LASER TECHNIQUES APPLIED TO DEFENCE PROBLEMS

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The discovery of the optical laser has given rise to a number of important military applications which make use of the highly coherent, monochromatic and directional beam coming out of it. The enemy targets can be located far more accurately than by the microwave radar because laser beam offers greater angular resolution and directionality. For communicating a large number of messages between the different units of the army, the vast bandwidth available at the optical frequencies of the laser can accommodate far more information than is possible with the conventional microwave and radio frequencies. A number of other defence applications like aerial reconnaissance, under-water surveillance etc are being tried with laser beams. A review of these applications is made in this article.

The optical laser is the most exciting discovery in the last few years of scientific development and its applications to many fields of science, technology and defence have already been demonstrated. The laser radiation is highly monochromatic and coherent and one can get beams of high energy density. The laser action which can be explained on the basis of quantum theory depends on the atomic transitions between different energy states of an atom. An atom in the ground state can be excited to go to one of the higher levels when light from a powerful source like a flash lamp falls on the substance. In this process called absorption, the atom absorbs from the incident light a photon and is raised to an appropriate excited level. After staying in that level for a very short duration (of the order of 10^{-8} sec) the atom returns to the initial lowest state with the spontaneous emission of the photon (the process is called emission). In the conventional light sources the above two processes take place. While the atom is still in the excited state if it is struck by an outside photon having precisely the energy necessary for spontaneous emission, the outside photon is augmented by the one given up by the excited atom. Moreover, both the photons are released from the same excited level with the same phase. This process is called the stimulated emission which is fundamental for laser action.

For the stimulated emission to grow, the ends of a laser rod are made optically plane parallel and are coated with silver. After repeated reflections at the ends of the rod a steady wave will be built up. If one of the ends is semitransparent a portion of the wave can escape through it, constituting the output of laser.

The output beam will be highly coherent because all the wavefronts are planes perpendicular to the axis along the length of the rod. It would be very monochromatic because stimulated emission is a resonant process and it is emitted always as the difference in energy between the same two levels of the atom. The beam would be highly directional because the only waves emitted would have to make repeated passages—perhaps thousands—without deviating very far from the axis of the laser. Because of the amplification in this process of stimulated emission a powerful output of the beam can be obtained.

