USE OF REMOTE SENSOR SYSTEMS FOR MILITARY RECONNAISSANCE

A Dissertation
submitted in partial fulfilment
of the requirements for the Degree
of
MASTER OF ENGINEERING
in
ADVANCED SURVEYING AND PHOTOGRAMMETRY

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C E R T I F I C A T E

CERTIFIED that the dissertation entitled ,

" USE OF REMOTE SENSOR SYSTEMS FOR MILITARY RECONNAISSANCE"

which is being submitted by Sri Narinder Singh, as a partial fulfilment for the award of Degree of Master of Engineering in Advanced Surveying and Photogrammetry of the University of Roorkee, is a record of bonafide work carried out by him under my supervision and guidance. The results embodied in this dissertation have not been submitted for the award of anyother Degree or Diploma.

This is further to certify that he has worked for a period of about six months for the preparation for his M.E. dissertation at the University of Roorkee.

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A C K N O W L E D G E M E N T S

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S Y N O P S I S

For planning and conducting war operations, reconnaissance plays an important role. The reconnaissance methods in the past were very crude and were conducted by actual field work. Military needs demand that such information may be gathered as far as possible from a remote point due to various political and environmental barriers and in the shortest possible time.

The development of photography was a step towards this side. But with the advent of electronics, most efficient types of sensors were developed. Each of these systems has been described in detail in separate Chapters in this dissertation.

Chapter I gives the general introduction of remote sensor systems and military reconnaissance.

Requirements of military intelligence and how these requirements have been met by photographic systems have been explained in Chapter II.

Chapter III deals with Radar systems, starting from basic working operation, radar scope or indicators, radar presentation, restitutor, side looking radar and its restitution, line scanning reconnaissance techniques, radar beacons, radar relays and military potential of radar have been explained with particular reference to military needs. Air borne profile recorder has also been discussed.

Modern types of remote sensor systems have been introduced in Chapter IV. Their potentialities, relationship with Electromagnetic spectrum have been discussed. Terrain Analyzer project with remote sensors has also been described.

Chapter V describes infrared photographic system and explains this technique with special reference to terrain feature analysis. The multispectral photographic system in general and a multispectral camera has been discussed in Chapter VI.

Chapter VII deals with Electro-optical photography at low illumination level.

Laser and its applications have been described in Chapter VIII, and in the last Chapter the most recent developments of Electronic photogrammetry and non-photographic photogrammetry have been discussed.

In the concluding Chapter some remarks concerning the applications of these sensor systems with particular reference to military reconnaissance purposes have been outlined. Some suggestions have been given which may be of some use to the present defence requirements of India for safeguarding Her Territorial integrity.

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INTRODUCTION

CHAPTER - I

I N T R O D U C T I O N

Remote sensing is a relatively recent term for actions as old as human vision. Basically it is the term assigned to the acquisition of data concerning a subject's status or the assessment and measurements of its properties without making physical contact with it.

Reconnaissance survey is the one made to record the geography of a country. More strictly speaking Military reconnaissance is the examination of terrain to determine the location of resources including equipment, buildings, bridges etc, so as to derive strategical and tactical useful information.

Hence the definition of Remote sensor system with regard to Military reconnaissance will be those systems, which collect strategical and tactical data without any direct access to the same. These systems basically involve a platform removed away from the object under observation. The essential component of the system is a sensing device (a transducer), which picks up the necessary signal and gives a suitable graphical or other types of record, which is subjected to interpretation by employing a suitable technique.

The necessity of remote sensing emerged due to various circumstances which made the data collection by employing ground survey methods, quite difficult if not impossible, due to various political and environmental barriers especially for military purposes.

In future,war operations will be conducted day and night. The most valuable asset of military will be its capability of mobility, its capacity to operate at any time, and in any direction. The weapons employed will be,whose effects are widely dispersed in width and depth. So the army in future, though may be small in numerical strength, will be adequately equipped with modern techniques.

The most important and efficient point of view is to consider the modern warfare as, " Battle of information-handling and optimisation of our decisions". This covers all the aspects of modern warfare, whether it be a programme of accelerated research, and development of new and efficient methods or it be a deployment of limited resources (men and material) or it be the selection of best of the alternatives. The effectiveness of these decisions decide the fate of manouvers.

With the advent of electronics, the above problems have been solved quite dramatically. The development of radar systems, infrared scanners, low illumination level sensing techniques and computerised mapping system have completely revolutionised the modern military reconnaissance techniques. Such systems have completely changed the data collection problems and have virtually put each and every part of any country within the easy reach of military strategists. They can collect varied information electronically within comparatively much short interval of time. Important conclusions can be obtained from computer by feeding the suitable data. Such systems have made it possible to achieve optimum success in different operations with bare minimum use of resources in men, material and military hardware.

The economy of modern warfare demands that the wastful operations should be minimised and most efficient arrangements should be used.

Remote sensing systems have helped to rationalise our Military reconnaissance requirements and thus result in most economical and effective method.

Turning towards the Indian scene, we all know that Indian Armed Forces have been till recently depending largely upon the conventional intelligence collection, surveying-mapping methods and techniques. The main factors for this state of affairs have been the slow adoption of modern methods and heavy reliance on the conventional, time consuming, manual and ground methods due to the non-availability of suitable scientific research organisations and facilities in the modern fast upcoming sciences.

The underlying aim throughout this dissertation has been to put before all concerned the various applications of photogrammetry and other modern remote sensing systems to modern warfare techniques as currently being used in USA and other advanced countries. These have been presented in a scientific manner with suitable illustrations wherever necessary.

CHAPTER - II

REQUIREMENTS OF MILITARY RECONNAISSANCE AND ROLE OF PHOTOGRAMMETRY

CHAPTER II

REQUIREMENTS OF MILITARY RECONNAISSANCE AND ROLE OF PHOTOGRAMMETRY

Centuries ago the ancestors of military probabilities wrote: 'Know your enemy as you know yourself'. Today and tomorrow the urgency of this maxim is even greater. According to Prof. Oswal, lack of Military intelligence means Military disaster.

For planning and conducting war operations effectively, the commander must be well versed with the enemy terrain, targets, disposition of industrial areas, disposition of enemy tropps, all the information needed to reach a specific point and analysi of what is located where. Military reconnaissance conveys in general, the sense of word surveillance. So it dows not restrict itself to gain the general impression of the strategy of the area but also deals with the most exhaustive and upto-date information connected with Military intelligence.

Effective Military intelligence prevents surprises, whil poor intelligence leads the commander to a disaster by creating a false or incomplete picture of the terrain and that of the enemy. Here 'surprise' means something more than sudden discovery that the enemy has launched an attack at a time and a place least expected. It means that commander finds the enemy forces where they were not reported to be; he finds that a river is deeper and wider than he had thought; he finds that his tanks, instead of advancing, have stuck up in mud. History reveals that intelligence failure means Military disaste

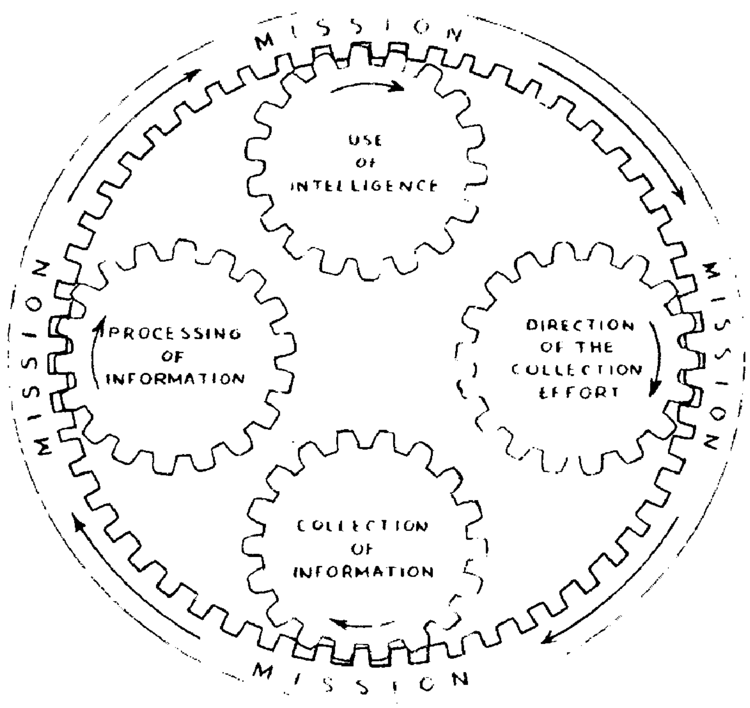


FIG. I _THE INTELLIGENCE CYCLE

For example Napoleon's disastrous defeat at Waterloo, when victory was almost in his grasp, was due to faulty intelligence. American intelligence failure in the Battle of Bulge permitted the Germans to gain a tactical, if not a strategic, surprise.

2.1. <u>Principles of Intelligence</u>:

"Information" in the Military sense means unorganised, unrelated and often distorted facts and data. It includes all documents and observations, which may serve to throw light on the enemy or theatre of operations. The information sought concerns the enemy, the weather, the terrain, and other data related to military operations in the area.

Military intelligence is evaluated from the interpreted information concerning an actual or possible enemy or theatre of operations, including the conclusions based on this information. Information is evaluated to determine the reliability of its source and the accuracy of information. It is then interpreted to determine its significance in the light of what is already known. The conclusions, which are drawn from this intelligence, include a deduction of the enemy capabilities and the determination of the tactical effect of the characteristics of the area on military operations.

"Tactical intelligence" or combat intelligence is military intelligence, which is produced in the field after the outbreak of hostilities by the intelligence sections of all tactical headquarters. Its initial and primary use is by a tactical commander in active operations against an enemy.

"Strategic intelligence" - the counterpart of tactical intelligence differs from it primarily in scope. It is produced in times of peace as well as in times of war. If must, therefore, include, within limits of available sources, complete studies of every nation and every possible theatre of operations.

2.2. The Intelligence Cycle:

The basic and elemental principle of military intelligence is embodied in the relationship between the following major features:

1) The collection of information;
2) The processing of this information to produce intelligence;
3) The use of this resulting intelligence and the direction of the collection effort.

Fig. 1 and Fig. 2 illustrate the principle.

2.2.1. Collection of information

Each collecting agency of a command is responsible for collecting and transmitting all information of intelligence value to adjacent and higher headquarters with the least possible delay, even in the absence of specific instructions. This may be done through troops, observation posts, patrols, listening posts and through air reconnaissance missions.

2.2.2. Processing of information

The intelligence section and specialists team process the collected information so as to evaluate the credibility and the accuracy of the information. Evaluated information is then interpreted to determine its significance in the light of all other intelligence at hand.

2.2.3. Use of information

The commander uses the intelligence in making tactical decision regarding the roles to be assigned to subordinate units in order to accomplish the assigned mission with the greatest chances of success. Nowadays, essenceof Military Intelligence is speed, as is rightly said -

"Mistress of Military Reconnaissance is speed."

Upto now the best way to do this is through aerial photographs.

"The aerial camera is the eye of modern Army and supplies vital information on hostile terrain and enemy's disposition and activities. These photos can be adopted to the needs of determining cover or topographic form by which the friendly forces or the enemy can approach without being seen. The commander must know places where the streams can be crossed. He muct obtain knowledge of boggy, muddy or gumbo ground and locate trails through dense woods, for which aerial photographs are considered indispensable. These photographs are also used extensively in infantry and artillery combat, in problems of military operations, in their many aspects. The air force is charged with, for the general procurement of information regarding enemy's operation far back the actual lines of combat and this information of enemy area is gained entirely through aerial observations. Military missions are more difficult than ordinary cross-country flying and it is all the more necessary for the pilot to know his sector so thoroughly that he will not lose his bearings under any circumstances.

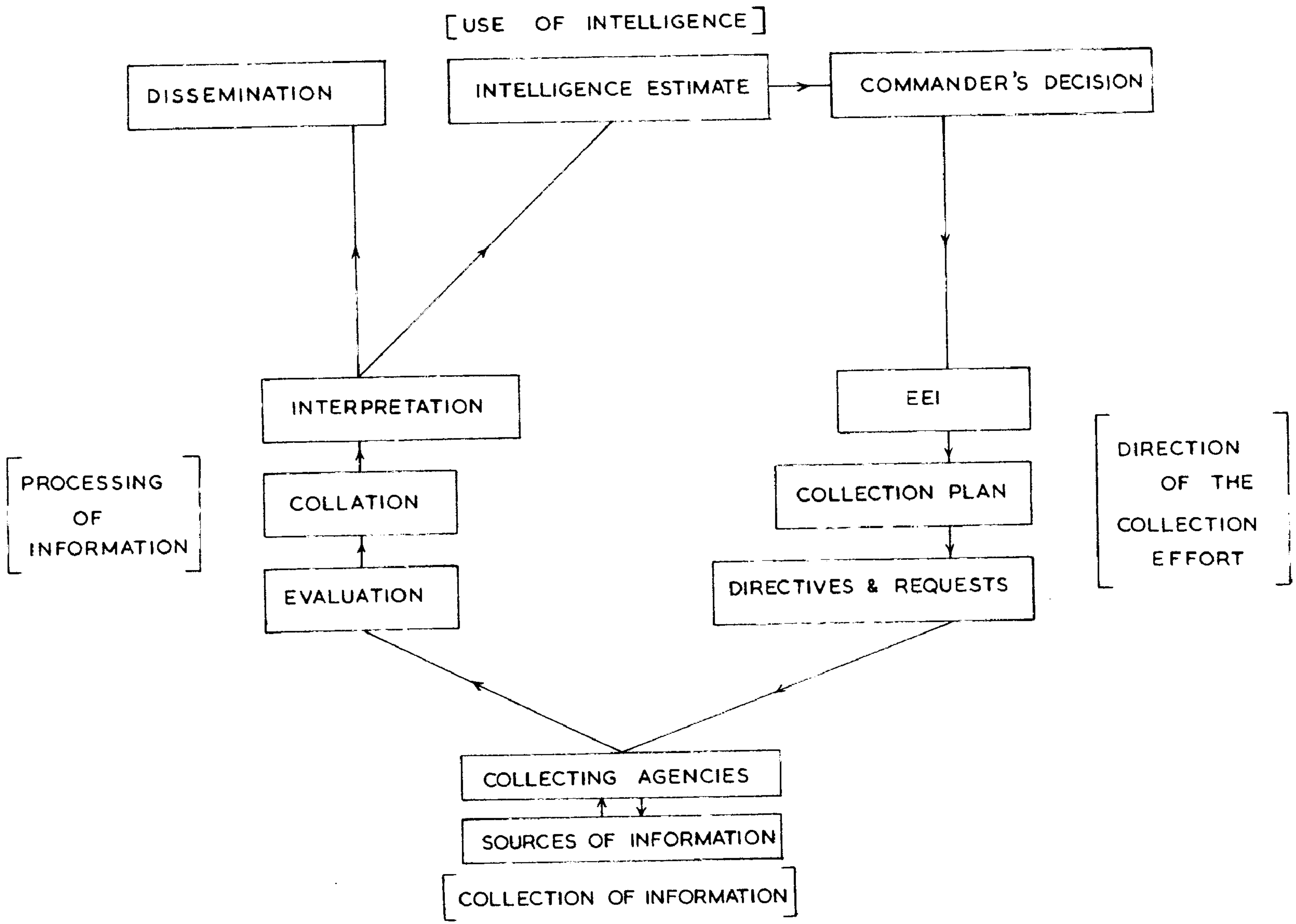


FIG.2 _ELEMENTS OF THE INTELLIGENCE CYCLE

"The nation with the best photographic reconnaissance will win the war."

-- Von Fritsch (1938)

Tactical interpretation of aerial photographs implies the detection on them of anything of military importance in the theatre of war operations. Aerial photographs have come to be one of the most important sources of combat intelligence.

"Photogrammetry was, in a sense, forced by war into a position of prominence in the survey world."

-- William

The fast moving and hard-hitting mechanised units can travel long distances at speeds undreamed not many years ago. Antiaircraft fire is too accurate and effective to permit low altitude flying. Fighter aircrafts are too fast and too deadly to permit higher altitude photography by slow moving photographic planes.

Multiple cameras are now installed both for vertical and oblique photography. In fast moving aircrafts which are stripped of everything except gasoline and cameras can outfly any other plane in the air. The pilot is the photographer who with the help of remote control takes the exposures at desired interval. The altitude of flight is 25,000 to 35,000 feet.

Trorey tells, "The maps tell a story to those who read them and the report they give must be true." The more so if they are to be used for military purposes. For herein, the ground cannot be occupied, either for control survey or for amplification of photographic interpretation. The military cartographer is thus required to make a better map from data, which is less complete. All this has to be done within limits of time quite unprecedented in civil practice; and with personnel who, for most of the work, are new to the job. Aerial photographs meet the challange fully. A military photo interpreter under combat conditions is a man working against time, under the formidable odds of handling and examining a large number of photographs when the field forces are waiting for information obtained through a hazardous air survey mission. Factors such as resolution, clarity and scale are only relevant in so far as they actually contribute to the military information.

Map is an essential article of soldier's equipment and it is rightly said, that every country is mapped for the benefit of its enemies. The air photographs look surprisingly innocent and beautiful, but in the hands of expert photo-interpreter, they betray exhaustive information as to be the best programme of attack. During war, air photographic technique, properly applied and effectively organised, supplies the speed that is essential to effective military defence and offence.

In the Russo-Finland war of 1939, aerial photo-reconnaissance came into wide use. In this war, Russian troops came up against the completely modern and well built defence of the enemy. In order to be able to plan attacks and break through defences, the Command of Red Army and Naval forces required precise documentationa and information regarding the strength of various defence installations, location of strong points, shore batteries, land fortifications, the fire section and overall defence plan of the enemy. To obtain needed information, an extensive aerial photographic project was initiated; Large areas in the region, where enemy defences could be expected, were photographed, A special photographic centre was set up to process and study the coverage obtained.

It is a recognised fact that uptil 1940, Germany led the world in Military photo-reconnaissance. The German offensive in the spring of 1940, culminating in the battle of France, had been prepared by intensive study of aerial photographs. From September 1939 to May 1940, the Germans were busy on the Western Front photographing all important military installations and transportation facilities, air fields, ports, bridges, canal and railways from Norway to Southern France. Effective reconnaissance was one of the reasons for the success of their strikes against allied airfields.

The successful sinking of 'TRIPLTZ' early in 1941 during the last way was due to the accurate air photographs, which gave accurate details of tonnage and armament layout, the exact berth she was occupying, the anti-aircraft defences, the extent of camouflage and other information which helped in planning of the attack by the bomber command. Normally, during war, intelligence is gleaned from different sources, some of them may be correct, some incorrect and others totally false. Air photos enable assessment of the information, which is more sound as compared to other sources, as cameras do not tell a lie. Since modern operational conditions have imposed considerable limitations on visual observation, the aerial camera, which records everything that comes into the field of view, has come into use and is now an important and major aid in modern warfare intelligence. Its significance can be best illustrated by citing the sorrowful plight of Sweden, which fell to Germans because of their own fault. Being overzealous, the country openly used picture post card and photographs of important and strategic spots for advertisement purposes. These photographs found way to Germany, who repeated a rich harvest in Her battle against Sweden. Having learnt a lesson, taking of aerial photographs, except by defence people, was prohibited in 1939 by Sweden.

Photo-reconnaissance is undertaken over enemy territory to ascertain disposition and location of enemy aircrafts, troops, warships, invasion crafts, military installations and factories producing enemy's war implements and other requirements. The material so obtained is invaluable for the briefing of aircrews, paratroops and landing parties. The special feature is that the enemy country can be mapped without actual occupation. The enemy's strength can be detected without being caught. The offence manoeuvres can be planned without enemy's knowledge. In fact, photo-reconnaissance can, at time, lead a country to success without the enemy having an inkling about the attack.

2.3. Air Reconnaissance Mission :

The Air force can fly reconnaissance missions of several different varieties. In 'area search missions' a limited number of specific points such as command post, locations etc., are kept under constant observation. The "specific search" covers bomb damage assessment or enemy movements at suspected sites. "Route reconnaissance" covers the main route of advance or transportation arteries. "Artillery reconnaissance" covers long-range artillery or Naval gunfire. In "contact reconnaissance" a communication link between isolated units and their parent organisation is maintained.

Such missions are meant for searching and rapid-recording of large quantities of detailed information in the shape of high definition photographs such as photographs of targets which may range in size and interest. Various official sources estimate that about 80% of all information secured about the enemy, during World War II and the Korean War, was obtained from photography - ground or aerial. Generally, air photo reconnaissance mission is divided into two types: -

1) Strategic photographic reconnaissance - Long range, high altitude reconnaissance for intelligence survey purposes;

2) Tactical photographic reconnaissance - Vertical and oblique photography which is required within the tactical area of operations, frequently at short notices to provide close support to ground forces.

Such reconnaissance is the most important source of intelligence available to the commander. Its main purposes are:

(i) To provide intelligence regarding strength, organisation, disposition, activity and equipment of the enemy in order to deduce his intentions and capabilities.

(ii) To supplement existing tactical maps and to act as a map substitute for areas whose maps are not available.

3. To provide topographical intelligence for map making and map revision.

2.3.1. Strategic Photo Reconnaissance

It is one of the most important method of intelligence both in peace and war. It is with the aid of such activities that belligerent countries prepare for offensive operations against each other during peace time. Industries, power stations and railway junctions etc and landmarks of importance for finding one's way from the air, such as roads, railways and water courses are photographed secretely both from air and ground and carefully described in comprehensive secret handbooks.

Strategic reconnaissance in war times is meant to contribute to the correct estimation of the enemy's resources, grouping of forces and intentions. Through such reconnaissance, information is gathered about strategic targets of different kinds such as war industries, communication links, power stations and dams etc. In this way information is also acquired about the physical nature of the area in question and registering of topographical changes which have been made . Through this a correct revision of existing maps and quick representation of special maps is made possible. These invasion maps can be kept upto date through daily reconnaissance . Military units are supplied with important intelligence about the enemy, right upto the last minute before the actual 'D' day.

On the other hand, the defender uses photo reconnaissance to gather reliable information about the enemy's intentions and preparations, which in many cases cannot be hidden from a vigilant air force. Suitable craft for the invasion must be directed to the pre-arranged places of embarkation and along the roads leading to them. Both traffic routes and unavoidable camps and dumps of pre-embarkation cana most likely be detected and studied in detail. Thus strategic photo-reconnaissance, which is well organised and carried out in the right way, has great possibilities of eliminating largely the elements of surprise in enemy's actions . To gather required strategic intelligence , the aircraft has to penetrate deeply into enemy held territory and as such, it must fly at considerable height and at high speed to protect itself from anti-aircraft fire. Such reconnaissance flights should continue throughout 24 hours during war, to deny the enemy the protection of darkness for his moves.

2.3.2. Tactical Photo Reconnaissance

Tactical reconnaissance is carried out within the tactical operation area or the actual battle zones and is intended to give exhaustive report about the nature of the terrain, details in the enemy fortifications, the position of artillary units, the formation and groupping of reserves and intelligence from which the enemy's probable plan of action may be estimated. If the enemy has succeeded in establishing a bridge head, it is of greatest importance to continuously register the tactical situation through photo reconnaissance. Then, with the help of these photos as well as through highly detailed target maps and mosaics, the successful break down of the enemy positions can be achieved by army, naval artelliary and aerial bombardment.

Strategic photo reconnaissance is generally, carried out as vertical photography, but tactical reconnaissance can be carried out both in vertical and oblique photography. Obliques have proved very popular with ground forces, owing to the fact that they give a survey of the terrain even beyond protecting ridges and of heights in a natural way. Through low oblique photographs, a clear information regarding terrain can be obtained.

A Swedish authority advised to those concerned with military intelligence service not to miss a chance of photo reconnaissance. This should be followed by a continuous thorough and accurate interpretation. This is the best way of keeping intelligence effective and upto-date.

As defences against air attack are constantly improving, it becomes imperative for purpose of survival that aircrafts should be capable of flying higher and higher over enemy held territary. Engineers are meeting this challange to the extent that aircraft coilings are being constantly pushed upwards. It is upto the photogramist to improve upon their cameras to suit these requirements.

2.4. HIGH ALTITUDE PHOTOGRAPHY

To meet the above said requirements, high altitude photography is gaining importance in military world. For this, long focal length cameras even upto 240" or so have been designed, which can be operated at high altitude of 80,000 ft or higher. In all such cases, camera capacity and complexity increases as the operational altitude increasesWith high altitude scale decreases. A photo scale not smaller than 1/10,000 is necessary in order to interpret details in the enemy lines. This poses a serious limitation on altitude coiling.

2.5. CONVERGENT PHOTOGRAPHY

To increase the coverage, two long distance cameras are now a days often used together with optical axes divergent somewhat. For vertical photography, this system provides almost twice the coverage than in ordinary photography. But in convergent low oblique ground area covered is 6 times greater than that in vertical photography with suitable flying height adjustment on the basis of 1000- C factor for the convergent system and a 600-C factor for the vertical system (C-factor is the ratio of flying height to the least contour interval that can be plotted accurately). A new 'High altitude long focus Convergent' (HALCON) mapping system is now a days proposed as a method of mapping from photography taken at altitude upto 100,000 ft in the event of some military necessity. The system would have converget camera system with a matching projection type stereoplotter, with which 20 ft contours may be drawn with reasonable accuracy. The 'trimetrogen' system was developed during world War II to obtain as great a coverage as possible. Two of the three cameras with metrogen type lenses are obliquely mounted usually at 60° to the vertical. All the three cameras were exposed simultaneously to photograph a strip of ground extending from horizon to horizon in a direction perpendicular to the direction of flight.

2.6. CONTINUOUS STRIP PHOTOGRAPHY

To account for aircraft speed, "continuous strip photography' was developed. The 'S-7, Sonne Continuous Strip Camera' developed by the U.S.Airforce, was used widely during World War II for military intelligence purposes. It employs a variable speed film drive, which moves a 200 ft roll of 9½" wide film past a permanently open narrow slit in the focal plane of the camera at a speed exactly equal to the image speed, thus producing a long continuous photograph of everything below the camera, as it passes over the terrain. Synchronisation of film speed and image speed is done automatically by an auxiliary photo-electric ground scanner.

It permits photography under adverse conditions of little light and with extremely low altitudes. This camera has produced undistorted, perfectly sharp images at speeds upto 1000 mph with P-80 jet aircrafts at 1500 ft altitude. A single roll of film can produce a continuous photograph, covering a ground strip 10 miles wide abd 2500 miles long. This camera has also been produced as a twinlens type for stereophotography, where the desired stereobase is achieved through setting of lenses at a greater distance apart on opposite sides of the slit.

To control image motion due to vibration of aircraft at high speeds and tip and tilt etc, gyro controlled self stabilising mounts have been developed for cameras.

2.7. INFRARED PHOTOGRAPHY

For taking photographs under conditions unsuitable for regular photography, infrared photography can be usefully employed. Here an infrared or minus blue filter with film sensitized to infrared rays are used. These emulsions have considerably greater infrared speed and still more moderate grain and good resolving power. Such films are specially suitable for haze penetration, in oblique long distance photography and for camouflage detection.

2.8. COLOUR PHOTOGRAPHY

Colour photography have proved of considerable value in camouflage detection, trafficability studies, amphibious operation and for general strategic and support operation. They assist in recognition of ground objects by virtue of colour contrasts, and hence they are very much useful for military reconnaissance purposes. The detection film is sensitive to infrared radiation. This emuls-ion not only detects camouflage but also gives other valuable information about the terrain. This film has very successfully supplemented the black and white film as a means of reconnaissance for military intelligence.

2.9. NIGHT PHOTOGRAPHY

To find enemy activities and movements under cover of darkness, nightphotography can be used. Flash bombs (Magnesium Flash bomb) or flash units are used to illuminate the target area. The bomb is dropped from air-craft. After release from both greater and lower altitudes, the bomb is set to explode at approximately 2/3 of the distance to the ground and reaches its peak putput in about 15 miliseconds. The initial flash from the bomb trips a photoelectric cell circuit which in turn trips the camera shutter, well before the light peak is reached and the camera automatically rewinds and is ready for next picture. In one of the new developments, the shutter opens ~~and~~ at the beginning of the explosion and closes after the explosion is completed and moving film is used to utilise the longer exposures available. Useful pictures are made at altitudes upto 20,000 ft. Fig. 3 is a night photograph showing the North Korean Machine Gun emplacement in rice paddies in a valley on the Northeast coast of Korea.

Fig. 4 is another remarkable photograph clearly demonstrating the great value of might photography. This shows tanks moving down a highway. The tank lights were on in the first picture; as the driver noticed the flashes, the tank lights were put off all except one - as shown by the arrow in the picture. These pictures were taken at 11.00 O'clock at night, processed and delivered to the fighter organisations early in the next morning and it was reported that all of these vehicles were destroyed.

2.10. ADVENT OF ELECTRONICS

With the advent of electronics, the air defence of a country has been completely revolutionised. Radio location, is the miracle of science, act as the sentry at the gate or battlement, ready to challange and give warning of the enemy approach by air.

The data collection and reduction programmes offered by radar have completely changed battlefield problems. Large areal coverage and relatively small scale maps produced leads to easier detection and measurement of large features. The systems are

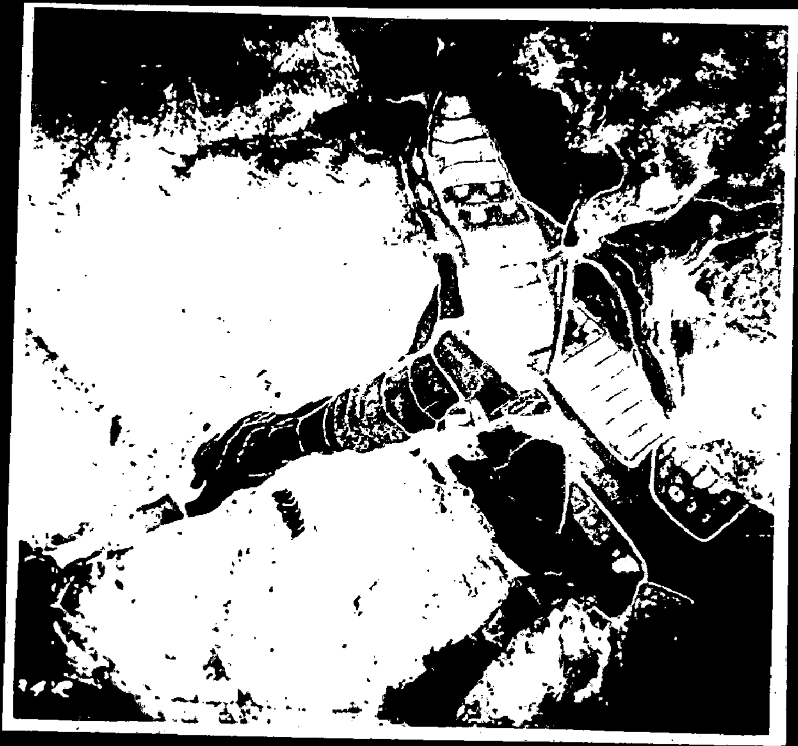


Fig.3 - Night Photography showing North Korean Machine Gun Emplacements in rice paddies in a valley

Fig. 4- Night Photography Showing North Korean Tanks Moving Down a Highway.

independent of solar illumination and weather conditions. Radio location (The system by which radio waves are transmitted into the air and then bounce back on the recording instrument from every object they meet) has made possible a defence system to be built with initial economy of effort. The controller operating the defence has a map of his sector and the enemy territary beyond infront of him. He is always in a position to know the direction and strength of attack which he has to meet. The purpose for which thousands of aircrafts are needed to watch every mile of the frontier or coast round the clock. The work on which thousands of unnecessary hours of flying would have to be wasted and millions of gallons of petrol would be needed. Through Radar control, the aircraft can be placed in position according to the picture the board gives to the operater, of the whole engagements. Radio location sees through clouds. It operates in visibility which is too bad for a fighter pilot to see what planes are with him. It enables the controller to intercept hostile machines which otherwise would slip as unattacked. It makes the planning of defence more effective. Instead of defence being a hazardous affair it would now be a systematic problem to be solved in a systematic way. The next Chapter deals with this system in detail and other electronic systems have also been discussed in other separate chapters.

CHAPTER - III

RADAR SYSTEMS

RADAR SYSTEMS

A convenient definition of Radar lies in its word origin, which is " Radio Detection And Ranging" It primarily constitutes methodology for extending the perception of man to determine the presence and location of objects by the use of radio wave echoes. Its closest competitor in performance of these functions is the use of optical techniques involving highly accurate telescopes together with photographic recording devices. This sensery equipment afford genuine and new facilities. It enables certain objects to be detected and located at distances far beyond. Advantages of radar over optical devices are the facts that radar works in darkness, through cloud cover, over long distances and can provide range information much more accurately than optical techniques. It can measure the instantaneous speed of an object towards or away from the observing station in a simple and a natural way. Another major advantage of radar system is its freedom from difficulties of perspective. By suitable design of equipment, the picture obtained from a radar set can be presented as a true plan in view.

Radar was developed essentially during World War II, strictly for military purposes such as blind nawigation and bombing, night studies of enemy ports and harbours, troops movement etc.

3·1 HOW IT OPERATES ?

Radar operates by sending radio waves from a transmitter of such power that measurable amount of radio-magnetic energy will be reflected from the objects to be detected. The reflected energy is picked up by a receiver, usually located in a suitable manner. The transmitter may send out signals generated in a variety of ways, but pulse radar has developed much further than any of the other possible methods. In pulse radar, the transmitter is modulated in such a way that it sends out very intense, very brief pulses of radio waves at intervals spaced rather far apart in terms of duration of each pulse. During the waiting time between the transmitted pulses, the receiver is active. Echoes are received from the various objects after suitable interval of time, after which another very short pulse is sent out and cycles repeated many times a second.

