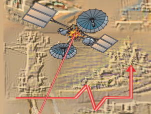
PHOTONICS IN WARFARE



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Light

from the sun sustains life,

from feeble flame fights dark and dispels fear,

(is the object of concentration for many)

On reflection informs and adds to knowledge,

(lack of it casts shadows and doubts)

In cosmic garb it is the very Existence;

but as weapon of war

it carries death and destruction.

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Photonics in Warfare

VV Rampal

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CONTENTS

PREFACE

The last quarter of the twentieth century has been particularly significant for the growth and maturity of photonics. It has seen the development of lasers and fibre optics resulting in a vast area of application both in civil and defence sectors. It made some optimists to declare that future belongs to photonics. To some extent it has come true. We are now living in an age dominated by optoelectronics and computers. Though application of lasers in Defence have been written about and emphasised time and again, an overall view of the role of photonics in warfare technology needed to be discussed in a single volume for the R & D scientists and managers. The book attempts to do just that. The literature is scattered and at time scarce due to security considerations. However, trends of developments are visible and an attempt can be made for forecasting the level of intrusion that photonics is likely to make in the defence instrumentation and weapons of tomorrow.

Chapter 2 to 8 emphasise the technology status in the last decade, in particular reference to optical or optoelectronic devices and systems used in modern warfare. Based on this information and the impact of emerging technologies of integrated optics and microoptoelectronic structures, an attempt is made to peep into the future directions of micro miniaturization and intelligent systems. It is easy to conclude that photonics does indeed have a future in warfare technology of tomorrow. The systems are likely to be more robust, more reliable, smaller in size and intelligent enough to take decisions without human intervention.

I wish to put on record the contribution of Dr. A Selvarajan in writing part of Chapter 2. I would have liked more from him, if circumstances had permitted to do that. I also wish to acknowledge all the help extended by DESIDOC in bringing the book into the present form. I am thankful to DRDO for providing the necessary

financial support, and to the Directors of some DRDO laboratories (e.g., DESIDOC, Delhi; DEAL, Dehradun; DLRL, Hyderabad; ARDE Pune; and ADE, Bangalore) for allowing the use of libraries and technical information centres for scan of research publications.

I sincerely wish and hope this monograph brings the necessary awareness about the role and importance of photonics in warfare technology and encourages the development of photonics based instrumentation in defence preparedness in the years to come.

Dehradun
April 2002 **VV Rampal**

CHAPTER 1

INTRODUCTION

Photonics has been truly described as the technology of future. Its increasing relevance in diverse fields has made it to emerge as a field of promise. It provides a hope to reach the frontiers not yet achieved, particularly in areas bordering science fiction, such as killer beams and optical computation.

Conventionally, photons are related to the optical region of spectrum. As such, photonics deals with light and, in some cases, with near infrared region. But over the years, rapid advancements in the field of optics and electronics have blurred the classical definitions of various related phenomena; thereby leading to the use of terms like electro-optics & opto-electronics rather interchangeably, even though conservatives would still like to use the terms with great caution. There is however, general agreement that the term photonics should embrace all the activities connected with generation and manipulation of photon stream either by optical means or by electrical methods or by both. This provides a generic nomenclature for all techniques, which employ electro-optical or opto-electronic components and devices for performing a particular function.

Like any emerging field, photonics also promises applications, which are only limited by the imagination of the users. In some areas, it not only supplements but even surpasses the expectations from existing techniques. There is already a vast body of literature existing, which provides optical/electro-optical methods for achieving desired objectives in scientific, industrial, medical and commercial sectors. But that is not our objective in this volume. The present monograph attempts to highlight the principles and uses in another, rather obscure area of warfare technology where photonics is increasingly becoming relevant. The emerging confidence in laser weapons, and consequently the need for countermeasures, is an obvious example.

The ability to strike military targets, while minimising the risk of damage to civilians and urban infrastructure, has proved to be an important policy option for military planners and political decision makers. Electro-optic targeting systems have already provided the ability to attack hostile elements deliberately placed close to or within urban areas and civilian population centres. These are important considerations for modern forces. Offensive actions need to be carried out with minimum risk to own forces and civilian infrastructure. In modern military systems, it is photonics that provides the option.