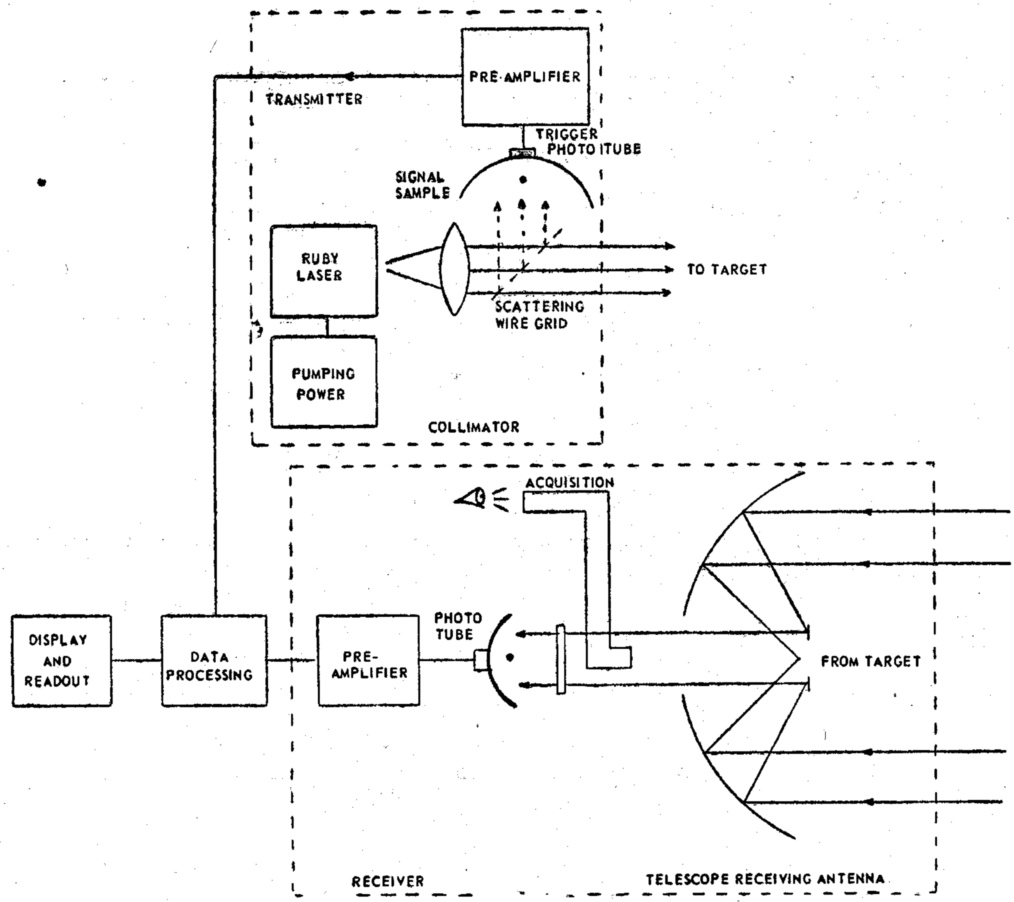

Fig. 1—Laser range finding system.

Different kinds of lasers

Lasers can be broadly divided into two classes those which operate on a continuous basis and those which work on pulsed basis. Among the pulsed lasers the ruby laser is the first to be discovered and is still being widely used. The laser is made from a single crystal of pink ruby (aluminium oxide with 0·05% chromium oxide). The ruby is machined into a rod of about 4 cm long and $\frac{1}{2}$ cm diameter. Its ends are polished optically flat and parallel. One end is fully silvered while the other end is semi silvered. A powerful electronic flash tube provides an intense source of "pumping" light.

In addition to ruby, a number of other solid materials such as neodymium are being used for laser action with more power output. Recently semiconductor materials like gallium arsenide are being used to get laser action on a continuous basis directly from the electrical energy supplied to it. However these lasers cannot deliver large output of energy which we can obtain from the pulsed lasers.

Among the gas lasers, the Helium-Neon laser is widely used for continuous output. The gas laser consists of a discharge tube (of about 100 cm long with an inside diameter o about 1 cm) filled with helium at 1 mm of Hg and neon at 0·1 mm. of Hg. To minimis unwanted reflections, the tube is terminated with optical flats oriented at the Brewster angle. Confocal spherical reflectors are placed outside at either end of the tube to provide the multiple reflections between the resonater cavity. An R.F. power supply is used to excite the helium atoms which transfer part of their energy to the neon atoms. Laser action takes place between the energy levels of the neon atoms.

LASER RANGE FINDER

The laser range finder [1,2,3] works on the principle of radar. It makes use of the monochromaticity, high intensity, coherency and directionality of laser beam. A collimated pulse of laser beam is directed towards the target and the reflected light from the target is received by the optical system and detected. The time taken by the laser beam from the transmitter to the receiver is measured. When this time is multiplied by the velocity of light, it gives double the distance to the target.

The laser range finder is superior to the microwave radar in the sense that it provides better collimation or directivity which makes possible high angular resolution. Compared to pulsed-arc optical radar developed in 1955, it has got the advantage of greater radiant brightness and spectral radiant brightness which are approximately 10^{8} and 10^{12} times respectively that of the sun. The fact that this brightness is also highly directional (after travelling a distance of 1000 miles the beam falls in an area 2000 square ft across approximately) reduces the size of the emitting optical system. The high monochromaticity permits the use of optical band pass filter in the receiver circuit to discriminate between signal and sunlight noise. The laser range finder is also free from the arc wandering difficulty which is common in arc-pulsed optical radar.

A laser range finder may be divided functionally into four parts (i) transmitting system (*ii*) receiving system (*iii*) range readout system and (*iv*) sighting telescope.

