SECTION 1 - ELECTROMAGNETIC SPECTRUM

INTRODUCTION

1. As an integral portion of the Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) concept, Situational Awareness consists of the tools and procedures, which bring the total and common picture of the battlespace to commanders. It is required to allow:

   a. better decisions;

   b. activities to occur faster;

   c. focus towards a main effort;

   d. teams to cooperate and synchronize their activities; and

   e. location of targets with sufficient accuracy to permit them to be engaged by our weapons systems, including the attack on enemy information systems.

2. To examine the technological basis for Situational Awareness, we need to study the use of the electromagnetic spectrum (EMS) by such devices as radar, lasers, and infrared (IR) and electro-optical systems. For convenience this chapter breaks the topic into short-range systems, with ranges up to the limit of eyesight, and long-range systems, with ranges beyond the limits of eyesight.

3. In this section we will also look at the definitions that meld the use of technology to militarily relevant objectives and then examine a number of issues related to both radar and electro-optical systems.

4. Examples of both passive and active electro-optical systems are:

   a. Passive Electro-Optical Systems:

      (1) human eyes,

      (2) direct vision sights,

      (3) television (TV) cameras,

      (4) night vision goggles,

      (5) thermal imagers, and

      (6) laser warning receivers.

b. Active Electro-Optical Systems:

(1) laser rangefinders,

(2) laser designators, and

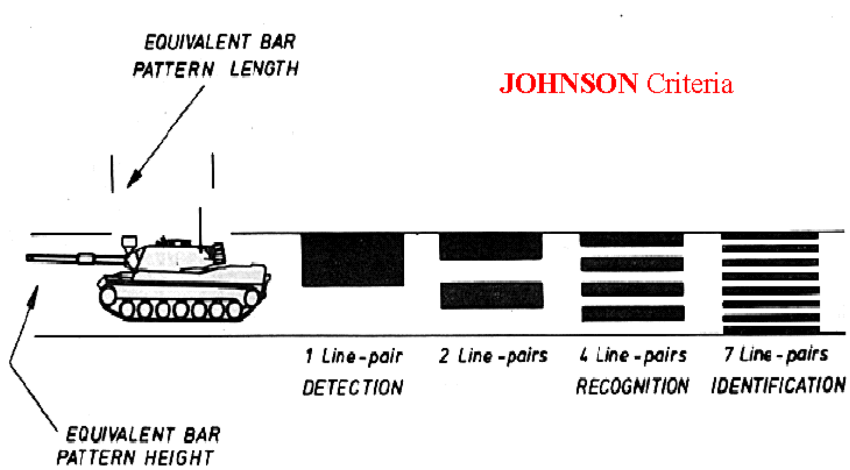
(3) laser guided munitions.

5. These are merely examples of systems which will be discussed later in this chapter.

DEFINITIONS

6. **Detection**. This is the discovery of a potential target. It is accomplished because of a contrast or some discontinuity between the target and its background. The observer's reaction is simply, "there is something there".

7. **Recognition**. This is the determination of the type or class of target; for example, it's a tank. A target can be recognized because of its appearance or its behaviour. Generally, only the key features, such as wheels, tracks, turret, gun, etc., are necessary to achieve recognition.



The number of lines occupied by your target on your display is used to help define the capabilities of the ISTAR system. These are called the JOHNSON criteria.

Figure 1 – Johnson Criteria

8. **Identification**. This is the determination of the true identity of the target. For example, it's an enemy tank, or, it's a T-72. Quite fine detail may be necessary to achieve identification. Operation DESERT STORM highlighted the problem of both friendly and enemy forces using similar equipments. Identification Friend, Foe or Neutral (IFFN) can be achieved through procedures, technology or both. The technological aspects of IFFN remain a considerable challenge.

9. **Location**. This is the determination of the position of the target with sufficient accuracy to allow effective engagement using a particular weapon system.

10. For the equipment designer, the required detection, recognition and location ranges are important, as each stage is more difficult to achieve than the previous one in terms of technical complexity and cost. Once a target is detected, it can be recognized either by reducing the range, or by improving the resolution of the viewing equipment.

ENHANCING THE SENSES

11. In Situational Awareness, we are principally dealing with our senses of sight and hearing. Whereas our ears are sensitive to most of the acoustic spectrum, our eyes operate in only one small part of the EMS. Technology enhances these senses in two ways, both of which involve the EMS:

a. **Amplification -** in this case we use technology to amplify our senses, for example, by using binoculars; and

b. **Extension -** in this case we use technology to extend our senses in the EMS, that is, we use a different part of the EMS not normally available to us, for example, by using radar.

12. Some methods use both amplification and extension; thermal imaging (TI) is an example. However, in either case you should realize that the enhancement could be achieved in either an Active or a Passive mode. In the active mode, we emit a signal that is reflected back to us. Unfortunately, this may also be detected by the target. In the passive mode, we detect radiation being emitted by the target (e.g., heat).

ELECTROMAGNETIC SPECTRUM

13. We will show how little of the information available is actually accessible by the naked eye. We will examine what can be detected from the EMS, from the radar bands through to the ultra-violet frequencies and wavelengths (see Figure 2).