The properties of received echoes are used to form a picture or to determine certain properties of the object. Since the radio waves used in radar are propogated with speed of light, the intervals of time between the transmission of a pulse and the reception of the echo from an object are very short. For precision of 5 yards in range measurements the time intervals must be measured with a precision ~~of~~ better than 1/30 of a microsecond, which can now be readily done with the development of modern electronic timing and display techniques. Measurement of accurate direction has been made possible by the development of radar tecn-niques on wavelengths short enough to permit use of highly directional antenna ~~to~~ which more or less shape a beam of radiation. The echoes will be received only from targets that lie in the direction, the beam is pointing. If the antenna is swept or scanned around the horizon, the strong echoes will be received from targets when the beam is directly towards the target and no echoes will be received from targets in other directions. The bearing of the target can be noted from the bearing of the antenna when the target gives the strongest signal. The signal received from a target after being reflected must be of certain minimum inten-sity before it can be detected by antenna. Let us call this S_{min} . Then the maximum range of a radar set on a target of a given type will be

$$S_{min.} = \frac{K.\ P_t}{R^4_{max.}}$$

$$\text{or} \quad R_{max} = \left[\frac{K.P_t}{S_{min}} \right]^{1/4}$$

Where,

P_t = Transmitted power.

$R_{max.}$ = maximum range.

To increase range performance by increasing its pulse power is quite difficult. A 16 - fold increase in power is required to double the range capability. The other method to achieve this is to increase the sensitivity of the receiving antenna so that even weaker intensity signals are detectable. The radars operating at micro-wave frequency are preferable and are more commonly used. Such a radar focus sharp energy beams so that direction as well as the range of target are determined more accurately. For an antenna of a given size, the width of beam is proportional to wave-length so for smaller wave-lengths smaller antenna will be required, which is the basic requirement of an airborne antenna where large dimensions cannot be tolerated for aerodynamic reasons.

Radar definition, i.e. its ability to discriminate between targets close together in space impreves as the beam width is narrowed. Targets can be distinguished by a radar as being separate , if they are separated in azimuth by an angle larger than one beam width.

Thus the quality of picture afforded by radar improves as the beam width is reduced. For an antenna of given size the beam width can be decreased by lowering the wave length. But radio waves in microwave regions have certain limitations. Like light, microwaves are propogated in straight lines. A lower limit on the wave length which can be used by radar system is fixed by the onset of atmospheric absorption of microwave energy. Below a wave length of about 1.9 cm serious absorption occurs in moist atmosphere, because of the molecular transition in water vapour which can be excited by the radiation . For this reasons 2 cm is about the shortest wavelen at which radar systems of good range performance can be built.

The equipment in simplified terminology, consist of a source of power, a transmitter to emit the signal, an indicator or scope to present the signal in usable form. Here we are concerned only with the sensory component i.e. radar scope or indicator which will be described now.

3.2 RADAR SCOPE OR INDICATORS

The device which presents radar data in usable form is called radar scope or indicator. It is usually a cathode ray tube but may be a pen, flashing light, moving coil meters, a loud speaker or mileage indicator. Two types of indicators are normally used, one is called 'Plan position Indicator' or PPI and the other is called continuous strip recording or 'side Looking Radar Equipment'.

3.3 PPI

The centre of the indicator represents the position of the aircraft. When a pulse of electronic energy is emitted from the transmitter, the electronic beam is trigged to move in a radial direction, outward from the centre of the scope forming a single sweep. As the radar beam scane the terrain beneath the aircraft through 360°, the corresponding sweep moves around the face of the PPI and images of terrain features appear on the indicator as spots of varying size, shape and intensity. As the transmitted energy is reflected by terrain features, the antenna rotates in a clockwise direction, the detail is recorded on the phosphor coated scope face by synchronised electronic trace that duplicates the antenna movement. The phosphor has a controlled image decay and the initial portion of the scan retains its characteristics to some extent until the entire 360° rotation is completed. Thus the whole picture is continuously visible, This rotation requires some time, during which the aircraft moves forward, So each consecutive scan represents a slightly different presentation of detail. Distance can be measured between different points by reference to the circular concentric range marker which appear on the indicator electronically along with the terrain images. An azimuth ring is mounted around the circumference of the PPI, so that approximate direction can be determined. A number of manual controls are provided which regulates the intensity of the images as well as the general appearance of the PPI radar scope.

3.4 RADAR PRESENTATION RESTITUTOR

An instrument designed and developed to correct positions on a 360° scan plan position indicator radar scope photographs to their equivalent ground positions. The instrument is optical-mechanical in nature of operation.

The following corrections are performed automatically.

1. Distortion due to slant range.
2. Distortion due to sweep delay.
3. Distortion due to aircraft motion during a single scan.

Provisions have also been made to introduce corrections for distortion due to:

i. Non-uniform motion of the electronic sweep.
ii. The lens of recording camera.
iii. Curvature of the Cathode ray tube.

All the above corrections can be performed simultaneously in one operation.

Photogrammetrically this instrument can be considered as paralleling to the rectifier used for optical photography.

Fig. 5 shows a radar PPI presentation. The centre of the photograph represents the nadir point on the ground. The radar antenna while transmitting, illuminates with energy a radial line on the ground emanating from nadir point. The antenna then receives the energy reflections and rotate through small increments continuously, transmitting and then receiving the electromagnetic energy, repeating this until it has rotated through 360°. The various distortions caused are given above. The first three distortions have the greatest effect on radar accuracy whereas the remaining distortions can be considered minor in the present state of radar mapping.

3.4.1. Slant-Range Distortion.

As is evident from Fig. 6, the radar measures the distance from the antenna to the target and records this distance rather than the true ground range.

3.4.2. Sweep Delay Distortion

If the trace on the cathode ray tube is started at the same instant when the energy is radiated from the antenna, the first return cannot show until the energy has travelled to the ground

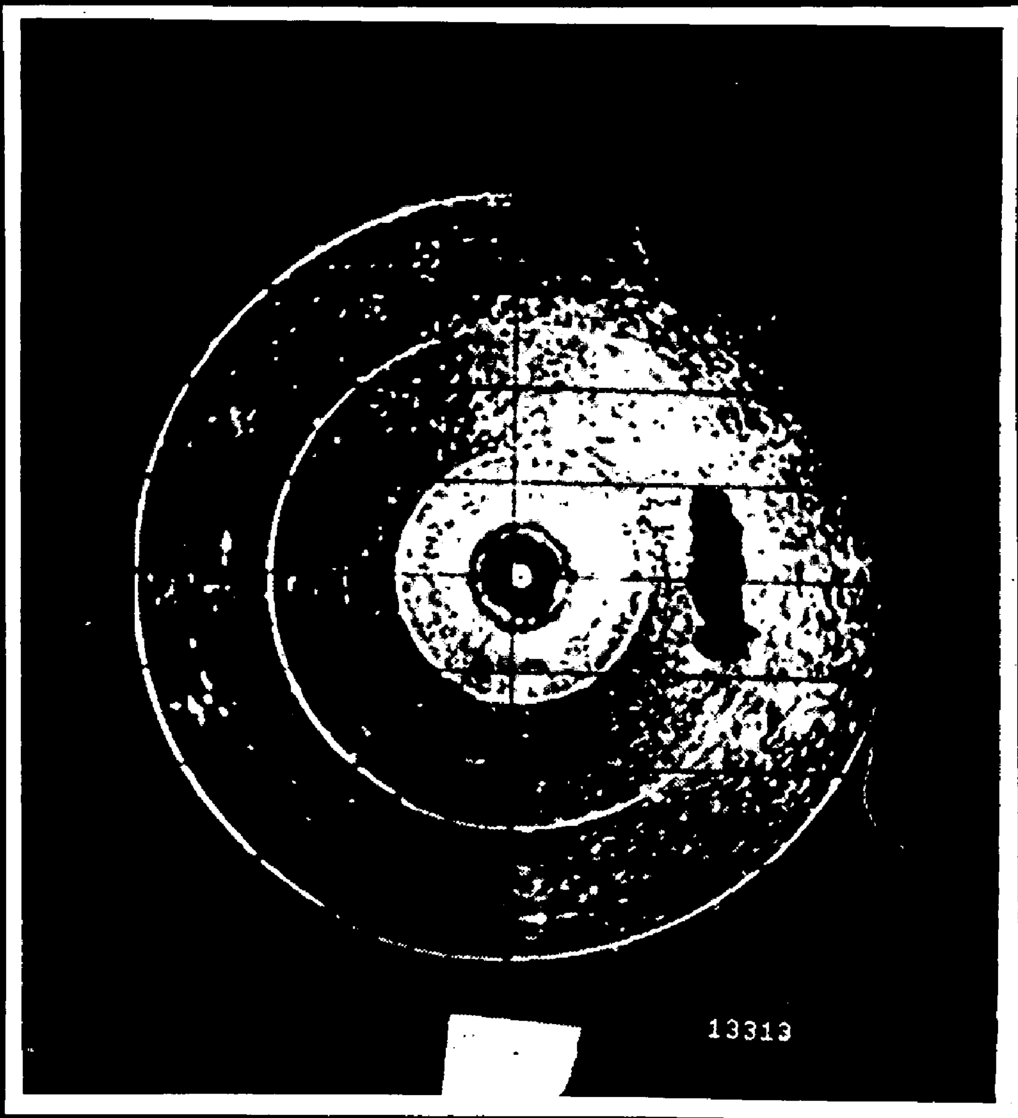


Fig. 5- Radar PPI presentation

and returned. A distance to scale, corresponding to altitude is therefore wasted on the cathode ray tube. The altitude hole- the area of no return at the PPI centre - is marked evidence of this effect. For this reason the trace on CRT is delayed for some interval of time depending upon altitude, in order to start the teturns closer to the centre of the CRT. Thus for any given range set into the radar, a maximum area of the CRT face is available for the display and consequently the scale of the display is maximized .

3·43 Aircraft- Motion

The distortion due to aircraft motion during a single scan results from the fact that the narrow radial sweeps making up the scan all have a common origin on the PPI presentation. Each successive radial sector should emanate instead along a line representing the motion of the nadir of the aircraft during a single scan . Fig. 8 shows the PPI presentation as it is and as it should be with each radius displaced in the direction of flight.

Now if mapping from radar is to be done, it is necessary to compensate for these distortions in order to achieve some degree of accuracy. This can be done by Radar Presentation Restitutor.

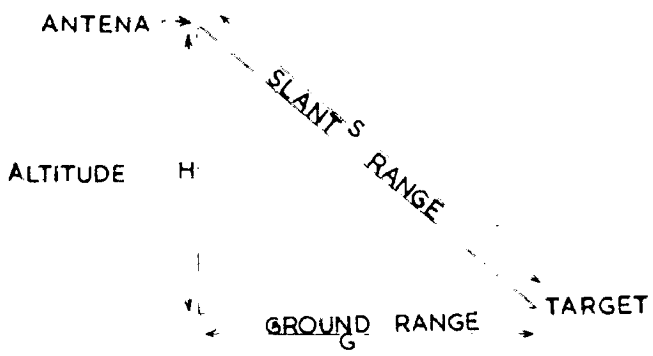


FIG 6 _THE BASIS FOR SLANT RANGE DISTORTION

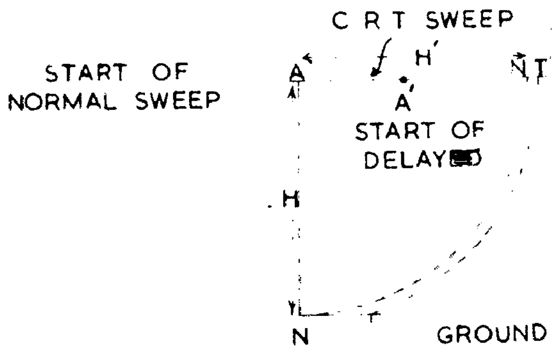
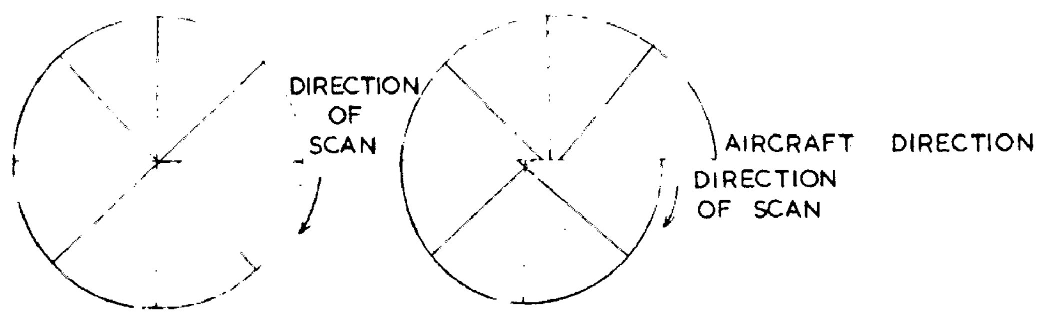


FIG. 7 _SWEEP DELAY DISTORTION



THE SHAPE OF THE RADAR PRESENTATION

THE SHAPE OF THE ACTUAL TERRAIN SWEPT BY THE BEAM AND RECORDED

FIG 8 _AIRCRAFT MOTION DISTORTION

3.5. SIDE LOOKING RADAR

The side looking radar equipment uses two antennas, transmits energy to either side of the aircraft at right angles to the flight path. The reflected energy produces individual single line image traces on two scopes, one for each side. Because of the increased power of this equipment and due to special design of antennas, the resolution of the terrain features in this presentation is greater by a significant factor than in most of the present PPI type equipment. This immediately improves the condition for interpretation.

The modern side looking radar has proved to be a veryuseful piece of equipment for small scale mapping of the earth surface scales between 1 : 10^6 to 1 : 10^5 , even under vary adverse weather conditions. It is a strip system with an antenna mounted on each side of an aircraft. It looks sideways and scans the ground by reason of the forward motion of the aircraft.

3.5.1. Radar System

In Fig. 9 , 1 - is antenna system, 2- is radar transmitter / Receiver 3- is image display tube on which one intensity modulated line picture is built up to a contiguous image on a moving film in camera system 4.

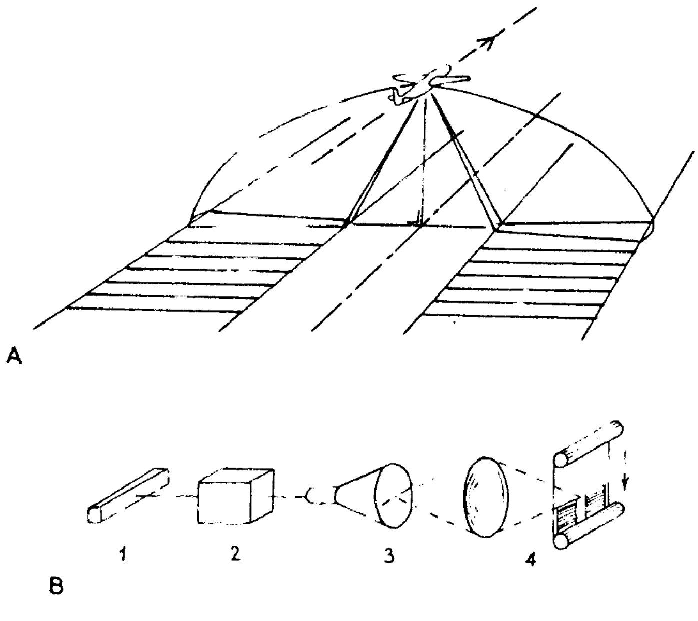


FIG. 9 — SIDE-LOOKING RADAR

A. SCAN CONFIGURATION;

B. RADAR SYSTEM

1. ANTENNA SYSTEM

2. RADAR TRANSMITTER RECEIVER

3 IMAGE DISPLAY TUBE ON WHICH ONE INTENSITY MODULATED LINE;

4 PICTURE IS BUILT UP TO A CONTIGUOUS IMAGE ON MOVING FILM IN CAMERA SYSTEM

The most common wave length bands lie between $\lambda = 5$ cm and $\lambda = 0.8$ cm . Longer wave lengths are possible and it's uses even upto P- band (λ about 50 cms) ~~are~~ is also mentioned in the literature. These longer wave lengths require very intricate and expensive machinery to obtain sufficient resolution Their application will certainly widen the range of possibilities but this equipment is still wraped under a cover of secrecy.

Each radar works at one single wavelength and as such is a 'monochromatic' device. The back scatter properties of ground vary with wavelength, and ~~with~~ polarisation(s) used. Knowledge of all these variables can give a clue to the properties of the terrain when different radars are used simultaneously at different wavelengths and polarisations.

3.52 Resolution and Distortions

The important parameters which determine resolution are antenna aperture, in azimuth and pulse length in range. Angular resolution of an antenna is given by the well-known formula

$$Q = 1.2 \lambda / D \quad \text{radians}$$

Where, λ = wave length and D the aperture size both in the same units. Absolute resolution in azimuth ~~thus~~ diminishes as a function of range.

As remarked, radar records range. This introduces distortions in a picture made with an airborne radar as compared with an on-scale map of the underlying terrain. The radar records the distances OA, OB , OC etc and not NA, NB, NC etc. It is possible to correct this in presentation but for mapping purposes one often prefers to correct the photographs on the ground. Fig. 10 clearly demonstrates that it is not profitable to look directly under the aircraft because of deteriorating picture quality. A depression angle for the antenna beam of upto 45° is a fair maximum value. This means that an area of at least twice the aircraft altitude immediately below it is never recorded. To introduce the necessary corrections for transforming slant range into ground range; the altitude of the aircraft above the datum plane has to be accurately known. At very low altitude or large range (large value of R/H, where R is range and H is the aircraft altitude), the corrections become very small and a nearly orthographic map is obtained. The radar parallax is also very specific. Flying at a somewhat higher altitude, the top of a high object is recorded before the bottom (See Fig. 11). This parallax diminishes rapidly with range. The shadow parallax, also indicated in Fig. 11 can give a means of determining spot elevation in a single image, when the shadow is clearly painted and its end lies on the reference plane.

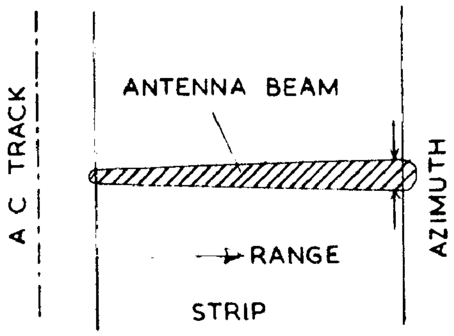


FIG.10a_ RADAR RESOLUTION DIMINISHES WITH RANGE

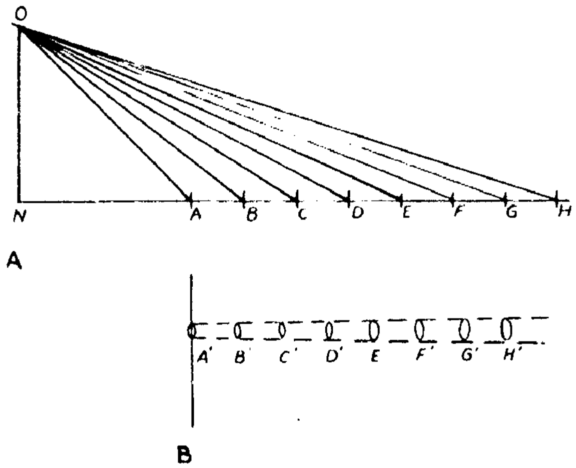


FIG.10b_ RADAR RECORDS THE RANGE TO AN OBJECT. A. ACTUAL SITUATION. B. DISPLAY; SINCE RECORDING STARTS AT A, THE DISTANCES (OB-OA), (OC-OA), ETC. ARE REGISTERED

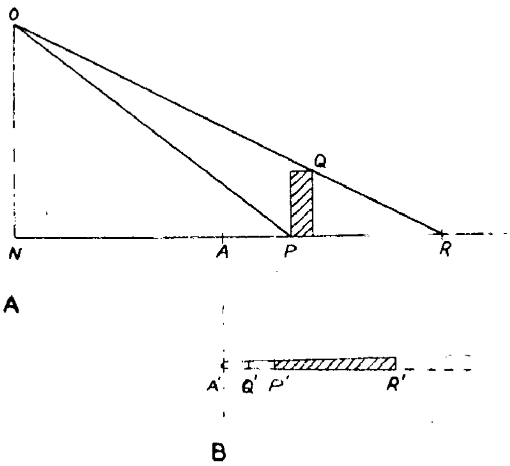


FIG. 11 _ ECHO PARALLAX

A ACTUAL SITUATION

B. RECORDING; A' BEGINING OF OF RECORD, P'Q': ECHO, P'R': RADAR SHADOW

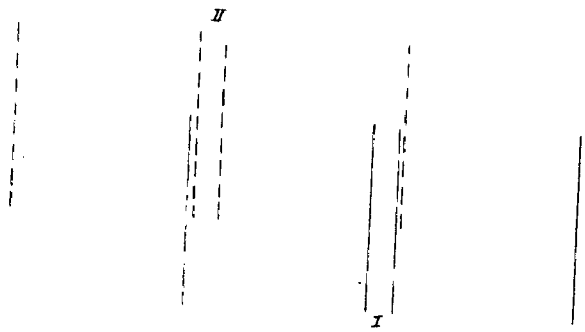


FIG.13 _ FLIGHT CONFIGURATION FOR SIDE-LOOKING RADAR

An accurate knowledge of platform ground speed determines the map accuracy along the flight track. Since the system is a strip system, for good mapping, stable and quiet weather is preferable (Not necessarily good visibility) to make it possible to fly accurately along the straight lines. The use of an established aerial system can eliminate some of the distortions due to unwanted aircraft motions. Simultaneous registration of aircraft altitude makes it possible to correct for these distortions afterwards. The above stresses the need for cartographic radar to register simultaneously with the map, a record of the sensor outputs giving the place of the platform with regard to the reference system chosen, its ground speed, altitude and attitude. Since radar is an electronic system such recording is relatively simple (Refer Fig. 12).

3.5.3. Flight Configuration:

Below the aircraft a strip of 1500-5000 meters is lost depending on the altitude. As mentioned, this is inherent with side-looking radar. This necessiates a special flying pattern in which a second track covers this area. Fig. 13 gives the procedure to be followed.

One can repeat this pattern by flying two other tracks adjacent to the two sketched, Practice, however, has taught that it is better to repeat the pattern as

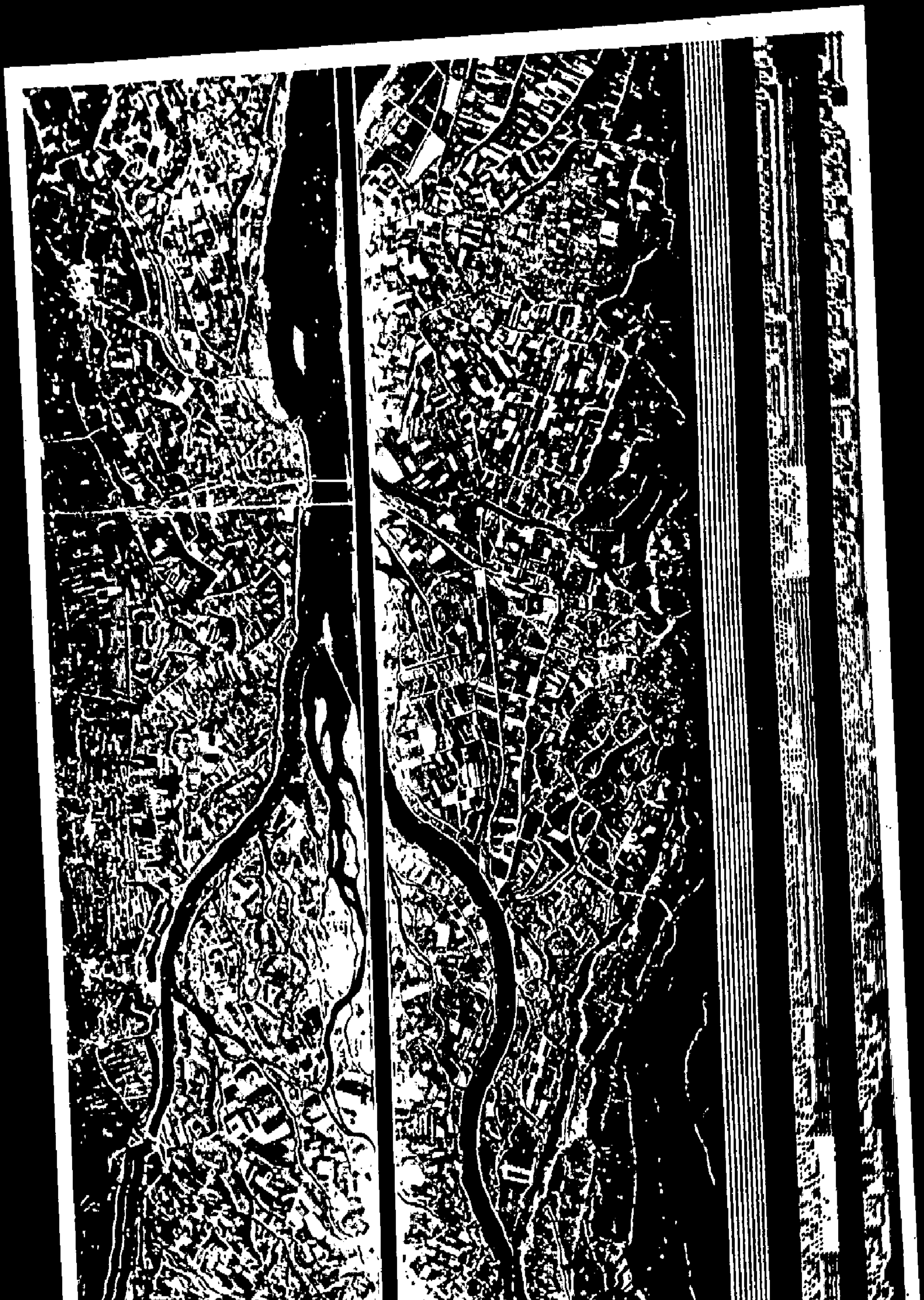


Fig.12- SLR Map along with Registration facilities.

given by shifting only one strip per track. This procedure may seem to be a waste of flying time, but it pays because of the greater freedom obtained in the choice of flying altitude. Flying at a very low altitude (say 80-100 m) enhances the small altitudes differences in the terrain. This, however, causes large radar shadows (which enhances the discrimination of small altitudes differences also) and thus screening of areas of possible interest. Flying at very high altitude prevents this, but can give a somewhat flat image. This procedure gives the possibility to avoid these difficulties of screening, since whole of the terrain is looked at from two sides. Furtheremore, a reduced resolution in azimuth on the edge of one strip is partly compensated by the better resolution in the next, which now lies nearer the aircraft. A fair amount of freedom in the choice of flying altitude is obtained in this way and this is a great necessity.

In ordinary photography a large number of large scale photographs are required to scan a large area. This requires sufficient time and money. The radar can do the same job in fraction of time with an accuracy high enough to meet the specification of the final map. So apart from being an addition to the group of mapping system, the side looking radar is an apparatus in itself, with which direct small scale mapping of large areas is possible even under adverse weather conditions and with a considerable reduction in flying time and stand-by-time.

3.5.4. Looking Radar Restitution

Two data gathering flights provide ground position information and terrain imagry. An engineering model restitutor corrects for most of the geometric distortions including aircraft motion, slant range, earth curvature, sweep delay, terrain relief, shadows etc. The information is processed by an offline computer, which correlates, corrects, compiles, extrapolat contours and synchronise the film with the data. The films are restituted and matched to eliminate blank areas and produce a planimetric map. The contours are superimposed on the format and finally the strips are joined and printed.

3.6. IMAGE CHARACTERISTICS

Image quality is initimately related with the size of the pulse packet. Decrease in area generally leads to an improved display . The images may be of different types e.g., the areas of strong intensity and persistance, the areas characterized by an indefinite patte of lower intensity and the dark areas formed due to the non reflectance of the radar signal back to the aircraft. The image quality depends upon the reflection characteristics of terrain features. From these characteristics, it may be deduced that built-up city areas and areas of rugged relief formation will produce the brightest image. Steel or other metal surfaces are the most perfect reflectors and result in the brightest images, while other materials provide images of lesser strength with minimum discernible image caused by wooden structures, earth features or vegetation of various sorts.

The size of an individual terrain feature or group of features contributes to the strength of radar images. The feature must be of a certain minimum size in order to reflect sufficient radar energy. The smaller features will not appear on the radar presentation. The arrangement of features is another factor which affects the radar presentation. Symmetrically placed buildings in a city or town which forms ideal corner reflectors and certain relief formations result in images which will be much brighter. But , the shape of the images may be distorted because of the strong reflections. The appearance of the area will vary with the distance from the aircraft. The radar images can be used for collecting intelligence for airborne landings and droppings, marine large scale landings, detection of vegetational camouflage, selection of sites for construction of air strips, determination of gravel or concrete nature of enemy roads, determination of soil conditions, underground water sources, mineral deposits, oil gas and determination of barren regions etc. A side looking radar is capable of revealin stratigraphic data, land use and off-shore details.

Cities can be identified because they generally appear as persistent images of high intensity, which contrast with the indeterminate pattern of the surrounding open area. The variation of intensity with the city boundries will vary depending upon the types of construction. The majority of hydrographic features will appear on the radar scope as block images, since the smooth surface of water will usually reflect the radar energy away from the aircraft. This is true of lakes, large rivers and oceans unless the water surface is very rough , which results in an intermittent bright images. Islands, roofs, sand bars ships docks, break water etc., will appear as bright returns within the dark areas if they are large enough to show on the radar scope. The presence of hydrographic features in proximity to urban areas will increase the case of interpretation, since they provide the strongest contrast. Since the bright images tend to become exagerated in size, dark areas will be decreased proportionally, Small lakes and rivers may not show at all because of this condition, although, it is some time possible to trace the coarse of a small river due to a strong bright return from its banks.

Relief formations of significant size can generally be detected, because they present image, which is related in a particular way to the characteristics representation of relief by shading techniques on standard charts. The radar energy is reflected from surface of hills mountains etc, which are towards the aircrafts, while the back slopes are not reached by this energy and are thus represented on the radar scope by a sort of 'radar shadow'. Areas of open country, not characterized by rugged relief, has been described as indetrminate on radar scope and is often referred to as ground clutter. The transportation features themselves do not furnish an identifiable returns, but the side structures normally found along roads provide a series of bright images, which indicate the presence of the transportation pattern. This is particularly true in the immediate vicinity of cities and towns. Cloud formation of sufficient density intercept the radar energy. They will appear as bright irregular shaped images. As the radar beam is completely cut off, the edge area of such images will be a dark wedge; being area of no return.

3.7. FULL COLOUR RADAR PRESENTATION

To improve the radar presentation for rapid and accurate recognisation of specific targets, colour radar presentation techniques have been devised. As a complete colour radar system would be prohibitive because of cost and complexity, a method has been developed for producing a full colour print from the original black and white radar-scope negative. Separate colours are assigned to specific targets types according to the signal strength of the targets. Cooler colours towards the blue end of the spectrum are assigned to targets of low signal strength mainly due to nature features. Warmer colours, towards the red end of the spectrum represent targets of high signal strength, usually by cultural features.

The transformation from black and white radar map original into full colour presentation requires several complex operations. Correlation of colours with target types is very important. A well balanced colour presentation is easier to read then a black and white picture. Individual targets are more distinct, and can be more promptly and accurately recognised. Coloured radar maps are available both as paper prints and transparencies, which can be projected to simulate airborne radar presentation.

3.8. RADAR BEACONS

These are devices which on receiving a pulse or a series of properly coded pulses from a radar set, will send back a pulse or series of coded pulses, in reply. A great increase in the flexibility and convenience of the use of the radar under certain conditions can be obtained by the use of such beacons.

Radar waves are reflected by targets of different sizes regardless of their importance to the use of radar set. The echo from an aircraft may be lost in much larger echoes from a near by mountains or it may become too week to be followed from larger ranges. The echo from a friendly aircraft is like that from a hostile one. The exact location of a place on the ground may be of importance to a radar equipped aircraft even through there is no distinguishable radar target at that point. In all such cases it would be advantageous if an echo could be much stronger or more readily distinuishable from other confusing ones. In such situation the beacon is quite beneficial.