The transmitting system uses a Q switched ruby laser which sends out single, short collimated pulse of laser radiation to the target. A scattering wire grid sends a small sample of light from the transmitted pulse on to the photomultiplier tube which, after amplification, is fed to the counter as shown in Fig. 1. This sample of light starts the counter. The reflected pulse is received by the telescope. After passing through the narrow filter it is focussed on to the cathode of another photomultiplier tube. A transistor preamplifier amplifies this output. The resulting signal is then fed to the counter. This stops the counter. The range, as determined by the counter, is displayed in the eyepiece of the sighting telescope to permit the operator to read the range while seeing the target.

Hughes Research Laboratories and Bradley have developed laser range finders which can measure the range from 300 to over 10,000 m with an accuracy of 10 m. Special circuits have been used to make the performance possible under all weather conditions for which the target can be seen visually through the sighting telescope.

COMMUNICATIONS

The discovery of the optical laser has aroused a lot of interest for long distance communication since the capacity of a communication channel is proportional to the frequency band width. Thus at optical frequencies which are at least million times higher than microwave and radio frequencies, the information carrying capacity is many times more than that possible at lower frequencies. Since the laser is a generator of highly coherent beams which are powerful and sharply directed, it is ideally suited for communications.[4–7]

In this regard millimeter-wave techniques offer direct competition to the laser as they have been perfected already to a high degree. Moreover, optical frequency waves suffer a considerable disadvantage for atmospheric transmission since they are scattered very much by snow, fog and rain. Therefore, the advantages and disadvantages should be carefully analysed for both types of communication before lasers are used for communications on a large scale.

Four types of techniques for long distance communications are now in existence: (*i*) coaxial cable system.—A large proportion of the messages between different cities is carried by this system. The standard coaxial cable consists of cables gathered in bundles of 8 to 20 and, depending on the amount of traffic to be carried, the amplifying equipment must be located every two to four miles along the cable. The carrier waves, used for this purpose, normally have wavelengths ranging from 600 cm to 15 m with frequencies from 500,000 to 20 million cycles per second. *ii*, microwave radio relay towers—in the USA, maximum commun cation traffic is transmitted by these towers, spaced some 20 to 30 miles apart. This is done by means of microwave radiation in the frequency band between one billion and 10 billion cycles per second. (*iii*) wave guide—It has been perfected in recent years but is not yet widely used. For transmission by this method, frequencies of 30 to 90 billion cycles per second are being used. (*iv*) artificial earth satellites—Operating in the microwave-radio band, the Bell labs have developed the Telstar satellite.

The principle behind these long-distance communication system is multiplexing the simultaneous transmission of different messages over the same path-way (Fig 2). For example, a channel for transmitting an individual human voice, requires a frequency band extending from 2000 to 4000 cycles per second. For modulating the signal without adding noise, the carrier wave should be of a very narrow spectral width. This single frequency carrier wave is then successively modulted by a large number of voice signals to create a new composite single wave. With the help of special electrical networks, several of the