Another benefit of photonic systems arises from the comparatively short wavelengths that they use (~1 to 10 μ). The spatial resolution of an electro-optical system and a radar are governed by the same laws – the aperture (antenna) must be large compared to the wavelength, if a narrow transmitter beam or a finely detailed return is needed. For similar resolution, a radar needs an aperture (real or synthetic) that is hundreds to thousands times larger than an electro-optical system. Further, unlike radars, electro-optic systems can operate passively, thereby reducing the risks of detection and counterfire. This is because the photonic systems can exploit the illumination provided by the sun, moon, stars, or even airglow and all objects radiate thermal energy in proportion to their temperature.

In a wider context, photonics can be described as the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. It is concerned with the study and uses of lasers, electro-optics, fibre optics, and both classical and quantum optics. One may also view it as a branch of science in which photons play the same role as electrons do in electronics. It is thus, related to the functions connected with the manipulation of photon beams in respect of its energy density in different media and the control it provides to other functions.

1.1 PHOTONICS AND ELECTRONICS

Electronics and optics correlate to the properties of electrons and photons. The two particles have some basic differences and limitations inherent in their very nature. Electrons are charged particles and follow Fermi Dirac statistics. Photons on the other hand, have no charge but energy hf and momentum hf/c, where h is the Plank's constant, f is the frequency of radiation and c is the velocity of light in vacuum. Photons follow Bose-Einstein statistics. The charged nature of electrons makes them easier to contain and guide but it restricts their concentration because of mutual repulsion. Photons can, however, crowd together without limit and, therefore, generate enormous amount of energy density. The charged beams (electrons) cannot cross without interacting but there is no such handicap in the case of photons, thus enabling cross connections of light beams.

Electrons have the property of interacting at a distance. This leads to inductive and capacitive effects, which cause delays in transmission due to limitation of channel bandwidth. This interaction, however, has a very desirable feature of switching. Switching enables digital working and provides advantages in communication and computation. The lack of interaction among photons would appear to make optical switching unrealisable. But fortunately, optical nonlinearity provides bistability, which enables optical switching and promises optical computation similar to digital computers.

Electrons acquire a velocity depending upon the accelerating field experienced by them. Their finite velocity, which is less than the velocity of light, poses transit time problems and leads to bandwidth limitation. Photons, however, move with the velocity of light and possess very large bandwidth (10^{14}–10^{15}) Hz as against (10^{11}–10^{12}) Hz for electronic signals of millimetre waveband.

The energy of photon is confined in a region of the order of its wavelength, which for optical band is in the submicron range. This short wavelength causes line-of-sight transmission with scattering loss mechanisms, which are in-built during the propagation of light beams. Electromagnetic theory interprets light intensity as energy flux of the field. This intensity of light has been defined as the time average of the amount of energy which crosses in unit time a unit area perpendicular to the direction of energy flow. Light differs from other forms of energy transport in the fact that it is a form of energy conveyed through empty space at very high velocity; light energy is always moving, the movement being only slightly affected by medium. When there is no movement, say after absorption, there is no light.

The first noticeable difference between optical and electronic systems lies in the input stimulation itself. Whereas electronic stimulation is by way of either current or voltage, the optical stimulation is by way of an incident wave of specific intensity. Secondly, we deal with positive and negative voltages depending upon whether the amplitude of electronic field is of one polarity or the other. In optics, we basically deal with intensity (proportional to square of field amplitude) and as such can have only positive values for the input variable. One can, of course, have path difference (leading to phase difference) as well as difference in polarisation state between two optical input waves. The total intensity due to summation of these waves then depends on the degree of coherence of the waves. Optical free space propagation, except for backscatter, is unidirectional. Furthermore, in electrical systems the input and outputs are real function of a one dimensional variable (i.e., time), whereas in optical systems the input and outputs are either real value functions (intensity) or complex value functions (amplitude) of independent two dimensional variables (i.e., space). Fourier formalism in electronic and optical systems therefore differs in this respect. Fourier analysis has played an important role in the field of optics where it is applied to the theory of coherent and incoherent imaging.