Since the modern trend is towards microwaves so Rebecon-Burke Beacon system operates at higher frequencies. The beacon is essentially a repeater of radar pulses. It has an antenna and a receiver that convert pulses of energy received at high frequency from a radar set or special interreger, into trigging signals. Each such signal triggers the transmitter in the beacon and causes it to radiate one or more pulses of radio energy that may have almost any desired power, frequency, duration number and characteristics spacing. Fig. 14 gives a block diagram of a beacon . Since it takes time for the beacon to react, the first reply pulse, comes back to the radar

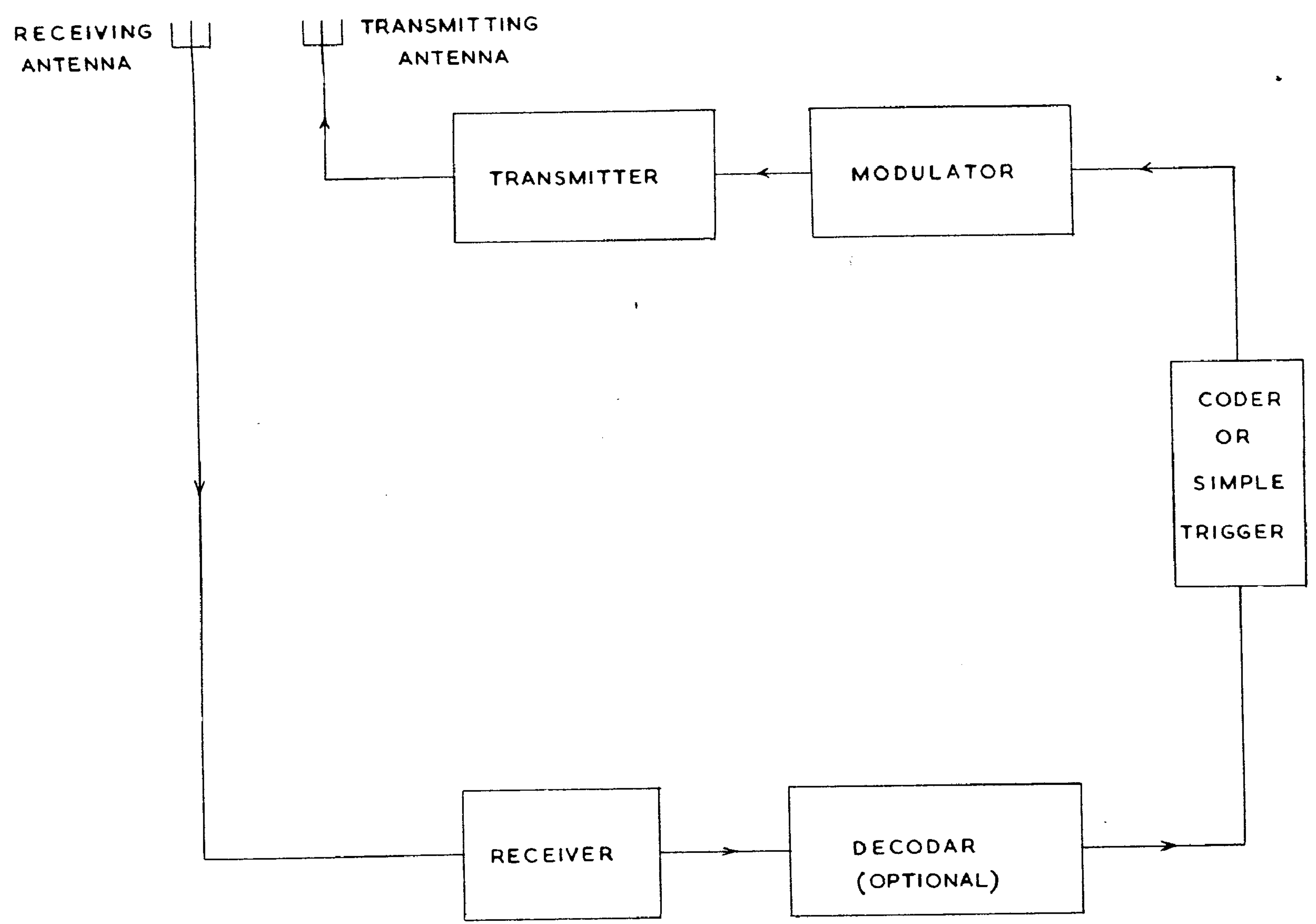


FIG. 14 —BLOCK DIAGRAM OF A BEACON

set slightly delayed and so indicates a range slightly greater than the true one. In many applications, this delay is negligible, in others it is made to have a constant known value for which allowance can be made. The delay can be kept down to a few tenths of a microsecond, when necessary. In the special case where the radiated pulse is single and has approximately the duration and frequency of the radar set and is not appreciably delayed, the beacon acts somewhat like an echo amplifier. The intensities of received and transmitt-ed signals, are to be sure, independent, rather than in fixed preportion as in the case of a true amplifier. In general, however, the frequency of the reply will be differing from that of the radar set. In order to receive such replies, one needs a receiver tuned to the new frequency of the pulses sent out by the beacon instead of to the frequency of the pulses sent out by the beacon. This may be either the receiver of the radar set tuned to the new frequency or a second independent receiver tuned to the beacon. In either case, the receiver of the beacon does not receive radar echoes since it is not tuned for them. Thus the beacon signals are separated from radar reflections and can be displayed without being summped by heavy permanent echoes. Since the pulse power of the beacon transmitter can be made as great as desired, there is no limit to the strength of reply. The range is limited only by the power of the radar transmitter and the sensitivity of the beacon receiver, which determines whether the beacon transmitter is trigged or not.

By its very nature, the radar beacon combination involves two send-receive links as does any two-way communication system. The two links are ordinarily connected automatically in a simple regular way and are uninfluenced by human reactions. Since the channels exist, however, they afford the basis for a communication system. In the past, beacons have sometimes been used in providing communication systems of a rudimentary sort and also for exercising remote control, intelligence has been conveyed from the radar to a beacon-carrying-vehicle by modification of the repitation rate and the length of the integrating pulses, their spacing in groups or the duration of the intervals of interrogation.

Beacons of the synchronous sort just described above have been variously called, "radar beacons" responder beacons, "reconnaissance beacons' and transponders. There being no essential distinction among those terms. Radar information is particularly useful because it gives accurate determination of range. It is obviously sensible to provide, as an adjunct to radar, the sort of beacon that makes the best use of this property.

3.9. RADAR RELAYS

Generally, the radar station and the control centre are located at different sites for optimum utility. The radar site is chosen from the standpoint of good coverage, freedom from permanent echoes etc. The criteria for the choice of a suitable site for a control centre is entirely different. A control centre should receive supplementary information from other radar installations located elsewhere, even though, a single radar equipment may provide the primary data for control of operations. This will enable the coverage of the primary radar to be supplemented by information from neighbouring sectors and will provide coverage of possible blind spots of the primary radar.

Means were developed for reproducing radar indications at a point located at a distance from the set that gathered the original data. The necessary intelligence was transmitted from the radar to the distant indicator by radio means. Radar Relay is a technique for separating these two main components so that each one can occupy the most favourable position and the indicator can be operated at several pluces simultaneously. As the name implies the radar collects the data from remote points and transmits by means of radiation link.

3.9.1. <u>The Use of Radar Relay</u>

Control of aircraft in military applications requires the review and filtering of a mass of information gathered from many sources of which radar is only one. Therefore control centres are located at sites chosen for their operational convenience, whereas radar locations are chosen mainly from terrain and coverage reasons. Sometimes, it is desirable to collect the data at great distances from one or more fixed stations. Advantages are also gained by obtaining the data at an airborne site with its extended horizon, but displaying and using the data on the ground or on a ship. On the other hand, occasions arise, in which an aircraft can usually employ information collected from another site. In any of these cases, the possibility of multiple dissimination of the data to many points offers attractive possibilities. Two general types of situations arise:

1. Those in which the data are transmitted between fixed points on land. In which case it is possible to use fixed and narrow beam antennas at both ends of the relay link. If the information is to be broadcast from a single antenna, then a directive antennas on at least one of the various receivers should be used.

2. Those in which one or both sites are moving. In such a case the antenna must be either omni-directional or controlled in directions. The first situation is simpler from the technical stand point, since large antenna gains can be used in a very simple manner.

3.9.2. The Elements of Radar Relay

One obvious method of relaying radar information is to televise an indicator screen at the radar site and to transmit the information by existing television means. This system leads to a loss both in signal to noise ratio and in resolution because persistant displays do not televise well. Furthermore any single televised display would have to be a PPI presenting the maximum radar range with the result that much inherent resolution is immediately lost even though expanded displays might be used at the receiving end. The first but not the second, of these difficulties might be overcome by storing the information on an orthican or other storage devices rather than oné a cathode ray tube.

A far superior method is to transmit the original radar data in such a way that any desired displays can be produced at the receiving location in exactly the same way as can be done at the radar itself. To do so it is necessary to provide at the receiving station radar video signals, the modulator trigger (or the pulse itself) and a mechanical motion or its electrical equivalent that faithfully produces the motion of the scanner. The elements of a system for transmitting this information are indicated in Fig. 15 . The radar data are delivered

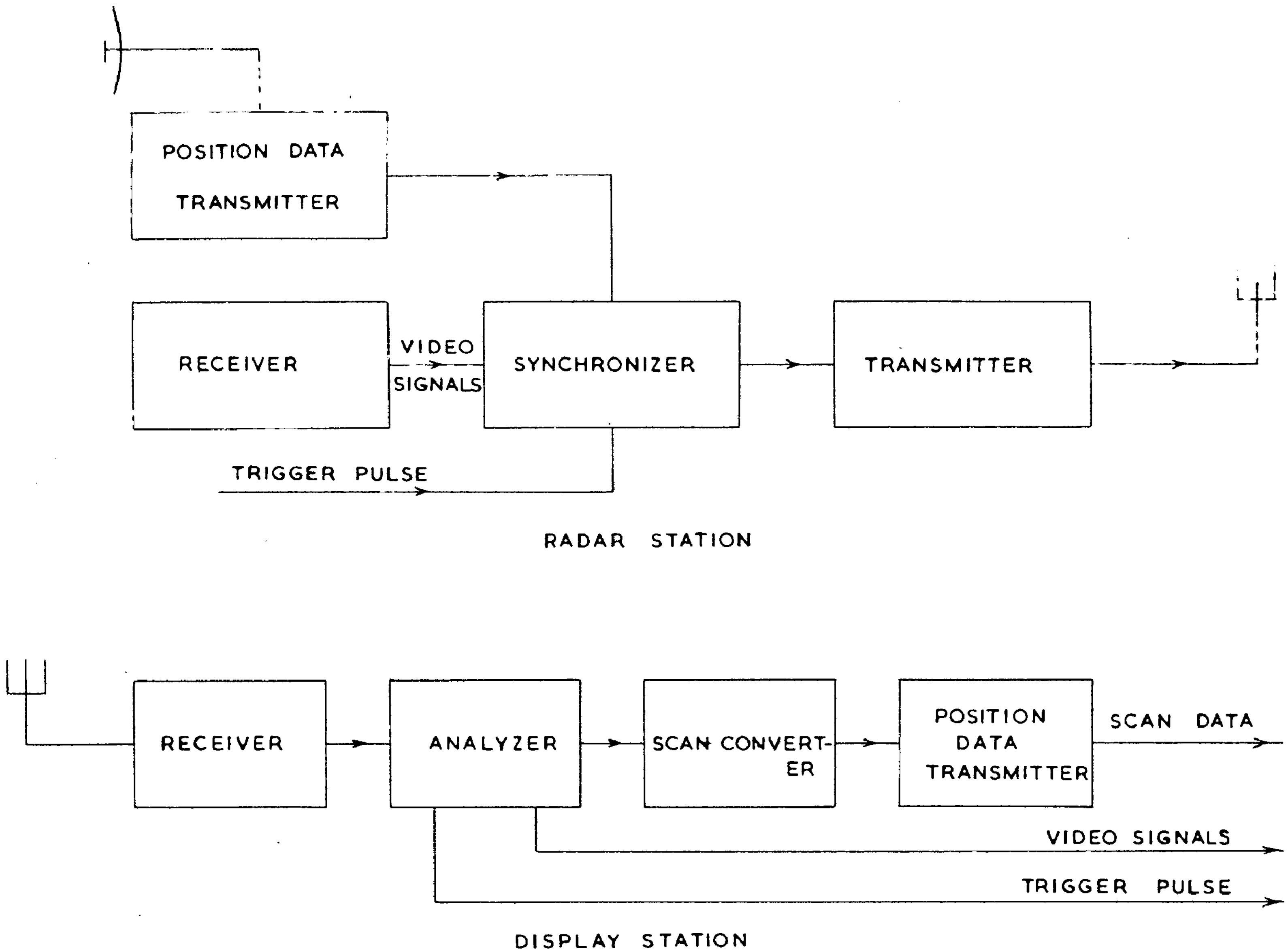


FIG. 15 _ELEMENTS OF A SIMPLE RADAR RELAY SYSTEM

from the set to a 'synchronizer' which arranges them in a proper form to modulate the transmitter. At the receiving station, the receiver amplifies and demodulate the increasing signals and delivers the results to an 'analyzer'. The latter performs the necessary sorting out into video signals, trigger pulse and scanner data. The video and trigger are delivered immediately to the indicater system. The scanner data must usually be modified in form before being passed on either to indicator for direct use in electrical display synthesis or to the scan converter. The scan converter uses these data to construct a duplicate of the scanner motion that can be used to derive a position-data transmitter associated with indicators.

Except perhaps when micro frequencies are used in the radio link, the ultimate limit of sensitivity is usually set by the degree of outs ide interference rather than by inherent signal -to-noise ratio of the receiver. Many factors must be considered in trying to minimize the effect of this interference.

1. The strength of the desired signal at the receiver input terminals should be made as high as feas-ible compared with that of the interference. This is chiefly a matter of making proper choice of frequency , transmitter, power and antenna characteristics.

2. The data signals, should as far as possible be made unlike the expected interference in signal characteristics and every advantage should be taken of those differences in the receiving equipment.

3. In certain cases a favourable signal-to-interference ratio can be enhanced by techniques such as the use of wide deviation ratio with frequency modulation.

3.10. MILITARY POTENTIAL OF RADAR

Each infantry, (airborne and mechanised infantry battalion) has now-da-days an excellent ground surveillance capability. The radar teem can perform the following tactical functions during various operations of War such as offense, infiltration, attack, defence, counter attack, patrol and ambushes etc. These can be summarised as follows:

1. To search enemy defensive position, avenues of approach, possible enemy attack position, assembly areas, or other sectors or areas at a time of schedule or at random times or continuously to report location, size, composition and nature of the enemy activities.

2. To monitor point targets - such as bridges, deflies or road junctions and report quantity , type of target and direction of movement through the point.

3. To assist in the adjustment of arteillary, antiaircraft and mortar fire.

4. To survey final protective fire areas or barrage position to permit fire in time.

5. To survey areas of nuclear and non-nuclear fires to detect enemy activity immediately after firing as an indication of firing effect, by surveying the periphery of nuclear effects and comparing this with the previous surveillance it may be possible to ascertain the extent and type of damage and thereby determine weather further neutralisation is required or not.

6. To expend the observation capabilities of petrols by enabling them to survey distant points or areas of interest.

7. To assist observation by units during day light by making initial detection of partially obsecured targets at long ranges by haze, dust, light rain etc.

8. To assist in the control of units during a night attack.

9. To guide patrols or other friendly attacking units through barriars during dark or poor visibility.

10. To communicate with adjacent units or patrols when radio silence is imposed. The use of surveillance radar in this task may be accomplished when positive means of identification and appropriate signals have been established in advance.

11. To determine the range to different terrain features.

12. To increase effectiveness of fire support when a target is detected with reasonable certainty, It may be fixed upon immediately. However, if the type of target is not definitely

established, the radar team can furnish range and azimuth information so that accurate illumination may establish which type of fire is to be used. Since radar can accurately detect the density of enemy activity, in a given area, as well as the rate of advance or withdrawal, this equipment may be used in determining the optimum time for employment of explosive, atomic demolition, munitions, chemical or destructive fires.

While radar equipment is an excellent means of obtaining information, it does not replace other surveillance means. Its use is closely coordinated with the employment of patrols, listening posts, observations posts and with infrared and other remote sensory devices. Its primary advantage lies in its ability to complement these other means and to detect information when these other means cannot detect the same. Ground surviellance radar can provide observation from a vantage points 24 hours a day and can detect targets and provide a much more accurate range and azimuth reading than is possible by other means. Although radar is used primarily for operation at night or under condition of poor visibility (haze, fog, smoke etc) the equipment may also be used effectively during day light.

3.11. CAPABILITIES OF MEDIUM RANGE RADAR EQUIPMENT

The medium range radar set AN/TPS33 is a light weight , man portable capable of searching for, detecting and identifying moving ground targets within a radius of 90 to 17,275 m approximately. Moving targets are detected by means of the Doppler Effect, which is varying pulse to pulse relationship of echoes received simultaneously from a moving target and stationary objects near the targets. It is powered by a small motor generator, not audible beyond 50 meters. The cabling system permits installation of radar 100 ft from the generator. The control indicator and the viewing scope can be emplaced to allow remote control of the radar upto 150 ft. This allows operators to provide more dispersion cover and concealment of their position. Visibility, terrain and weather have no significant effect on the range capabilities of the radar set. However, rain and wind may cause an increase in background noise which makes detection of single personal target more difficult.

3.11.1. Capabilities of Short Range Radar

The radar set AN/PPS-4 is a light weight ,man portable, partially transistorised radar capable of searching for , detecting and identifying moving ground targets such as personnel, vehicles, within a radius of approximately 80 to 7800 meters. It is also capable of detecting certain large stationary features such as tanks and buildings. Moving targets are detected by means of Doppler Effect. Target detection is made possible by monitoring the pulse returns of the target within a movable electronic 'range gate'. Moving targets and certain stationary features within this range gate produce a characteristic audio-tone in the operator head set and a deflection in the range extension meter needle. When a target is detected, information of range, azimuth and elevation of the target is shown on the equipment. If the radar is properly oriented, the operator can read this information directly from his equipment. The equipment is powered by a small motor generator mounted in an accoustical case which effectively suppress noise and inhibits detection. Batteries may be used for absolute silence. Visibility, terrain and weather have no significant effect on the range capabilities of the radar set as long as a line of sight exist between radar set and the target. However, rain and wind may cause an increase in background noise.

3.11.2. Counter-Mortar Radar

A vital new use of radar in ground combat is to help in detecting and tracking down of enemy mortar fire. The mobile and versatile radar eye acts as a sentry, warns of enemy movements and pin point enemy mortar locations for destruction. It helps in locating and destroying a carefully concealed enemy mortar just after one or two shells have been fired. No matter how often the enemy relocations his mortars. With the help of this electronic locator, front line forces can detect and lock on the path of the enemy mortar shells, automatically track their trajectories and obtain complete range data, which reveals the enemy position These coordinates are then relayed to the artelliary units which responds with precisely aimed fire to elliminate enemy mortar within movements after they begin an attack, The equipment is compact and mobile and can be towed by a light army truck for quick movements in the battle field. It consist of a large automatic radar tractor with dish shape antenna, a gasoline powered motor-generator a portable tracker meant for rapid movement to new positions and a separate remote control console with radar scope and all controls used during operation of the radar set. The modified gun carriage mounts six major assemblies of the radar system, including elevation and range computers. Extension cable permits the operator to work with the set from remote position, more than 100 ft away from the large automatic tracker, which tilts up and down and rotates in any direction for continuous search.

3.11.3. Silent Sentry Radar

Probing through might and in conditions of poor visibility, this radar device warns of approaching enemy personnel and vehicles. The 35 lb. set is powered by a small silenced motor generator. Secret of units extreme lightness is absence of bulky viewing radar scope, instead radar echoes produce characteristic audible signals in place of visible images on a screen.

The device is operated by a team of two soldiers. The operator interprets audiable radar echoes, while second soldier tracks reported movements on plotting boards. The unit supplies elevation, azimuth and range data. It warns of surprise over the ground attack by an aggressor and greatly enhance the effectiveness of battle area surveillance. It instantly reports any movement of men and vehicles within a 3 mile range at night in fog or smoke. So accurate is the set, that it detects one soldier walking ½ mile away and even tells weather a vehicle has wheals or tracks.

An improved version of the silent sentry radar has been developed which is designed to look behind enemy lines and provide photographic plots of battle information. This portable system will sweep enemy held territory in a 25 mile semicircle and by periodic photo plots will help to determine wheather the enemy build up or attack is impending or a withdrawal is in progress. In actual practice the radar system is transported by a helicopter to a point overlooking enemy terrain, where a three men crew assembles the equipment in a relatively short time, the radar is plotting movements of enemy targets and is relaying information to higher headquarters.

3.11.4 AN/APQ- 55 RADAR

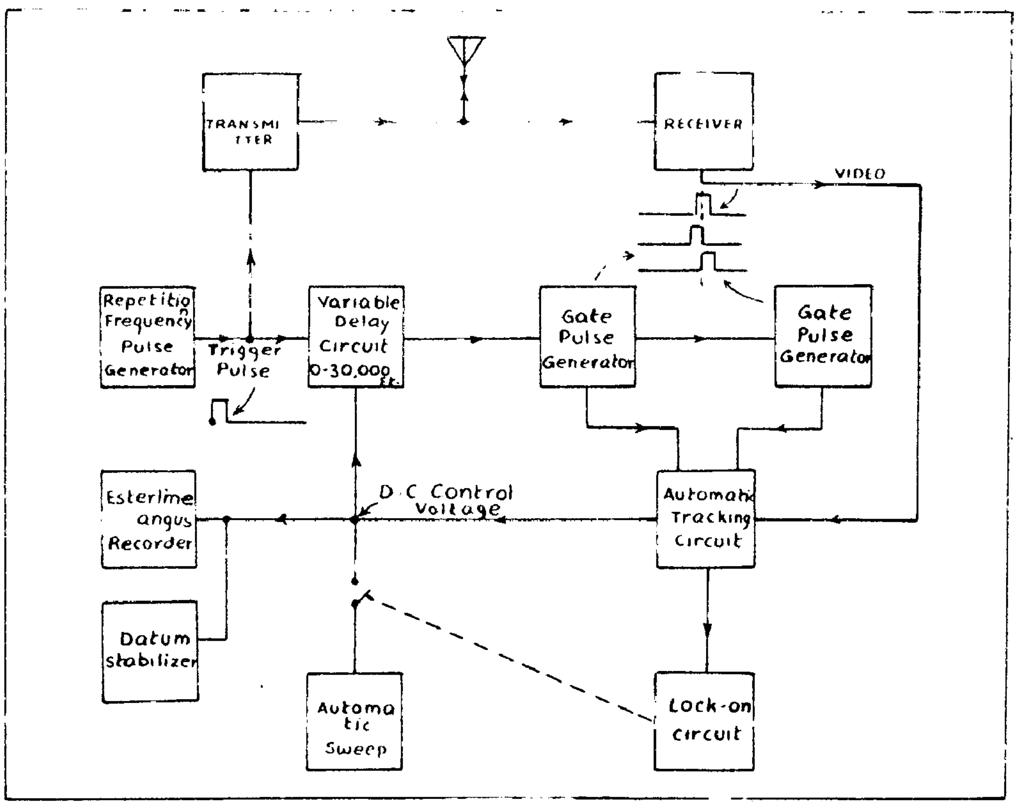
A new radar that will produce aerial maps of thousands of square miles of terrain per hour, night or day in any weather conditions, in which an aircraft will fly, has been recently developed. This new device will give field commander near photographic upto the minute information on troops and material movement well behind aggressor's front lines and will pin point targets over wide area. This new mapping radar will penetrate camaflouge and can see through rain and fog. ID is designed for low altitude operation 1000 to 5000 ft . Its light weight is 350 lbs. which makes it possible to be used in small aircraft without the removal of other normally carried armaments and equipment. Field commanders are provided with data within moments, after the aircraft makes it pass by means of a microwave data link which transmits it directly from the radar receiver back to film recorder and processes at the command post.

3.12. AIRBORNE PROFILE RECORDER

It is basically a pulse type altimeter which uses a narrow microwave radar beam projected downwards from an aircraft , flying at constant pressure above sea level, to measure the actual clearance between the aircraft and the ground. A four feet parabolic reflector mounted in the body of the aircraft directs the energy vertically downwards in a narrow beam 15^{o} wide to illuminate area as small as possible in order to preserve detail. The time lapse for the impulse to return to the aircraft is converted into the distance between the aircraft and the terrain. The instrument contains special electronic circuits for graphic recording of height information. It thus produces an elevation profile of the terrain on a

5" w ide moving tape in the form of a continous record of height meas-urements. When the radar is directed vertically downward in a narrow beam, the signal strength received is increased with the result that a cathode ray tube can be used for display. But for recording data for later examinations implies a laborious photographic process. For this reasons special circuits were engineered to provide graphic recording of height information. The graphic instrument used is Ecterline Angus type in which the heart of measuring circuit is a crystal oscillator so that stability is inherently that of the crystal itself. This crystal controls the lining of the transmitter and initiate the timing cycle. A block functional diagram of the circuit is shown in Fig. 16 .

Airborne profile recording requires that the aircraft fly at a constant height above sea level. However it is impossible to maintain an exactly constant altitude over long periods and some means of ironing out the variation is necessary. A standard altimeter contains too much of inherent delay and therefore an auxiliary unit call-ed a Datum stabilizer has been developed. A small sensitive aneroid which operates by virtue of change of pressure with altitude, is used to produce an electric current proportional to height varia-tion without necessarily loading the aneroid. This current is fed simultaneously with the radar signal to the same recording meter in a manner to correct for



FUNCTIONAL DIAGRAM SHOWING CIRCUITRY OF APR

FIG. 16

deviation from level flight. The result is an APR record which is a scale drawing of the terrain below. For best accuracy, the system should have as narrow a beam as possible to provide fine detail. At present the beam width is 1½° . Because of this, however, pitch and roll must be kept to a minimum especially over a rough terrain.

As far as the effect of atmospheric condition is concerned, these conditions have little effect on APR. In heavily wooded areas the height of growth must be ascertained by inspection of the photography since the microwave radiations are reflected by tree tops.

As a reconnaissance instrument, APR, has provided contour information for aeronautical charts to fill a much needed requirements for the safety of expanding air services. Until the development of Shoran, it was impossible to apply sensible ground scale to photographying without the aid of ground parties. The use of Shoran still requires field parties to set up ground stations. This brings us to the problem of mapping over an enemy's territary where it is hazardous to send field parties. There are intelligence methods for fixing a target including, of course aerial photography, but unless the position of target is expressed geodetically, the possibility of attack by day is difficult while the attack by night is greatly eliminated.

So we can use Astro-fix method. While astro-fixation may be possible by day, it is more likely to be a night problem, Combining night photography with astro obser-vation. This method does not still provide means of controlling or scalling the air photography such as is needed for positioning and mapping a whole target area. Such a problem is easily solved by APR - solving the two adjacent air-triangles in which the height dimension is known.

Considering all these factors the APR has been giving accuracies as good as ± 10 ft on water surface and ± 20 ft over land at altitudes upto 20,000 ft. At greater heights the accuracy over water is not reduced, although over land errors of ± 50 ft may occur, due to greater terrain area illuminated by the 1.5° wide radar beam. For military purposes it will be necessary to map from higher altitudes to use APR at these altitudes, a few refinements such as Gyro-stabilisation of the antenna and narrowing of the beam width, have recently been incor-porated in the original equipment. APR has been widely used to speed up topographic mapping and to obtain rapid vertical control for photogrammetric mapping.

CHAPTER - IV

REMOTE SENSOR SYSTEMS

CHAPTER - IV

REMOTE SENSOR SYSTEMS

As defined earlier, such systems acquire data concerning a subject status or assess and measure its properties without making physical contact with it. The essential component of such a system is a sensing device.

Photogrammetry using conventional visual spectrum devices has been the primary means of earlier modern remote sensing devices. The ground and airborne camera systems are being employed for tactical studies of terrain, procurement of information as to the enemy works and activities, the planning of bombing attacks and the surveying of results. Later with the development of colour photography and infrared colour photography, air photo reconnaissance and air photo interpretation have been the most exhaustive and authentic sources of military terrain intelligence about the enemy held territary and battle areas.

The detection, discrimination or measurement of certain objects is difficult or impossible using only visual spectrum energy. This is because ~~first~~ surface energy reflection phenomenon are primarily involved which has got certain limitations. But by employing reflections of electromagnetic energy and other modern sensing techniques these limitations can be overcome. Some of these sensor view a subject under specified wave length or forms, and thus are independent from most of the environmental conditions.

Throughout the history of warfare terrain reconnaissance has had an important part in operation. The big difference between military reconnaissance today and that of many generations ago is that the information is now needed much more quickly and for larger and more widely separated areas than in years gone by. In earlier wars, the information sought was only about general topographic features, whereas with the present fast moving armies, knowledge of every aspect of the terrain is required.

In military operations, the effect of terrain on the movement of ground vehicles is a major concern. Obstacles that would deter the progress of these vehicles usually (but not always) are obvious and easily identified from maps or conventional aerial photography. But the trafficability of the soil - the ability of a level or sloping soil to support the passage of a vehicle is an aspect of terrain that is difficult to analyze by conventional means. Instruments have been developed for use by reconnaissance parties in measuring soil trafficability. However, military situation will not always permit physical access to an area and so remote means of assessing trafficability must be used. Conventional aerial photographs have been used for this purpose with some success, but the services of experts are required and results are approximate at best. The AMRC (Army Mobility Research Centre) has accummulated much data regarding weather-soil relations, which can be used in estimating the trafficability of remote areas, but again the accuracy to be expected is not great. A need exists, therefore for a technique, which by investigating terrain from a remote location, will produce fast, accurate information regarding the trafficability of the soils. To fulfill this need the terrain analyser project was established at the WES. The ultimate goal of the terrain analyzer project is to be able to predict quantitatively the effect of terrain on military activities through utilization of remote terrain sensor data. For the present the project will be directed towards the study of soil types and soil conditions, since these factors are of primary importance of trafficability. As progress is made other features of the terrain such as microrelief, slope, vegetation and hydrographic factors will be included. The eventual equipment is visualised as an aircraft with a multisensing terrain analyzer system capable of perceiving, registering and integratting terrain data of the region over which it flies, with sufficient accuracy and in such forms that the military commander will immediately have readily interpreted quantitative measures of the terrain factors. That will effect his mission. From the beginning it was realized that no one sensor would provide all the data needed. For example, sensers utilizing the infrared portion of the electromagnetic spectrum would provide information on only the surface of the terrain, whereas sensors operating in the radar frequencies would give information on soil conditions in the upper several feet of the terrain. Both areas are important for military manoeuvre over unknown ground.

The glamour of the engineering of the newer sensors and the results achieved by them have tended to overshadow a basic fact that remote sensing is not an end in itself. But it can be promising and often a unique tool whose potentials must be appreciated.

4.1. POTENTIALS OF REMOE SENSOR SYSTEMS

Here we are mentioning remote sensing system for military engineering purposes for which airborne data collection techniques and equipments will be emphasized. Advantages of placing remote sensors on airborne and satellite platforms are the rapidity of data collection because of the high forward velocity of such vehicles . The large area coverage is obtained due to high the altitude of the vehicles. This latter feature has an additional asset that the aircraft/sensor system can collect data data beyond political and environmental barriers, that could hinder the acquisition of information by other means. With the large areal coverage, the relatively small scale produced by many advanced sensor systems frequently leads to easier detections and measurement of large areas/features.

Previously, where only segments of such features could be shown on large scale, identification was limited. A further technical advantage of remote sensing with advanced systems is that many of them can produce useful data independent of solar illumination.

Fig. 17 shows the comparision of a view (a) across San Francisco Bay Collected with visual spectrum aerial Ektachrome film (approximately 0.40 - 0.76 μ) and (b) a view taken simultaneously using infrared (IR) Ektachrome film (approximately 0.76 - 0.90 μ). The improved distant detail in 'b' was obtained because the less electromagnetic energy of the latter wave length is less susceptible to absorption and scattering by atmospheric constituents than the former. Generally as sensor wavelength increases, atmospheric factors present fewer problems.

The term 'signature' is used with reference to detected features characteristically produced by viewing a subject with specified energy wavelengths or forms and under specified (environmental and operational) conditions. An example of this is shown in Fig. 18 Sensors exist that can provide information concerning a subject's composition and conditions in terms of optical, electrical, magnetic and other phenomenon which could not be readily discerned otherwise.. Fig. 18 shows an 8-14 μ IR scanner image of cold water flowing and ponded beneath heavy vegetation . The feature cannot be seen in the concurrently collected visual

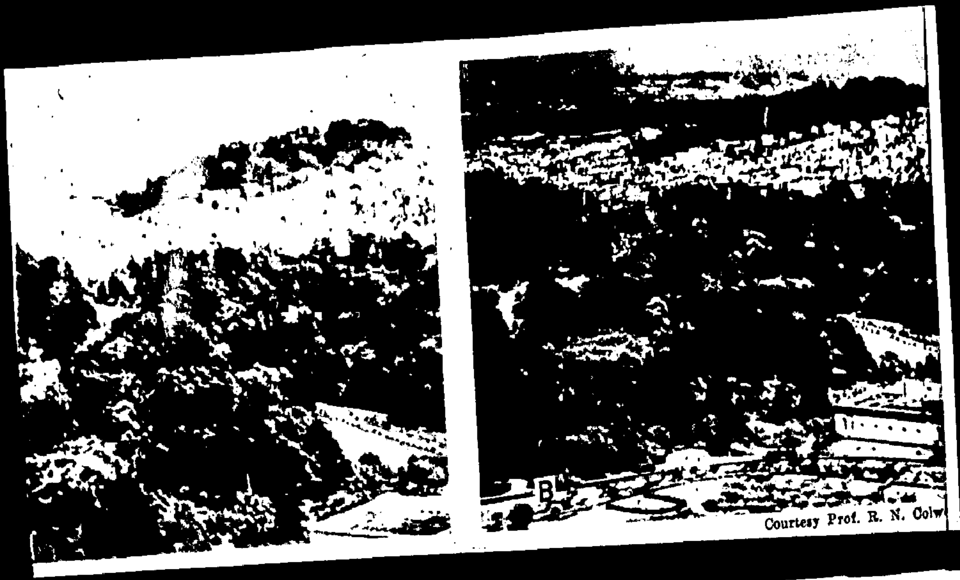


Fig.17- Comparision of visual spectrum aerial film (A) and Infrared film(B) performance - Infrared(B) shows improved distant detail.

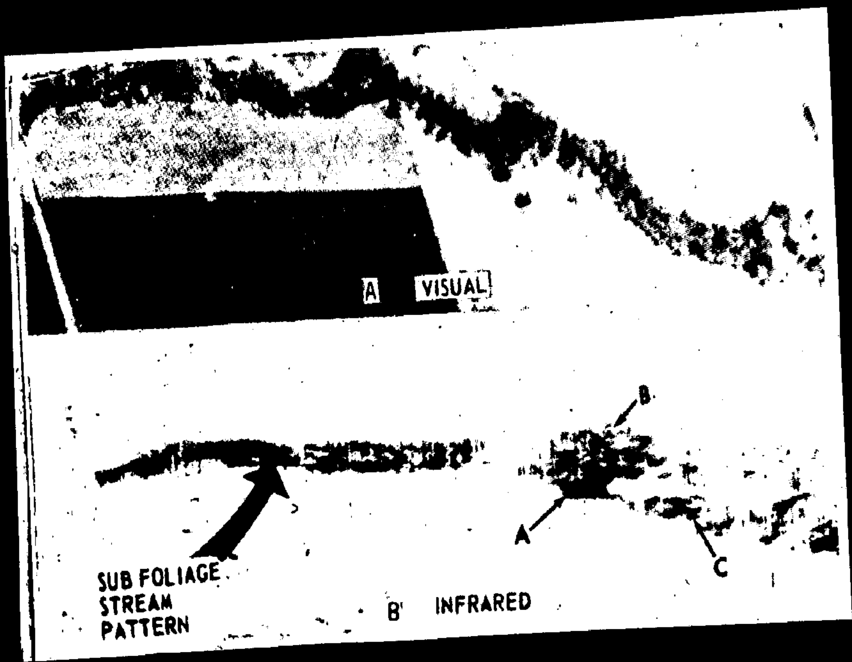


Fig.18- Comparision of Visual and Infrared Images - Cold Water flowing and ponded beneath heavy vegetation is not visible in (A) but detected by infrared (B).

spectrum image Fig. (18) because the energy for this image's generation was returned for sensing from the tree crowns. The thermal signature of the subfoliage water exists because of the temperature differential discrimination which can be made by the sensor in the 8-14 micron region due to the ability of these wave length of energy to pass through the tree crowns. One of the environmental condition permitting the existence of this signature was the time of the day at which the data were collected - early afternoon. At some other time, such as just after sundown, the relatively rapid cooling rate of the surrounding soil and vegetation compared with that of the water would find the water and its background at the same radiometeric temperature. No signature would have been available for the subvegetation water under these conditions.