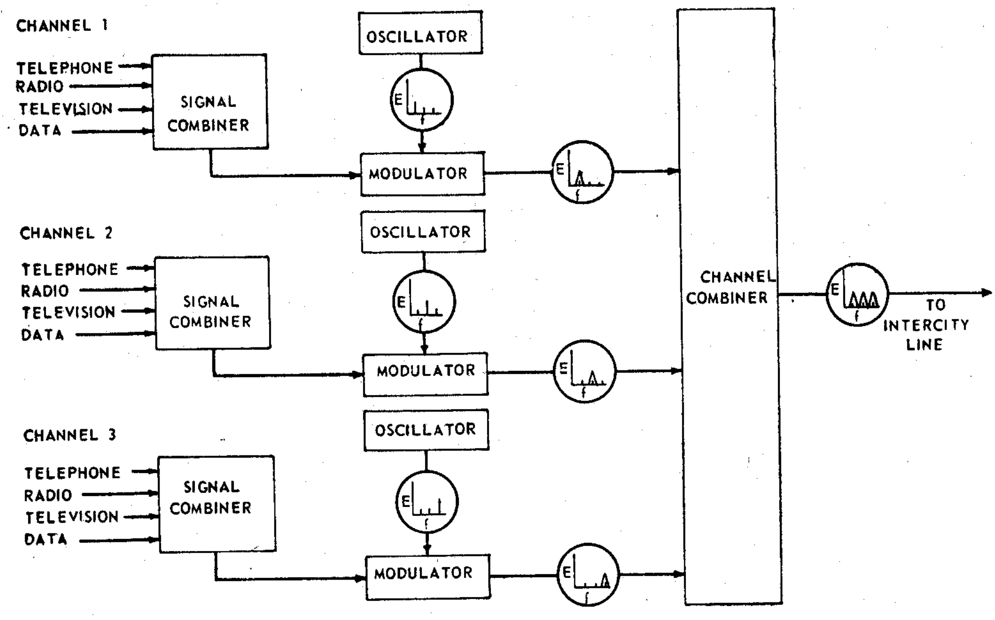

Fig. 2—Transmission by multiplexing.

broad energy bands are combined for simultaneous transmission over a single intensity path-way. On the other side of the line, a similar network separates the single signal into its component broad bands and they are demodulated into individual telephone calls. Thus much economy is achieved by multiplexing process.

It is quite obvious from the above that the visible and near infra red regions of the laser frequencies, which are about 1,000,000 times those of the millimeter waves, offer great economy for communications, since an individual communication channel requires the same bandwidth regardless of the region of the spectrum in which it is located. Because of the high monochromacity, the bandwidth of the laser beam is of the order of a few kilocycles. When it is modulated by some information, the bandwidth of the resulting modulated beam (the signal bandwidth) will be broadened to say 10^{10} cps. Therefore, the fractional bandwidth which is signal bandwidth/carrier frequency is one part in 10^5. Since this ratio is very small, a large part of the noisy background light can be filtered away before the beam is passed to the detector. This is something which is not possible with the conventional electronic oscillators.

The spatial coherence of a laser beam makes possible highly directional transmission which cannot be attained by conventional radio techniques. A plane-wave source emits a beam that is almost constant in width for a distance $a/4\lambda$ where 'a' is the diameter of the source and λ is the wavelength of the radiation. Beyond this distance, the beam gradually expands to form a cone, the angle of which is equal to a/λ. Due to the vast difference in wavelength, the laser beam and a radio-wave beam spread differently. In microwave-radio relay system, the transmitter and the receiver are spaced 20 to 30 miles apart with the result the rec ived power is about $1/10^5$ of the transmitted power. For a laser, on the other hand, a 2-in. diameter beam will travel for about 3/5th of a mile without spreading. At a distance of 3/5th of a mile, the beam can be collected by a lens about two inches in diameter with a little loss of transmitted power. By using two inch lenses at 3/5th of a mile apart, one can confine the beam for longer distances and guide it to the receiver with a loss of only about $1/10^5$ of the transmitted power.

For communication by laser, the laser beam is modulated by the signal. At the receiving station, the modulated beam should be demodulated (detected) to separate the required signal from the laser beam (carrier). This is done mostly by photomultiplier. When the intensity is varying according to the signal, the output current will also vary accordingly. This current is amplified and then fed to the speaker.

Modulation

Most of the optical modulations devised so far have been based on the variations in the refractive index of some substance according to the signal wave. The continuous laser output from a gas laser passes through a KDP crystal as shown in Fig 3. Ring electrodes are placed on the crystals and an electric field, proportional to the signal wave, is applied to the crystal parallel to the axis. Due to the change in refractive index of the crystal which follows the electric signal, the angle of refraction in the crystal changes and hence the path of the beam in the crystal changes. Due to the change in the path of the light, the output intensity also changes according to the signal voltage ($I = I_0\ e - \alpha t$ where I_o is the incident intensity, $\alpha =$ attenuation constant and $t =$ path in the crystal).