14. One scientific phenomenon of special note is that at very small wavelengths, the EMS begins to act according to two different laws of physics. For example, light can be treated as either a wave of energy or a small particle with a mass called a photon. Given this phenomenon, radar waves are manipulated in amplitude, frequency, phase and power to carry or obtain information; whereas electro-optical devices manipulate the EMS as particles or photons. These electromagnetic waves are so small, that currently only the power and frequency (sometimes called colour) of the photon can be studied. In the EMS radar bands, we usually discuss waves in terms of frequency (KHz, MHz), while in the visible and near visible, we describe the waves in respect to their wavelength (450 nanometres, or simply 4.5).

15. Figure 2 depicts the EMS and shows some useful applications of these waves. Remember the relationship between frequency and wavelength. When multiplied together for any electromagnetic wave, the product is always equal to the speed of light: 300,000,000 m per second. A radio wave of 1 m in length will oscillate at 300,000,000 cycles per second (300 megahertz), while a wave of 300 nanometres (near IR) will oscillate at 100,000,000,000,000 hertz.

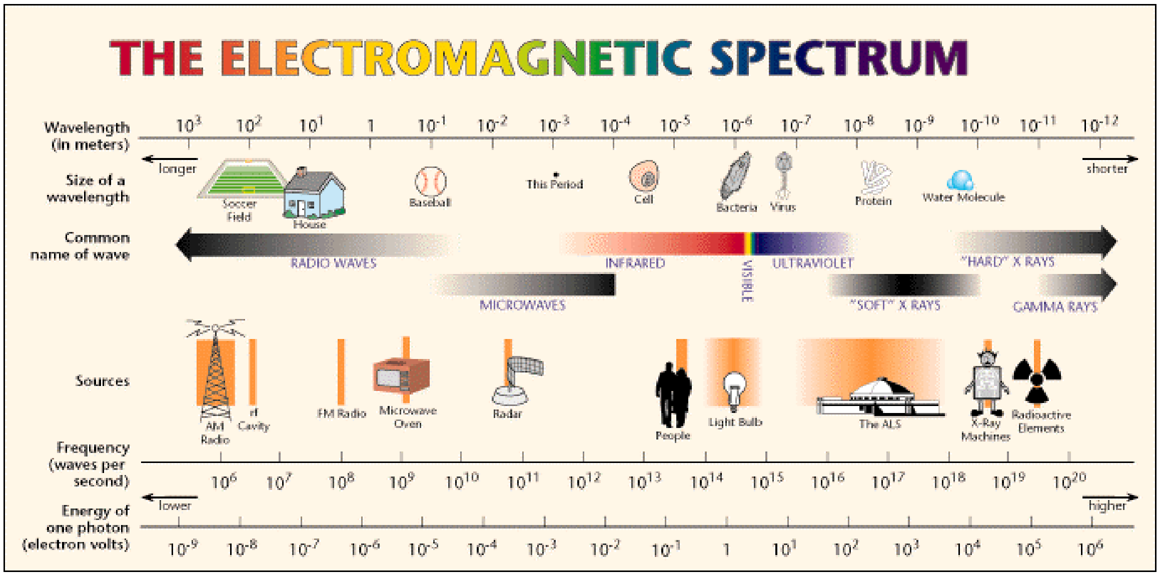


Figure 2 – The EMS

PHOTONICS

16. In that part of the spectrum where light is treated as photons as opposed to waves, the three segments of the EMS of most interest from a military point of view are:

a. visual,

b. near IR, and

c. far IR.

17. The naked eye operates in the visual portion of the EMS; that is, it captures light of wavelengths from 400 to 700 nanometres or 0.4 to 0.7 microns. Essentially, the eye's retina converts light energy into electrical signals that are carried by optic nerves to the cortex area of the brain to produce the sensation of vision. The function of retina, optic nerves and cortex are all replicated in man-made devices to produce the same sensation of vision extracted from some of the non-visual segments of the EMS.

18. By using devices that amplify light just short of the visual range, the near IR range can be accessed. Devices such as image intensifiers (IIs) operate in the 0.2-2 micron range. These wavelengths are radiated by bodies at about 2,000 to 3,000 degrees. A detailed explanation of how IIs work is covered later.

19. Farther out from the visual range, in the far IR segment of the EMS, energy can best be detected as radiated heat at about body temperature (25 degrees Celsius). Thermal imagers render this portion of the EMS visible to the human eye. They operate in two bands: 3-5 microns and 8-13 microns.

LIMITATIONS

20. Two important characteristics have an impact on the detection of electromagnetic waves. Knowledge of these limitations helps us to exploit the EMS to best effect. These are:

a. Atmospheric Attenuation, and

b. Resolution.

21. **Atmospheric Attenuation**. The atmosphere consists of molecules of various gases, principally nitrogen and oxygen, but it also contains small particles of dust, smoke and water. The number of these particles and their size varies with weather conditions.

22. Most sensors operate in the EMS at wavelengths between 300 mm and 300 nanometres. If radiated energy, either from the target or the detection device, meets a particle of a similar size to the radiated wavelength, then the radiation may either be absorbed or scattered. For example, haze particles, which are up to 1,000 nanometres in size, will absorb and scatter visible light, which is in the range 0.400 to 700 nanometres, but haze will not effect thermal imagers, which work in the 800-1,400 nanometre region.