If one sensor can provide a s-ignature, the use of several sensors together can provide comppehensive evidence concerning a subject without making physical contact with it. Multisensing broadens the restraints on environmental conditions required for acheiving information. Thus in Figure 18 visual spectrum photography 'suggested' the presence of surface water beneath the vegetation; with the additional data from 8-14 μ IR scanner , the presence of surface wate-r was confirmed, although time restraints were cited. If the data collection system had included a vertical incidence, vegetation penetrating i.e. (1 m wave length) radar, the water could have been mapped(as high signal reflectances) without concern for the time of day. On the other hand, the long wave length radar could not be used alone for such water mapping because a dry stream bed veneered with material such as magnetite sand could also give a high signal return. The recent advances made in sensor performance, the increasing availability of sensors, the better understanding of sensor/environmental/subject interactions and the demand for rapid and economic data acquisition have stimulated the development of sophisticated multisensor system with three or more sensor types combined.

4.2. RELATION OF ELECTROMAGNETIC SPECTRUM TO REMOTE SENSING TECHNIQUES

Fig. 19 shows an electromagnetic spectrum from shortest to lengest wave length. The various systems employing a specified range of wave lengths will be discussed, along with the equipment. If any, employing the particular range of wave lengths.

4.2.1. Gamma Rays

Many natural terrestrial materials radiate gamma rays. However, the low energy levels involved, the omnidirectional radiation paths taken, the relatively high absorption of such energy by natural atmospheric

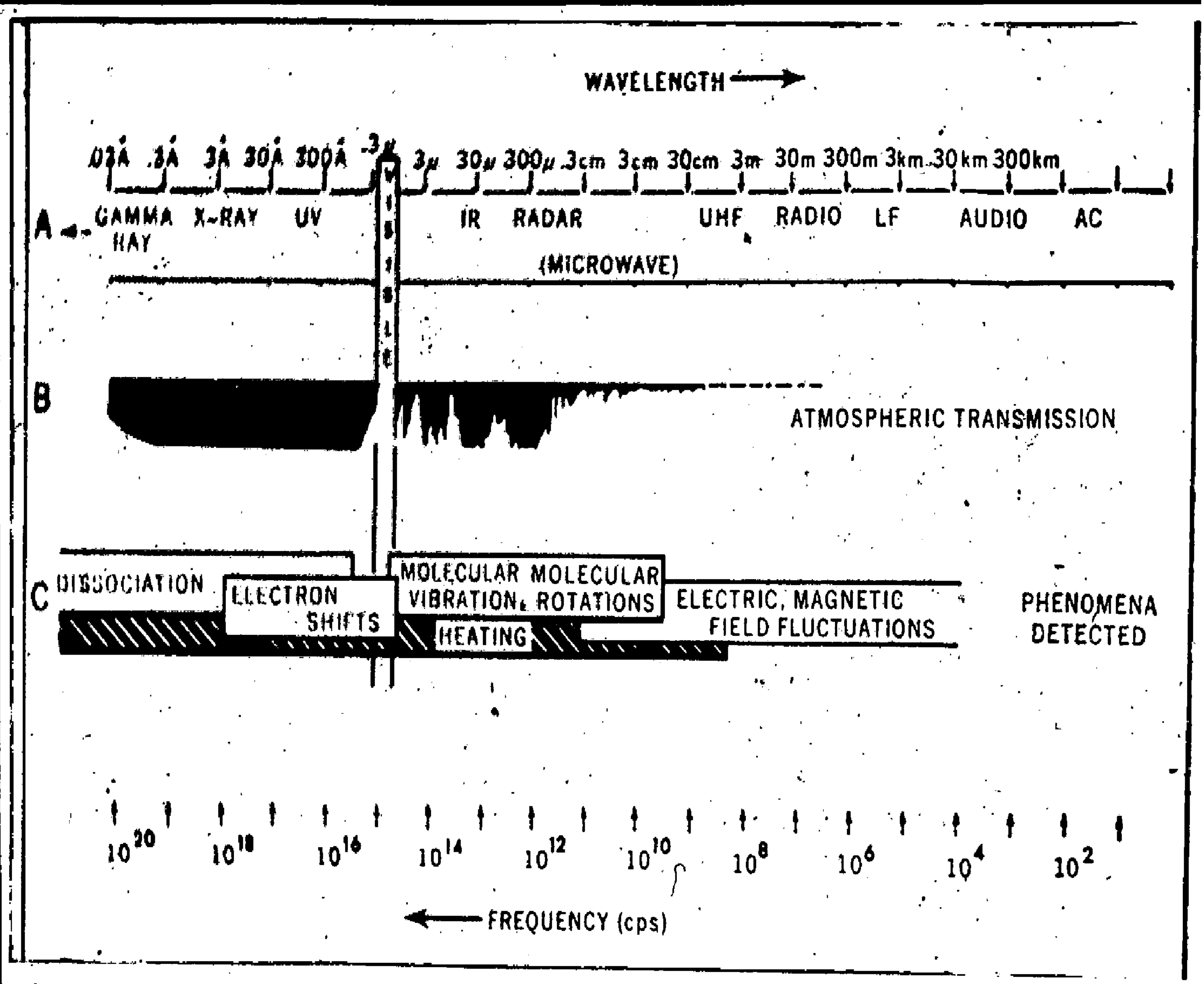


Fig.19- Relation of Electromagnetic spectrum
to Remote Sensing Techniques

constituents such as water vapour, and high background 'noise' levels (cosmic radiation) demand that sensitive and often complex sensors be used and under only certain conditions. Such limitations have delayed gamma ray sensing from becoming a fully operational technique.

Frequently a compromise is necessary between detector sensitivity and resolution in airborne gamma ray sensing of terrain. The airborne sensor must fly low enough (altitude 250-1,000 feet above ground) and slow enough to collect sufficient energy for generating a signature. Forward motion of the vehicle extends the ground track covered, thus reducing resolution along the flight path before sufficient gamma ray energy to be recorded has entered the system.

Trafficability information can be effectively gathered using gamma ray. The gamma-ray spectrometer appears to be well suited for use in areas where the soil is obsecured by a heavy vegetation cover as in tropical rain forests.

4.2.2. X-Rays

X-rays may be essentially discounted for remote engineering surveys. The naturally occurring energy levels are too low for any logical recording process, and the power supply required to induce sufficient radiation from a remote platform is not practicable.

X-ray image intensifier can be used to identify objects at very low illumination level.

4.2.3. Ultraviolet Rays

Natural atmospheric constituents preclude sensing of ultraviolet (UV) wave lengths much below 0.25 μ (2,500 Å) . Between this wave length and approximately 3,200 Å , the dearth of energy requires some form of photomultiplier to be used as a detector. Conventional cameras equipped with quartz lenses (typical lens glass absorbs shorter UV wave lengths) and special film/filter combinations can be used to give UV images in the 3,200-4,000 Å region.

Active airborne UV systems have been attempted for inducing fluorescence for mineral exploration. But for engineering,application tests indicate that the use of the sun as the UV energy source is more effective. In tests, UV sensing has been shown as particularly promising for revealing freshly exposed soil as in slump areas, delineating relatively high calcium-content soils and rocks, and detecting anomalous soil moisture areas. Despite the encouraging results obtained, it has been suggested that most of thedata collected with operational UV sensors ~~through~~ uptill 1967 were heavily 'tainted' with energy of other wave lengths. Several of the UV photomultipliers used have been found to have one or more unexpected additional sensitivity peaks between 7,000 Å and 1.2 μ , and few of the so-called camera/film/filter combinations actually had quartz lenses. The system has been discussed in Chapter on Electro-optical photography at low illumination level.

4.2.4. Image Intensification

To clarify the image details obtained by low energy level illumination system, image intensification of thousand of times can be done to produce a clear image of the army personnel or equipment through the eye piece of the intensifier. Remote viewing is also possible by using this device with a TV orthicon pick up tube.

4.2.5. Visual Spectrum and Photographic Infrared(IR)

The visual spectrum is accepted as extending between 4,000 Å and 7,600 Å. The photographic IR region extends from the visual to approximately 1.35 μ but present operational sensing seldom uses film sensitive to wave lengths longer than 0.9 μ. In the uses of visual and photographic IR in engineering, color film types - aerial Ektachrome and IR Ektachrome- appear to be supplanting black and white film for photogrammetric and photointerpretation operations.

4.2.6. Middle and Far Infrared

At wave lengths longer than approximately 1.2 μ camera/film/filter combinations cannot collect sufficient energy to satisfy requirements; therefore, devices are used which amplify and convert the energy which can be collected into electrical signals. These signals are used to activate visual and near-visual wave length light sources for exposing photosensitive materials. The signals also can be used to drive a flux head for magnetic tape recording or a pen for some type of paper tape recording. Where the sensor provides an analog trace or digital tape output, it is referred to as a radiometer. Where detector output movement, such as a light beam, is made to correspond with movement of the energy collection elements of the systems (optical scanning), the sensor is called a thermal or IR scanner or , less accurately a mapper.

Operational IR radiometry at present emphasizes the use of indium antimonide (I_nSb) detectors for sensing in the 3.5 - 5 μ (middle IR) region, and mercury-doped germanium (Ge:Hg) for sensing in the 8-14 μ (far IR) region. The 3.5-5 μ (middle IR) wave lengths appear most satisfactory for sensing artificial thermal energy sources. Consequently, a good engineering application might be in pollution and combustion efficiency studies Fig. 20. When 3.5-5 μ data are collected during daylight hours, they must be interpreted with caution because solar effects (shadows) are experienced out to atleast 5.5 μ. The 8-14 μ sensing wave lengths correspond with the broadest peak in natural earth radiation; therefore, this wave length region is

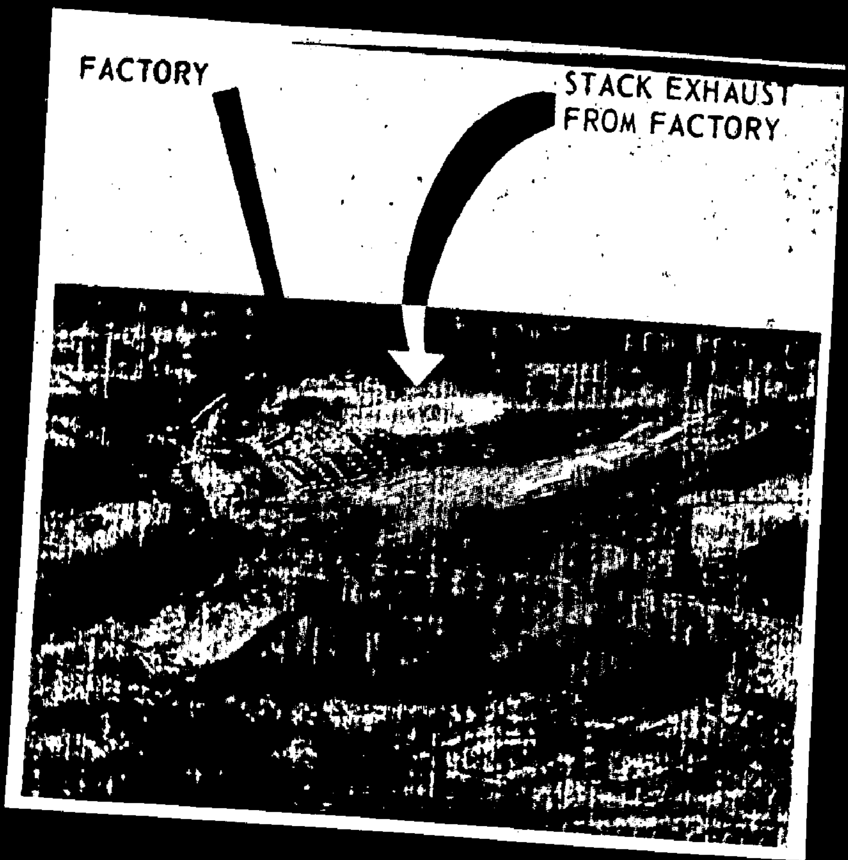


Fig. 20 Night Collected 35-50 μ IR Scanner Image of Factory Exhaust to study Pollution and combustion efficiency.

particularly suitable for detecting discrete variations in natural radiation. The IR images shown have only been cropped or scaled, and are not retouched. However, some of the corresponding data have been altered for security of proprietory reasons. In Figure 21 , the main feature shown in the 8-14 μ image is a cold water stream flowing into the warmer water of a lake. This flow appeared to be polluting a special installation at point A. This stream flow could probably have been discovered by many other means including conventional aerial photography, but IR image may be the most effective means for showing the stream as a thermal pollution source. Also, as indicated by its meandering course at point B, the stream is draining a swampy area which is a source of organic sediments and possible chemical pollution.

The water mixing pattern provides a guide for planning a diversion grain or other remedial construction. This pattern can be easily discened by IR sensors.

In Fig. 22 the upper figure is an 8-14 μ IR image showing the bottom conditions off the California coast. Camparison with the fathom readings of the chart shows where sedimentation has been taking place (A).

Fig.21- Day-time collected 8-14 μ IR scanner image showing stream flow and mixing pattern.

Fig. 22 Night Collected IR image and corresponding Hydrographic Chart

IR image clearly shows bottom conditions off the coast. At A sedimentation has been taking place.

In a conventional aerial photographic image of terrain only soil surface features appear. In a corresponding 8-14 μ image, near subsurface rock strata will show as alternating light and dark image tones. Assuming that uniform lithologic and soil conditions exist, the loss of these tones may indicate that overburden thickness has increased to an extent where thermal differences between bedrock types and their surroundings cannot be detected. Overburden thickness from IR images cannot be determined at this date, but such IR subsurface information could be useful for a route survey, for example.

4.2.7. Microwave Radiometry

Microwave radiometers are passive devices for sensing electromagnetic energy from approximately the far IR to 30 cm wave length region. At the longer wave length end of this broad response band, the amount of energy available for sensing may be considered significantly greater than that available to IR radiometry. A simplified, partial explanation for this is that the texture of the surface being sensed is less likely to present irregularities having dimensions that are resonant with the longer wave lengths.

Microwave radiometry is still under development. Field testing has indicated that the technique has excellent promise for terrain material identification, and location and mapping of near subsurface voids.

4.2.8. Radar

Radar sets are useful for engineering, generally as a function of the involved wave length. Field tests have shown that from a K_a-band wave length ($\lambda \doteq$ 85 mm) record it is possible to distinguish between surface materials as a function of amplitudes received at various aspect angles; from K_u-band ($\lambda \doteq$ 1.4 cm) data it is possible to obtain moisture content or depth of snow cover, and to determine sub-vegetation terrain sconditions; with an X-band (λ = 3 cm) system, an in-situ sandstone having only a 2 percent iron content could be distinguished from an adjacent sandstone that was otherwise identical.

The potential use of radar for discriminating between surface and near subsurface materials is indicated by Fig. 23a. The lower image made with a SLR, readily presents alternating strata of shale and chert in a manner permitting coarse measurements. While the equivalent conventional photograph 23b. , could permit more precise outcrop measurements, all rock types appear to have the same grey scale level.

Radar has remained largely a developmental tool as far as engineering applications are concerned.

Fig.23 Radar and Corresponding Visual spectrum photographic images of a sea cliff.

Lower image made with a SLR descriminates between surface and subsurface materials.

This may be because the World War II types produce relatively poor resolution images and the SLR types are costly. Also both types present difficult maintenance and logistic problems.

4.2.9. Automation

There are problems in efficiently correlating and reducing the data produced by a combination of instruments such as cameras, IR scanners and radiometers, radar sets, gamma ray sensors, and magnetometers. In one commercial multisensor system, the output of most of the sensors and all of the control instruments is recorded on a magnetic tape. This is one approach toward alleviating the data handling problems. A data processing subsystem has been developed to correlate and reduce the huge volume of multisensor information that can be produced in a single mission by the complex airborne system. The subsystem provides controls for any navigation and aircraft altitude and attitude errors that may occur during data collection.

It is likely that a multisensor data processing sub-system can provide quantitative values for imaged data and means for extending these data, for example, via graphic portrayal of outputs from nonimaging sensors such as magnetometers and terrain probing radars. Multisensor data may be correlated to provide an object's location, geometry, composition, and condition - for example, by superimposing plots produced from data from several sensor types, or by computer selection of programmed combinations for plotting .

Aid to the image interpreter or film processing staff may be provided by indicating which segments of coverage for large areas merit particular or priority attention. Other advantages of such a system are the means for reducing human errors, as can occur in conventional forms of image interpretation; low cost and rapid data reduction, compared with human interpretation alone; and an orthographic presentation of radiometric and radar signals without the distortion presented by other methods.

4.3. TERRAIN ANALYSER PROJECT

The project can be divided into two phases; Data gathering and applications. In fact this division separates the project into ground and airborne programme.

In the first phase - classification and identification of terrain properties such as soil types, moisture content, density and other factors pertinent to trafficability by examination of their electromagnetic characteristics in the gamma-ray through radar region of the spectrum is done. This work is done under controlled conditions and the effect can be known by varying one particular parameter (such as grain size or moisture content) on the electromagnetic reflectance and emissivity properties of various materials.

The field exploration will be done by choosing larger natural soil tests plots in which reflectance and emissive properties of materials will be obtained by using sensing instruments on an elevated platform or in a helicopter. The observations will be compared with known characteristics.

4.3.1. Infrared Studies

Infrared sensors - a double beam reflectance spectrophotometer, which is an analytical instrument designed for spectroscopic studies of the radiant energy reflected by natural objects under laboratory or field conditions. This instrument is an active sensor and uses a carbon -arc light source for operation in the following spectral regions; Ultraviolet (0.25-0.39 micron) Visible (0.39-.76 microns) and Infrared (0.76-5.0 microns) Precise control is exercised in preparation of the soil sample to be tested. The amount of water that must be added to obtain the desired moisture content for a particular test is mixed with the soil and the material is stored in containers to cure for 24 hours. Cured cohesive soils are placed in a cylindrical mold 15" in diameter and 7" deep in four equal layers and compacted by a mechanical hammer to the desired density. During compaction process samples are taken from each layer to determine the uniformity of the moisture content. The wet density is also determined. The surface temperature of each sample is monitored at regular intervals with a low temperature pyrometer.

The effect of any one soil parameter is studied by maintaining allothers constant while systematically varying the soil parameter under investigation. The soils under test may be sand, silt, and clay and various combinations of them.

Prior to the spectroscopic testing of each sample a 'Thermometer-White -Plate Glass' reference standard is used to adjust the optical attenuators to 100 percent reflectance. This calibration prior to each test assures true comparisons of results.

The selection of wavelengths for analysis of the test results was based on known absorption bands and atmospheric windows for moisture and CO_2. Since the moisture content of soil is a major factor in trafficability, the moisture absorption bands were considered of primary importance in obtaining information on this parameter. Wavelengths chosen for analysis ranged from 1.40 microns to 4.5 microns. Other wavelengths between 0.25 and 5.00 microns have been examined and the same general type of results were obtained. The relation between reflectance of the soil samples and each of the soil parameters were established.

4.3.2. Radar Studies

In selecting the radar sets to be used in the investigations, the need for noncontact determination of terrain material composition and conditions to a depth of approximately 1 to 2 feet was considered. Short wavelength electromagnetic probes such as visible light, infrared, and Ka - band radar cannot penetrate to the necessary depth, and reflectance levels obtained with them are primarily due to surface conditions. This type of data is also essential in the trafficability study because often surface manifestations are indicative of conditions at depth, and surface effects must be known before radar return from soil depths can be interpreted with accuracy. Ka-band radar was therefore selected as the minimum wavelength probe, and, to obtain information at the necessary depth, P-band radar which has the longest wavelengths available was selected. From the limited data available on depth of penetration of the radar portion of the electromagnetic spectrum, it was found that the Ka-band radar wavelengths will normally provide surface data and P-band radar wavelengths will normally yield some penetration data, but that other wavelengths should also be included. C and X- band wavelengths were included to help fill the gap between the Ka-band surface effects data and the P-band data on the extreme depths for relatively dry soils. Through the use of a wide range of radar wavelengths it may be possible to interpolate values for intermediate wavelengths.

4.4. MULTIBAND REMOTE SENSOR SYSTEM

Multiband sensing consist of detecting, defining, resolving, recording and analysing distant objects by means of single or multiple imaging devices sensitive to the electromagnetic radiations, either inherent or reflected emanating from these objects. The sensing of the emanations is not limited to a narrow frequency band, but compasses the range from very short wave length to long wave radio frequencies. As already discussed, this range can be roughly devided into three major segments, the conventional photographic system, the infrared detectors system and the radio frequencies. Each of these band contains wavelengths which are capable of detecting and resolving useful information and thus those sensors utilising such wavelength become tools for studying the terrain features, natural or cultural. It is believed that by exploiting all three general band groups or spectrum areas, it is possible to gain information which might otherwise be denied by the use of only one sensor and one band of energy alone. Whether the various sensors are flown simultaneously or not is immaterial. This concept is of extreme importance and urgency to ensure optimum utilization of airborne remote sensors for adverse nature of military intelligence studies.

No single sensor possess all requirements for an optimum device. But neither does any sensor have so many disadvantages that it is valueless . Camera possess the best resolution and give geometrically accurate reproduction. Infrared system record minute temperature differences. Side looking airborne radares operate independently of the time in almost all weather and maintain constant image quality over extremely long ranges. But some remote sensor problem require the interpreter to be very cautious. For example one of infrared's most confusing situation occurs when an object temperature is same as its background. Then the two cannot be separated. Properly positioned metal cenners reflecters produce radar reflection as strong as industrial complexes. However to hide a large object like a factory from radar detection presents more serious problem. O

Optimum system, then consist of more than one sensors, each contributing its special information. To exploit the advantages of multisensor reconnaissance, modern military reconnaissance aircrafts such as B-25 have been equipped with a side looking radar - a far infrared scanner, two conventional photographic cameras and the hyper sensitives radiometers. Another multiband remote sensor reconnaissance system has been equipped with a nine lens multiband camera, three 70 mm frames a sky light recording camera, a cartographic camera, a spectrometer system and an electronic control console. A more sophisticated and integrated sensor system consists of four radar systems including one side looking radar, a far infrared detector, several aerial cameras, the radiometers and a magnetometer array.

4.5. CAPABILITIES AND LIMITATIONS OF REMOTE SENSORS

Modern remote sensors imagery has greatly improved in recent years. These systems extract data from sections of the electromagnetic spectrum several million times wider than that available to conventional camera systems.

These systems can obtain larger areal coverage. This added coverage has revealed new identification signatures for both natural and cultural features in spectral areas beyond camera's capabilities. Under certain conditions infrared and radar system can produce imagery of specific subjects of nearly photographic quality. But they will only supplement, not replace, aerial cameras; atleast not for a coming few years. A comprehensive system still needs several sensors to satisfy the needs of military reconnaissance.

Each sensor resets only to energy bands of specific frequency and wavelength. Radar receivers cannot detect visible light; transmitted microwaves are invisible to infrared scanners. Active sensors like radar, record echoes of reflected electromagnetic energy which tye themselves transmit. While passive sensor (infrared devices, camera) detect radiations that would be present whether or not the sensors were operating.

Aerial cammras produce their best imagery on choudless, hazeless days, but with new techniquesw and equipment, they do obtain reasonably good imagery on clear nights.

Infrared systems also produce good day time imagery. However, since they respond to energy radiated from beyond the visible spectrum, night infrared missions with middle and far infrared imagery yield excellent results. For many purposes, far-infrared flights obtain their best imagery after dark when there is no interference from solar isolation. Military needs for night time operatbns are obvious. Infrared radiation may penetrate dust and haze depending upon the size of the aerosoil particles, but clouds, high surface winds and rain greatly reduce image quality.

Radar, an active sensor, provide its own source of energy. Therefore, it too is independent of time of day. Its longer wavelengths penetrate haze, fog and clouds with minimum signal loss. Rains attenuates the signal but the extent depends upon system wavelength and rainfall rate. Thick moisture-ladden clouds, however, can effectively block transmitted waves. To what extent these factors affect radar imagery, depend upon several system parameters.

All these systems can be 'tuned' to be more selective to specific frequencies within their operational bands. Narrow band film filter combinations enable cameras to record spectral responses of one colour. Filters are often added to infrared systems to eliminate effects of solar reflection below the middle or far infrared images, depending upon the system.

Pulse, repitation rate, polarisation power, radar system resolution and sensitivity are functions of wavelength and gain setting. For example, weather radars (which requires only moderate resolution) use long wavelength systems. Terrain reconnaissance and mapping radars use much shorter wavelengths (comparatively) to record natural and cultural features with almost photographic clarity. System components (such as Cathode Ray tube and film) cannot record with equal discrimination all signal levels received at the antenna. Whether, the film records maximum differences between high and low intensity signals depends upon the settings according to mission's main purpose.

An object's surface smoothness and orientation affects the radar image. Surface smoother i.e. with irregularities smaller than the wavelength of the impinging electromagnetic energy, will reflect most energy specularily or mirror like, while rough surfaces create mainly diffuse reflections.

Because visible spectrum wavelengths are so short, most surfaces reflects light diffusely regardless of orientation. Longer microwaves create specular reflection off the same surfaces. For example, aim a flash light at a wall, first perpendicularly then at an angle. One sees the wall equally as well regardless of the illuminating level. A radar system illuminating a simmila-r wall shows much stronger returns for head-on orientation than oblique.

On aerial photographs, images of bodies of water frequently vary in tone. Wide density ranges often occur on the same negative. Many times these density changes vary with respect to water depth, other times to the sun angle.

With radar, water smooth surface reflects most transmitted microwave energy specularly , it gives 'no return' image. Radars can record some of water's phenomena however, surfaces broken by break waters, waves or submerged rocks are often detectable. Contrast between normal no-return images and slight returns of broken waters are usually sufficient to assure surface detection of submerged features.

Infrared system can extract considerable information from bodies of water. Hot effluents discharged into streams or lakes are readily detectable because of temperature differences between them. Densitometric analysis show how far and in what direction effluent travels before the stream or lake absorbs it. Chemical waste or other polluted discharges are easily detectable because of temperature anomalies they create.

Table 1 given below, summarises the advantages and disadvantages of remote sensors. No single sensor system possess all requirements to be an optimum device. Studying the tabulated comparasion of different sensor systems it will be found that camera possess the best resolution and gives geometrically accurate reporduction. Inrared systems can record minute temperature differences. Radar is an all-weather system.

Table - 1

REMOTE SENSOR COMPARISON

		Camera	Infrared	Radar
1.	Day/Night	5	10	10
2.	Haze Fog Penetration	3	6	10
3.	Cloud Penetration	1	2	9
4.	Temperature Discrimination	2	10	1
5.	Subsurface detection	4	6	3
6.	Stereo Capability	10	2	3
7.	Accurate image representation	9	6	5
8.	Long range capability	7	4	8
9.	Resolution	9	7	5
10.	Interpretation of imagery	9	6	6
11.	Availability of equipment	10	4	4

Poor = 0

Good = 10

To exploit the advantages of multi sensors reconnaissance, an aircraft can be converted to multi-sensor platform. Fig. 24 is a block diagram of a multisensor system. It will have four radar systems (side-looking 360° scan vertical incidence and terrain avoidance) a far infrared detector, several aerial cameras, three radiometers and a magnetometer array. Such a system can make interpretationof various cultural and natural features more easy.

Only the remote sensing technology that remains developmental or that is in operation has been discussed so far. The part of the technology that involves sensors such as 8-14 μ scanners still has not been operated sufficiently to guarantee results in every mission/environmental situation. The present terrestrial remote sensing technology is one wherein the data collection developments have outstripped the data reduction and interpretation developments. Despite this sensors/satellite vehicle use and development programmes remain in good progress. Some of them have established the civil engineering value of remote sensing from space, atleast for providing data on the situation wherein airborne remote sensing system may be more effectively and economically applied. It is forecast that the application of remote sensing for civil and military engineering purposes will grow at a faster rate, because of its promise for many applications and the economy of the technology compared with contact data collection methods.

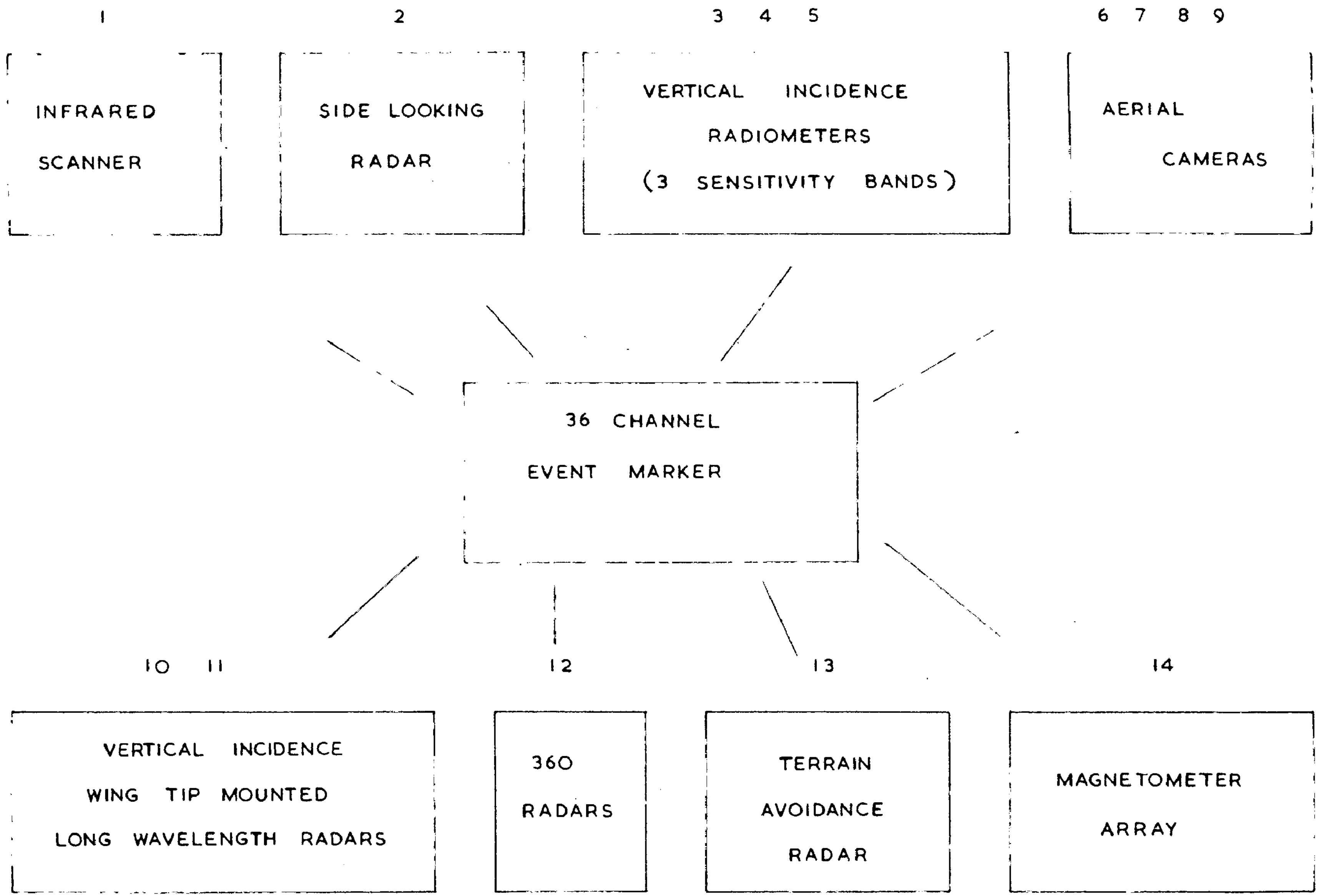


FIG.24 _TEXAS INSTRUMENTS' MULTI-SENSOR SYSTEM CONCEPT

An understanding of its limitations as well as its possibilities is needed in properly identifying the sensors/environments/mission factors that comprise any remote sensing programme.

CHAPTER - V

INFRARED PHOTOGRAPHIC SYSTEM

CHAPTER - V

INFRARED PHOTOGRAPHIC SYSTEM

The infrared photography is rapidly achieving importance in many fields. Much progress has been made in developing infrared thermal sensing and its applications in terrain feature analysis. Infrared imagery is quite useful in inventory of hot springs, water resources, sea-ice reconnaissance and shore line mapping. Infrafed scanners are quite successful during periods where visual observations and photography almost fail. The majority of present day infrared photos are produced by various types of scanning devices rather than by conventional camera and film combination.

The infrared radiation is generated by vibration and rotation of atoms and molecules within any material whose temperature is higher than absolute zero. Consequently, practically all material things in man's surroundings, emit energy in the infrared portions of the electromagnetic spectrum, as long as they are above absolute zero temperature. The infrared radiation emitted from solid or liquid objects is spread over a broad spectral range between the 0.72 and 1000 μ . Since the spectrum falls between those of visible light and radio waves, infrared radiation exhibits some of the characteristics of both visible and microwaves. It can be optically focussed and directed and can also propogate through some material that are opaque to visible light.