The possibility of system synthesis with frequency domain techniques applied to imaging have increased and it is now possible to apply many of the properties of filter functions for electrical systems to optical systems in the field of imaging and information processing. In the optical band, fourier transformation can easily be done using a lens. Fourier plane filtering techniques are, therefore very usefully employed for analogue optical signal processing. The optical signal (e.g., an image) is a two dimensional variation of intensity so that Fourier transformation consists of various spatial frequencies. The spatial frequency band can suitably be modified by allowing either the low frequencies or the high frequencies or a particular band by using spatial filters. The inverse Fourier transform gives the modified spatial signal (i.e., the processed image). These analogue methods have been used for image processing for quite sometime and have the advantage of parallel processing inherent in optical techniques, which result in fast processing of a vast amount of optical data.

Transfer of information from sender to receiver may involve sending either audio, video or digital data or a combination of these. The process involves acquisition of information, transmission through the medium in the open or guided mode, processing in a classified manner (for reasons of secrecy), presentation in the desired format and storage and display. Optical as well as electronic techniques can be used effectively for realising the above mentioned processes. The optical band may be optimistically viewed as an alternative to the electrical band as research progresses further in time. Already, fibre optic communication links and fibre optic sensors have established their place in technologically advanced society. In signal processing, the development of spatial light modulators, real time generation of spatial filters, transformation of an electrical or acoustic input to a coherent optical signal, are creating renewed interest in optical methods.

To appreciate increasing relevance of optical methods, it is desirable to look deeper into the similarities and dissimilarities in electronic and optical processes. Although both wavebands form part of the general electromagnetic spectrum, the wavelength difference causes certain differences in the design of components, devices and overall operational features. Differences in quantum energy (hf) and variable coordinates (temporal in electronics and spatial in optics) and similarities in signal processing techniques (filtering, band limiting and switching) are easily noticeable. Analogues in modulation and detection processes exist and optical feedback techniques leading to development of light gates and optical flipflops have gained recognition.

1.2 PHOTONIC ENGINEERING

Historically speaking, the need for the use of optical spectrum in engineering systems has followed the same route that other necessity-based inventions have taken. In specific terms, the crowding of communication frequencies in lower bands for information transfer led to the necessity for higher frequencies and wider bands resulting in fibre optic systems for large data transfer over long distances. Advantages of getting over EMI problems, use of compact structures and secrecy considerations have been much desired additional bonus. The need for increasing power densities in laser beams for attack and destruction of remote targets, improving availability of coherent radiation over wide range of frequencies, and use of quasi-optical region have provided the necessary trigger for further growth and, consequently, a bright future for photonics in the years to come.

Development of components and devices for engineering systems in the desired frequency range has always been a major factor for the growth and utilisation of that frequency band. Components and techniques have to be developed for carrying out some basic functions, such as generation, detection, amplification, low loss transmission, change of volume density, direction and directivity, spectral narrowing, and frequency translation. With change of wavelength, the techniques for achieving these functions also change. Further, wide use of the spectrum leads to interference problems and strategic and tactical needs dictate the use of countermeasures. In situations where hf/KT values differ considerably, a conceptual difference in approach is needed.

In the optical domain, incoherent light sources, natural and man-made, are all too familiar. In fact, familiarity with light is one of the earliest experiences of man. However, coherent light sources are more recent in origin. In going over from microwaves to higher frequencies of infrared and visible region, the nature of particles interacting with the field to be amplified changed from energetic free electrons in electron beam devices to material particles (ion, atoms, molecules) raised to high energy states. This thinking brought into focus a whole new range of possibilities for amplification and generation of coherent radiation at optical band. The requirement of population inversion (the number of particles in the higher energy state being larger than those in the lower energy state) for providing amplification and the need for reducing the number of modes by resonant cavities at these optical frequencies was found necessary. The practical implementation of these requirements enabled the emergence of what is now known as the laser.

Optical filters provide spectral narrowing. Multilayer dielectric thin film filters and Fabry-Perot etalons are familiar examples. Detection of radiation in the optical band has two possibilities: incoherent detection or coherent detection. The latter technique involves frequency scaling with the use of a local oscillator as is normally done in the electrical case. Coherent detection at optical frequencies has become feasible comparatively recently with the availability of stable oscillators (frequency stabilized lasers). Local oscillator stability has been a difficult problem with lasers, since purity of mode and polarisation constancy are difficult to achieve. However, with the emergence of injection-locked lasers and use of various other factors contributing to stability of lasers, coherent detection in the optical region is now established in fibre optic systems. This provides an order of magnitude improvement over incoherent detection.