The laser beam from a semiconductor laser, eg GaAs diode can be directly modulated by varying the current through the diode according to the signal. Since it takes long for

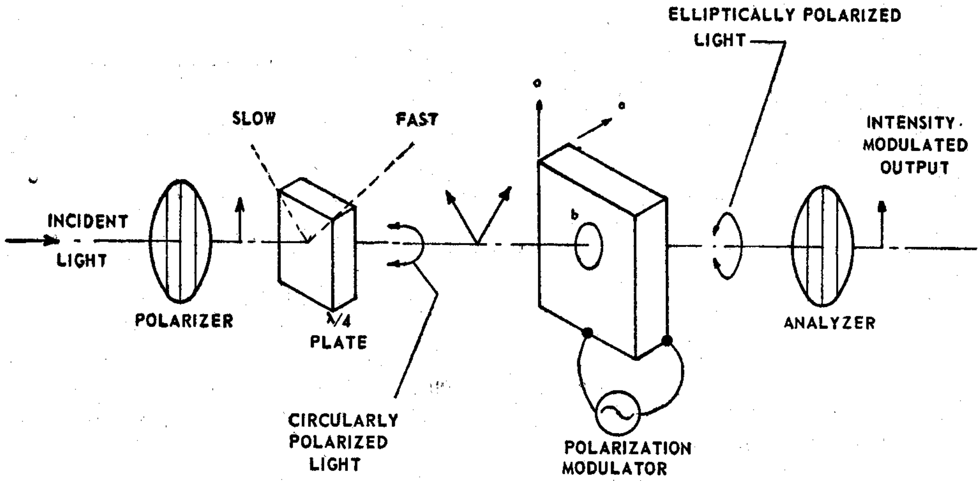

Fig. 3—Modulation of a laser beam.

radiation to respond to a change in electric current, an upper limit for this type of modulation is imposed by the radiation lifetime of the emitting carriers (infra-red radiation at $0 \cdot 84\ \mu$). For GaAs, this is of the order of 10^{-10} sec. Thus modulation bandwidth of 1000 Mc may be possible.

Demodulation

The demodulation of the laser beam can be accomplished in two ways : (1) by direct photodetectors and (2) by photomixers. The usual photodetectors are square law devices such as photo-multipliers or photodiodes. The detected output is given by

$$e_0 = ae_i^2$$

where e_0 = detected output voltage; e_i = input voltage, and a = constant.

Photodetectors are good to use in the visible and ultraviolet regions and their efficiency falls as we go towards the infra-red. The quantum efficiency of a photodetector is defined as the average yield of electrons per input photon. For photoelectric detectors, the yield is generally small with quantum efficiencies between 10^{-5} and $0 \cdot 2$. The method of demodulation by photoelectric detectors is shown in Fig 4. Silicon photodiodes have developed rapidly with the discovery of the laser. They have a peak response at about 8500–9000 Å, which is the spectral region of GaAs lasers and so they can be used as sensitive detectors in that region.

Demodulation by optical heterodyne detection is done by superimposing on the incoming incident signal a beam of light from an unmodulated laser, called a local oscillator and allowing the resulting combined beam to fall on a photoemissive surface as a cathode of photomultiplier as shown in Fig 5. The electron current from the cathode will then be modulated at a frequency that is difference between the signal and local oscillator frequencies. In photomixing, the output power from the detector is theoretically i^2_{s0} R where $i_{s0} = (i_s\ i_{Lo})^{1/2}$ where i_s and i_{Lo} are the current components of the signal beam and local oscillator respectively. The chief disadvantage in this method is that, unless the local oscillator and signal are in phase over the entire photo-surface, photomixing action is sharply degraded.