Although infrared spectroscopic techniques were first used in 1920, the major factor influencing the relatively slow development of infrared techniques was the lack of sensitivie detectors. Intensive research just prior to and during World War II, resulted in the development of new, highly, sensitive detectors. Although infmared sensitive mosaic devices are under development, a mapping system for practical use at present utilize a single element detector in conjunction with some type of optical scanner.

5.1. SOME BASIC CONCEPTS

The significant data in deriving a thermal map are the variations in effective temperature across the scene and not the absolute values. We are interested then in the incremental thermal sensitivity of the system.

The radiation emitted by a body at a given temperature is proportional to the characteristics of its surface. This leads to the concept of 'emissivity' and 'the black body' . A black body is by definition any object which completely absorbs all radiations. If such a body was placed in a uniform temperature enclosure it would come to equilibrium at the temperature of enclosure and would therefore emit just as much radiation as it absorbs. This can be shown to be true for each wavelength and not just for the total amount of radiation. It follows that a peffectly black body at a uniform temperature T always emit, 'full temperature radiation'. It is for this reason that such a radiation is called a black body radiation.

The radiation emitted by a black body at any given temperature is the maximum possible . Its emissivity is said to be unity. A high polished surface is an extremely poor radiator and absorber, its emissivity is close to zero.

Most surfaces of interest in thermal mapping lie between these two extremes in emissivity. Since the determination of emissivity of portion of a scene is practically impossible, it is conveneint to adopt the assumption that the entire scene radiates as a black body and to interpret the flux emanating from the scene as representing 'Equivalent Radiation Temperature'. The other bodies absorbs only a fraction of the radiation falling on them and this fraction may vary greatly with wavelength. This is the basis of thermal mapping technique. The distribution of contrast in each image represents the pattern of energy radiated from the scene due to its temperature and emissivity distribution. The individual bodies lose their identity in a uniform temperature enclosure. This may readily be observed by locking through a small hole into the interior of the furnace. It is only in conditions where 'we do not have temperature equilibrium that bodies appear different. For example in day light, which is radiation from a body (The Sun) where effective temperature is about 6000°K we see bodies at room temperature in different colours according to the wavelength they absorb.

In the application of any photo-type imagery the primary information is derived from the tonal structure of the image. For infrared imagery the energy source lies in the temperature characteristics of the scene itself; the emitted energy is a function not only of the physical characteristics of the surface but of the surface temperature as well. One can envision many situation where temperature alone will be significant defining factor. Incipient forest fires would probably be unmistakable as would gas or steam, fissures, hot springs, gas or stream fissures. A more subtle pattern will be formed by ocean currents. In all these cases the temperature differential alone would be sufficient to separate the source from its background.

5.2. ATMOSPHERIC TRANSMISSION

Infrared transmission through atmosphere is of primary importance in infrared imagery. Although obtaining infrared imagery is possible on a 24-hour basis, the constantly changing atmosphere will effect the infrared radiation from the earth surface to the system. Attenuation of radiation is produced by absorption and forward scattering by CO_2, Water vapour, Clouds and fog.

The effect is not constant across the infrared spectrum as 'windows' or areas of peak transmission are present. 'Windows' are however not perfectly transparent - say 80% transmission will be more correct Also they are not sharply defined and gradually fade out rather than exist as an abrupt decrease in attenuation The two primary windows for infrared imaging are 2-5 μ and 7-14 μ. The most important window concerning the infrared geologist exist at 7-14 μ, the region of maximum terrain emission. The window is bounded on the short wave length side by water vapour absorption at approximately 7 μ and on long wave length side by CO_2 absorption bands, centered at 15.0 and 16.2 microns. So window is defined as an area of least attenuation across the infrared spectrum.

Infrared reconnaissance mission schedules, though influenced primary by mission requirements, are generally designed to take advantage of peak periods of emission, a fact pertinent to infrared geology. Immediately after the sun dawn - when earth surface is at the highest terrain emission with absence of reflection appears to be an appropriate time for imagery.

5.3. RECORDING SYSTEM

The atmosphere selectively absorbs a certain amount of infrared radiation and being material body itself also emits infrared radiations characteristics of the constituent gases. The radiation which finally arrive at infrared recording system is first brought to focus by optical surface to a detector. The detector translates the fluctuations of infrared radiation into fluctuations in electrical currents. This detector is more properly called a transducer, since it transforms signals of one form of energy to another. The detector is analogus in function to photomultiplier cells used for detecting visible light intensities. After the signal have been transformed into A.C. currents, amplification of these signals can be done by suitable electric means.

If there is a desire to make a full photographic coverage of a scan, one can use a single element having a very narrow field of view and can scann this small element over the full field of view to be photographed. Line-scan is one of the many possible scanning methods which is capable of providing continuous ground coverage from an airborne equipment. The instantaneous field of view is scanned from one side to the other. The aircraft motion carries the equipment over the next scan. As the scanning system scan over and feels out radiation coming from each small portion of the scan, a recording system usually in the form of a cathode ray tube re-scan this scene, such that there is 1 : 1 correspondence between points on cathode-ray tube and points in the field. In this manner, the second transducing occurs so that the scene is made visible. Direct viewing or visible photography can be used at this stage. The ultimate sensitivity of equipment will depend upon the information capacity or the rate at which signal must pass through the detector and the rest of the equipment.

5.4. LINE SCANNING TECHNIQUE

Many scanning patterns have been investigated but perhaps the simplest to generate and implement is the line scanning pattern. The line scanning function is performed by means of a plane mirror scanner whose axis of rotation is parallel to the longitudinal axis of the aircraft. The mirror reflects radiation to a parabolic mirror that is used to focus the radiation on the infrared detector. This optical system focusses a bundle of radiatnt flux on the detector, which senses the incoming radiation and converts the change in radiation into an electrical signal. This signal is amplified by solid state circuitary and is used to modulate the current through a crator lamp whose output is an intensity modulated spot of light. An image of the crator is focussed on the surface of a photographic film and is scanned across the film in synchronism with the rotating scanner. The film moves accross the exposures station at a speed proportional to the aircraft speed to altitude ratio (w/h) and the result, after processing, is a strip thermal map of the area flown over. In which the film density represents relative effective radiation temperature. Here the scanning of the area of interest make use of forward motion of the aircraft. The scanning device in the aircraft permits sampling incremental areas of the scene along a straight line normal to the flight path. At any instant the field of view is represented by a cone having a small included angle α.

A basic requirement of the technique is that the line-scan rate be high enough to provide atleast continuity of the scanned strip of the scene. The width of the scanned strip in the direction of flight is directly proportional to the altitude of the aircraft above the terrain and to the instantaneous field of view α. So to ensure complete area coverage, the minimum line-scan rate is inversely proportional to altitude and to the angular field of view α. It is directly proportional to ground speed. Assuming a linear repititive scanning pattern as shown in Fig. 25 the minimum line scan rate becomes

$$n = \frac{v}{h.\ \alpha}$$

Where,

n	=	line scan rate lines per second.
v	=	ground speed ft/sec.
h	=	aircraft altitude in ft.
α	=	instantaneous field of view - radians.

This signal band width generated by the scanning pattern shown in Fig. 25 may be simply derived. The number of incremental picture elements sampled per second may be expressed as follows:

$$N = \frac{\beta\ n}{\alpha\ D.}$$

N	=	Data-aquisition rate - elements / sec.
β	=	Total angular field of view - radians.
h	=	line scan rate lines/second.
α	=	instantaneous field of view-radians.
D	=	line scan duty cycle

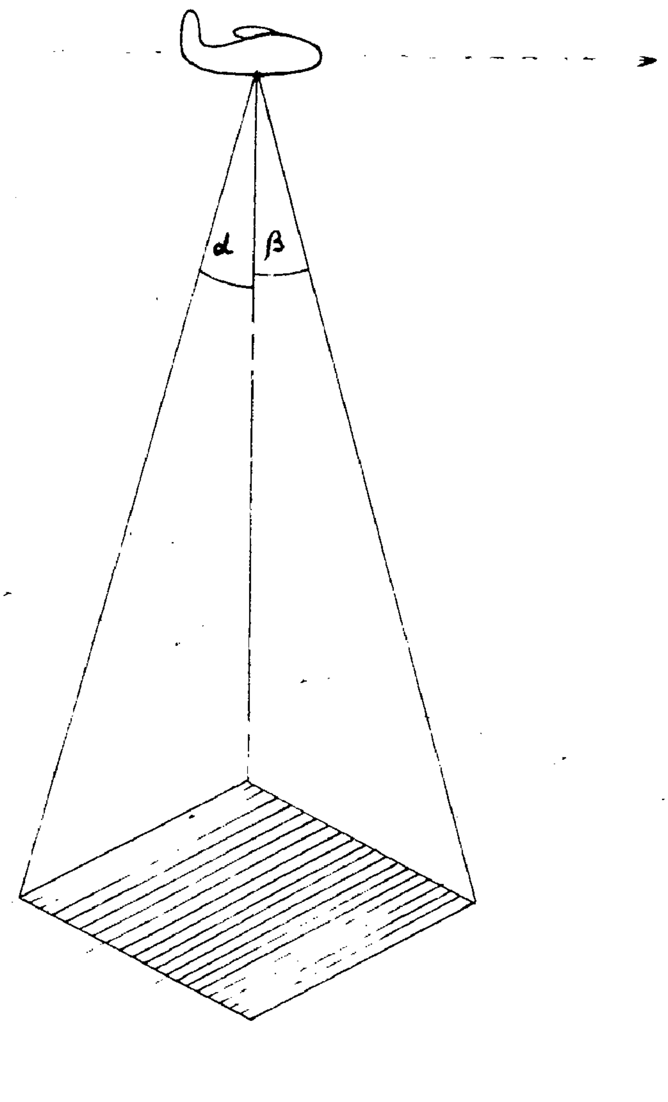


FIG 25 _ SIMPLE LINE SCANNING TECHNIQUE

The signal band width is not a primary consideration here but the reciprocal of N , the dwell time (mean 1/N) per element may be as essential aspect. If the value of 1/N approaches, or is less than the response time constant of the available detector. It may be impossible to meet the scan speed requirements. Equilization techniques in the video amplifier will permit extending the scan rate to a limited degree but at the expense of over-all systems sensitivity.

Actually the signal of interest is represented by the change in amplitude at the detector output in scanning from one picture element to the next. In other words, the significant data in deriving a thermal map are the variations in effective temperature across the scene and not the absolute values. We are interested therefore, in the incremental thermal sensitivity of the system.

5.5. THERMAL MAPS

It is a representation of the pattern of energy radiated from the scene due to its temperature and emissivity characteristics.

Fig. 26 is a comparison of the use of the visible and 0.3 to 2.5 μ spectral region. Both strips were made using the same line scanning device during

.g.26 IR Thermal Map(Top) and Visible Light (Bottom) map of same Area the afternoon of a summer day. The strip on the top was made using an infrared detector while the one on the bottom is a result of using a detector in the visible spectrum. The visible light strip is the result of reflected sunlight while the infrared strips of both radiation from the scene and reflected solar energy.

The outstanding feature is the different appearance in the two images of small streams and the road. In the infrared image the creek appears at a high contrast while in the visible image it almost disappear into the background.

The cultural targets show more clearly in the visible spectrum perhaps due to a greater range of reflectiveness. The vegetation appears quite similar in the two. The highway in this image is warmer than the background in contrast to the colour appearance noticeable in daytime infrared images.

Fig. 27 is a representative of infrared imagery of desert terrain. The figure is presented mainly to demonstrate two findings:

1. The imagery does descriminate major terrain features such as an eroding terrace, an old alluvial fan (covered with desert varnish), a major wash and roads, rails etc.
2. That to interpret infrared imagery it is necessary to know the time of day and conditions under

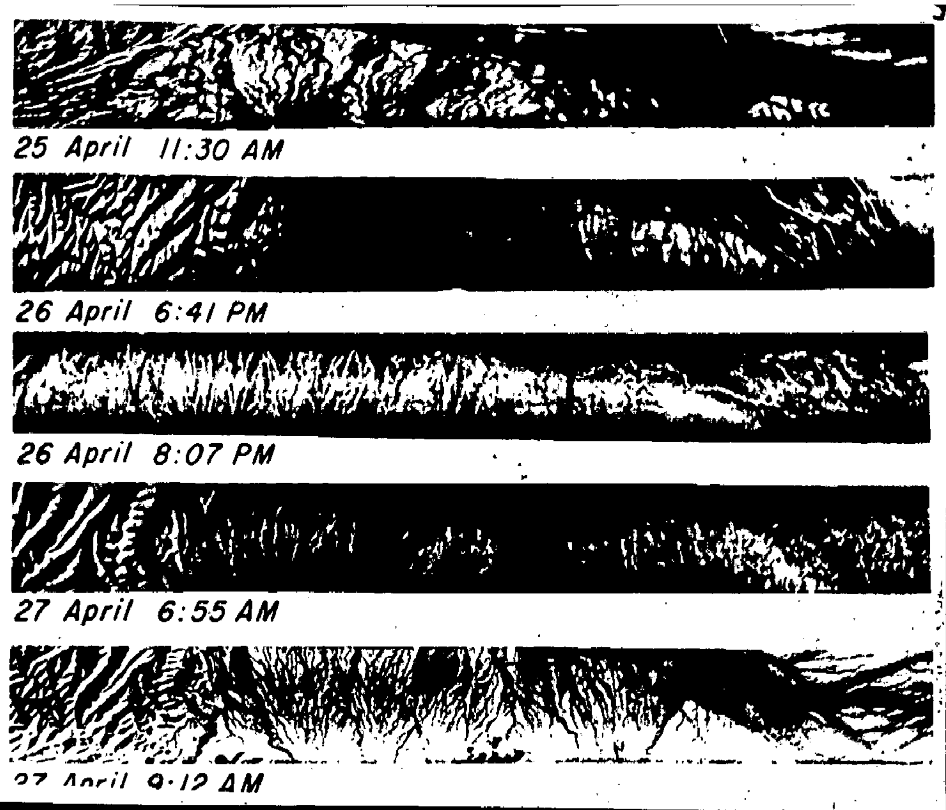


Fig.27 IR Thermal Imagery illustrating Diurnal changes during early summer for a desert Terrain

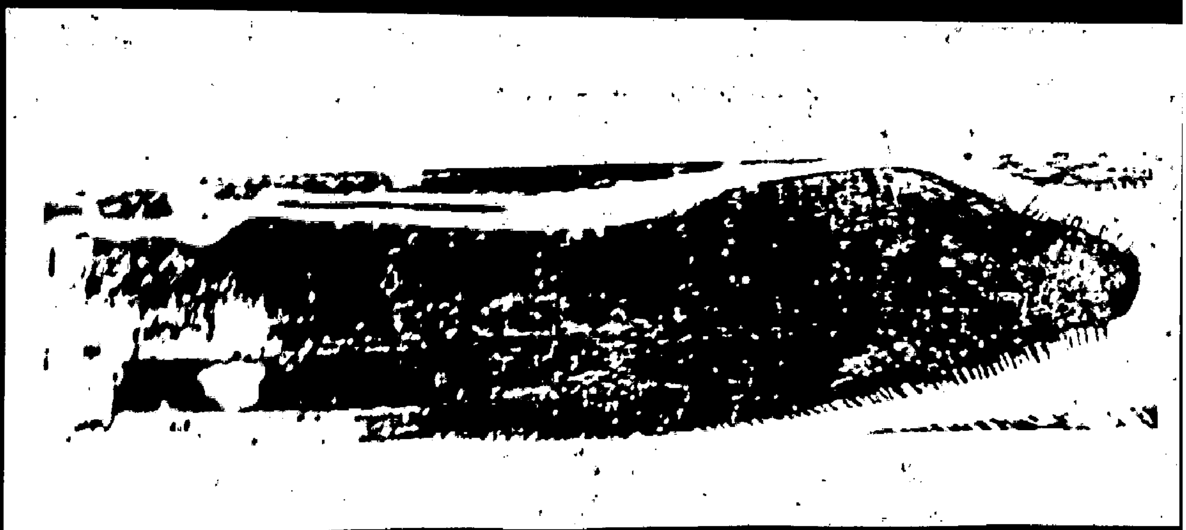


Fig.28 Thermal Map of Mahattan Island

which it is obtained. Conditions effecting the interpretations are, temperature, sky conditions, ground fog and rainfall just prior to obtaining imagery. The five strips in above figure were taken at various times of day and illustrate what the diurnal changes can do to the imagery. Note the tonal reversal between the centre of strips 2 and 5 . Strip 3 was taken during the night and the central portion of which consist of an old alluvial fan, with the flat original surface covered by desert varnish is shown as a cold surface while the gullies show as warm. In strip 5 taken at 9.00 a.m. the surface covered by desert varnish appear very warm and the gullies appear very cold. Vegetation in the wash appears warm at night and cold during the day.

The Fig. 28 shows a thermal map of Mahatton made about 11.00 p.m. in winter. In the central park area the large lake was not frozen while the smaller bodies of water were ice covered. The paths appears warmer than background probably because of the higher emissivity of the surface material. There are also some hot spots in the surrounding city.

In general the things in nature which will freeze over on a cold night are the ones which will appear dark in an infrared photo, while other objects will appear brighter. The surface temperature effects of water areas clearly demarcate the outflow of warmer river water into the cooler share area, by which one can study the local currents distribution and depth of beaches. The different emissions of the plowed and unplowed fields indicate the farmer being loose and the latter being compacted and covered with grass. For the same reasons, old snow has a different appearance than a new snow.

The supply and flow of underground water into the surface streams can now be studied by infrared methods. The infrared ground water detection method is relatively easy although the instrumentation is complex. As already seen invisible heat waves radiating from the water surface can be detected to a fraction of a degree by the infrared sensors. It is known that underground water temperatures are more uniform than surface water temperature, tending to be considerably higher than streams temperatures in winter and lower in summer. The infrared photographic film and temperature scanners detect these differences and reveal points where underground water of a different temperature flows into a surface stream. The amount of water contributed by any ground water spring is determined either by soil and hydrology studies of the area or by making conventional streams flow measurements of the area both upstream and downstream from the point of heat irregularity.

The applicationof thermal maps with special reference to military geology can be summarised as given below:

1. Infrared imagery is an excellent tool for tracing drainage pattern because moisture in terrain materials will alter the radiometric temperatures considerably.
2. "Geothermal" features (e.g. thermal springs, active valcanoes) make excellent targets for infrared systems.
3. Underground anomalies are detectable through their surface manifestations (e.g. near-surface salt domes).

The most desirable time for scheduling infrared mapping missions appear to be immediately after sundawn. This is the period of highest relative terrain emission. However, day time imagery records shadowing much like conventional photography and tends to enhance terrain features.

The detectors sensitive to 7-14 μ range are preferred as this range covers the peak emission of ambient surface materials.

Terrain surface features can be defined as infrared imagery and a great deal can be obtained from infrared thermal maps by an interpretation that takes due accountof the physical principles involved. Improvements in spatial and thermal resolution is being made and results achieved to date indicate that thermal mapping technique is very much promising technique for the determination of terrain features.

5.6. INFRARED COLOUR FILMS

5.6.1 . Technique of Colour Processing

Popular processes of colour photography are based upon the facts that :

1. The colours perceived by the human eye can be produced by the mixture of only three suitably chosen colours called primaries.
2. Photographic emulsions can be made to respond selectively to each of these three colours.
3. Chemical reactions exist which can produce three individual colorants each capable of absorbing essentially one of the chosen primary colours.

The primary colours chosen in practice are those produced by light from successive thirds of the visible spectrum, red green and blue. When these choices have been made for the primary colours, the colourant of each of which will absorb one of these primaries are uniquely specified and are cyan, which absorbs red, magenta which absorbs green and yellow which âbserves blue. These latter colours are referred to as the complementary colours, or as the substractive primaries.

The visible spectrum is shown in the following summary:

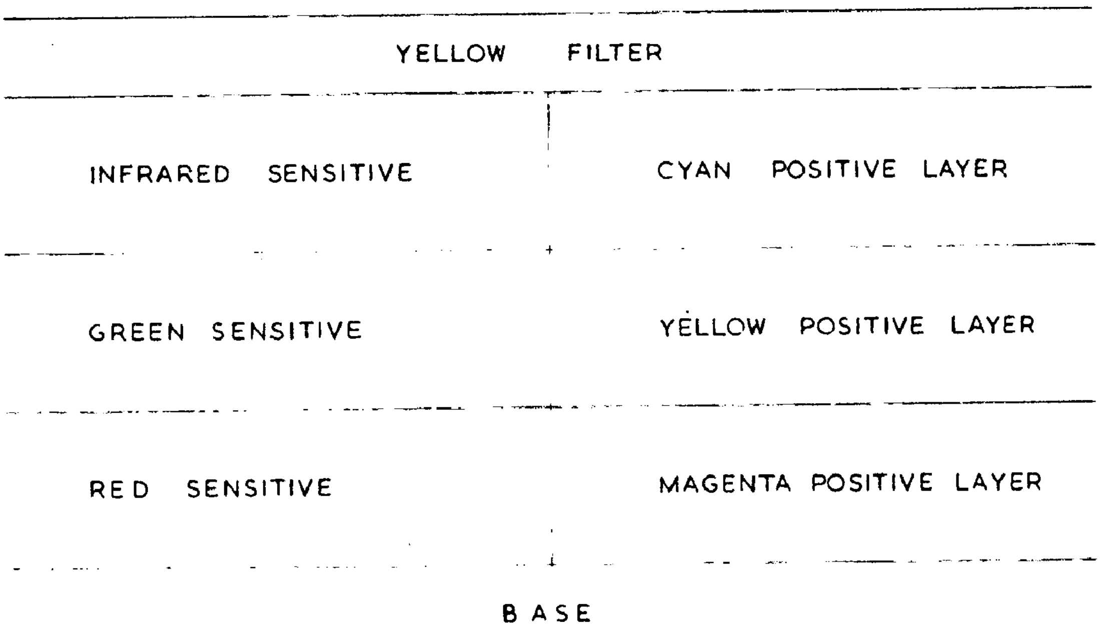
Wave Length (0.000001mm)		Colour.	
200-400		Ultra violet	
400		Violet	
450		Blue	
500	Blue	Green	Visible
550		Green	light
580		Yellow	
600		Orange	
650		Red	
700	Dark red		
> 700	Infrared.		

Technically any portion of the spectrum to which photographic materials are sensitive (within or outside the visible spectrum) can be recorded and the colourant developed by this record can be any that are available, without regard to the spectral region initially chosen. Such processes have been proposed for specialized purposes and are known as infrared sensitive colour system or false-colour systems.

In aerial photography particularly for interpretation purposes, spectral regions can be chosen to emphasize differences between particular objects which are quite similar. The structure of Kodak Aero Film manufactured by Eastmen Kodak Company is shown in diagram No. 29 .

The diagram shows the sensitivities and the colour developed by various layers. The material was always used with a yellow filter over the camera lens which absorbed blue light to which all photographic emulsions are sensitive.

The bottom layer is sensitive to the red spectral region and on processing, forms a magenta positive image; the middle layer is green-sensitive and forms a yellow positive image top layer is infrared sensitive and forms a cyan positive image. The relationship between spectral regions of individual layer sensitivities and resulting dyes can be better explained with the aid of Table I. (on next page).



<u>KODARK EKTACHROME INFRARED AERO FILM</u>

FIG. 29

Table - I - PRINCIPLE OF OPERATION OF NORMAL COLOUR FILM AND OF KODAK EKTA CHROME INFRARED AERO FILM

1. Spectral region	Ultra-violet	Blue	Green	Red	Infrared
2. Normal Colour film sensitivities		Blue	Green	Red	
3. Colour or dye of layer		Yellow	Magenta	Cyan	
4. Resulting colour in Photographs		Blue	Green	Red	
5. Ektrachrome infrared sensitivities		Blue	Green	Red	Infrared
6. Sensitivities with yellow filter			Green	Red	Infrared
7. Colour of dye layers			Yellow	Magenta	Cyan
8. Resulting colour in Photographs			Blue	Green	Red

On the first line, the portion of the electromagnetic spectrum to which photographic materials are sensitive is divided into five regions, blue, green and red regions of the visible spectrum and the ultraviolet and infrared regions at shorter and longer wavelengths respectively. A normal colour film has three principal layers one of which is sensitive to blue light, one to green and one to red (line 2). On processing positive image of yellow, magnets and cyan dyes are formed in the respective three layers (line 3). Without going to chemical details, we know that the resulting image combine to form colours which closely matches those of the original subjects i.e. blue will be rendered blue, green and so on. With Ektachrome infrared film, one layer is sensitive to green, one to red and the third to infra-red. In addition, however, all three layers are sensitive to the blue region. To limit the exposure of each layer to only one spectral region, a yellow filter is always used over the camera lens to absorb this blue light before it reaches the film (line 6). The same three dyes are used as in normal colour film and in the same order, - yellow, magenta and cyan for successively longer wave lengths regions (line 7). Again after processing, the colours blue, green and red are formed, but the blue has resulted from green exposure, green from red exposure and red from infrared exposure (line 8). Here the sequence of the reproduced colours is in the same order (blue green red) as it in the spectrum but the correspondence to the colours being photographed (green red and infrared) is one block towards longer wavelength. So it is easy to preddict reproduction colour of any of tthe coloured object provided its infrared reflectance is known.Likewise it is possible to predict reproduction colour changes with colour changes in the objects photographed.

At present the main application of this film involves the photography of folliage of one form or another. The high reflectance of foliage in the infrared region in general and large difference in reflectance are essential characteristics of such a film. So this film is capable of decting foliage conditions and its different varieties. Such a property is quite useful in camouflage detection.

CHAPTER - VI

MULTISPECTRAL COLOUR AERIAL PHOTOGRAPHY

CHAPTER VI

MULTISPECTRAL COLOUR AERIAL PHOTOGRAPHY

A programme is being carried out for extending present aerial photography capabilities and improving the imagery interpretationprocesse Optical-mechanical scanning devices in combination with aerial camera are employed for the simultaneous generation of the pictorial data in the ultraviolet, visible, infrared atmospheric transmission regions for a variety of maturally occuring conditions.

6.1. MULTISPECTRAL CONCEPT

Depending primarily on its atomic and molecular structure an object (e.g. a leef, a tree or a forest) transmits, reflects, abs-orbs, emits and scatters electromagnetic energy selectively with regard to wavelength. The tone or brightness with which the object is registered on a multiband photograph is in direct proportion to this energy. Therefore two objects which may be difficult to discriminate on imagery obtained in one spectral band, because they have similar reflection or emission characteristics in that band. But these objects will have different tones when imaged under different bands of the spectrum thus offerring easier discrimination between different objects. The technique of simultaneously obtaining imagery from one spectral band is termed as multiband spectral system . Briefly stated, this technique exploits differences in tone signatures in the various bands of electromagnetic spectrum. This is done by using a humber of film-filter combinations to obtain a set of photographs in different bands of the spectrum e.g. near ultraviolet, visible and infrared. The lower band of spectral sensitivity is believed to exist at about 260 nm (namometer = 10^{-9} meter) due to ozone absorption in the atmosphere. An upper band exists at 980 nm which is the current upper limit of the spectral sensitivity of available practical photographic emulsions.

Ground objects usually exhibit a variation in the percentage of radiant energy they reflect. This difference in the reflectance in the visible part of the spectrum is what wauses the apparent colour of an object. A difference in spectral reflectance of an object can be detected as images of different density on a set of multispectral photographs.

Numerous applications of multispectral techniques using a multiplicity of cameras or using one camera to take successive exposures at different times have been reported. A special nine-lens camera was constructed in USSR as a research tool to establish optimum film-filter combination to use in photographing selected ground objects. A similar camera was constructed in U.S.A. as a part of the multis pectral system for detection of surface indications of underground nuclear explosions. Experiments using multispectral cameras have shown that more information concerning physical features of our environment can be obtained with sensors which operates in spec tral bands as compared to panchromatic photography. Such studies have demonstrated that the human interpretor possesses vary low data input and output rates. Herein lies the basic difficulty in using conventional multispectral photography, It cannot discriminate between information collected and therefore provides the interpreter with much more non-relavent than relevant data. The inherent complexity in attempting to compare tonal values on even a few multi-spectral images and to interpret the results with confidence is still under initial stages of development.

A colour photograph can be considered as a special type of multispectral photo. In conventional colour film the yellow, magenta and cyan dye layers respond to the blue, green and red spectral regions of equal energy visible spectrum in a proportion fixed by the chemistry of the emulsion. In infrared colour films the dye layers respond to the green red and infrared parts of the spectrum in a similar manner. When viewed under white light, colour photographs subtract from the viewing light the undesired colours and the remaining spectral components of light fall upon the observer's eye to produce a sensation of colour. The considerable advantage of this subtractive technique of colour in aerial photography have been explored.

A number of authors have also pointed out the disadvantages of colour aerial photography which are primarily; fixed spectral sensitivity; fixed relative exposure for each dye layer; inadequate exposure latitude and relative processing complexity compared to black and white films and either (1) a lack of true colour fidelity to what is seen by a human observer or conversely (2) inability to produce significant colour differences between objects which have slight spectral reflectance differences.

Colour can also be produced by the addition of coloured lights rather than by substraction of unwanted colours from white light. This so called additive colour theory can be used to create a composite colour image from photographs taken in different parts of the spectrum under certain conditions.

If blue, green and red primary colours are used to illuminate three positive transparancies taken in three respective region of the spectrum and these spectral positives have images in identical spatial locations relative to their respective principal points and if these photographs are optically projected one upon the other so that no mis registration exists, a composite colour rendition of the scene will be produced.

Not only will the primary projection colours be produced but every hue will be seen in varying degrees of saturation and the colour od most natural objects will be recreated rather well.

Every image which exhibits a density difference on the individual black and white spectral positives will be seen as a colour. If no density difference exists a composite colour willbe achromatic (a shade of grey) If the minimum perceivable density difference is about 0.02 not more than 200 shades of grey can be differentiated on a black and white photograph whereas under certain conditions over 7500,000 colour differences can be perceived.

6.2. SPECTRAL ZONAL COLOUR RECONNAISSANCE SYSTEM

This system would provide an interpreter with an image presentation having the following features:

1. A 'true' colour presentation of the ground scene as would be seen by a standard human observer.
2. False colour presentation which would allow very small density differences between multispectral ph-otographs to be seen as colour differences.
3. A dynamic colour presentation which would permit the interpreter to correct for variations in colour caused by the special distribution of the sun at different times of the day and for different atmospheric conditions.
4. A black and white presentation of one or more

of colour. The considerable advantage of this subtractive technique of colour in aerial photography have been explored.

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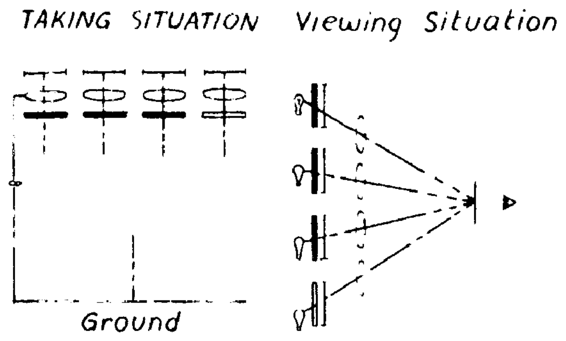

FIG. 30 _ SCHEMATIC REPRESENTATION OF THE TAKING AND VIEWING SITUATIONS FOR ADDITIVE COLOUR PRESENTATION

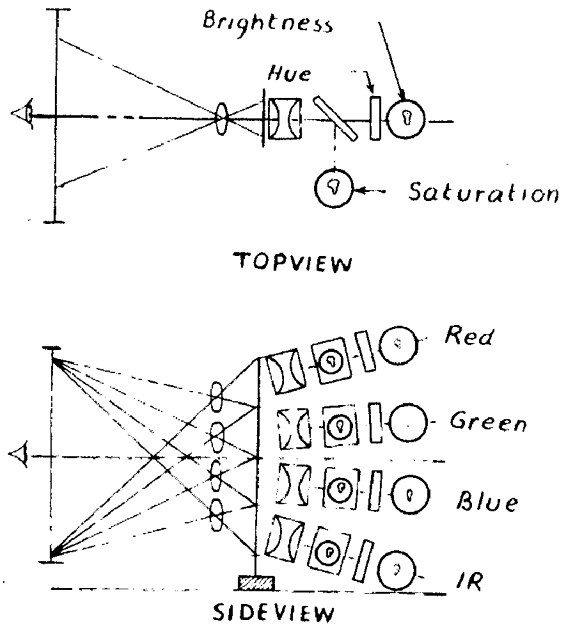

FIG.31 _ SCHEMATIC DIAGRAM OF THE ADDITIVE COLOUR VIEWER

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3. A dynamic colour presentation which would permit the interpreter to correct for variations in colour caused by the special distribution of the sun at different times of the day and for different atmospheric conditions.
4. A black and white presentation of one or more

of the individual multispectral photographs.

5. An acceptable level of spatial resolution in composite presentation along with the spectral discrimination achieved by colour.

6. A minimum amount of time between taking the the photograph and subsequent viewing of the composite colour images.

A breadboard model of the camera system was constructed using four Fairchild KA-56 Panchromatric cameras which were used to take photographs in different parts of the spectrum. The four spectral bands chosen were blue (3[illegible]5 to 520 nm) green (480 to 610 nm) red (590-700 nm) and infrared (700- 960 nm) . The choice of filter bands was made to cover completely the visible spectrum to approximately the standard observer colour sensitivity mechanism of the human eye, and to permit comparison with conventional colour and infrared colour films. The four cameras were aligned in an inner rack in such a manner that all the lens optical axes were geometrically normal to a plane common to each exposure slit. The cameras also had the same azimuth orientation to ensure that the film of all cameras was transported parallel with respect to each other. Care was taken to assure that differental distortion and focal length differences between each of the four cameras was minimized for the spectral bands used.

A central unit was constructed which permitted control of both the exposure of all the cameras simultaneously, as well as each camera individually. This allowed for the variation of exposure with change in brightness as well as changes in the relative spectral reflectance of the scene.