In photonic systems, atmospheric effects are most severe at optical wavelengths. Absorption and scattering at optical wavelengths occur because of the chemical composition of the atmosphere and interference between wavelengths and airborne particles of similar dimensions (fog particles are about one micron in diametre and therefore thermal systems fare better).

As in microwaves, low loss transmission of optical radiation in a given medium requires that the loss due to absorption and scattering be kept to the minimum. However, unlike microwaves, very small spot size can be obtained in optical region by focussing with suitable-size lenses, since the minimum size of a diffraction limited beam is of the order of wavelength of radiation. Changing the direction and directivity of light beams is made possible using electro-optic modulators and combination of negative and positive lenses. Directivity considerations may vary with spherical and Gaussian wavefronts. Frequency translation and tunability of optical radiation is achieved by using the nonlinear optical properties of certain materials (crystalline, liquid or gas). Harmonic generation, parametric oscillation, up conversion and down conversion use the now well-known nonlinear optical techniques. For reference one can consult any standard text on nonlinear optics[1].

In warfare terminology, countermeasures assume great significance. Once the radiation is sensed from enemy sources, efforts are required to find the location, power level, wavelength and duration (prf) of the source. The information helps to counter the threat from the incoming radiation. The subject is important enough to deserve detailed discussion in view of laser-based instrumentation and killer beams used by adversaries.

1.3 THE QUASI-OPTICAL REGION

The region of electromagnetic spectrum between about 100 GHz (λ=3 mm) and 1000 GHz (λ= 0.3 mm) has become increasingly important over the last decade. Because of the very short wavelength, it is possible to produce well collimated beams, which propagate in free space and occasionally need to be refocussed by lenses or mirrors. Because of close similarity with conventional optics, the name quasi-optics has been considered to describe application of optical techniques to the far infrared and millimetre/ submillimetre wavebands. Components for quasi-optical systems therefore, generally, have dimensions characteristic of the beam diameter, making them easier to manufacture than their microwave counterparts at the same frequency (in electronics, the component size is $\leq \lambda$, whereas in optics it is >λ).

1.4 PHOTONICS IN CIVILIAN LIFE

This monograph is essentially concerned with the role of photonics in warfare technology. However, photonics has a great potential as dual-use technology. Communication through optical fibres, high density data storage and retrieval with optical discs, laser and holographic displays, satellite cameras for earth observation, night vision devices, medical diagnostics, etc., are some such areas. This indirect use of civil facilities for battlefield scenario, both strategic and tactical, is apparent in the use of hospitals, telephone exchanges, and satellite imagery both during war and peace. Real time information transfer from the battle scene to the planners at HQrs is an important aspect of military operations. The existing civil facilities are shared by the services in times of emergency. Further, modern warfare establishments are frequently called upon to fight insurgency and proxy war by the enemy. In such operations, civil institutions are an integral part of the joint strategy to meet the challenge. The role of photonics in civil sector therefore, also have a place, though indirectly, in contributing to the success of war effort. This aspect needs to be kept in mind while differentiating between the defence applications and the scientific, industrial, or medical applications of any specific technology for the community at large. Laser applications, both civil and defence, have been described in various texts[2]. New applications, however, keep emerging (as in medical science and in manufacture industry in recent times) and a continuous update is needed.

1.5 PHOTONICS IN DEFENCE

A coherent optical source, such as the laser gives radiation that has high intensity, good spectral brightness and low divergence. These properties have led to a number of applications for the civil and defence use. Some of the devices and equipment based on photonics technology (e.g., laser range finders, laser guided bombs, target trackers, and simulators of weapon training) have matured enough to be inducted into the services with full acceptance. These devices use laser as source with optical components and electronic instrumentation for measurement and fire control. Others, like beam weapons for destroying targets, thermal imaging for night viewing, surveillance (airborne and satellite platforms), fibre gyros for navigation, and concepts of multisensor fusion and countermeasures are more recent in origin. Satellites for critical information, and fibre-optic links for communication and weapon systems, provide vital support to the total concept of information, attack, and destruction of enemy targets. Tactical requirements need updated information. Smart weapons need eyes (optical sensors) and computer-based computation to take fast decisions. Estimation of damage caused to enemy is also an important parameter for the planners of further attack. Sensory input (visual and non-visual) plays an important part in everyday life as it does in the war scenario. Multi-sensor fusion for reliable operation is becoming increasingly relevant in the present warfare setups. To prevent enemy from causing damage by intrusive radiation and also to create a confusing environment for the incoming radiation, countermeasures are adopted. It is expected, of course, that countermeasures lead to counter-countermeasures and so the effort goes on.