23. The following table shows the effect of natural events on some of the transmitted waves:

Smoke	0.2-2 microns
Dust	1-10 microns
Fumes	up to 100 microns
Haze	up to 1 micron
Fog/Cloud	5-50 microns
Mist	50-100 microns
Drizzle	100-500 microns
Rain	500-5,000 microns
1 micron = 100 nanometres	

Table 1 – Size of Atmospheric Particles

24. As an example, a laser range-finder (LRF) operating at a wavelength of 700 nanometres is inefficient in determining the distance between its current position and the target location in a smoky environment. In this case, the distance returned by the device would be to the smoke particles and not to the target. The smoke can be called a countermeasure to this particular range-finder, since it hinders the LRF's ability to accomplish its aim. The atmosphere with a suspended aerosol or any of these natural obscurants can be thought of as a sieve, filtering particles of an equivalent size to the holes and letting only smaller objects pass through. However, this applies only to electromagnetic energy of high frequencies and very short wavelengths. When we move into the radio and radar portion of the EMS, their very large

wavelengths are able to bend around small objects and their effectiveness is not limited in this way. Figure 3 shows the effect of the atmosphere at each wavelength. The plot can be seen as a wall at each wavelength. The higher the wall, the more difficult it is for the wavelength to travel in the atmosphere. Notice how rain and fog tends to fill the windows at most frequencies.

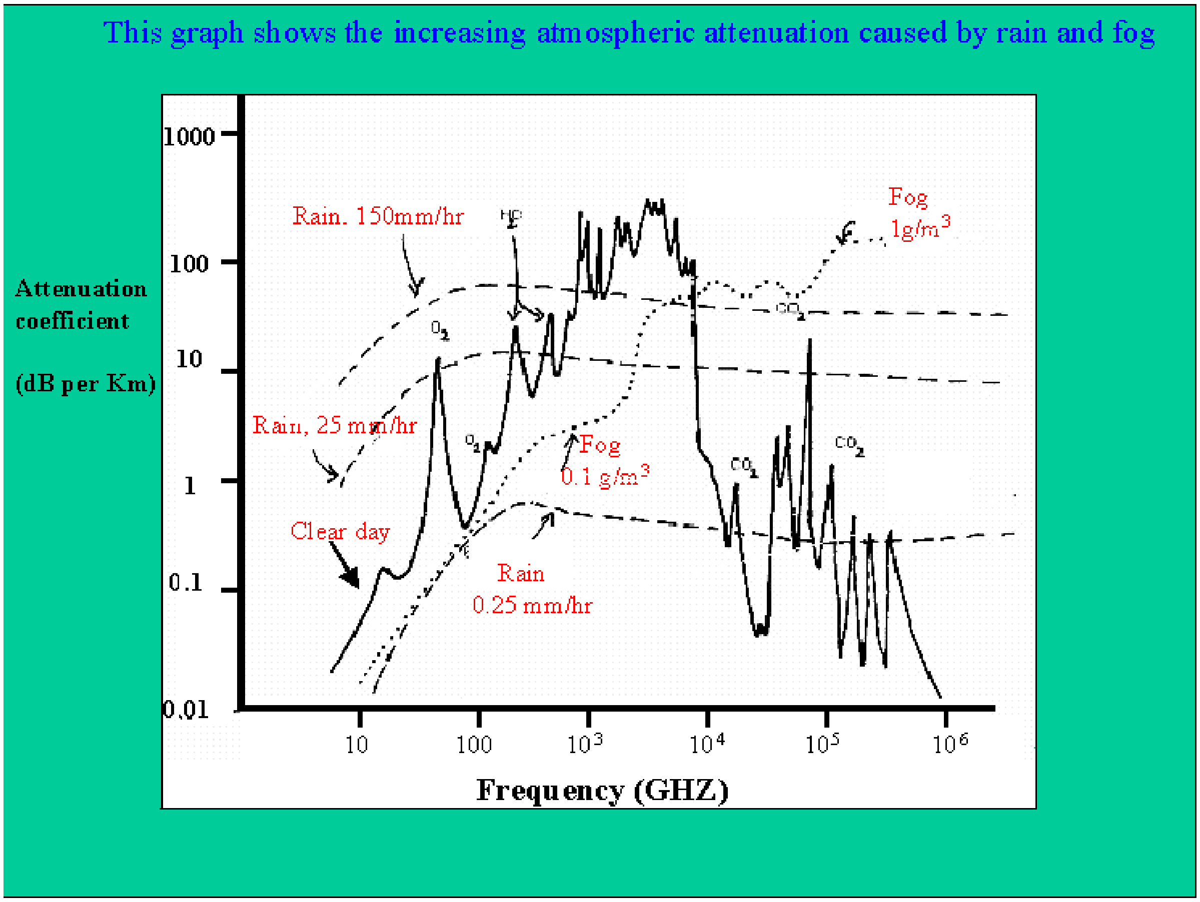


Figure 3 – Atmospheric Attenuation

25. Resolution is a measure of the ability of a system to distinguish detail and to differentiate between two objects close together. The ability of a piece of equipment to resolve detail determines whether we detect, recognize or identify a specific target at a given range. Resolution can only be improved by increasing the size of the collecting device or by reducing the wavelength of operation. It cannot be improved by magnification or by increasing brightness. These operations improve the clarity of the image only. For example, binoculars magnify an image, apparently bringing the object closer. Using binoculars with a 50 mm collecting glass will give you better resolution than pocket field glasses with 30 mm or less collectors.

26. Resolution depends on wavelength. Short wavelength radiation, such as visible light (400 to 700 nanometres) allows resolution of fine detail. The eye is optimized for light wavelengths. A radar operating at wavelengths of a metre can only resolve targets of an equivalent size, hence

the lack of detail on most radar screens. Obviously, the development of millimetric wave (MMW) radar has vastly improved resolution in this mode.