Laser transmission through the atmosphere

Since rain, snow and fog severly attenuate a laser beam, for long distances the beam requires some sort of pipe in which the atmosphere can be controlled. The beam has to be guided in the pipe with the help of lenses or mirrors. The periodic refocussing of the beam by the lenses offsets the spreading due to diffraction. In this way, transmission over several hundred miles without prohibitive loss may be possible. For this application, the lenses required must have longer focal lengths than the optical lenses. The scientists at Bell labs have been experimenting with gas lenses. The principle is that when a cool gas flows through a warm tube, the gas near the tube-edges is heated and due to heating, the refractive index is decreased. Thus a stable lens is formed so that the light beam is kept focussed down the centre of the tube.

If the atmospheric difficulties which the laser beam encounters are overcome by such techniques, the laser systems would be more economic than the microwave and millimeter-wave systems.

AIR RECONNAISSANCE

Laser beam can be used as a secretive illuminator for night aerial reconnaissance[8]. At present, camera equipped with either magnetic flares or powerful strobe lights with their cumbersome powersupplies is used for this purpose. A Helium-Neon gas laser is used as the light-source. Two properties of the laser namely narrowness of the beam and its radiance or brilliance, are of great importance in this particular application.

The block diagram of the laser camera is shown in Fig 6. The radiation from the continuous wave laser is split into two beams. One of the beams passes through a six-sided prism scanner down towards the earth. The prism scans through a selected angle (30° to 40°) at right angles to the direction of flight of the aircraft. The other beam passes through a pockel cell modulator. On emerging from the modulator the beam strikes the prism scanner and is then reflected towards and recorded on the film. The camera is used only as a recording device, because only film can provide the high bandwidth and resolution storage required by laser.

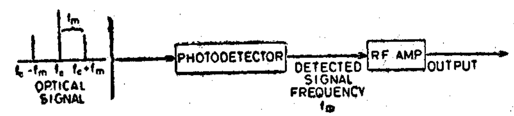

Fig. 4—Demodulation by photoelectric detector.

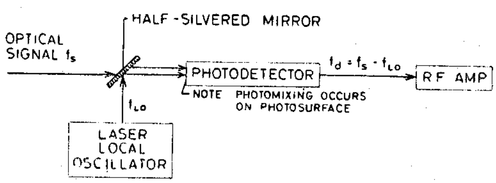

Fig. 5—Demodulation by optical heterodyne principle.

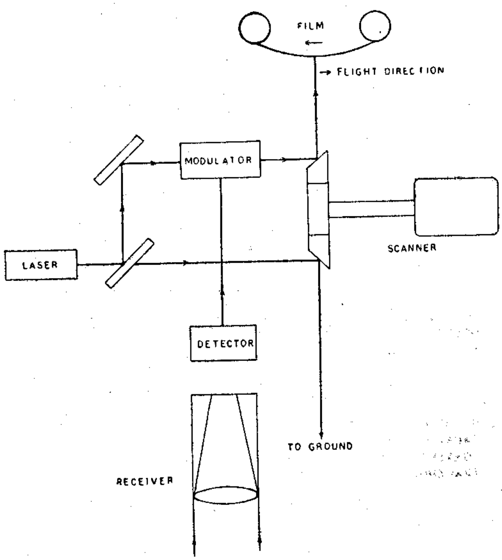

Fig. 6—Air reconnaissance by laser scanning camera.

The returns of the laser from the target area are picked up by a schmidt lens, which images light on to a photomultiplier detector. The video output of the detector, corresponding to the reflectivity of the observed terrain, drives the modulator. Thus the returned beam is modulating the original beam.

The pictures obtained are comparable in resolution with those taken under day-light conditions. The resolution of the laser system is better than that of microwave radar system but the laser system does not have the weather capability of the microwave radar because of atmospheric absorption and scattering.

The laser camera asystem was tested successfully by USAF tactical air reconnaissance centre.

ANTIMISSILE DEFENCE SYSTEM

Lasers can be used as an antimissile defence system[9]. To completely burn the missile, tremendous energy will be necessary, which at present is not practically feasible. However, to dispose of the enemy warhead by laser one need not have to vaporise or melt it. Destruction of the missile can be achieved by drilling a hole so that an important part of the missile is damaged. If a guiding vane is fractured severe vibrations will be developed in the air frame thereby disintegrating the major sensitive portion of the missile.