The use of laser radiation for distance measurement has been one of the earliest uses of lasers. The short wavelength of the optical radiation compared to the microwave radar enables very small beamwidth of the order of a milliradiation or less. This makes it possible to range different specific targets, a few metres in size, individually, at distances up to 10–20 km. Unlike conventional microwave radar, this also makes it possible to range the target area at low grazing angles and the possibility of the direct interruption of the beam is considerably reduced. The laser range finders (LRFs) used in defence are normally of the one pulse optical radar. Such LRFs have been developed for maximum range of 10–20 km with range accuracy of ± 5m at all ranges. They have now found their acceptance in the defence services all over the world. Different versions are available for use in infantry, artillery, tanks, observation posts, and aircrafts. The stringency of requirements of size and weight, however, depend upon the particular role for which the instrument is made. There is emphasis on miniaturization and LRFs are now available in the form of handheld binoculars. For reasons of greater penetration in fog and lower atmospheric losses due to scattering, CO_2 laser operating at 10.6 μ is used as the source. Sealed CO_2 laser unit is necessary for this. Range resolution is decided by the pulsewidth and the clock frequency of range counter (one count error). The strong backscatter in the first 100–200 m causes the masking of echoes and determines the minimum range of the instrument. The use of time variable gain in the receiver amplifier obviates the problem due to backscatter and unwanted echopulses in the range measuring circuits. Range gating or range blocking is another technique to achieve the same objective. Circuits have also been designed whereby more than one echo can be detected and range due to each echo displayed at will. Multiple echo discrimination and range gating capabilities are essential features of an LRF meant for defence use.

Laser radar systems[3] combine the principles of microwave radar and optics. High frequency operation (10^{14}–10^{15}) Hz coupled with excellent spatial and temporal coherence, results in the laser providing diffraction limited operation, large aperture gain, high intensity illumination at long range, photographic size spatial information of the target, and coherent detection receiver operation. Short wavelength (0.3–3 μ) optical coherent detection systems provide very large backscattered Doppler shift (2 MHz per m/s at 1μ wavelength versus 200 Hz per m/s at 1 cm radar wavelength) from moving target and allows accurate velocity measurement during a single-short-pulse-range measurement. Modulation of the laser beam and the addition of a coaxial passive thermal imager provides range, velocity, and temperature measurement of the target. Azimuth and elevation scanning of the laser beam over a target and subsequent signal processing of the received signal allows target acquisition, tracking, and imaging. Computer processing of this data with process specific algorithms can result in each pixel having 6-D data (azimuth angle, elevation angle, range, velocity, reflectance, and temperature), which can be utilised to provide multi-dimensional imaging.

An important phase of laser application for defence purposes has been in the guidance of weapons whereby the object to be destroyed is illuminated by the laser radiation and the weapon is homed-onto the target. The development of laser guidance started in the late sixties and practical devices, called the smart bombs, have been in operation. The higher accuracy of attack and overall cost-effectiveness make the system of laser designation worthy of serious consideration. Modern low flying aircrafts used for ground attack are fitted with suitable laser instrumentation to provide range finding and target designation capabilities for seeking the target, measuring its range, and sending the weapon onto it thereby reducing the human element to the minimum. Carbon dioxide laser giving 10.6 μ radiation has been used to improve the capability of the system under conditions of fog, smoke, haze, etc. The laser illuminator is generally a high repetition rate pulsed laser source in the infrared, which sends the laser radiation onto the target. The selection of target is done by a viewing telescope, which forms part of the illuminator.

Depending on the particular requirement of the guidance system, the illuminator can be either

(a) Ground-mounted,
(b) Handheld by the person proceeding ahead for the selection of target,
(c) Placed in the attacking aircraft or the helicopter in the pod configuration (or along side designator), and
(d) Mounted in the remotely piloted vehicle (RPV).