The objective in using this camera arrangement was to obtain four photographs which contained images in identical spatial locations with respect to the principal point of each individual spectral negative except that the density of simmilar images would differ from negative to negative. Extreme care was taken to assure that the density of similar images on the four spectral negatives was proportional to the intensity of reflected radiation in the particular interval of radiation sensed by each camera. Plus X(Ek 8401) film was used with the blue green and red filters and infrared aerographic (EK5424) film with the infrared filter. The sets of spectral negatives were developed so that density of any image on each individual spectral negative was a correct representation of the brightness of the object. In addition to compensation for differences in exposure, it was necessary to correct for reduced gamma particularly in the blue negative in order to produce an identical relationship of exposure to - density on all the four negatives. A gamma was chosen to produce medium contrast without excessively reducing the exposure range. Positive transparencies were then made which were also of medium contrast with low minimum density.

The composite colour rendition of the spectral positive was accomplished by construction of a rear projection viewer using additive colour principles. The source of illumination for each of the spectral positive was controlled in illuminance, dominant wave length and purity which in turn controlled the colour sensation of brightness, hue and saturation, and at the same time superimposing each spectral positive, one upon the other, on a screen by optical projection, produced a composite colour presentation.

6.3. EXPERIMENTAL RESULT USING THE SPECTRAL ZONAL COLOUR SYSTEM

The modal of four KA-56 panachromatic cameras was flown. The solar angle at the time of photography was 30^{o} approximately, with scattered cloud cover and moderate haze.

The spectral negatives and positives were processed with various characteristics. Each set of photographs was placed in the viewer, aligned and analyzed for registration and colour presentation characteristics.

The set of photographs in plate 32 shows the individual block and white spectral positive as they appeared in the viewer screen. These four positives are indicative of multispectral photography in which interpretation procedure is to compare the density difference of selected objects on the individual photographs.

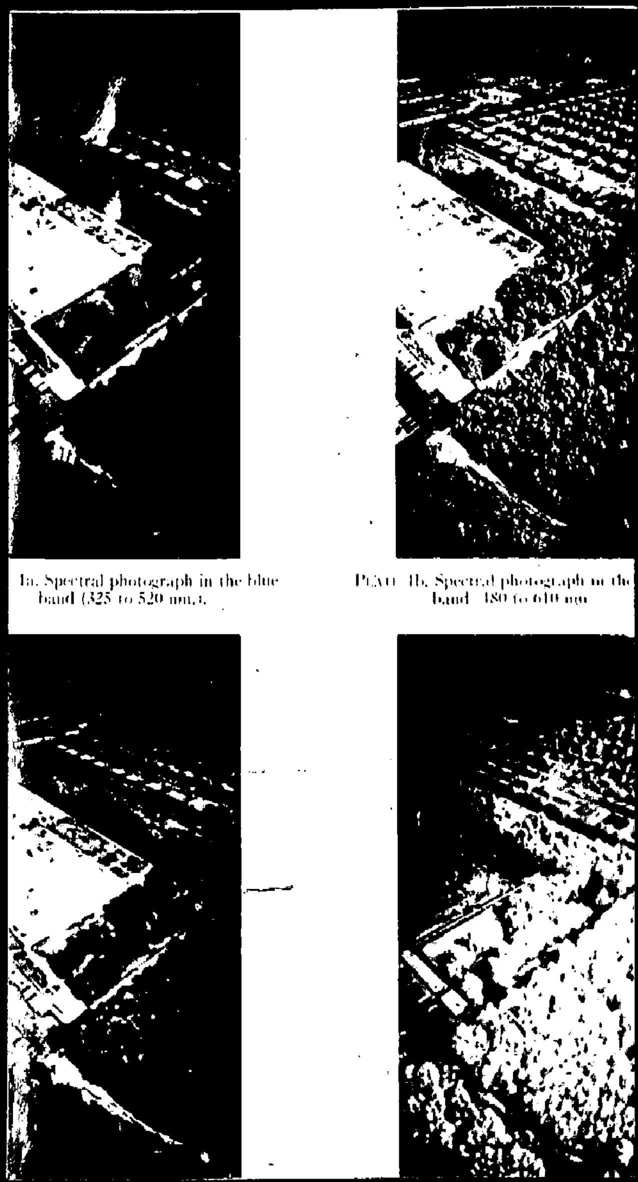

Fig.32 Four Multispectral Photographs each having images in identical spatial location with respect to principal point.

If the blue, green and red spectral positives are projected each with its respective primary to form a composite image on the viewer screen, a true colour rendition is seen. The colour characteristics of the composite rendition can be varied by adjustment of the brightness, hue and saturation of the source of illumination for each spectral positive.

If the green spectral positive is projected as blue, the red as green and the infrared as red, the standard camouflage false colour presentation will be observed. Here the living foliage appears as red, dying foliage as magenta and dead foliage as a green brown colour. It will be noted on examining the reproduction that composite colour renditions show all density differences between individual spectral positives as colours, Images which have the same density on all spectral positives, such as shadows , and a shade of grey in the composite presentation.

Another flight test of significant interest was performed. The targets consisted of equipment in a typical military deployment camouflaged by various types of military camouflaged nets. These nets were embedded in foliage cover and generally in deep shadow. Two productions show a comparison of a panchromatic photograph(EK 8401 film with Wratten 25 filter) taken at 750 ft altitude and a colour multispectral rendition of the same scene. The greater target detection capability of the composite colour presentation particular the nets in the trees, was the successful result.

6.4. RECENT EQUIPMENT

A four lens camera has been manufactured by Fairchild space and Defense system to take multispectral photos in four bands from 360 nm to 980 nm. The spectral region covered by the camera includes part of the near ultraviolet, the visible and part of the near infrared Fairchild has also manufactured a companion colour viewer which projects the set of four spectral photographs on a screen to form a single composite colour presentation for interpretation.

The camera takes a set of 4 spectral negatives at exactly the same time and records all of them on one piece of film. The spectral region recorded may be any three bands. In the ultraviolet, visible and one band in the infrared without making any adjustment to the camera. Accommodation of more than one infrared band, If desired, can be made by an optical adjustment. If no prior knowledge exists of the spectral reflectances of a target, a set of broad band filters which overlap throughout the spectrum are used. In those instances where spectrophotometric analysis has isolated wavelengths regions and where the phenemenon may be spectrally detected, appropriate film filter combination can be used, which together with transmission characteristics of the camera lenses, will permit accurate multispectral photography in the particular wavelength bands. As each band is photographed to its own lens, it is possible to obtain the correct exposure of each negative for the spectral radiance of any scene. This control of exposures for all four bands permits repeatable accuracy under a wide range of illumination and ground reflectance conditions.

Each one of the four spectral negatives which together comprise a set of multispectral photographs, is taken exactly the same time by four matched lenses. As the optical axes of all the lenses are normal to the film plane, four spatially identical negatives are produced. All the images appear in identical coordinate positions as measured from the principal point of each photograph.

The viewer illumination system is designed to give interpreter control of the dominant wavelength, purity and brightness of the illumination source for each spectral positive. He can adjust any one of these three variable for each of the four spectral bands, to achieve the desired colour space for viewing. In any colour space, the composite additive colour photograph shows all density differences between the individual spectral positive as colours.

This method of abridged spectro-radiometric sensing of radiant energy reflected by ground objects in the 360 nm to 980 nm spectrum and subsequent colourimetric analysis of the composite additive colour image is designed for rapid and accurate photointerpretation and for camaflouge detection. The rapidity is obtained by using a unitery piece of film upon which the principal points of the four photographs have been precisely located with respect to the film edge. This permits automatic registration of the composite additive colour images after the interpreter has checked the registration of the first frame in the roll.

6.5. REQUIREMENTS FOR ACCURATE MULTISPECTRAL PHOTOGRAPHY

The first requirement for accurate multispectral photography is to establish the spectral reflectance of the ground object. When subtle differences are to be determined, object to background spectral reflectivity must be established, and the spectral bands where relative difference in reflectance occur must be located.

The camera must be spectrally calibrated in order to relate energy falling on the film plane to that entering the lens. This requires calibration of the spectral distribution and magnitude of radiant energy as a function of field angle of the camera lens. The camera system must be designed to obtain spatially identical photographs. This means that the focal lengths and distortion of the lenses must be identical for each wavelength band. All the photographs must be taken at the same instant of time to avoid shift in relative positions of the image on the spectral negatives due to aircraft angular motion. Film processing is critical for accurate results. So called panchromatic films have different characteristics curves as a functionof wave length. When the film is processed, each spectral band can be expected to have a different relationship of log exposure to density. This difference in the characteristics of multispectral photoes can be connected by differential processing or eliminated by printing on a polycontrast materials. Theese gamma differences cannot be incorporated in a s-tandard definition of chromaticity of a ground object because density variation will occur in the particular spectral bands due to exposure differences and will not be necessarily caused by a differences in spectral reflectance. Using positive transparencies for additive colour projection creates a dilemma between contrast and exposure latitude. The higher the contrast, the more saturated the colour but more compressed the scene brightness range and vice versa. In general good colour reproduction is achieved using positives with low base density and moderate to high contrast.

If the spectral positives are to be viewed in additive colour, the viewer optical design must allow accurate registration and be free of colour errors . Manipulation of the colour variables of, hue, brightness and saturation must be calibrated and not be distorted by shifts in cooler temperature of the illuminant as the brightness of the projection lamps is varied.

By using the above mentioned techniques and precautions quite good results have been obtained.

CHAPTER - VII

ELECTRO-OPTICAL PHOTOGRAPHY AT LOW ILLUMINATION LEVELS

CHAPTER - VII

ELECTRO-OPTICAL PHOTOGRAPHY AT LOW ILLUMINATION LEVELS

During the past few years there has been a considerable development of devices to improve upon the capability of seeing or recording images at extremely low light levels. The basic ability of image intensifier and television tubes to amplify light has led to several important research and industrial applications that required now only minor modification of the equipment to achieve the purpose.

One of the primary advantage that electro-optical imaging units have over conventional cameras is the large reduction of the theoretical f/(number) of the optical system. Although these units suffer a loss in resolution, in many cases, it is possible to reduce the field of view sufficiently to overcome the problem.

For instance, it has been found that by using electro-optical recording techniques with medium sized-telescopes, it is possible to obtain records equivalent to those produced by the largest astronomical telescopes. In addition , the used image orthicons and image intensifiers in large telescopes has reduced recording by an order of magnitude or more. As a result of special applications in the field of military, astronomy have been developed.

The high utility of these new electro-optical instruments results from the development and use of a photocathode (photo-emitter) material with a quantum efficiency better than that of a film or a human eye. It is this capability of converting photons into visible information, at a high efficiency that makes electro-optical low - light level imaging instruments extremely effective. However, even instruments with high quantum efficiency reach a point where the information arriving at the photosensitive surface is photon limited. It is then necessary to increase the light-gathering capability of the instrument which means increasing the lens size. But increased lens size means increased instrument size and weight and so more difficulty in using it in situations that call for mobility . When the photon-limited point is reached it becomes necessary to consider illuminating the target in some manner and replacing the bulky lens system with a light source. The purpose is achieved by intensifying the image collecting capabilities of the instrument through suitable electro-optical means.

Before going into the details of technique of photography at low illumination level through electro-optical means, let us consider some basic facts related with it.

7.1. RADIATION CHARACTERISTICS

It is well known that light transfers energy in discrete entities or photons. The transfer of information by these photons, in ideal case, requires that the receiver respond to each quantum. However , the photons arrive at a random rate, like rainfall. The number of photons arriving at any point controls the brightness of the image. The image brightness being greater where a greater average number of photons strike per unit of time. Image information depends upon the total number of photons that arrive in a given time, rather than on their rate of arrival. A relatively small number of detected photons cannot produce a sharp demarcation between objects reflecting different quantities of photons. An inadequate number of photons causes image edge blur and a resultant loss of resolution that becomes worse as the ratio of a number of photons in adjacent areas (contrast ratio) becomes smaller.

7.2. ELECTRO-OPTICAL IMAGING TECHNIQUES

Passive night-vision aids fall in two categories-those that operate on the entire image simultaneously and those that employ scanning techniques. These two basically different techniques are embodied in the image intensifier and low light level television. The image intensifier are the instruments used to improve upon the low light level sensitivity. Both the image intensifier and the television system convert photons into photo-electrones for amplification purposes. The image intensifier utility is based upon the fact that the images are not retained and therefore its operation does not depend upon signal integration. Because of this characteristics there is no blurring of the image from rapid object or instrument motion. In high speed photography image intensifiers have been developed with better than 10^{-9} sec. capabilities. They provide a direct view of the object so that they may be used between properly designed lens system and film in electro-optical camera. However, in television tube the photo electrones are used to produce an electron image on a target. The target both stores and integrate the electrical image. A scanning electronic beam reads and erases this image. This line-by-line target scanning permits a new electron image to be received and stored between scans.

7.2.1. Vacuum Tube Intensifiers

The basic characteristics of image intensifiers is that they amplify and transmit complete images simultaneously at very fast signal processing rates. They continuously process light images and do not store or integrate the signal. The techniques by which this type of signal processing is accomplished include a number of different vacuum tubes and solid state designs. Vacuum-tube image intensifiers have been the most successful. The vacuum tube intensifier has three essential elements:

1. A photocathode material that generates and emits electrones proportional to the incident light intensity.
2. An electron accelerating and focussing field.
3. A phosphor for converting the electron kinetic energy into an amplified light image.

This image may then be recorded on a light sensitive material either by relay lens or fibre optics.

The photocathode material has the ability to convert photons into electrons with high efficiency. These emitted electrones are accelerated from the photocathode to the phosphor anode by high voltage. The electron impact on the phosphor causes it to emit light. The emission intensity is directly proportional to the number of electrons per unit area and their average momentum.

7.2.2. <u>Photo-Cathode Materials</u>

The principal reason that low light level image intensifiers have been successful is due to the development of a photo cathode material with a high quantum efficiency e.g. S-20 tri-alkali which is the basic photocathode material used in all present passive night intensifiers. When illuminated with radiation of the appropriate wave length, all substances will emit electrones, but only a few will emit a large number of electrones when struck by radiation in the visible portion of the spectum. All of these efficient photo emitters are semiconductors. For photoemission to occur it is necessary for a photon of incident radiation to exbite an electron to an energy above the top of the valence band. If this does not happen the electron will not have sufficient energy to escape through the barrier presented by the electron affinity of the material. Because of this the long wave length limit of present photo emitters is about 1.2 microns and of course, depend on the materials used. Many have much shorter wavelengths limitations.

It is also necessary for the electron to move from its point of excitation to a point external to the photo-multiplier. As the electron moves through the semiconductor, it will give up some energy by one of the several differntinelastic scattering process. If this energy loss is too great, the electron will not have sufficient kinetic energy to overcome electron affinity. As a consequence all good photoemitters have electron affinities that are small as compared to their band gaps.

The most widely used photocathode material is S-20, a multi-alkali material with a quantum efficiency of about 20 to 30 percent at short wave lengths, which drops to about 1% in the near infrared region, of the spectrum. The other photo cathode material is S-11 which is not so efficient but is less costly.

7.2.3. Electron Focussing

One of the most widely used means of focussing electron images is by electrostatic electron lenses. It can be shown theoretically that if the electric field between a cathode and a receptor has radial symmetry, a first order image will be formed. In these images a radially symmetric field is produced by electron lenses Coaxial cylinders or apertures are placed at different potentials in the tube to form this type of field. The image is inverted in this type of electron lens system.

In the proximity-type image intensifier the photocathode is located very close to the phosphor and because of the short distances, the spread of the electron image is small. No exterior forces are used to regulate the electrons and of course the image is erect.

7.3. PHOSPHORS

Present image intensifier capabilities are determined primarily by the phosphorus light - emission characteristics. Electron phosphor impact causes the phosphor to emit light in a highly coloured form. Because radiation received by the photocathode will have a different spectral composition, the displaced image spectral characteristics are always different from those of the scene. Only the relative scene intensities and contrasts are reproduced by the phosphor.

7.3.1. Light Sensitive Recording

The phosphor-emitted light intensity is usually adequate to record on standard film and other high-quantum efficiency light sensitive materials. Because of the variation in phosphors, optical systems and films, it has been necessary to determine proper exposure time by trial and error techniques. Proper information on proper matching of film to phosphor radiation characteristics is required for the recording purposes.

7.4. PASSIVE NIGHT CAMERA OR IMAGE INTENSIFIER CAMERA

7.4.1. RCA image-Intensifier Camera System

The RCA two stage intensifier camera is shown in block diagram form in Fig. 33 . Figure shows the optical system. The fixed focus lens system contains a refractive six inch focal length lens which focuses the image on the intensifier photocathode. The relay lenses focus the phosphor-produced image on the film.

This camera system has a resolution of the order of 12 line pairs/ mm for high resolution targets. A mechanical shutter produced exposures times from 0.01 to 1 second.

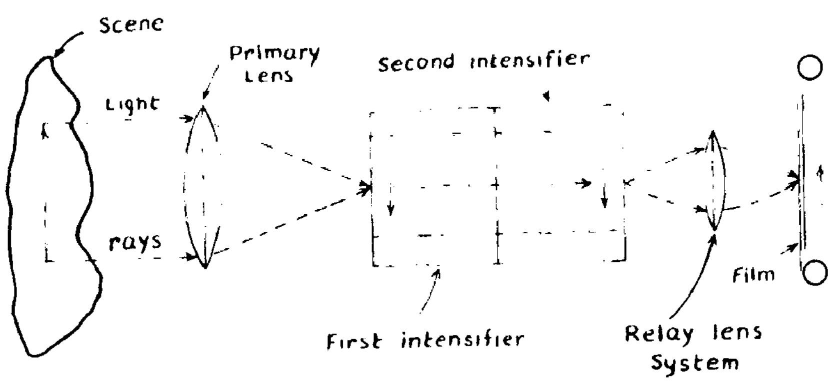

FIG.33 _SCHEMATIC DIAGRAM OF THE OPTICAL SYSTEM USED IN THE RCA IMAGE-INTENSIFIER CAMERA

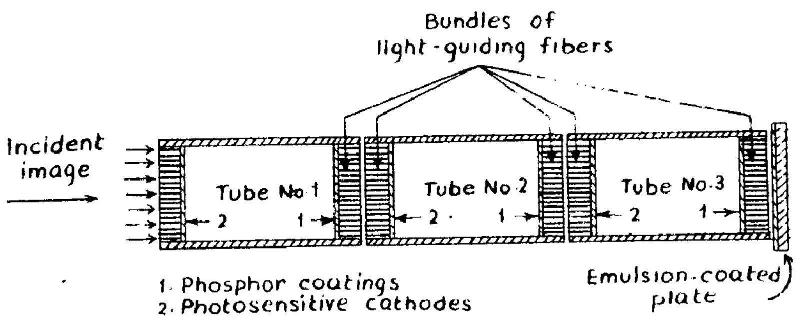

FIG.34 _SCHEMATIC DIAGRAM OF IMAGE-CONVERTER CAMERA

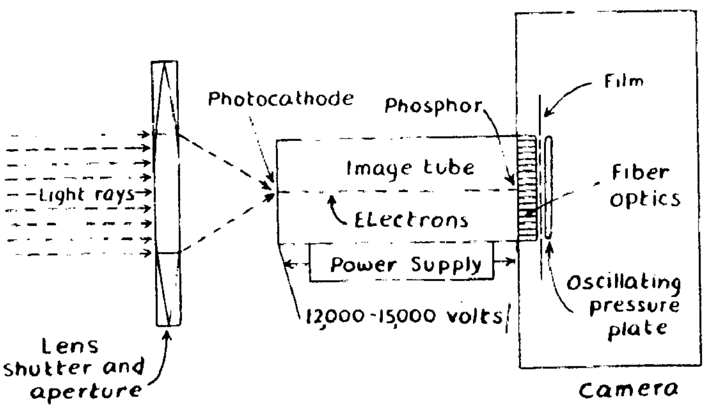

FIG. 35 _FUTURE CAMERA CONCEPT (SINGLE-STAGE INTENSIFIER)

7.4.2. Future Camera System

Fig. 34 shows one of the first fibre optic image converter camera designs patented in England. The other Fig. 35 shows a more detailed schematic of a fibre optic framing system. Here the film would be pressed against the fibre optics during each exposure by an oscillating plate.

In image intensifier camera design it is highly desirable to place the film in contact with the image tube fibre optics in order to provide the best image transfer. This has successfully accomplished in two ways. One method uses an oscillating pressure plate and the other uses a vacuum technique to draw thefilm into contact with the plate. If the camera is to be portable and compact, It would be desirable to use electrostatically focussed image tube and very compact light weight power converters. There are several converters in the market that operate on flash light type batteries and for a 15000 volt requirement weigh less than a pound. However for 40,000 to 50,000 volts requirements the systems may weigh several pounds. Minimum converter life is 1000 hours or more. In these power converter high efficiency is usually achieved with a transistorized oscillator driving a transfer rectifier sypply. Silicon diodes rectify and multiply voltage to the specified output.

7.5. LOW LIGHT LEVEL IMAGE EVALUATION

Present low level instruments have no colour presentation ability and even under ideal conditions are resolution limited. At very low light levels the quantum nature of light limits the resolution and at higher light levels the intensifier limits it. The factors for object detection or identification are target to background contrast target shape and shadows. Studies indicate that despite target shape, complexity and size, the human visual system relies mainly on angular subtense for image detection. The idea has been extensively developed and it is possible to predict the probability of object detection for low light level instruments under most of the conditions. In addition it is possible to set up a series of values for target search ranges and search patterns that, with a given instrument, will produce the maximum probability for target acquisition and identification.

7.5.1. General Considerations

In imaging it is possible to quantize human response to a minimum of four levels. These are indicated in the overall system as a block diagram no. 36 .

The characteristics of the image produced by the low light level will produce a viewer response that falls between no response and target identification. It is possible to treat the low light level instrument as a black box with an image recepter and either a visual or hard-copy output. Thus eliminating the need to identify the

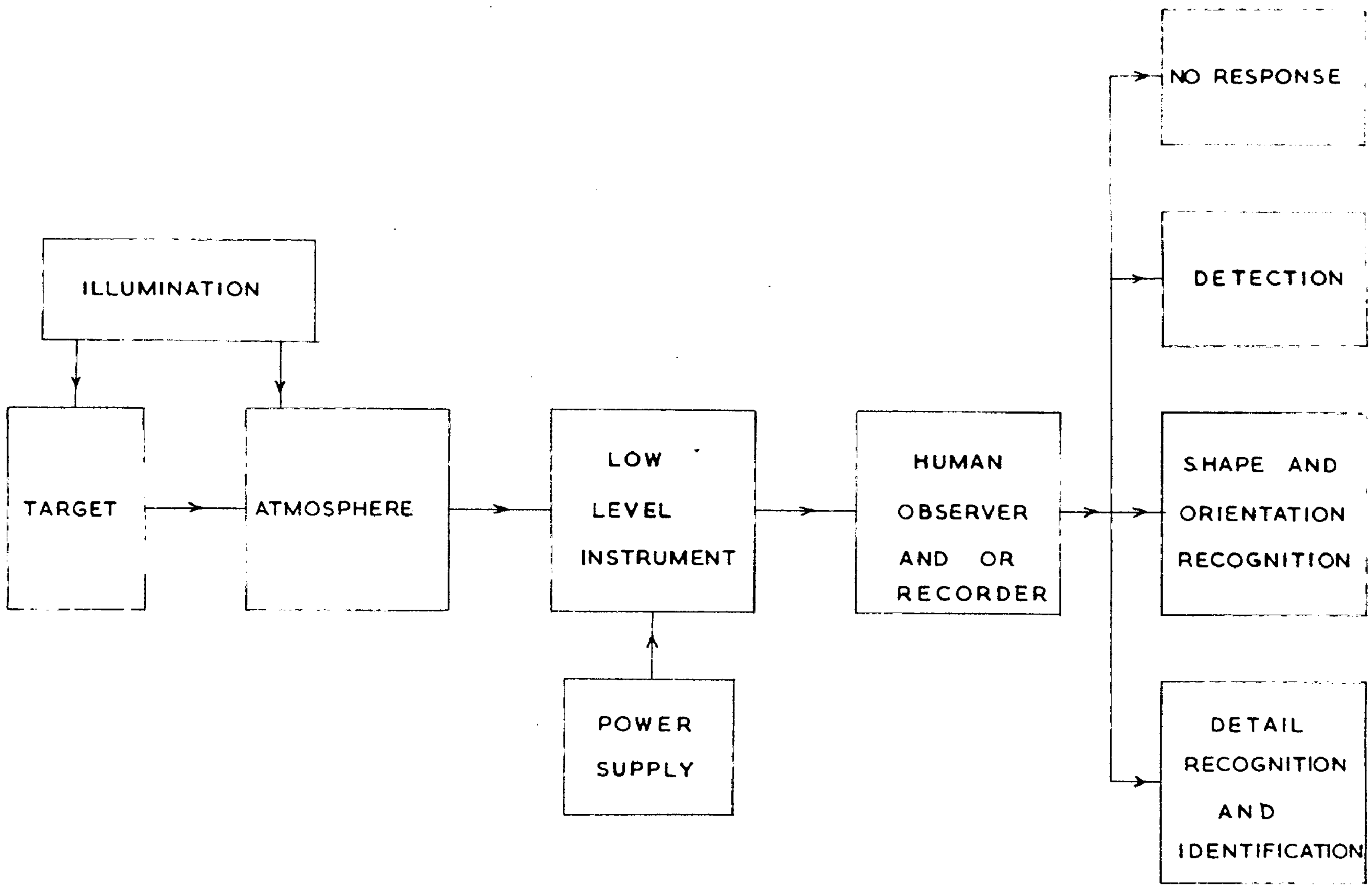

FIG. 36 _LOW LIGHT LEVEL INFORMATION FLOW DIAGRAM

instrument as either an image intensifier or a television camera. The low light level instrument image presentation may be analysed by assigning quantities such as target to background contrast, target brightness and target angular subtense. Both the instrument and the eye require a certain threshold illumination in order to produce any usable information. As the average signal illumination increases, the information content improves until the system resolution capabilities limit the information content of the presentation.

7.5.2. Target Description

The whole general appearance and shadow pattern of an object can change dramatically with lighting geometry. The number of pattern for a single object is almost unlimited. In order to be detected and / or recognised it is necessary that the object subtend a certain angular dimension in the instrument display. This immediately places practical bounds on the range at which the object may be seen with a given instrument. It is also possible to assign a detection probability to any given distance within this maximum range.

In order to treat target displays mathematically it is necessary to quantize the target signal into various s size blocks or for easier mathematical analysis, bars of constant intensity, which are represented in the form of circles in Fig. 37 & Fig. —— shows a set of six

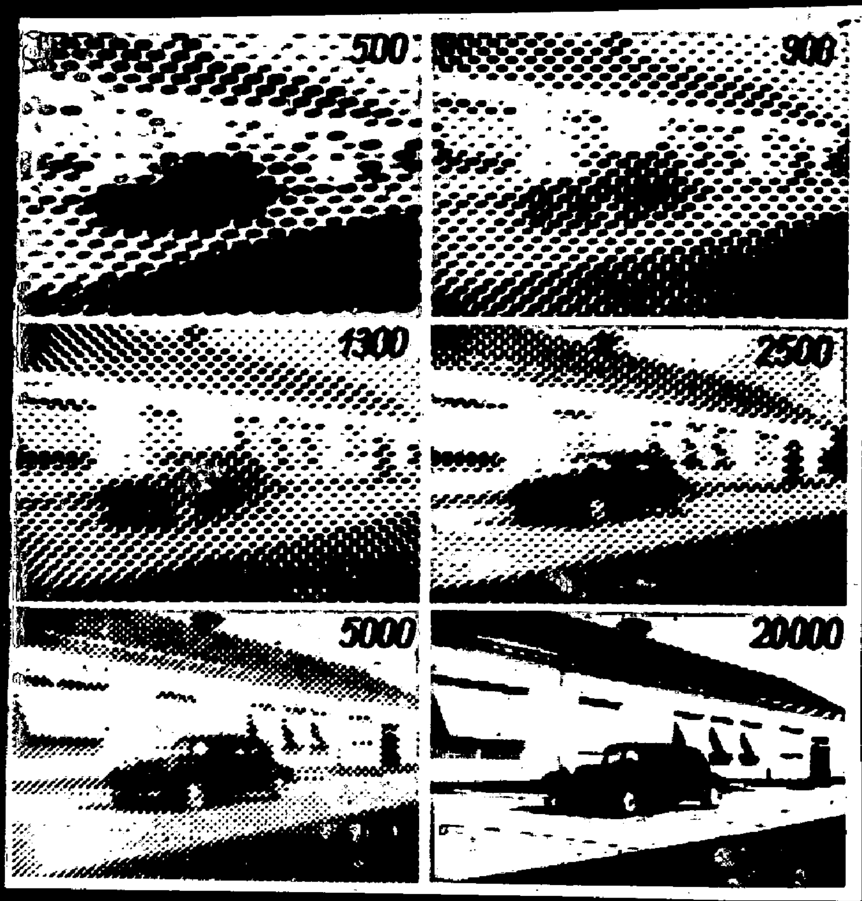

Fig. 37 Six Pictures of the same scene with different resolution. The pictures have been divided into blocks of constant density. The total number of blocks in each picture is indicated.

pictures that have been quantized in a binary fashion (black and white) . It will be noted that the 500-block scene yield detection information but that of the order of 1300 blocks are necessary for shape and orientation recognisation. Although 5000 blocks give good detail 20,000 block produce more detail than is usually required in most battlefield situation. It is interesting to note that in the 500 block picture, it is not easy to detect car due to very low background contrast. If the picture is held at a considerable distance , the car can be recognised. The high contrast ratio together with the angular subtense and familarity with cars or perhaps with the set of pictures make this possible.

7.6. NIGHT IMAGING PROBLEMS

In general, night -vision devices transform radiation from the outside world into a visual display that differs in illuminance and contrast from the original scene. For a night vision device to have light utility it is necessary that it provide the observer with a display having a greater overall illuminance than the original. The contrast and resolution must be adequate so that objects in the field of view are easily recognised.

There are some problems of seeing under low light level that must be recognised. Colour perception is not available. The comparative brightness of colours is different

-red usually appear less bright and blues brighter than in daylight. Depth perception is highly impaired at night and the eye is subjected to negative after- images, which may be taken for a real object or may appear to move and change distances. Because distances are mis-judged, driving combat vehicles at night can be particularly hazardous. The use of image intensifiers as binoculars remove this difficulty but introduces other psychological problems. Even if only very low resolution is available it is still better than driving with no light.

7.7. NIGHT VISION TACTICAL DEVICES

These devices employ the amplification of low level of light intensity to produce visual capability similar to that of twilight.

The devices use infrared light and produce visual capability upto 45 Km or more through thin cloud and fog.

The near-infrared weapon sight is adaptable to infantory weapons as is shown in Fig. 38. These devices convert near infrared radiation into visible light.

Another development is the tank mounted standard 18" and 30" search lights, used to provide near-infrared illumination for night operations. An infrared filter

Fig.38 Simulated view using infrared weapon sight.

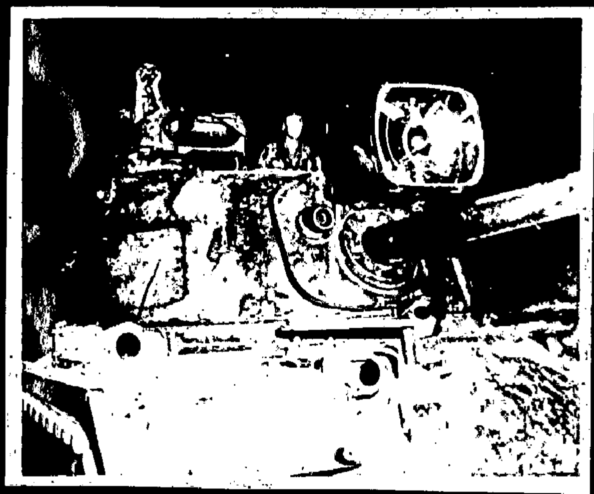

Fig. 39 Tank Crew Using the Infrared Tank kit.

converts the search light beam from visible light to infrared light not visible to the unaided eye but which permits good observation by a person equipped with a metascope Fig. 39 illustrates one of such system.

7.8. LOW LIGHT LEVEL INSTRUMENTS

These instruments have been established as invaluable aids to military, industry and the scientific world. Even in their present relatively underdeveloped state, the image intensifier and image orthican with only s light modifications have produced results that could not be equalled by any other technique.

The development of image converter and television recording has replaced expensive units of large telescopes with relatively small units. As with low light instrumentation, the large telescopes may be used even more effectively because of the magnitude reduction in exposure time required to obtain pictures.