27. Your eyeball requires only a two per cent variation in contrast between a target and its background to detect the target. Figure 4 below shows how the resolution of a target is complicated by all the information received by the eye. The atmospheric effects, the lens quality and the background will all affect your ability to find a target.

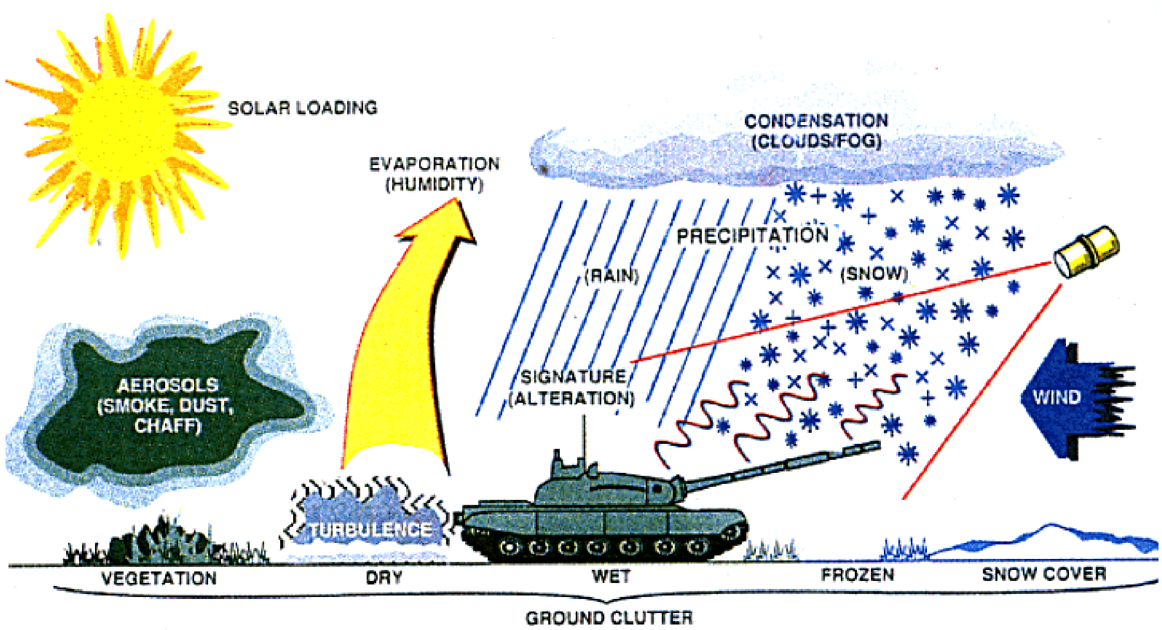


Figure 4 – Factors Affecting Target Resolution

28. Wavelength, atmospheric attenuation and resolution are all connected, but the latter two work against each other. The crucial point to take from this is the absolute requirement for a range of detection devices to exploit as much of the EMS as possible in a given situation. Radar can detect a potential target at long range, for example, which can cue us to direct a different device, say an IR sensor, at closer ranges to get the necessary resolution for identification and even target acquisition.

29. The human eye is the basis for most observation devices, except of course, acoustic ones. Even radar is of little use unless it can be converted onto a screen and 'seen'. How the eye works by day and by night will be covered later.

30. Binoculars are an example of a family of devices, including telescopes and periscopes that aid the eye in the visible spectrum through amplification. All of these devices are quite sensitive to the level of ambient light available. Clearly, the eye sees better in sunlight than on an overcast day. Similarly, our night vision is better with moonlight than with only starlight. As the ambient light declines, IIs come into their own, amplifying the available light of even the darkest night to enable the eye to resolve to a remarkable degree.

31. Active IR is considered obsolete today, in part because of its signature, and in part because of the greater effectiveness of other devices such as TIs. TI devices are in fact extremely significant on the modern battlefield; opening up the far IR spectrum to the eye and greatly enhancing surveillance, target acquisition and weapons guidance.

SUMMARY

32. To conclude this first section on Situational Awareness, the following principles should be remembered:

a. the shorter the wavelength, the greater the resolution;

b. the shorter the wavelength, the greater is the effect of atmospheric attenuation and therefore range is reduced; and

c. the converse is true in both previous cases.

33. Since the atmosphere affects electromagneticwaves differently across the spectrum, there is a requirement to combine various devices in order to adequately conduct situation awareness tasks.

SECTION 2 - SURVEILLANCE AND TARGET ACQUISITION

INTRODUCTION

34. In this section, we will examine:

a. the human eye and how it functions;

b. the different aspects of day and night vision;

c. electro-optical military equipment;

d. a series of mobile sensors, from ground to satellite mounted;

e. radar systems and their mode of operation; and

f. laser technologies, safety and defence.

THE HUMAN EYE

35. The human eye is the basic optical surveillance device. It can distinguish between colours and tones and has a moderate field of view (FOV) - approximately 30 degrees in elevation and 40 degrees in azimuth. It can detect movement by peripheral vision out to nearly 180 degrees in azimuth. The eye also has a dynamic response range of about 10:1, which is far greater than any other single light-sensitive device.

36. The retina extends over the whole of the rear hemisphere of the eye. It is a complex multi-layered structure and converts light energy into electrical signals that are carried by optic nerves to the cortex area of the brain to produce the sensation of vision. In the penultimate posterior area of the retina lie the rods and cones. These photoreceptors perform the transduction process of converting light energy into electrical signals via coatings of light sensitive material. The area from which the optic nerve leaves the eye is called the blind spot and is the only part of the retina that is insensitive to light under all conditions. The Fovea is a small depression in the retina and is the region on which light from a distant object on the optical axis is focussed. It contains only cones and this gives it the ability to perceive fine detail and colour vision under daylight conditions, although it is inoperative for night vision.