The guided weapons can be either

(a) Glide bombs, i.e., free falling gravity bombs, or
(b) Missiles, or
(c) Artillery projectiles.

The laser guidance of missiles and artillery projectiles requires a quick-acting-sensing and control-mechanism since these weapons are very fast moving. Usually, the laser radiation used for guidance is modulated in a certain fashion and the seeker and control mechanism is sensitive to that modulation. High probability of first hit and destruction of pin-pointed targets are main advantages. This results in lesser number of sorties.

Tracking of satellites can be done by laser. This assumes importance for defence when the satellite under observation is a spy satellite. This application, however, requires highly sensitive and accurate control mechanisms to follow the trajectory of satellites. High intensity and high directivity of the laser beam is utilised to shine onto the satellite and return echo is used to keep the target in view. The same principle is adopted to follow the movements of high flying airborne platforms including missile and aircraft.

Laser-based weapon simulators have the advantage of saving ammunition during training exercise. For practice of aiming, the laser source is used as a gun. To have an estimate of the accuracy of aim, the target is fitted with sensors of laser radiation. When the aim is right, the sensor provides a signal to show the hit. In this arrangement the miss distance can also be obtained and the information is automatically recorded for later analysis. Such simulators are useful for providing armament training. The shooting distance of course has to be such that ballistic error does not creep in. This is true for bullets and missiles fired from guns with high velocity.

Laser weapons work on the principle of depositing a large quantity of energy on a small area in a short time. Heat deposited by a continuous beam, shock waves produced by a pulsed beam, or a combination of thermal and shock produced by a series of rapid pulses can penetrate the skin of the target. The intense laser beam disables the guidance system of warhead, or trigger an explosion of the fuel or warhead. The main attraction of the laser weapons is the speed with which the laser beam travels. By the time it takes the beam to travel one kilometre, an aircraft at Mach 2 speed will move only one quarter of a centimetre. Thus no ballistics or leading the target is necessary. Also, since there is no missile or fuse in the weapon, it is less vulnerable to electronic countermeasures than conventional weapons. Correction for thermal blooming, turbulence and other atmospheric effects requires adaptive optics, which corrects the wavefront of outgoing laser beam to compensate for atmospheric distortions. Laser weapons could be used in all the three wings of the armed forces. In the army, it can be mounted on tank or at radar installations. In the navy, laser weapons could be used for defending ships against air attack. In air force, lasers can be fitted in aircraft for use against hostile aircraft, air-to-air and ground-to-air missiles. It has been suggested that they could be used against satellites. Optical phase conjugation-based self-targeting could be useful for autotracking of target objects.

For imaging at low light level (night conditions), following methods can be adopted:

(a) Increase the light level in the image by a factor of about 10 million to bring it within range of eye vision, and
(b) Improve poor contrast on account of noise in images

Increase in light level of image is brought about by (a) collection of large flux from object and then forming a very small size image on a high quantum efficiency photocathode and (b) high gain image intensification, either by a single high gain tube or cascading a number of image intensifier tubes. The first process controls the image contrast whereas the second provides image intensification to bring it to a level fit for eye vision. The instrument is designed to provide proper resolution, a proper intensity level, and a desired field of view. Image contrast is a measure of the detection of the difference in brightness between two adjacent object elements and depends on the ability of the detector to distinguish between average number of photons it receives from the two elements. Statistical fluctuations in the number of emitted photons create an associated noise in the signal. The lesser the light level, the larger the noise and hence lower the contrast. Even if the image is intensified, the image quality will still remain poor since the performance in respect of resolution will depend, in addition to diffraction and aberrations, on the noise level. Active and passive infrared sights for night vision have been developed. The passive infrared system utilises the principle of thermal radiation emitted from hot body. At ambient temperature of 300 °K, the peak emission wavelength lies at 10 *m* while the heated body, say at 100 °C, will radiate at around 8 *m*. Thermal systems provide a temperature differential image. These systems are finding use in various armoured vehicles, platforms, and installations and have a range around 4 km. They use large aperture optics and sensitive detectors in the mid IR region either in single point or array configuration.