The area of high speed photography has received considerable attention from image intensifier equipment manufacturers in the United States , Europe and Russia. Photography of events occurring in 10^{-9} second is now possible and goal of image recording in 10^{-12} second is not far out of reach. Development of complete image deflection techniques has resulted in special image tubes capable of recording multiple successive images of extremely high speed phenomenon. The result is a group

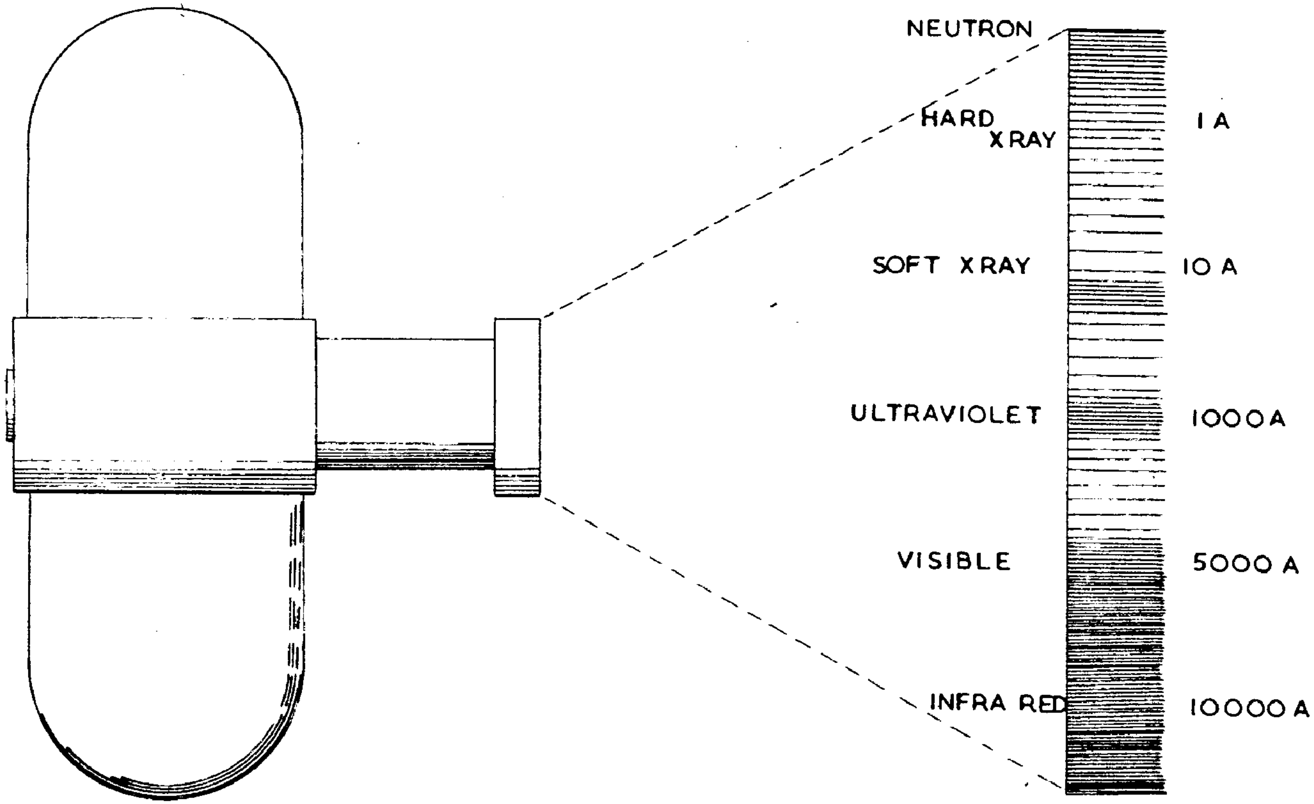

FIG. 40 _SPECTRAL CAPABILITY OF A LOW LIGHT LEVEL SPECTRAL CAMERA

of pictures containing the history of an event that occurred in microseconds.

The potential of low light recording is almost unlimited. One of most interesting applications at low light recording is in producing moving pictures using neutron, X-ray or ultraviolet radiation. Near infrared radiation viewing and recording has already been extensively used. Large gains in instrument capability can be attained by a complete integral low light level multispectral camera design. (Fig 40)

The great advantage of a low light camera is that it can record faint light images produced by radiation conversion screens when they intercept high energy radiation . A properly designed camera with a suitable radiation source will permit recording of moving events. This capability together with new techniques of three-dimensional viewing and recording is certain to increase the use of low light level systems.

7.8.1. Low Light Level Telescope

Using orthicon imaging tubes, it is possible to greatly improve the capabilities of relatively small telescopes. Because image intensifying equipment improves the capabilitie of a telescope so much, it becomes practical to construct and use small telescopes with large image intensifying and integrating equipment that would otherwise required considerably large optics. The basic improvement is in the quantum efficiency of photocathodes over film. Use of various television enhancement techniques permit considerable signal to noise improvements.

7.8.2. Lallemand Camera

The Lallemand electronic camera is a direct electromagnetic system in which a photocathode, an electrostatic lens system and a photographic plate are contained in an evacuated envelope . No other element that might degrade and distort information are used in this camera system. Because of the high quantum efficiency and the fine grain of the electron sensitive plates, the electronic camera has the capability of discriminating fainter sources against bright background than would be possible by using ordinary film. These plates are bleached in proportion to the incident number of electrons and thus the response of the unit is linearly dependent on the incident light intensity on the photocathode.

7.8.3. Channel Plate Space Camera

Development of channel electron multiplier has previded an unusually electro-optical techniqye for space photography in the γ ray X-ray and vacuum ultraviolet spectral regions.

The output from a channel mosaic will produce a film image of very low intensity sources. The extremely low tube noise makes this type of image intensifier quite useful. The channel multiplier makes it possible to produce very small radiation detectors that may be used in confined spaces. Because no pretective envelope is required in space, there is no radiation attenuation and only the quantum efficiency of the material is important. However because the unit has such a wide spectral capability it will usually be necessary to use spectral filters for data analysis purposes.

7.8.4. Future Potential

Low light level cameras provide a tremendous potential for taking moving pictures of phenomenon in other regions of the spectrum. This is possible because screens can be produced that convert high energy radiation into visible radiation. These energy conversion screens will operate from neutron through the X-ray and ultraviolet spectral region.

The ability of the low light level camera to record a very low luminous flux allows both the use of low radiation intensities and framing rates adequate to record object motion. With the exception of the open Fresnel Zone plate, it is difficult to produce lenses suitable for focussing ultraviolet radiation. Therefore most images in these spectral regions will be shadows graph and generally require a large radiation conversion screens. However , an image intensifier camera system with interchangeable screen could be developed that idealistically would be capable for the required operation.

7.9. SCOTOSCOPES

Basically scotoscopes are nothing but image intensifier tubes so as to be able to detect object at very low light level by improving upon the low light level sensitivity.

These intensifier often employ close coupling of the photocathode of one tube with the phosphor screen of the second tube. This help in achieving large gain and high resolution.

It is possible for scotoscopes to reveal faint light sources not seen by the unaided eye. This would be true, for instances, for the blacked out driving lights of vehicles, artelliary aiming post lights and phosphorscent panel markers. Target detection will be facilitated in such circumstances. In some airborne operations this capability might also be useful in locating weapons firing on helicopters or troop carrier aircrafts. In such cases it is necessary to locate flashes with references to other visible land objects so that an attack can be mounted on the unknown, unseen objects by looking through a scotoscope.

Early target acquisitionof known targets at might should considerably be aided by use of scotoscope, which would help the pilot to see the target, especially in night attack on semimobile targets when their locations are known. It would be possible to make a target even more visible by use of a phosphoresent bomb, or rocket. The faint illumination resulting from the covering of the target with the powder might not be visible to the naked eye, but by use of scotoscope the signal to noise could be made to produce adequate contrast to cause the target to stand out in a number of cases in which proximity of target to friendly forces permit it to be marked by artillary or mortar shells. Scotoscopes are still under the very early development stage and their performance in operational situations is not yet known. However, there is nothing in present literature that is adverse to the use of scotoscopes for essential tactical mission during darkness.

The present trend towards the use of fibre optics for the input and output windows makes the series coupling of single-stage intensifier units into multistage units both feasible and economical. Tubes can be matched so that if one fails it is possible to replace that; whereas with a single ~~sta~~ multistage unit failure of a stage ruins the whole expensive unit. There is also a possible requirement for powerful scotoscopes at airfield control towers to monitor aircraft taxing, take offs and landings. Permanent scotoscopes using exceptionally large lenses would permit operation of an airfield during blackout out conditions.

7.10. NIGHT TELEVISION

Night television techniques were developed in parallel with scotoscope techniques. However, because of the line-scanning technique and electronic image processing night television should have somewhat different military applications from scotoscopes.

The two biggest assests of night television are its capability to present specially processed images and the ability of the camera to be placed in a remote location with a number of viewers conveniently positioned. The electronic processing of survelliance pictures has often been demonstrated. The remote - viewing capability of night television permits its use in guarding bivouac areas or any area that may be subjected to infilteration at night. If used properly it would relieve sentries of some problems. Of course if the enemy knows the location and use of such units, there are a number of techniques to negate their utility. However, even sentries are quietly eliminated by suitable tactics.

The fact remains that for adequate watcfulness at night the combined use of several techniques and several men could be made very effective . If considerable study is devoted to the problem. Increasing the area surveyed by each man- even double surveillance of the surrounding terrain by television techniques - would afford considerable security with minimum man power.

CHAPTER - VIII

LASERS AND ITS APPLICATIONS

CHAPTER VIII

LASERS AND ITS APPLICATIONS

The optical maser or laser (Light Amplification by Stimulated Emission of Radiation) is a new scientific development with many potential civilian and military applications. The laser is a device that produces a new kind of light-coherent light - which has predictable properties that can be controlled in a manner comparable to signals at radio and microwave frequencies. Before lasers were developed generators of light energy had been essentially noise sources, whose outputs were broad bands of randomly phased multifrequency energy, as uncontrollable as the radio signals produced by the early spark-gap radio transmitters.

Fig. 41 shows the location of the optical region in the electromagnetic spectrum. Visible light waves are signals in the frequency range between 10^{14} and 10^{15} cycles per second with wave lengths of the order of 10^{-5} cm. By comparison, the X-band microwaves used in some radars are signals of 10^{10} cycles per second in frequency and 3 cm in wave length.

In order to maintain stable signals of prescribed frequency in the radio and radar regions, precisely dimensioned crystals and cavities are fabricated and used as the frequency determining elements. As the

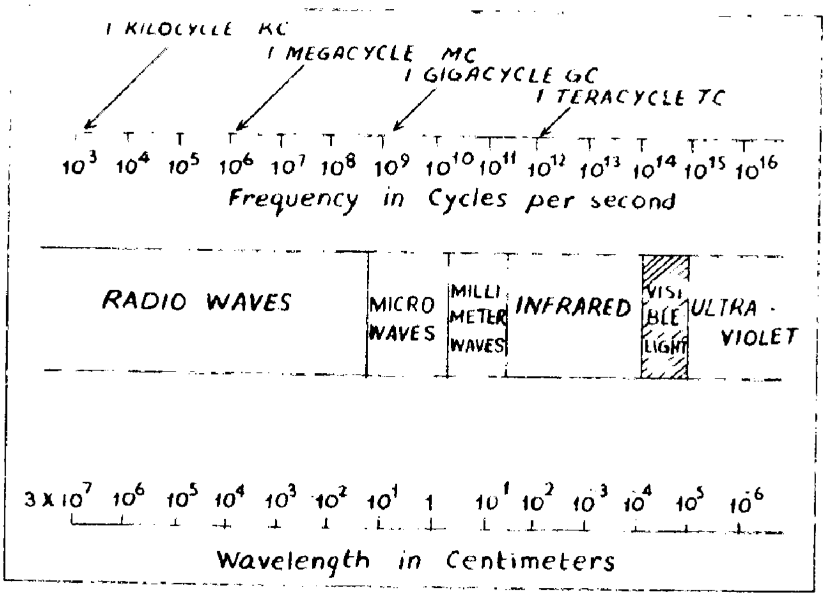

FIG. 41 _ THE ELECTROMAGNETIC SPECTRUM

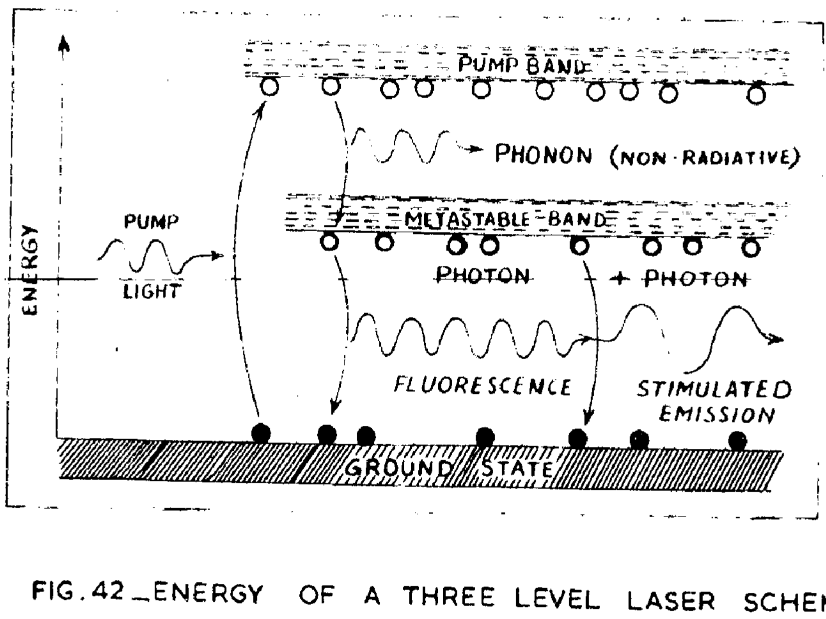

FIG. 42 _ ENERGY OF A THREE LEVEL LASER SCHEME signal frequencies go higher and the wave lengths shorter, critical dimensions and tolerances becomes more and more difficult to achieve and maintain. To attain control and stability at light frequencies, man-made dimensions and tolerances have been abandoned in the laser in favour of nature's precisely dimensioned and superbly miniaturized atomic structures.

8.1 HOW LASERS WORK

Some fundamental physical facts about light and its interaction with matter are needed to explain how a laser operates. According to atomic theory, the electrons which orbit the nucleus of an atom may do so only in orbits of certain specific radii. From angular momentum considerations, this means that the orbiting electrons, and hence the parent atom, can possess only certain allowed energy levels; in other words, the energy is quantized.

~~Light is emitted or absorbed in transitions or~~ quantum jumps when an electron moves from one orbit to another.

Light, being a form of electromagnetic radiation, is emitted and absorbed in discrete packets of light energy called photons, whose energies are proportional to the frequency of the radiation. The formula: Energy per photon equals Planck's constant times frequency.

Thus, when an atom drops from a higher energy level to a level of lower energy it must give up an amount of energy corresponding to the difference between the two energy levels; this energy is given up by emission of light energy in the form of a photon of the specific frequency corresponding to the energy difference. Similarly, an atom can jump from a lower energy level to a higher energy level by absorbing the precise amount of energy required in the form of a photon of the proper frequency. This correspondence of prescribed amounts of energy with specific frequencies (or colours) of radiation, coupled with the rigidly quantized electron orbits in the atom, is at the heart of the precise frequency control achievable with the laser.

Fig. 42 is a simplified energy-level diagram of a three-level laser scheme such as is used in a ruby laser. Ruby crystals are made up of a small percentage of chromium atoms in an aluminium oxide lattice. Chromium atoms in the lowest energy state, called the ground state, are pumped up or elevated to the higher energy pump band by irradiation with an intense light, called the pump light, of the precise frequency (colour) corresponding to the energy difference between the ground state and the pump band. The excited atoms in the pump band give up some of their energy by non-radiative transitions (in units called phonous) to the crystal lattice in which they are embedded, and drop down in energy to the metas-table band. Each atom in the metastable band, when it drops down to the ground state, will emit a photon of the frequency corresponding to the difference in energy levels, and the material will spontaneously fluoresce. If one of the flourescing photons collides with an atom in the metastable state (which has not yet given up its excess energy) it can cause that atom to give up its excess energy by stimulated emission of a photon, in phase and coherent with the stimulating photon. Each of these photons in turn may collide with other metastable atoms, resulting in further stimulated emission. If conditions are right, the stimulated emission will build up in an avalanche action resulting in the simultaneous and coherent emission of many photons. Otherwise, the atoms decaying from the metastable band to the ground state will gradually do so independently, and fluorescence alone rather than stimulated emission will result.

The condition for stimulated emission is that there be a 'population inversion' between the metastable band and the ground state; that is, there be more atoms in the excited state than in the normal ground state. When this condition exists, the probabilities that a spontaneously emitted photon will collide with another excited atom and cause it to release a photon are great enough for an amplification and growth action to take place whereby more and more photons are released by stimulated emission. If the population is not inverted (less than 50 percent of the atoms being in the excited state) a spontaneously emitted photon will most probably hit an unexcited atom and be absorbed in the process. The incipient avalanche action will then decay and die out.

Successful lasering of gaseous, liquid, and solid-state materials has been reported. Some have been operated continuously, while others have been operated in pulsed fashion. The details differ from one material to another, butthe underlying principles of operation are similar. The differences permit the designer some degree of freedom to suit particular requirements, such as output frequency and energy level.

8.2. LASER DEVICES

The basic laser device consistso of : some laser material, a pumping source of the proper energy or colour, and a means for coupling the pump energy into the laser material. A variety of engineering solutions have been developed to solve problems of optical coupling, efficiency, and cooling for particular applications. On the whole, laser devices are rather simple mechanically, despite their complicated theoretical basis. Most laser devices are in the form of oscillators rather than amplifiers. The laser's amplification capability is converted to self-oscillation by feeding some of the self-generated energy back into the laser.

The overall efficiency of different lasers devices from electrical input energy to laser light output varies. In general, the gas lasers have very low efficiency, while the solid-state lasers have efficiences that range from a fraction of 1 percent to several percent.

8.2.1. Characteristics

The characteristics of lasers that offer promise for fruitful application are their high power focussability and high frequency radio like signal properties.

Even small amount of energy per pulse when delivered in a short period of time can result in tremendous peak powers. Laser beams can be focussed into small spots to a theoretical limit of about 1 micron. Coherence of laser light also makes it possible to focuss the laser energy into very narrow beams. Some 1000 times narrower than the beams preduced by most so-called narrow beam radars. A 7½" dia aperture could focus laser energy into a beam with a divergence of 1 second of arc. Such a beam generated on earth and aimed at the moon would cover an area of 1.2 miles in diameter, compared to moon's diameter of about 2160 miles (i.e. 1/3" per mile).

Lasers are capable of producing light with the coherent properties of radio signals. As shown in Fig. 41 such electromagnetic radiation is in the frequency region of 500,000 kilomegacycles 5×10^4 . This is about 10,000 times higher than the highest radar frequencies in common use to-day, 5×10^6 times higher than television signals and 5×10^8 times than radio broadcast signals. Only 0.1 percent bandwidth of a center frequency of 5×10^{14} cycles per second (cps) represents the enormous bandwidth of 500 kilomegacycles, an information handling capacity that could encompass the entire presently used electromagnetic communications spectrum. If a 5×10^{14} cps signal were used in a radar application, the doppler shift from a radially moving target would be 1.5 megacycles per mile per hour. Better sensitivity and higher accuracy can therefore be achieved than at, say, X-band microwave frequencies, where the doppler shift is only 30 cps per mph of radial motion.

8.2.2. Applications

Many potential applications of military interest are envisioned for laser, based on analogy with existing systems and techniques in the radar communication and radiation weapon fields.

8.2.2.1. Radar: Light weight range finder of 15 to 20 pounds are an elementary use which takes advantage of the small size of the laser components. The narrow-beam properties can be used to obtain high precision angle trackingl Doppler information can be extracted to derive accurate target velocity and acceleration data. The angular resolution and small " antenna " size of a laser radar also makes possible a target-imaging capability. It will be possible to see, recognize, and identify a target - something that has not been possible with conventional radar. Gating the image will make the target visible despite the presence of nearby backscatterers.

8.3. LASER RANGE FINDER

The optical radars of which the Mark II COLIDAR a light weight range finder which can be backpacked by one man has been extensively used by military for range finding purposes. The unique characteristics of laser output which makes it useful for such systems are short wave lengths, monochromaticity, high-radiance and short time duration pulses.

A direct result of the short wavelength is small physical size for the transmitting system required to produce an extremely narrow beam (less than one milliradian). The system size required to place a given amount of energy on a distant target is several orders of magnitude smaller than that required by a microwave system. The narrow beam also results in high angular resolution and the absence of sidelobes with the consequent elimination of the ground clutter problem common to radar. Thus an optical radar can be used in the immediate vicinity of trees, bushes, and buildings, without detrimental effects. In many cases the transmitted beam is sufficiently small so that the target completely intercepts the beam.

The monochromaticity of the laser output makes possoble the use of a narrow-band optical filter in the receiving system to reduce unwanted daylight. Such daylight, the principal source of interference in optical radar systems, arises from two sources; sunlight reflected from the target and sunlight reflected (or scattered) by the atmosphere between the target and the receiver.

Radiance (the radiated power per unit area per unit solid angle), and not the total radiated power of a source, determines the amount of power that can be concentrated onto a distant object of a given size. For the laser with its high peak powers(1 - 100 megawatts), the radiance is eight orders of magnitude greater than that of typical radars.

High -powered , short-duration single pulses are produced by a special laser switch. Such pulses are needed for high range resolution and accuracy while high power is needed for good range performance. The conventional laser rangefinders were used with the output consisting of a train of randomly spaced spikes of varying amplitude. Under these conditions, the light from the transmitted laser beam which is reflected (backscattered) from the atmosphere into the receiver from the secondary pulses (after the first pulse) can be of sufficient strength to mask distant target signals; Hence early systems were constructed with wide separations between the receiver and transmitter so as to reduce the backscatter by increasing the range at which the transmitted beam and the field of view of receiver intersect.

8.3.1. New Q-Switched Laser Rangefinder

The new lightweight rangefinder is a two-unit system composed of a triaxial ranging head and a power pack. One barrel contains the laser transmitter and recollimating optics; the second, one accommodates receiver photodetector, narrow-band optical filter, and power supply for the detector; and the third one contains the sighting telescope for aiming. The stock houses the receiver amplifier and other miscellaneous electronics appliances. Like a rifle, the unit is armed by a cocking lever attached to the trigger guard and a measurement is made by pulling the trigger. The range in meters is presented by a direct reading

Fig. 43 New Q-switched Laser Range Finder.

decimal display. The power pack, mounted on a lightweight pack frame, contains the battery, flashtube modulator, power inverters, and the digital ranging circuitryl The ranging head weighs about 13 pounds and the power pack about 30 pounds. A reduction in total weight to udder 25 pounds appears feasible.

In one operation, arming the rangefinder with the cocking lever initiates the charging cycle for the laser flashtube modulator capacitors. After a few seconds charging is complete as indicated by a signal lamp and the operator aims and fires. At firing the energy contained in the flashtube modulator is discharged into a xenon flashtube. The blue-green portion of the light emitted by the flashtube excites the laser material (ruby, in this case) and laser action occurs. This action is the result of optical feedback produced by the optical resonator containing the ruby laser element. If the feedback path is controlled or Q-switched very rapidly, a very short high-powered light pulse is generated. The transmitted pulse is sampled by a small photo detector and the resulting signal opens a gated amplifier which then passes the output of a precision crystal oscillator to a digital counter. When the returning target echo pulse is received by the photomultiplier detector, the gated amplifier is shut off and the cycles counted indicated the range. The oscillator frequency (29.9793 mc) is so chosen that each complete cycle corresponds to 5 meters range, thus providing a range readout resolution of 5 meters.

8.3.2. Design

The transmitter consists of a Q-switch, the laser pump reflector housing with its associated flashtube circuits, and the recollimating optics. The Q-switch is basically a rotating reflector system. The optical feedback within the laser cavity occurs when the two reflectors comprising the cavity are parallel. One reflectors is partially transparent so that energy can be extracted from the cavity. The roatating reflector is a roof-prism mounted in a torsional pendulum. The pendulum is cocked against a spring during aiming and released by the trigger at firing. A switch contact attached to the shaft activates the flashtube at the proper time for excitation of the ruby.

The ruby laser element is placed at one focus of a highly polished elliptical aluminium cylinder while the flashtube is placed at the other focus. Thus, the light from the flashtube is focused into the ruby.

The optical system in the transmitter and in the receiver uses 2- inch - diameter optics. The transmitted beamwidth is 0.5 milliradian, corresponding to a beam diameter of about 8 feet at a range of 5,000 meters, generally smaller than most of the targets at that range. The sight is a variable power telescope.

8.3.3. Performance

This rangefinder has been tested against a variety of targets at ranges varying from 250 meters to over 15,000 meters. These targets have included tanks, tree stumps, trees, rock piles, sloping asphalt roads, boats, buildings, and smokestacks. Target colours have ranged from brown through green, black, and white. Tests have been made in broad daylight, in light and heavy rain, and on very hazy days with limiting visibility at about 5,000 meters. The chief limitation of an optical radar is atmospheric absorption, especially in adverse weather. Since, however, the target for an optical rangefinder is selected visually by an operator and since the atmosphere is at least as transparent to the laser output as to normal white light, there is no real problem. Special provisions have been made to reduce the appearance of flase targets caused by low visibility atmospheric anomalies such as dust and light rain. Of 2,000 test shots made, 1,000 were used to establish the repeatability of range readings against fixed targets. The standard deviation of the repeatability was found to be less than 5 meters.

Maximum range performance is greatly improved at night by the absence of sunlight, but the difficulty of aiming at a target increases. Visibility of the beam during night operation has been found to be of little practical concern. Because of the colour, short duration, and high collimation, it is virtually impossible to see the beam unless the observer is directly in line with the transmitter, hence, there is little risk of detecting the rangefinder's location.

8.3.4. Military Application

The military applications of laser rangefinders are derived from their use of the radar principle and from the unique characteristics of the laser output; e.g. a needle beam, high radiance, and monochromaticity. This provides; high angular resolution and security from detection from outside the beam itself; a fixed range accuracy out to the maximum usable range; day as well as nigh operation; freedom from ground clutter problems caused by sidelobes; small scale and light weight; high speed and accurate range measurements under military field conditions; and a high degree of security against countermeasures.

Typical artillery applications include surveying to lay in a battery and pinpointing the location of a forward observer. For forward observation, a lightweight unit will be specially valuable. Unlike conventional bulky rangefinders, it can be used by relatively untrained personnel. Ranging information when relayed to the battery allows 'fire for effect' on targets without preliminary straddling shots. The advantage of surprise and the saving of ammunition will be significant.

In tanks such a unit provides a critical time advantage over an enemy not so equipped by allowing first-round kill. The equipment may be easily adapted for use with infrared sights for night operation.

Airborne tactical situations in which the range-finder is valuable include battlefield surveillance, air-to air ranging, and weather surveillance. For example, a helicopter so equipped willbe useful in pinpointing concentrations of men and material, and the information may be used to direct subsequent air attacks.

As developments continue with this new instrument wider applications and improved performance will follow.

8.4. LASER OPTICAL SYSTEM FOR PRECISE DISTANCE MEASUREMENTS

Development of this instrument with a laser as a light source was used to increase the surveying range in moderate haze, to measure longer distances in bright sunlight and to increase accuracy.

8.4.1. Optical Design

A diagram of the transmitter and receiver in the laser-optical system is shown in Figure 44 . All

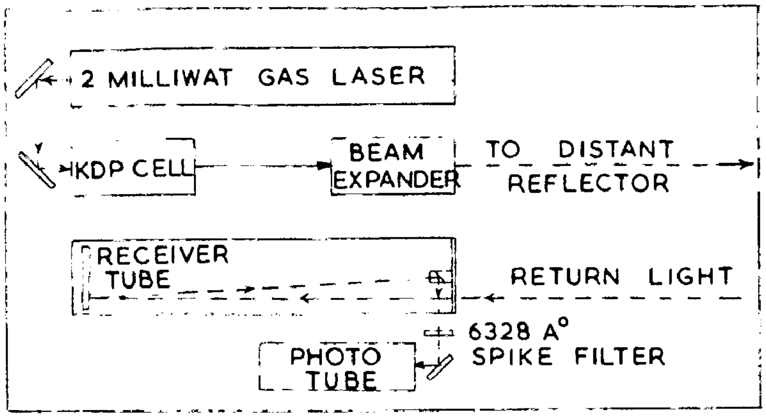

FIG. 44 _DIAGRAM OF LASER—OPTICAL SYSTEM

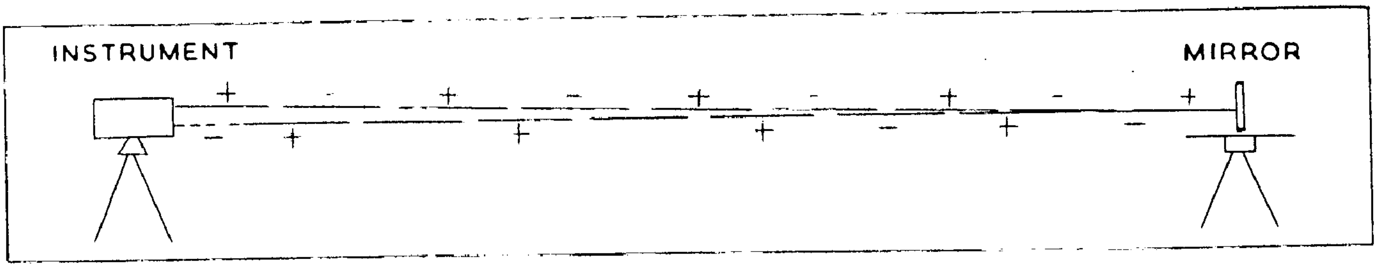

FIG. 45 _MEASURING METHOD SHOWING UNIT LENGTHS FOR ONE MEASURING FREQUENCY

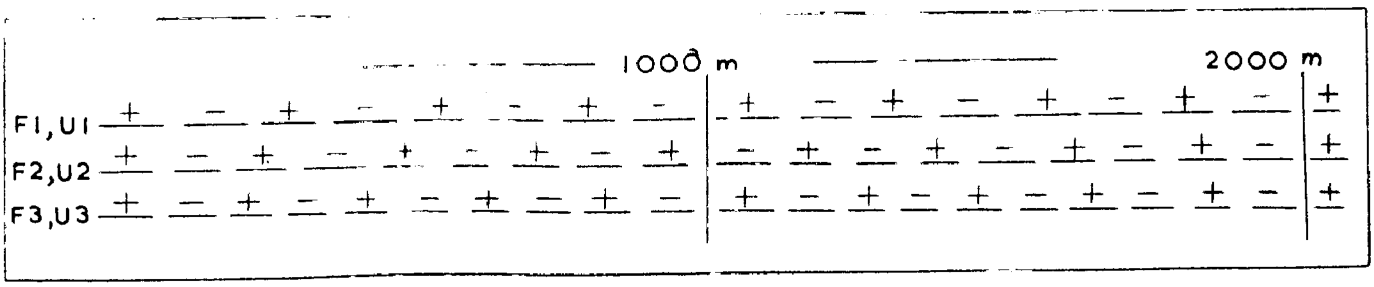

FIG. 46 _MEASURING METHOD USING THREE DIFFERENT FREQUENCIES

components in the transmitting section are on an adjustable plate which can be removed from the instrument to facilitate alighment of the KDP CELL and the beam expander. As the 2- millimeter laser beam passed through the beam expander, the beam is expanded to 20 millimeters. The beam expander is adjustable, and the beam can be collimated from about 1.5 meters to about 30 meters in diameter at 10 miles.

To align the transmitter to the receiver in the field, the receiving optics are broad-band coated and the 6,328 Å spike filter is mounted so that it can be moved into or out of the light path by the operator.

8.4.2. Crystal Oven

To eliminate as much error as possible in the modulating frequencies, a crystal oven was developed with a mercury thermometer to control the oven temperature. A thermistor is placed in the oven, and the temperature is monitored on a meter mounted on the instrument panel. The oven operates at 50 degrees centigrade and the maximum fluctuation is plus or minus 0.2 degree centigrade. The three modulating frequencies are around 30 MHz. A change of 30 Hz per second will introduce an error of one millionth of the distance measured. A small change in temperature on the crystals will cause a change in the modulating frequencies. The maximum fluctuation on any of the frequencies is about 1 part in 5,000,000.

8.4.3. COMPUTATIONS

The computations with the laser electro-optical system are based on the following constants:

Velocity of light, VL	=	299,792,500	m/S
Measuring frequencies F1	=	29,970,000	Hz/S
F2	=	30,044,920	Hz/S
F3	=	31,468,500	Hz/S
Refractive index, RI	=	1.0003086	

The refractive index, RI, is a constant, and it is uncorrected for temperature, pressure, humidity, and the wave length of light.

U1, U2, and U3 are computed as follows:

$$U1 = \frac{VL}{4(F1)(RI)}$$

$$U2 = \frac{VL}{4(F2)(RI)}$$

$$U3 = \frac{VL}{4(F3)(RI)}$$

8.4.4. Laser Safety

The power output of the laser electro-optical instruments ranges from 0.7 milliwatt to 1.4 milliwatts.

The laser light is not dangerous except to the eyes and this danger can be avoided by observing a few safety precautions. Care should be taken not to look into the modulated beam without proper eye protection. A safe distance without such protection is considered to be 5,000 meters or more with the present lasers. The Coast and Geodetic Survey safety standards require this precaution and the use of protective glasses under specified conditions. Instruction in safety is given all personnel, and laser danger signs are displayed.

Eye safety must be considered for the personnel in the aircraft when using airborne thermistors, in case they come into visual contact with the laser beam. The pilot should not wear laser safety goggles because they will filter out red light which is used in aviation warning lights but polaroid sun glasses will provide the needed protection.

CHAPTER - IX

ELECTRONIC PHOTOGRAMMETRY AND NON-PHOTOGRAPHIC PHOTOGRAMMETRY

The entire process of photogrammetry and map compilation is a flow of information which begins when the aerial camera shutter opens, and ends when the map user reads the finished map. The whole process can be done automatically through electronic means and it has now become possible to compile maps automatically by modern electronic methods.

Starting with unrectified aerial negatives electronic equipment can conceivably rectify scale, orient and print a photomosaic, measure relief and carve a relief model, all automatically. However the aerial camera and negative do not acquire and store the terrain information in the form most suitable for fully automatic electronic map compilation. Terrain scanning system has been digitised to scan the ground photo-electrically from the aircraft, record the terrain information as electrical signals on magnetic tapes and then automatically print a photomosaic, curve a relief model and produce a map to any desired project. An electronic method for automatic identification and interpretation of images of targets on aerial photographs is at present in the last stages of development, which will result in complete automization of collection and giving the end results of enemy intell-

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The entire process of photogrammetry and map compilation is a flow of information which begins when the aerial camera shutter opens, and ends when the map user reads the finished map. The whole process can be done automatically through electronic means and it has now become possible to compile maps automatically by modern electronic methods.