Two types of antimissile defence systems have been visualised by the scientists. One such system —"laser kill system" (Fig 7)—is completely earthbound Here. an early warning miscrowave radar gives the rough position of the approaching missible. Then a laser radar is aligned on the target by the tracking radar. The laser radar gives the position of the missile precisely. This data is fed on to another high intensity laser beam which actually does the killing. In order to fully exploit laser's killing capability, a high speed servosystem and a complex focussing system are very essential.

The other antimissile defence system is the orbiting space station which is equipped with the detecting, tracking and killing laser devices. An infra-red homing system on the laser weapon is used to close with an enemy vehicle and then fire a high energy laser

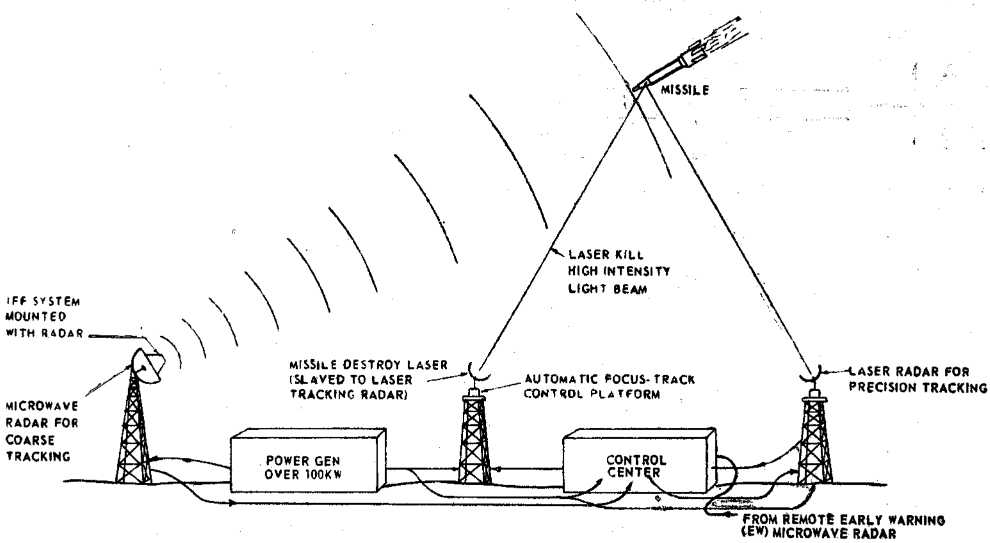

Fig 7—Anti-missile system using laser.

beam. Firing of laser weapons would not change the space station's positional or altitude stability. Conventional boosted weapons would present the problem of 'compensating for added thrust moments'.

In the case of a laser killing system one need not discriminate between the decoys and the actual missiles because laser bursts are readily repeatable. As a counter measure one can use smoke screen on the path of the laser beam or make the warhead of highly reflecting surfaces to reflect the laser beam.

UNDERWATER DEVICES

Laser can be used as a source of radiation for underwater transmission [10,11]. A laser in the blue green region is most suitable because in this region the attenuation is least for sea water. The attenuation in underwater transmission is due to absorption by materials in water, scattering by suspended particles, and variation in optical density along light path. Scattering also causes high background light levels which makes the signal to noise ratio sufficiently low thus making the target difficult to distinguish.

The green light laser (emitting radiation at 5,300A) is produced by frequency doubling the output of an infra-red laser (Neodymium-glass laser emitting radiation at 10,600A) using a non-linear crystal either Potassium Dihydrogen Phosphate or Ammonium Dihydrogen Phosphate. The efficiency of conversion is 1 to 3%. An output pulse of 10 KW with a bandwidth of 2A at 5,300A has been reported by Laser System Centre, Lear Siegler's Corp, USA. Actually three sharp lines in the green visible region are observed 15A apart—each being 2A wide with 90% of the energy in one line at 5,300A.