Military lasers, thermal imaging and image intensifying systems are central to the aiming and delivery of ordnance on land, at sea and in the air. Development in micro-electronic devices, packaging techniques and data processing have so improved the performance and capability of these technologies, that both new weapons and new ways of using them have become available.

Thermal imagers find favour because they provide true night vision as compared to optical systems and can see further under adverse weather conditions. They compete well with image intensifiers in respect of night vision capabilities; however they are, in general, larger, heavier and much more expensive. The advantages of thermal technology, in addition to better weather penetration and day/night operation, include the fact that military targets often have a unique thermal signature (hot engines, power plants and exhausts), thereby greatly assisting target detection and identification.

As early as 1965, it was pointed out that using a giant pulsed laser for illuminating a target for photography has certain advantages. The exposure of the camera can be for a very short time (30–50 ns corresponding to laser pulse duration) and the exposure can be delayed by a known amount, thereby reducing the backscatter. Also, knowledge of the delay, which can be adjusted at will, gives information about the range of the target. This is apart from the fact that nanosecond exposure of the object remains almost undetected by the object particularly when infrared laser is used. Also, use of interference filter at the laser wavelength enables the operation both during day as well as night. There is also a scope for electronic signal processing to extract the desired information, which can be done almost in real time. In desert environment, where problems of shimmering and index variation in space and time are present, this method is likely to give better results. This is so because the exposure time is so small that the medium is almost frozen in time for each observation.

The reflectance image is similar to a conventional picture of a target except that laser illumination is utilised. Range imaging allows a range gated picture, which provides atmospheric and ground clutter rejection while supplying ranging to each pixel. The range measurements can be utilised to isolate a stationary target and provide its shape and size, while a thermal image portrays the hot and cold elements of the scene. Doppler imaging can reject stationary targets, provide images of moving targets, and measure velocities of each pixel.

Surveillance satellites gather enormous data and processing this quickly presents a difficult problem. Optical technology helps in this by enabling pre-processing of the data in parallel configuration. Parallel processing is an inherent feature of optical data processing. Pre-processed data is then transmitted downward to the ground station for further processing in order to extract the desired information. Ground processing may be electronic in nature to achieve flexibility in data handling. An important component of pre-processing is to reject the unwanted information, such as data obtained under cloud cover or over vast areas of uniform terrain. Pre-processing steps, like removal of *dc* component, edge enhancement, etc., can be done optically to take advantage of parallel processing feature of optical technique. Optical pre-processing followed by electronic processing provides an efficient hybrid processor, which combines good features of both optical and electronic techniques. It is a useful method for handling large data inputs to provide near real time information to the user. Hybrid processing reduces load on the image processing infrastructure. Another aspect of on board image processing in satellite platforms is the use of optical spectrum analysers for EW purpose. Integrated optics versions of acousto-optic or electro-optic modulators are used for the spectrum analysis of microwave signals. In this arrangement, a laser beam passing through the modulator is deflected in accordance with the frequency components present in the microwave signal. The unknown microwave signal is applied to the modulator to cause deflection of the laser beam. The electronic signal to be analysed may span even GHz range. Simplicity of operation and miniaturization of the device are some of the noticeable features of this spectrum analyser.

Gyroscopes play an important part in the development of navigation devices. These are needed in the navigation of aircraft and missiles. Optical fibre gyro is a recent development which is based on the phase shift generated between two counter-propagating light beams proportional to the rotation rate. Compared to the mechanical gyro, the laser version is substantially cheaper, lighter, has no startup time and is a strapped down device. Its life is also very long (several tens of thousands of hours) and it has no moving parts. The use of integrated optical circuits make the fibre gyro very small in size compared to the bulk version. The integrated version-based on resonant structures offer the same sensitivity as fibre gyros and are also compact but the technological problems are severe.

