the pitfalls in detection of the flying objects. Light sensors/ photoelectric devices convert light energy (photons) whether visible or infra-red light into an electrical (electrons) signal.



Motion sensor or passive infrared device, PIR, is used to detect any object comes in the range of the sensor



V. DETECTOR-FIRING COUPLING MECHANISM

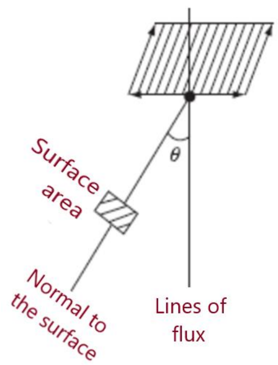
The laser tube and the lens system lie on the two ends of the leverage, such that when the lens system go up, the tube goes down and vice versa. By Newton's 1st law, the inertia of the lens system will move in advance of the target, that allows time to intercept the target. Unlike the radar, the spherical sectional aiming device detects the rate of change in illuminance from the target. That means it works despite the erratic positions of missile and the fighter aircraft. Suppose the fighter has a vertical height ***h*** above or below the target.

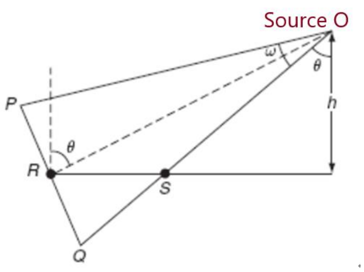
1. When the missile is approaching the fighter, the infra-red illumination and the rate of change of illumination (dE/dθ) is increasing.

2. When the missile is directly over/ under the head of fighter, the infra-red illumination will be the greatest but dE/dθ is zero.

3. When the missile is leaving the fighter, the infra-red illumination and the rate of change of illumination (dE/dθ) is decreasing.

In the spherical section lens system, the rate of change of illuminance is employed. By Lambert's cosine law, if the surface is inclined at an angle 'θ' to the lines of light flux, the illumination 'E' on the surface area A is given as follows.



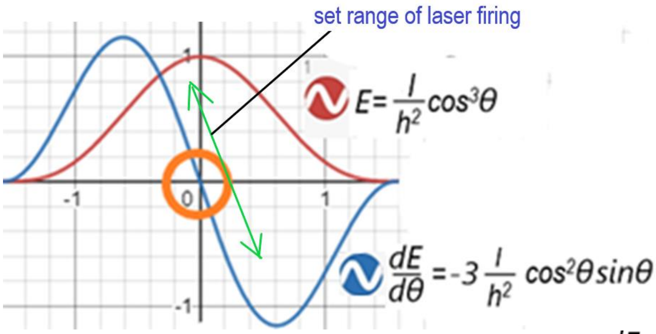


$$E = \frac{I}{d^2}\cos\theta = \frac{I}{h^2}\cos^3\theta$$

$$\frac{dE}{d\theta} = -3\frac{I}{h^2}\cos^2\theta\sin\theta$$

Where E is illumination per m^2,
I is light flux,
d is distance from the missile,
h is verticle height of missile above the aiming device, and
θ is the angle of missile made with vertical.

There are certain advantages of this design. Firstly, there will be wide range of defense without need for multiple aiming tubes.



Secondly, l*aser system can be set to fire when $\frac{dE}{d\theta}$ changes from +0.001➔ -0.001* .

Thirdly, using light- and motion- sensitive detecting systems concurrently are good in extreme weather or weak IR irradiation.

Fourthly, the laser will ignite the missile for a longer time to increase the success rate by adjusting the firing $\frac{dE}{d\theta}$ threshold such as *+0.5➔ -0.5*

In contrast to the system using cylindrical plano-convex, absolute illuminance is detected instead. IR homing on linear actuator will move until incident infrared light is normal to the plano surface of the lens and the buddy solar cells on periphery of lens and either end of actuator receives the same illumination.

The orientation of IR homing sends command signal to servos to control the movement of aiming tube. By Arduino light tracking, incident IR is normal to the lens surface. The IR homing device further refines the tube orientation, which guides the direction of laser emission. Multiple aiming tubes in fan-like manner increase the range of detection of missile.

However, the detecting system may misinterpret /being confused by artificial reduction of the IR irradiation or the temperature of the missile. This can be achieved by the following.

(1)Silica aerogel for thermal insulation,
(2)*Germanium*/ Zinc Sulphide multilayer wavelength- selective emitter for radiative cooling, and
(3)IR camouflage covering the missile

VI. CONCLUSION

Defensive systems should be modified in the hypersonic missile era. Fast accurate response, automatic standalone device, low manufacture and operative cost are preferred. Laser is the field that warrants further study because of its intrinsic properties and widely use in different territories like medical and surgery, cosmetics, industry, astronomy, defence system, to say a few.

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