Presently submarines have to rely on sonar to find out enemy crafts and to avoid underwater objects. This has serious limitations. Whales, dolphins and other marine life give false signals. Sonar cannot give a well-defined picture because sonar beam is broadened or scattered by sea water. A difference in the saltness of water can cause the sonar beam to bend and make the target appear where it is not. Another difficulty of using sonar is that it gives away to the enemy the position of the ship from which it is transmitted. Another factor to be considered is the mines which are detonated by the sonar beams and the torpedoes which home in on the sonar.

Laser can be used efficiently for the above purpose. We can make laser scan the target under the sea. The returned signals are picked up by a phototube and displayed on a special cathode-ray tube enabling one to have a clear outline of the target. Since the laser beam is very narrow, the targets will be precisely defined in size, shape and location.

Laser can be used for (*i*) communications between submarines ensuring absolute privacy, (*ii*) mine detection without triggering sonar activated pickups and (*iii*) guidance systems for torpedoes and other unmanned undersea vehicles.

OTHER APPLICATIONS

Laser alarm

Electric eye alarm is presently used to guard against undetected intrusion. It accomplishes this by making use of photomultipliers which have good sensitivity in the visible region and therefore, the visible light used for the purpose can be seen easily by the intruder.

A laser which produces a pulsed beam can be used as an alarm[12]. Here the energy is not visible and the pulsed beam can be coded for security. The high peak power of the injection laser due to its high electrical efficiency increases the useful time and range of operation. Because of its high directionality, laser can be repeatedly reflected by prisms and mirrors to produce final beam of large dimensions. With laser alarm one can seal off path, area or a volume.

Laser beacon

Presently incoherent infra-red sources are used as ground beacons in order to identify the ground points so that air dropping of the supplies can be made as accurately as possible. These beacons are very heavy, inefficient and easily imitatable. Using a lensless diode array, a laser beacon[12] can be made multi-directional. The laser beacons are light in weight, efficient and have long life. Another advantage is that the pulses can be coded to guard against imitative lures.

CONCLUSION

Applications of lasers in range finding, communications, air reconnaissance, under water surveillance, anti-missile laser systems etc have made them an important tool for defence. But there are certain limitations because laser beams can be severely attenuated by the atmospheric conditions like rains, snow, fog, etc. Therefore, unless further experiments are conducted to minimise the atmospheric difficulties, it will not be economical to use the lasers in preference to the conventional microwave systems.

Except the pulsed solid state lasers which deliver high energy outputs of the order of megawatts, the c.w. lasers eg *He-Ne* gas laser and the semi-conductor lasers give energy outputs of the order of only few watts. Further improvements have to be made for not only increasing the energy outputs of the lasers but also to make the systems more compact so that they can be put to better use.

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REFERENCES

1. STITCH, M. L., WOODBURG, E. J. & MORSE, J. M., *Electronics*, **31**, April 21 (1931), 51.
2. STITCH, M. L., MEYERS, E. J., MORSE, J. M. & WOODBURG, E. J., Conf. Proc. (5th National Convention on Military Electronics, Washington D.C.) 1961, 279.
3. CROWLEY, "Modern Communications", (Columbia University Press) 1962,
4. MILER, S.E., *Scientific American*, **214** (1966), 19.
5. GORDON J. P., *Sci. & Technal.*, **44**, Aug (1965), 60.
6. BERREMAN, D. W., *Bell System Tech. J*, Jul (1964),
7. ANDERSON, L. K., *Microwaves*, **44** (1965), 42.
8. MILLER, B., *Aviation Week*, **82**, April 26, (1965), 80.
9. VOGEL, S., DULBERGER, L. H., *Electronics*, **34**, Nov 3 (1961), 40.
10. DULBERGER, L. H., *ibid*, **34**, June 9 (1961), 24.
11. CARROLL, J. M., "The Story of Laser" (Souvenir Press, London), 1965, p 114
12. WATTERS, J., *Signal*, **20** (1966), 68.