Laser communication systems in open atmosphere are limited to the line of sight application in an environment, which is free from fog, rain and dust. Effects of temperature variation causing fluctuation in refractive index, also limit the range. The carbon dioxide laser holds promise for high power transmission over large distances. Atmospheric absorption at 10.6 μ, principally due to carbon dioxide and water vapour, is relatively low. Since 1977, however, optical communication has been entirely taken over by fibre optic system. Such systems are finding use for both civil and military applications. Intra and intercity telecommunication services are increasingly adopting fibre optic systems for their large bandwidth capability resulting in increase in number of channels per cable. Reduction of size, weight and volume of cabling, availability of wide bandwidth, improved EMC and immunity from crosstalk, EMI and EMP, have made the use of optical fibres for communication an attractive option. Both civil and defence sectors are beneficiaries of this development. Justification for the military use, however, is quite different. In civil use the low overall system cost is the sole motivation whereas for defence application it is usually the advantage of small size, weight and good EMC of optical fibres. For military use the environmental constraints are far severe but distance and data rates are rather modest.

A number of applications have been cited for defence use. These lie in the area of

(a) Replacement of wire signal links by fibre optic channels in aircraft and shipboard installations

(b) Multiterminal data buses for transfer of digital data and video information for on board installation
(c) Sending analog signal from a sensor array on a submarine to a computer for processing
(d) Interconnecting satellite antenna to a computer processing centre on fixed land-based systems
(e) Replacement of existing communication facilities, and
(f) Replacement of electrical cables in sonar telemetry systems, guided torpedo and towed array surveillance systems in undersea applications.

Underwater TV surveillance systems based on optical fibres are already in use. The real advantage of optical fibre communication is realised best when fibres form an integral part of the overall integrated optics concept. This not only retains the obvious advantage of large bandwidth and freedom from EMI but also conforms to the small size, compactness, and long time reliability associated with integrated circuits. The trend of fibre integration with integrated optical circuits is of paramount significance for the future systems.

To summarise, we may state that photonics has now found its way into nearly all aspects of surveillance, observation, weapon targeting and missile guidance. It dominates where operating ranges are in the region of 1 to 10 km. At greater ranges, the required apertures for target detection are manageable only in highly specialised systems (for example, space-based sensors or fixed installations). Therefore, it is in the air-to-ground battle that photonics has had its major impact because combat ranges are well matched to what the technology can provide[4]. Generally, electro-optic systems are added as an adjunct to radar fire control systems in normal warfare to provide a secondary control mode and a visual means of damage assessment. However, for detecting sea skimming missiles within horizon range, infrared search and track systems are emerging as an important alerting device. Similarly, for close-in weapon systems, thermal imageries are increasingly seen as a necessary adjunct to radars for timely identification, engagement and damage assessment of close-in threats from missiles and enemy crafts. Further, photonics has benefits under conditions of radar silence and for identification and recognition. For inshore operations, threats from enemy craft, mines and shore-based assets can be countered more effectively with electro-optic systems.

In numerous applications, from infantry weapons to airborne ground attack systems, photonics provide the ability to see, detect, recognise and engage targets with speed, clarity and precision that no other systems can match. In nearly all cases, photonics provide the primary sensors. An exception is land-based air defence, where although photonics can provide passive alerting and visual confirmation of the engagement, target speeds and the need to search large volumes of airspace make radars the primary sensor unless passive operation is a necessity.

In active electro-optical countermeasures, however, photonics can still be said to be in early development. But where ranges or required powers exceed the capability of lamps and flares, the case for laser systems is a strong one since a laser is inherently directional, and energy can be transmitted much further and with much more accuracy.

The relevance of photonics in warfare is an everwidening area of potential applications maturing to actual use depending on the developments in other fields, such as micro-miniaturisation of electronic and mechanical devices, the security aspects, increased reliability, and development of new devices in weapon technology and delivery systems. A case in point is the emergence of micro-structures and integrated optics in providing micro-electro-mechanical (MEM) and micro-opto-electro-mechnical (MOEM) components. Micro-actuators, monolithic structures and multi-function semiconductor devices have an impact on future warfare in terms of reduced cost and volume of devices, greater reliability and accuracy in operation and a higher level of intelligence in the systems employed. This has special reference to smart photonic sensors and weapons systems.

A survey of all existing and potential applications of a known technology in specific domain is at best a sketchy affair. What is pertinent is to describe in reasonable detail the matured applications and to indicate the potential ones so that an overall picture is created about the usefulness of the technology for the purpose in view. The emerging trends need to be pointed out to complete the scene. This is attempted in the following pages. It is obvious the horizon is always expanding and there is no finality about the description of applications. The picture is always changing with time. It is hoped that this is kept in view while reading the ensuing chapters.

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