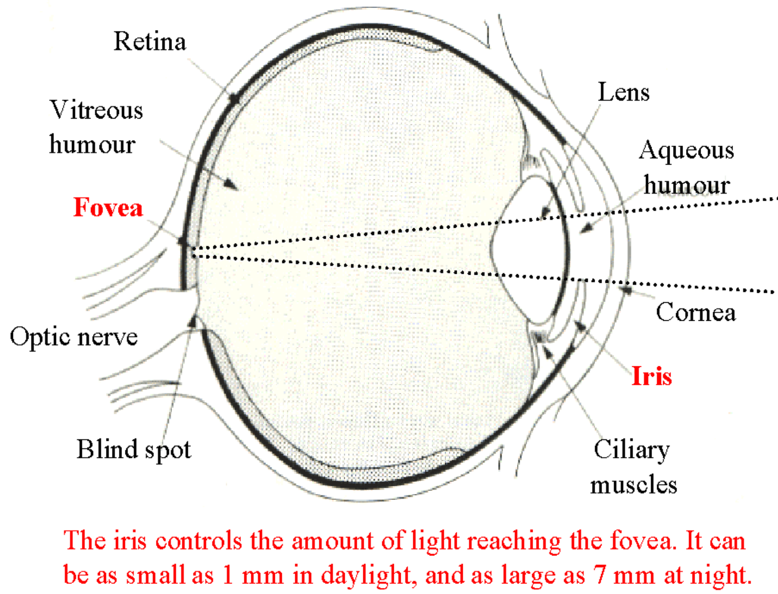
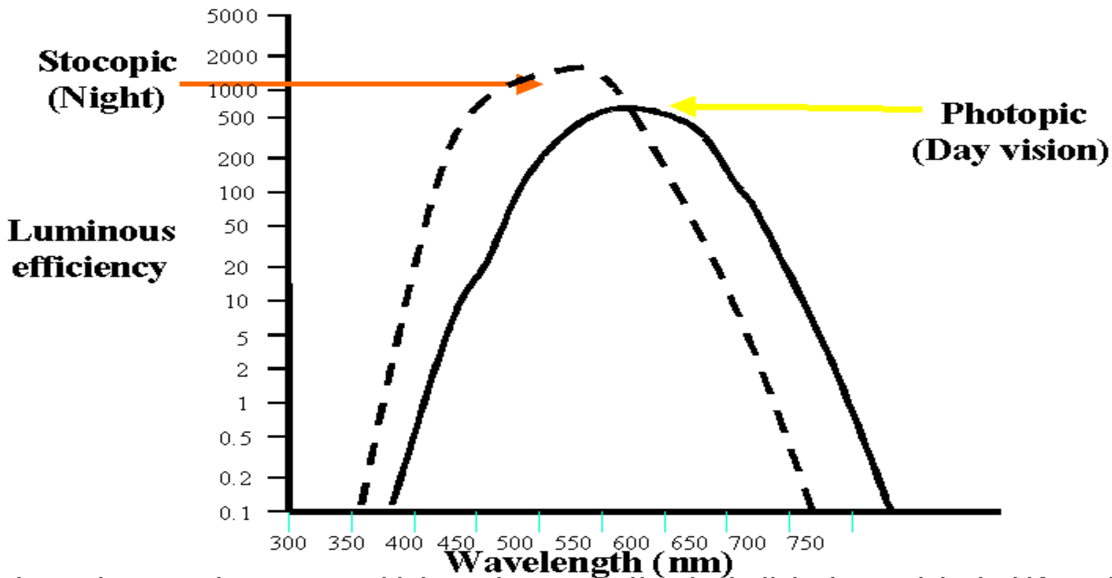


Figure 5 – The Human Eye

37. There are approximately 100 million rods but only 6 million cones and 1 million optic nerve fibres in the eye. Hence some of the nerve fibres are connected to very large groups of rods, which act to sum the effects of light over a comparatively large area of the retina. Only a small proportion of cones are connected by a single line to the brain, these being confined to the Fovea region and explain the high degree of visual perception when this region of the retina is employed.

38. **Day and Night Vision**. Daylight vision is also known as photopic vision and there is an associated photopic retina area that is composed almost entirely of cones. The photopic retina is capable of colour vision. Scotopic vision is associated with rod response and dominates at low light levels. The time taken for full dark adaptation depends on the change in lighting conditions, but is typically about 30 minutes from full photopic vision to the scotopic threshold. This is the time taken for the build-up of a sufficient concentration of the chemical Rhodopsin in the rods. The Rhodopsin is quickly bleached out by exposure to light leading to stimulation of the optic nerve.



The eye has an optimum responsitivity to the green/yellow in daylight; but at night, it shifts to the green/blue. The eye also has a large dynamic range, having a luminous efficiency ranging from .1 to 1500. Using red light during the night makes it difficult to be detected at long ranges, while illuminating the inside of a cockpit in green makes it easy for the operator to read the displays.

Figure 6 – Day and Night Vision

39. With the human eye, the ability to see detail in a scene deteriorates as the luminance decreases, until only large objects can be discerned, but not clearly recognized. Under low light conditions, because sensitivity for the dark-adapted eye is lower, peripheral vision using rods is more effective than foveal vision using cones. This has an important bearing on visual perception in night surveillance operations.