Starting with unrectified aerial negatives electronic equipment can conceivably rectify scale, orient and print a photomosaic, measure relief and carve a relief model, all automatically. However the aerial camera and negative do not acquire and store the terrain information in the form most suitable for fully automatic electronic map compilation. Terrain scanning system has been digitised to scan the ground photo-electrically from the aircraft, record the terrain information as electrical signals on magnetic tapes and then automatically print a photomosaic, curve a relief model and produce a map to any desired project. An electronic method for automatic identification and interpretation of images of targets on aerial photographs is at present in the last stages of development, which will result in complete automization of collection and giving the end results of enemy intelligence connec-ted with this field by remote sensors.

The application of electronic methods becomes feasible when we see that the entire process of map compilation from photographs is a process of acquiring, storing, interpreting, transmitting information from the time of shutter clicks in the aerial camera through a complicated chain of events, to the time the eventual user reads and employs the map. A simplified way of considering this chain of events is through a block diagram No. 47 , for the case of map compilation from aerial photography with stereoplotting equipment. The rectangular block in the diagram represents stages in the overall photogrammetric process during which the information is processed or transmitted or affected in one way or another. Now the rectangular blocks represent filters, and the circular blocks in the diagram represent stages in which the information is stored i.e. memory devices. The diagram show the flow of information beginning with light reflected from the earth's surface into the aerial camera. The first filter through which the information passes is the aerial camera, the shutter and lenses which process the information by collection and focussing light on to photographic emulsion of the aerial negative. The information is again filtered during the developing of the negative. Another filter process takes place when the image in the developed negative is transformed into an image on the diapositive.

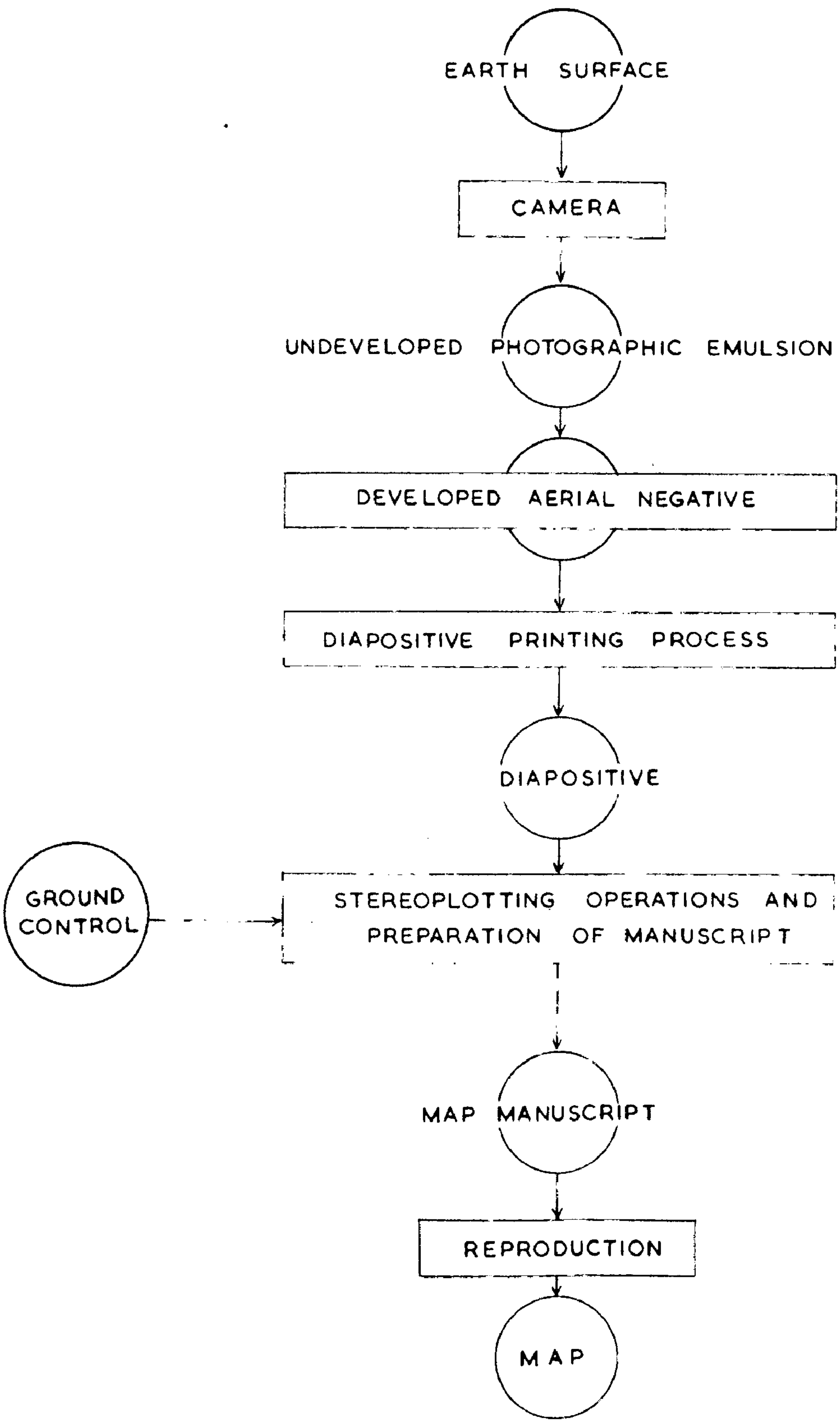

FIG.47 _ BLOCK DIAGRAM OF THE FLOW OF INFORMATION IN CONVENTIONAL MAP COMPILATION WITH STEREOPLOTTING EQUIPMENTS
CIRCLES REPRESENTS STORAGE
RECTANGLE REPRESENTS FILTERS

The steroplotting operations and the preparation of the map manuscript are another set of filtering operations, some quite complicated, which are lumped together in the rectangular box f or simplicity. Additional information enters the information chain in the form of ground control. The information from these two soucres, filtered by the steroplotting instruments, is stored in the map manuscript. A final filtering operation takes place when the map is reproduced and the final storage in the finished map.

9.1. PHOTO ELECTRONIC METHOD

The scheme of operation of the system is shown by diagram No. 48. The spot of a flying spot scanner is focussed optically on to a conventional unrectified aerial negative. The light transmitted through the negative is coll-ected and measured by a photo-electric cell, the output of which is amplified to a recordable degree. The aerial negative is scanned in a series of closely spaced straight lines first in the longitudinal direction and then in the transverse direction. An electronic switch routes the amplified photocell output to the appropriate magnetic tape of storage A, one of which stores the longitudinal scans and the other transverse scans. The scans are then oriented, rectified and scalled by electronic comparison adjustment and matching. A change of scale is

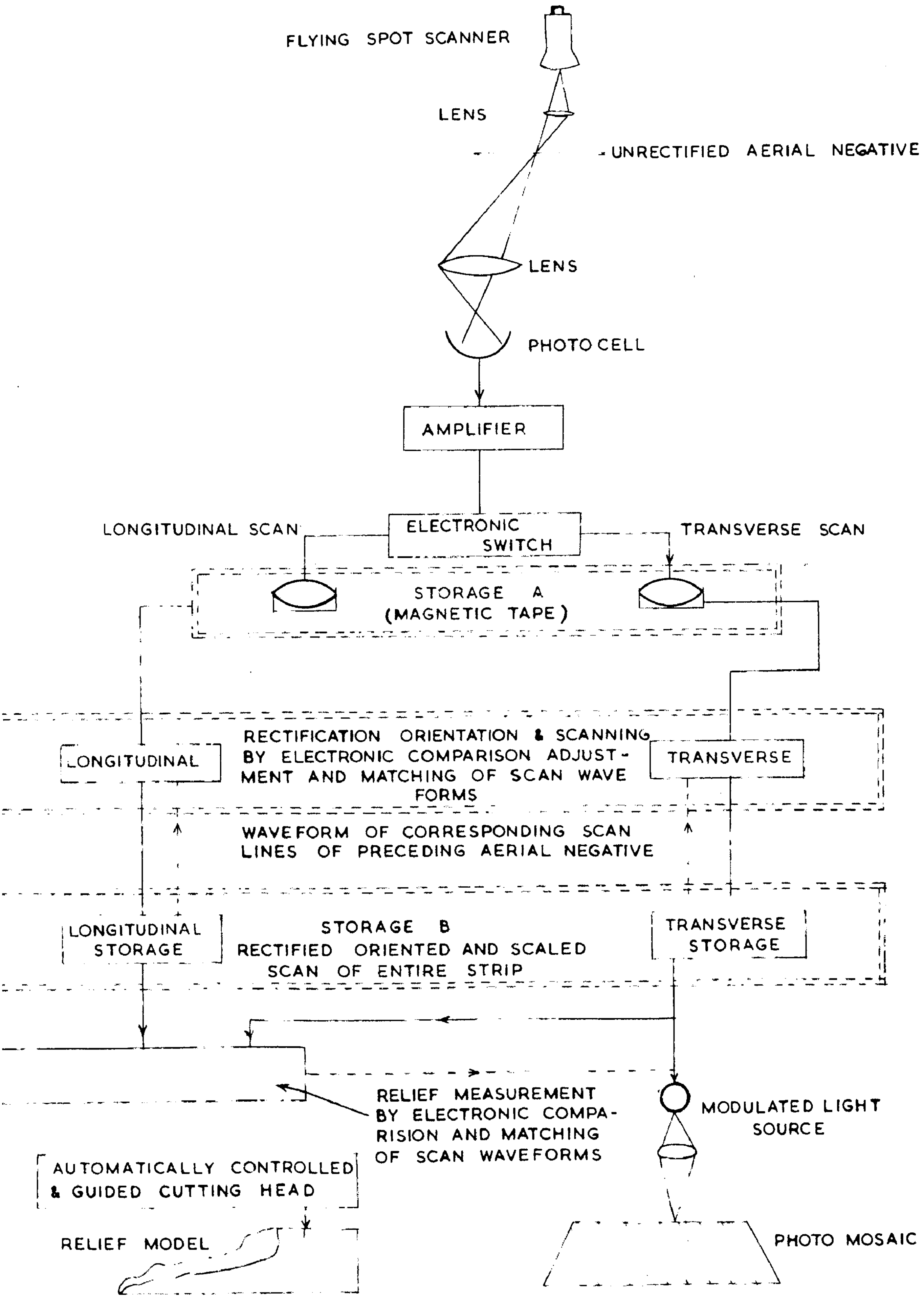

FIG.48 _SCHEMATIC DIAGRAM OF PHOTO ELECTRONIC METHOD

electronically equivalent to change in speed of playback (of one set of scans signals from storage relative to the speed of play back of another set of scans). Rectification is performed electronically by differentially expanding and contracting the time base upon which the signals are played back from the tape, as well as by shifting the signals along the time base (crudely speaking this is equivalent to making the tape play back fas-ter and slower in different portion of the play back). Relief measurement is carried out by comparing and matching the electrical wave-forms produced by scanning corresponding areas on the overlaping aerial negatives of the adjacent exposure station. Relative orientation is also accomplished by matching waveforms obtained from the overlapping portions of the aerial negatives. The rectified scans are stored in storage B. Then they are fed back to be matched with the wave-forms of corresponding line scan from overlapping areas of the adjacent aerial negatives. Control can be carried out automatically by readjusting the indicated coordinates in the least square fit to known coordinate values.

The final electronic outputs of the foregoing system automatically print a photomosaic and automatically cut a relief model. Due to the development of digital computer some variation in the above method have crept in. The concept of 'Digital terrain model' have been developed.

9.2. DIGITAL TERRAIN MODEL

In brief, a band or an area of terrain is represented in numerical or digital form from data taken from a contour map or directly from the stereoplotter, and stored on computer input material. The stored digital terrain model may be used to obtain solutions to many types of terrain analysis problems by processing through an electronic digital computer according to photogrammed instrumtions. Such an approach enables the engineer to evaluate numerically an unlimited number of possible locations, designs and other geometric solutions to the various problems presented.

The electronic digital computer can be applied to the two major areas of application. The first is concerned with the reduction of raw data to obtain the basic photogrammetric output (the spatial location of points) The computation associated with analytical, space resection, intersection, aero triangulation , transformation and adjustments are example of this area of scomputer application. The other field is the solutions of engineering, scientific and military problems which involve the use of photogrammetric output data.

A fundamental requirement for using a computer efficiency is to have terrain data in a form which the machine understands. In the case of the electronic digital computer, this form is of course, digital data on computer input material such as punched cards, punched tape or magnetic tape. The method has been explained in brief as under:.

9.2.1. The Concept

The DTM is simply a statistical representation of the continuous surface of ground by a large number of selected points with known x,y,z, coordinates in an arbitraty coordinate system. Storing the DTM data on computer input material makes it available to the computer for an analysis of a wide variety of terrain problems and also for the evaluation of an unlimited number of independent solutions to each type of problem.

9.2.2. The Coordinate System

The origin and direction of xy horizontal axes of DTM coordinate system and the z- datum may be selected at will, with due regard to convenience and the requirements of the particular problems at hand. This coordinate system is independent but should be related to an established system such as state plane coordinates and mean sea level datum. With reference to known coordinates of two points the DTM coordinates may easily be computed.

9.2.3. Digital Representation System

The surface of the ground may be represented in the DTM by any one of a number of possible sets of selected points. The only requirement the set must meet is that it should be stored systematically to facilitate recovery by the computer. This could be accomplished by specifying that the points are stored sequentially in order of increasing x (or y or z). Such a sequence might be used if a system of points such as used by the plane table topographer was selected.

If the points are located along a system of parallel scan lines, a more practical sequence of data would result. Such scan lines will normally be lines of constant y(x scan lines). The distance between or spacing of the scan lines may be variable or constant. With constant spacing of the scan lines and constant frequency of the points along the scan lines, a square or rectangular grid would result. Such a system would permit:

1. The highest degree of automation of the data procurement phase.
2. The simplest processing of the data by the computer.

With a variable frequency of points along the scan lines, the selected points might be on:

1. Equal increments of z or contour line crossings.
2. Increments corresponding to a constant product of yz increments.
3. Terrain control points such as high and low points and slope breaks.

Hereagain, the engineer has complete freedom in selecting the system of points best suited to the problem at hand. His choice might consider the type of terrain, available data procurement, equipment and the nature and requirement of application of the DTM. In any of the system the density of points for a given type of terrain will depend upon the accuracy requirements associated with the application. In some problems, a series of DTM's with progressively higher densities of points for smaller areas might be advisable for example in the various stages of the location and design of a highway.

9.2.4. The Mathematical Terrain Model

Since with the high-speed electronic computer much more sophisticated interpretation with the DTM is quite practical. It is proposed that the actual model utilized by the computer be a mathematical model of the surface generated with the data furnished by the DTM. Instead of connecting each successive pair of points with a s traight line a third degree polynomial will be generated by the comput er. A scan line will then consist of a number of continuous curves, each good for a specified range of y values. The slope at any point along the scan line may be obtained by differentiating the equation of polynomial. By setting the differential term equal to zero, the location of high and low points may be obtained . By integrating the polynomial the area under the curve may be obtained. Interpretation between the scan lines may be accomplished in a simmilar manner by evaluating the polynomials accross the scan lines and parallel to scan lines which pass through the deisred points; from points previously interpolated on the polynomials, along the scan lines.

Considerable work is being done on this subject but it has not yet reached a sufficient advanced stage.

The mathematical terrain model can be justified if the number of DTM points necessary to represent an area of interest can be greatly reduced. A single third degree polynomial might, for example, represent a given profile as accurate as would 50 ft straight lines interpolation . The speed and efficiency of electronic computer permits one to think in terms of representing the surface of a project area by thousands or literally tens of thousands of mathematical equations.

9.3. DATA MAPPING

The method is based on the principles discussed earlier and uses a new languaged that quickly and economically, produces legible and valid maps of sufficient accuracy to be used as primary sources of information in conjunction with - or instead of - the written words or mathematical equations.

This development, originally programmed by H.T. Fisher of Havard, was designed for graphic displays of census and demographic data in 1963. A new programme has been developed and expanded into the data map system which combines the use of data gathering techniques in photo interpretation and remote sensing with a unique method of digitizing the data and selectively retrieving it in graphic form by computer print out hardware.

At the present time the datamap programme incorporates two types of maps - conformant and proximal. The conformant map is based upon conformance to the boundaries of a spatial data zone and is used to record the size and shape of mapable units that encompass large areas to outline at any given scale. The proximal type of map (based on proximity to a data point) is qualitative and record information that is too small to outline at any given scale but can be pin pointed and given X and Y ordinate value. For an administrator, who needs current information at his finger tips, the data map system offers a very powerful tool, that is easily used and is particularly applicable where large amounts of valuable data must be compared, synthesized evaluated and communicated.

The land use photointerpretive code, used in the data map system was developed by Professor D.J. Belchor and his staff at Cornell University. This code involves some 135 categories. Some of the broad categories are given below and it is suggested that an inventory framework be set up on the basis of unmet data needs, interpretive qualities and anticipated usefulness of various interpretation keys that are applicable to specific projects.

9.3.1. Programming Code

Agricultural Land (A) ranges from high intensity cultivated cropland to inactive forms. On the proximal point map identification keys for dairy farms, poultary farms, horticulture farms etc will be establibhed

Forestry Land Use(F) consist of forest plantation.

Water Bodies (W) area delineation of open water as naturally impounded or artificially dammed.

Outdoor Recreation (OR) i.el golf courses, ski areas, beaches, marinas etc.

Residential land Use (R) urban and Rural residential area, Urban residences are catagoriesed into high medium and low density zones, and in rural area (a) active ferm residents (b) non-form resident and rural hamlets etc are categorised further.

Commertial Areas:(C): are delineated into urban commercial areas, shopping centres and general strip categories.

Industrial Zones (I) : are simply identified in light and heavy industry categories.

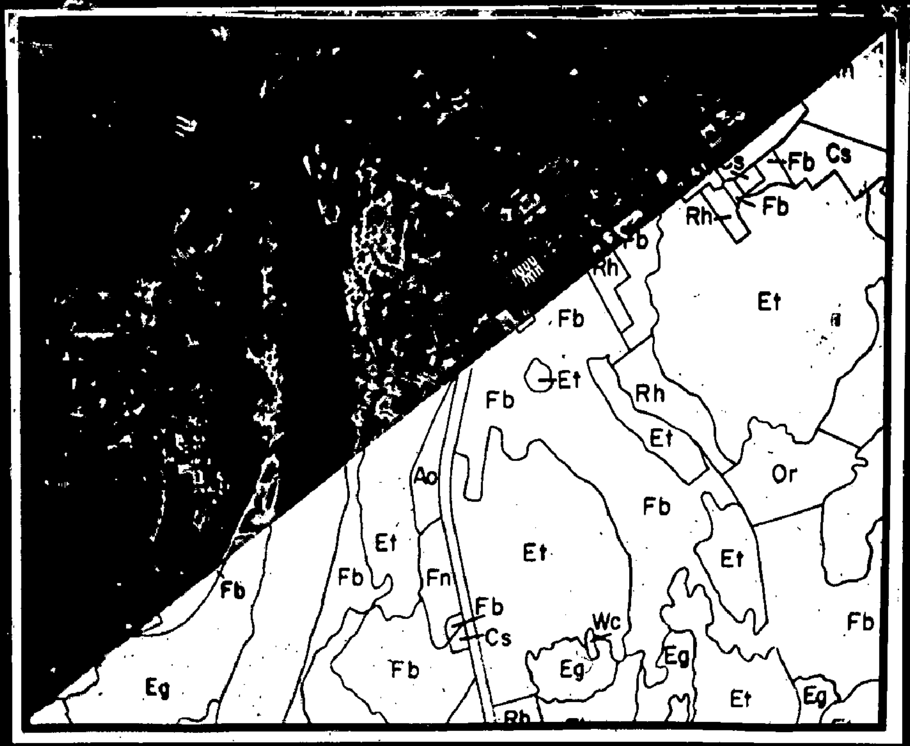

Fig.49 A Typica-1 Data Map

The data map system produces maps of varying types for both industry and government. All of these maps are complete and products within themselves and are very suitable for displaying the cartographic information required. Data map also provides in its system the earlier mentioned computer programme that allows the convenience and speed of computerized data retrieval . In fact as the motto goes " anything we can map - we can computerize. "

To adopt maps to the computer, all map information must first be related to a geographical reference. Each grid is referred to as a data cell and is located and identified by the metric coordinate value of the southwest corner of the grid square.

For greater printout detail and qualitative analysis, the data cell can be reduced in size to quarters or even linear subportions. Additional identification digits are needed to accommodate the added software load.

The grid cell is used in all data compilation with reference to the data cell . Any information with a known mapable location can be combined with data map information on a cell by cell basis. These procedures apply in working with large areas such as states or entire countries. This is a truely a mapping system of the future and a significant advance over our present mapping procedure of using many different coordinate grids, which are to be compared to a standard grid of the country to get the correct results.

To-day we utilise the incremental digitizer to automatically record the data directly on tape- in a fraction of time and expense. This type of computer appplication relies heavily on map and cell order. The normal contiguous manner starts with the Westmost unit in the Northmost row moving from west to east accross the row,then from west to east on next row etc to the end of the project.

The data map system is specially designed with built in flexibilities. For instance, raw digitizing and computer mapping can be applied to existing maps that do not need additional photointerpretive or remote sensing analysis. For example in existing forestry maps where a computer programme can put selective forestry and stand data at the forest's fingertips in an efficient manner.

The data map system will have further developments along with new developments in computer system and have an unlimited future. The more an administrator searches his files for recorded information the more he will realize that the very information he is searching can best be presented to him faster and more economically by a computerized map.

9.4. PRESENTATION AND UTILIZATION OF THE OUTPUT DATA

The output of the electronic computer will be a digital or numerical form of data. Quite often the results of interest will be in the form of a numerical answer and no further transformation of the data will be necessary. However in many cases the engineer will require an analog form of data presentation for human study. A graphical plot will be the most commonly used analog form. Continuous line plotters are now available for graphically plotting the results of DTM problems. The potential applications of the DTM will call for a family of such plotters. For example, the output of the mathematical terrain model approach would call for a system which would permit plotting of the continuous third or higher degree of polynomial equations defining surface profiles. An electronic computer programme has been written by the M.I.T. Computation Centre, for plotting plotting and recording a contour map of a matrix of digital values with the Type 740 Cathode Ray tube output recorder of the IBM type 704 Computer. This programme is being extensively used and illustrates a number of possibilities in the engineering field. In addition to the two dimensional continuous plots, the output data can be used for controlling three dimensional cutting machine for carving physical model of the DTM area.

In essence, it may be said that whenever two surfaces of interest are to be related and computations are required, the DTM offers a possible approach. Photogrammetry will usually offer only the practical approach to the probelm of obtaining the required data and electronic computer makes it possible to consider computing problem which would require an army of men with desh calculators.

9.5. NON-PHOTOGRAPHIC PHOTOGRAMMETRY

The conventiona l aerial photography and aerial negative acquire and present the terrain information in a fom that is not convenient and efficient for subsequent, fully automatic compilation. Consequently methods have been developed for acquiring the basic terrain information without using aerial negatives. These methods are:

1. Television method.
2. Single line-scan method.
3. Spot -scan photomultiplier method.

9.5.1. Television Method

The Survey aircraft carries a television camera instead of conventional photographic camera . An image of the ground is projected through a lens system upon the face of a TV pick up tube, where the image is electronically scanned. The output of the scan modulates an FM transmitter which radio the scan waveforms to a ground station where they are recorded and stored on magnetic tape. Map compilation then proceed automatically by electronic methods.

9.5.2. The Single Line Scan Method

The Survey aircraft carries two TV pickup tubes, each with its own lens system, one looking forward and one looking backward. Only a single line on each pick up tube is scanned. The scanned line is perpendicular to the direction of flight. At each instant, therefore the system looks at only a narrow line on the ground in the transverse directionforward of the aircraft and a similar transverse narrow line backward of the aircraft. The forward motion of the aircraft causes these lines to sweep out the area being surveyed. The scan wave forms are transmitted by radio to a storage and computer station on to the ground. Relief is determined electronically by comparing and matching portions of waveforms from the two scans of the same ground line, corresponding to the stereoscopic view of this ground line. The other steps in the map compilation process are accomplished electronically.

9.5.3. Spot-Scan Photomultiplier Method

The light from a s mall spot on the ground is collected upon the photocathode of an airborne

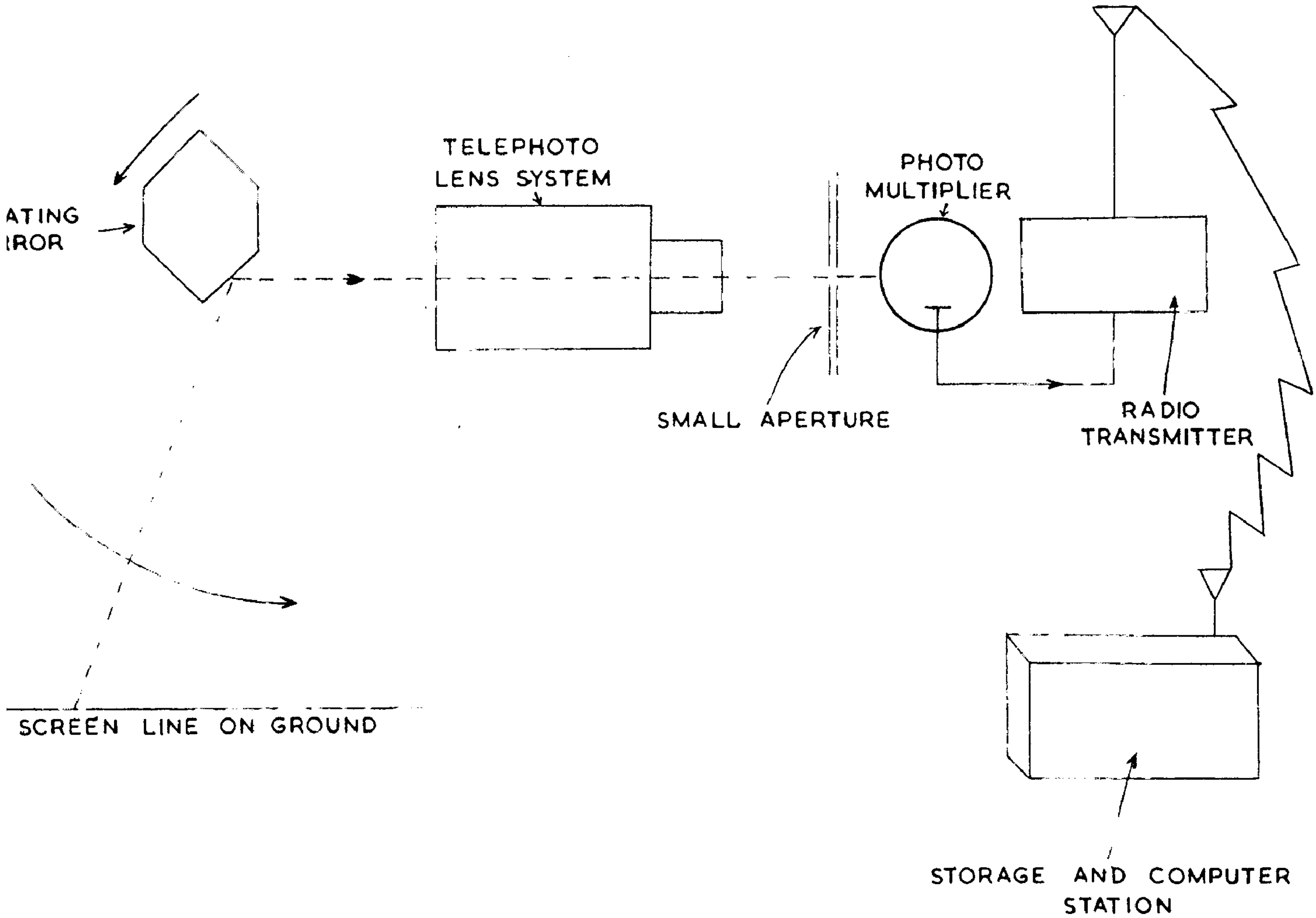

FIG. 50 _ SPOT-SCAN PHOTOMULTIPLIER METHOD FOR ELECTRONIC PHOTOGRAMMETRY photomultiplier tube through a lens and aperture system. Rotating mirrors or prisms move the viewed spot along the ground in a line at right angles to the aircraft direction of flight, thus scanning the terrain. Two such photomultipliers are carried in the aircraft, each with its own set of lenses and rotating mirrors. One photo-multiplier looks forward and the other in the backward direction similar to the arrangement of the two TV pickups tubes, thereby providing the stereoscopic type of information required for relief measurements. The photomultiplier output signals are transmitted by radio to a ground station when the scan wave forms are stored on tape and used for automatic map compilation in the same way as in other electronic methods.

This method has a major advantage over other two methods in that it has much higher sensitivity to low levels of ground illumination, which is even greater than what is obtained in conventional aerial photography. As such this method has much higher resolution than the other two electronic methods and appear capable of having a resolving power equal to or possibly greater than that of conventional aerial photography. This method has been used in the fully automatic map compilation system called the Terrain Scanning System or simply TSS.

CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS AND SUGGESTIONS

Science is giving now excitments and now visions and in fairness to ourselves, we must come to appreciate the excitations of our times.

The knowledge of these new excitations is very much essential as far as the defence system of a country is concerned. The modern warfare techniques must be adopted to keep up the prestige and honour of the country. The modern army may be small in numerical strength but must be well equipped. Military intelligence should be quite exhaustive, accurate, uptodate and as far as possible should be impersonal in nature. The least delay should occ-ur between the collection of military intelligence and supply of the classified intelligence to the front line troops in order to derive maximum benefit from it , so that well timed surprises on the enemy may be made. The reconnaissance missions should be fast and should be independent from effects of weather and visibility.

To promote Military reconnaissance towards efficiency and to obtain effective military intelligence in microseconds, some of the sensor systems have been discussed in the foregoing Chapters, which in brief may be concluded as follows :

1. The latest remote sensors devices have made it possible to gather nearly an alltime military intelligence about the army movements and transmit the same to the forward line troops almost immediately.

2. Air photo reconnaissance can provide the most exhaustive and authentic sources of Military terrain intelligence about the enemy held territory. But such sensors are greatly affected by visibility conditions.

3. Radar installations can keep a thorough surveillance against enemy strikes on strategic and tactical targets and such systems are free from effects of weather and visibility. These installations enable certain objects to be detected and located at distances far beyond and can measure instantaneous speeds of moving objects in a simple and most natural way. APR can be successfully employed for obtaining rapid vertical control. Radar mapping systems give large areal coverage and is quite useful from military point of view, as it offers minimum delay between collection and supply of military intelligence.

4. The infrared scanners are also quite successful means of detection of water resources, hot springs (even sub surface water bodies). The thermal maps are quite successful in the determination of terrain

features, drainage pattern and geological characteristics of the area. The infrared colour sensitive film is invaluable in ~~camaflouge~~ camouflage detection. The multispectral system is a newer concept which will make detection and identification more clear by exploiting the differences in tone signatures of an object in the various bands of electromagnetic spectrum. The multispectral system, which uses positive transparencies taken simultaneously with different filter combinations, can obtain more information concerning physical feature of an environment as compared to conventional panchromatic photography. Here the objects are recorded in their natural colour, making the descrimination easier. The promising results obtained indicate potential applications of this system to military problems of target acquisition and camouflage detection.

5. The Laser range finder is invaluable in battlefield surveillance, air to air ranging and weather surveillance. This equipment may be easily adapted for use with infrared sights for night operations.

6. Electro-optical photography at low illumination levels has got its own place in military reconnaissance missions. The image intensifiers can improve upon the low light level sensitivity. Lallemand camera

and channel plate space camera are quite sensitive at low light level. The development of fibre optics will further improve upon the situation. The Neutron photography and ultraviolet photography are still in nascent stage of developments and hope for a bright future.

7. The Electronic photogrammetry have transformed the traditional graphical form of map into numerical means of representation and communication of information through electronic digital computers, magnetic tape storing and other electronic gadgets.

The digital terrain model system, which stores the terrain information in numerical or digital form, can be used to evaluate many types of terrain analysis problem at a much faster rate.

The combination of aerial camera or remote sensor systems with computer cartography has resulted into a new science which can communicate scientific ideas with the added features of fastness, low cost and updating capabilities.

Data map system offers a versatile and easily used tool that is particularly applicable in situations where large amount of valuable data must be compared, synthesized, evaluated and communicated.

Considering the present state of affairs of Indian Armed Forces, it is proposed that the steps must be taken immediately to make the country self sufficient and at par with other neighbouring nations in Her defence requirements.

Some of the proposals are listed below:

1. The latest Electronic Remote Sensors Devices should be acquired to gather nearly all time military intelligence about the enemy movements and transmit the same to forward-line troops almost immediately.

2. Such reconnaissance systems should be used as to provide detailed and most upto date terrain intelligence of Border Areas and neighbouring hostile countries so as to prepare latest topographical and geological maps of these areas for the general military requirements and for the construction of heavy duty roads for defence purpos-es.

3. An exhaustive net work of Radar installations should be established to warn the armed forces against enemy air strikes on strategic and tactical targets and to direct blind bombing raids on enemy installations through navigational and positioning devices.

4. Hand held or portable infrared intensified night survelliance and surveying equipment should be provided

for conducting night operations and for achieving complete surprise over the enemy. Such equipment will help in keeping the Jawans and officers active even in pitch dark without any danger of getting lost.

5. The scientific methods of operational research system analysis etc., should be developed and must be used to evaluate weapons and new reconnaissance and surveillance devices. The developed systems should then be merged in existing Military organisations, otherwise to learn from battle experience will be quite expensive.

6. The application of electronic digital computers, magnetic tapes storing devices and gadgets have transformed the traditional graphical form of map into numerical means of representing and communication of information. This aspect of the present day mapping needs very careful consideration and the traditional training programme and syllabii of military personnel , engaged on military reconnaissance and intelligence missions, production of maps and charts, has to be completely revised so as to include training in operation of electronic computers.

Foreign countries are making very rapid progress in this field. India may not be able to catch them up in near future, but it is desirable that She should narrow the widening gaps, so that She may not have to pay a heavy price to be victorious against an enemy heavily armed to the tooth with latest weapons and assisted by modern warfare techniques. Only then, the optimum success in different operations with the bare minimum use of resources in men, material and Military hardware is possible.

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