40. The ability of the eye to discern fine detail is produced by the cones. The range of response to luminance levels of the cones, known as the photopic response, is from 3 to 300,000 Candle Power. Below this level, the ability of the eye to discern details falls off quickly.

41. The rods are much more sensitive than the cones, but because many rods are connected to an individual nerve fibre, they are usually unable to discern fine detail. On the other hand the interconnection of the rods allows the signal to be integrated over larger areas of the retina, thus improving the signal to noise ratio. The signal to noise ratio refers to the ratio of useful information to false or irrelevant information.

SHORT RANGE SYSTEMS

42. **Optical Instrument Design**. The purpose of an optical instrument is to improve the performance of the eye by making sighting more precise and by improving the detail perceived in the observed scene especially under low light conditions. Some magnification of the object makes targets more easily identifiable but FOV is usually reduced in proportion, aiming errors are increased and, if the magnification exceeds the diffraction limit of the lens, no further enhancement of detail is possible. The diffraction limit is a fundamental limitation on the quality of the image, which applies no matter how well the lens is designed or manufactured. In fact, an optical sight of unity power, on a rifle, has advantages over the unaided eye in that it superimposes a sighting mark exactly on the image plane and thus eliminates the necessity of trying to aim a foresight on a distant target through a backsight aperture.

43. In any optical instrument design, the magnification has to be considered with all other interdependent factors, which often leads to a compromise. In general, relatively low magnifications and larger FOVs are used for surveillance instruments such as binoculars, whilst relatively higher magnifications and smaller FOVs are necessary for target acquisition. This is because a relationship exists between FOV, objective distance and magnification. In general the smaller the FOV, the better the resolution that, combined with higher magnification, gives greater detail. With regard to surveillance, the critical factor is FOV, i.e., the wider the better. Lower magnification can give wider FOVs.

44. The problem of improving night vision can be stated simply: we need to increase the illumination level of the scene to a level at which the cones of the eye begin to operate and pick out enough detail to perform the required task. This can be done by illuminating the scene or by increasing the size of the lens of the instrument in order to collect more light from the scene. Table 2 shows luminance levels for various day and night situations.

ILLUMINANCE LEVELS IN CANDELA	
Clear Sunlight -	10,000
Good Interior Illumination -	100
Twilight -	10
Full Moon -	.01
Clear Starlight -	.00001
Overcast Starlight -	.000001

Table 2 – Illumination Levels

45. It can be seen for example that to enhance the brilliance of the scene from overcast starlight to twilight requires a gain of about 100,000 Candela[1]. Some enhancement of vision at night can be gained by the use of purely optical aids such as night binoculars. However, this improvement is limited and although it may be adequate in moonlight, it loses efficiency as the level of luminance decreases under starlight conditions. Ultimately the aid makes things worse as the minimum visual threshold is approached because of light losses in the optics themselves. To obtain significant improvement in vision at night, some type of electro-optical device is necessary to provide an image that is many times brighter than the scene when viewed with the unaided eye.

[1] The Candela is the foundation unit for the measurement of visible light (SI). It replaces the word Candlepower.

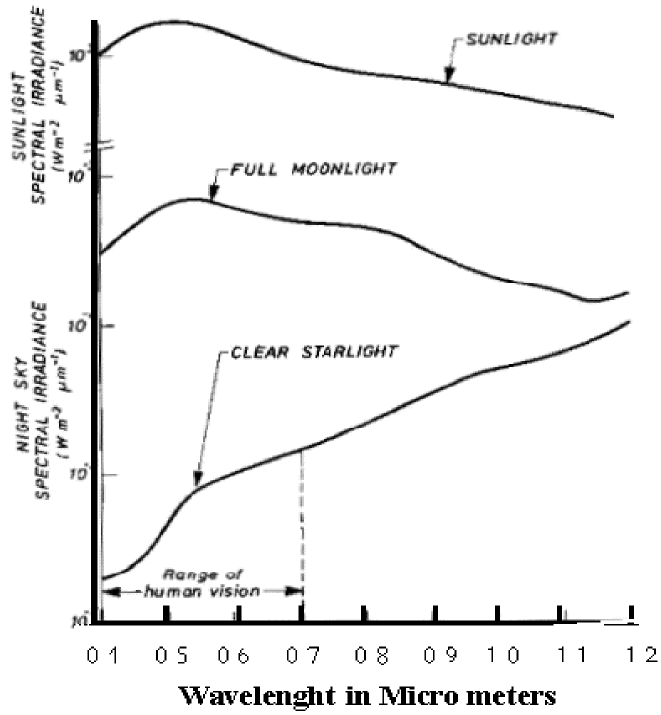


Figure 7 – Spectral Distribution of Sunlight and Night Sky

PASSIVE OPTICAL AND ELECTRO-OPTICAL SURVEILLANCE DEVICES

46. The main generic types of military equipment operating in the visual spectrum are:

a. telescopes,

b. periscopes,

c. binoculars,

d. optical weapon sights,

e. video cameras, and

f. visual display units (VDUs).

47. **Charge-Coupled Device (CCD)**. Most of our current imaging equipment uses CCD technology, which refers to the self-scanning imaging device (CCD) semiconductors at the heart of the devices. There are a number of limitations with regard to using CCDs. They are:

a. consume large quantities of power;

b. are more expensive;

c. inflexible in operation;

d. require an array of supporting circuitry to function;

e. limited in readout speed; and

f. affected by high read out noise (compromises CCD sensitivity at low light levels).

48. An alternative imaging sensor technology is Complimentary Metal Oxide Semiconductors (CMOS). This technology, in relation to CCD imaging, offers the following advantages:

a. lower power usage/requirements;

b. more functionality on chip results in savings in size and complexity;

c. cheaper to manufacture;

d. more flexibility in image application;

e. higher quality imaging; and

f. faster readouts.

49. Both of these technologies will continue to exist into the foreseeable future. They both provide high performance but with higher developmental costs in most CMOS than CCD technologies. One area of clear advantage to CMOS technology is in reduced power consumption. In terms of future trends, CCDs will tend to focus on high performance, low volume applications while CMOS will go in the direction of low cost, high volume applications.

50. **Periscopes**. From the days of trench warfare in The First World War and even before, periscopic devices have been used to see 'around corners'. Today these are very sophisticated devices indeed, utilizing light sinks and/or optical fibres to obtain very high-resolution images in the visual spectrum. A good current example is the prism periscope mounted in the LAV III APC for use during hatches-closed operations. In the near future, periscopes using Head Up Display (HUD) techniques combined with next generation electro-optics and holography technology will allow operators inside fighting vehicles not only to see the field of vision covered by the periscope but also have situational awareness data presented in the same vision. One technique that is being investigated is Immersive Visualization. This is where imagery is gathered around a full 360 degrees using a panoramic camera. Using Global Positioning Systems (GPS) and pan-tilt orientation information, the vehicle pose and orientation are determined, and symbology to represent navigational and tactical information is injected into the imagery on a Head-Mounted Display to give a "glass turret" sensation.

51. **Binoculars**. Binoculars are two connected telescopes of relatively low magnification with a generally wide FOV. They work by using a large lens, called the objective, to gather visible light, which is focussed into an intermediate image that is then magnified by a lens next to the eye, called the eyepiece. Between the objective and the eyepiece, there are one or more prisms used to direct the light and to make sure we are viewing the image the right way up and in focus. A graticule is placed in the focal point of one of the eyepieces to assist in measuring lateral distances and altitudes.

52. Ideally the emergent beam from the eyepiece, which focuses at where the eye is to be, is matched to the eye's pupil diameter; in this way maximum image information is transmitted into the eye. In daylight, the pupil diameter is about 1 mm. At night, it expands up to 7 mm. It is therefore important to optimize your binoculars for a specific employment scenario. Normally, we compromise the optics in favour of twilight operations.

53. In general, the greater the magnification, the smaller the field of vision, hence:

a. for surveillance we use relatively low magnification, about, (x 7); and

b. for target identification, we use high magnification (x 15).

54. Binoculars have, of course, limitations, the most significant being very limited poor weather capability and limited performance at night. However, remember that if the eye can resolve to 3 mils at night, then magnifying the image by x 6 will enable resolution to 0.5 mils. Don't discount binoculars as a night surveillance aid.

55. **VDUs**. These are found everywhere today and what they display and how well they display it are important issues. VDUs are interposed between the eye and the processed data derived from a given sensor. Therefore, there is an inherent loss of information due to the process of converting this data into a visual display. This loss of information is brought about by a number of factors such as low sampling rates, jitter and distortion of video signals. This information loss must be minimized through the use of appropriate materials, filtering and other techniques. All of the factors that influence the effectiveness and efficiency of other optical devices in the visual spectrum must be taken into account when these devices are designed and employed. A critical element is the size of the collecting aperture. The larger it is, the more information is available to be processed by the imager or the brain.

56. There are two types of passive electro-optical surveillance devices. One uses the ambient visual light plus some of the night sky radiation reflected from the scene, and the other uses the thermal radiation emitted by objects. The former are known as IIs, that is, they amplify the available ambient light to a point where objects are readily visible to the human eye. The latter are known as TIs. These detect minute differences of temperature between a given object and its background. These systems will be described later in this section.

WHITE LIGHT AND ACTIVE INFRARED

57. On the battlefield, white light is produced using searchlights, flares and illuminating shells. All these systems are active, which is the major limitation of white light. Cost, mix of ammunition natures and the effect of white light on our electro-optic sensors on the battlefield are additional considerations to take into account when white light is used. The following chart illustrates a number of characteristics of current illumination means on the battlefield:

SOURCE	CANDELA	BURN TIME	FOOTPRINT
LAV III MAXA BEAM SPOTLIGHT	6,000,000		NOTE: PORTABLE WITH IR FILTER
ARTY 155 MM ILLUM	1,000,000	120 SECOND	1,000 M
ARTY 105 MM ILLUM	450,000	60 SECOND	800 M
MORTAR 81 MM ILLUM	500,000	30-60 SECOND	1,000 M
TRIP FLARE M49 A1	40,000	55-70 SECOND	275 M
C3 HAND HELD PARA FLARE	30,000	30-35 SECOND	250 M

Figure 8 – Examples of White Light Illumination on the Battlefield

58. Active IR works in the same way as white light but uses the near IR region of the EMS, out to about 1.1 micron wavelengths. Active IR relies on an IR light source, perhaps an IR filter placed in front of a searchlight or a headlamp to provide IR illumination. This is easily detected by passive IR detectors and II systems. Such systems were useful before the advent of II and TI, but are now obsolete.

NEAR VISIBLE WAVELENGTH SENSORS

59. II systems use an electronic process to amplify light. This amplification can be up to 100,000 times. The process works as follows: packets of light energy, or near-IR radiation, called photons, that reach the objective lens are focused onto the front of a glass tube. This surface is coated with a photo-emitting material, a material that emits electrons when struck by light. This is called a photocathode. The electrons are accelerated by an electric field through an electronic focusing system. The electrons hit a luminescent screen at the far end of the tube producing a visible picture. This screen is similar to a TV screen.

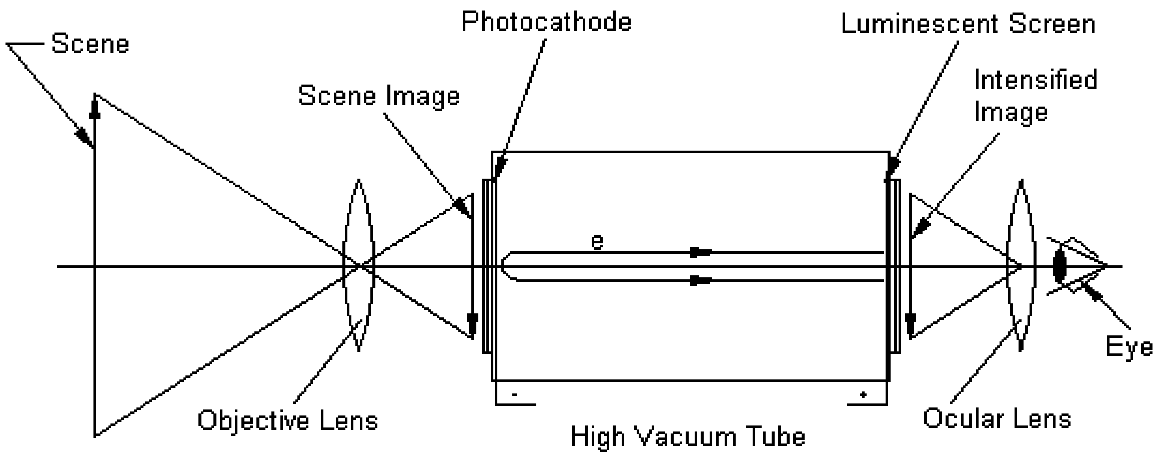


Figure 9 – Basic Principle of Image Intensification

60. **Advantages and Disadvantages of IIs**.

a. Advantages:

(1) excellent low light sensitivity;

(2) enhanced visible imaging yields best possible recognition and identification;

(3) high resolution;

(4) low power and cost; and

(5) ability to identify personnel.

b. Disadvantages:

(1) because they are based on amplification methods, some light is required. This method is not useful when there is no light;

(2) inferior daylight performance; and

(3) possibility of blooming and damage when observing bright sources under low light conditions.

61. **Photoemission**. The photocathode is made from a substance that releases electrons when it absorbs electromagnetic radiation. This process is known as photoemission.

62. There is no photoemission if the frequency of radiation is below a certain threshold. In addition, the energy of emitted electrons depends only on the frequency of the radiation. Also, the number of electrons emitted per second is proportional to the intensity of the radiation. The equation which gives the energy of emitted electrons is shown below, where **E** equals the energy of emitted electrons, **f** is the frequency of incident radiation, **h** equals Planks constant and **W** is the work function of the photo-cathode in electron volts:

$$E=hf-W$$

63. The minimum incident frequency necessary to cause the emission of electrons from the cathode occurs when **hf=W**. All frequencies above this threshold will produce some visible photons to appear at the eyepiece.

64. **W** is called the work function and for metals is relatively high, and **f** lies in the ultra-violet portion of the EMS. To get photo-cathodes that work into the IR part of the spectrum requires materials with much lower work functions than simple metals. In practice, photo-cathodes are made up of layers of several elements of low work function that act as semiconducting layers. Sodium, potassium caesium and antimony have all been used. One of the best materials, frequently used for military applications, is Cesiated Gallium Arsenide.

65. **The Phosphor Screen**. In IIs, electrons released at the photo-cathode are accelerated by an electrical field of about 15 KV and directed onto a phosphor screen of Cadmium Activated Zinc Sulphide. The high-energy electrons excite the cadmium atoms that radiate their excess energy as fluorescence in the visible portion of the spectrum. Thus, at the phosphor, there is a point-by-point correspondence with the IR image at the cathode. The initial IR image has now been converted into a visual image. The intensification of the image has come about because the acceleration of the electrons through 15 KV gives them enough energy for each electron to activate many cadmium atoms. For each photon of IR energy at the input, there are many photons of visible energy at the output.

66. **Types of II Devices**. We will look at several types of II devices:

a. Cascade IIs (First Generation),

b. Microchannel Plate Intensifiers (Second Generation), and

c. Third Generation concept.

67. ‘First Generation’ devices consist of three of the tubes already described, linked end to end to achieve the required amplification of light. Older (pre-1970) II systems are of this type. They are bulky and tend to ‘white-out’ if a bright object such as a flare is viewed. In more recent tubes, this latter problem has been much improved by an auto-brightness control.

68. ‘Second Generation’ devices have a thin (0.5 mm) honeycomb-like (micro-channel) plate between the focusing guide and the phosphor screen. They are a later development than cascade systems and achieve a similar gain to that of the old three-stage system but in one stage. The tubes are less prone to ‘white-out’ and are much less bulky. Figure 10 demonstrates the concept of operation.

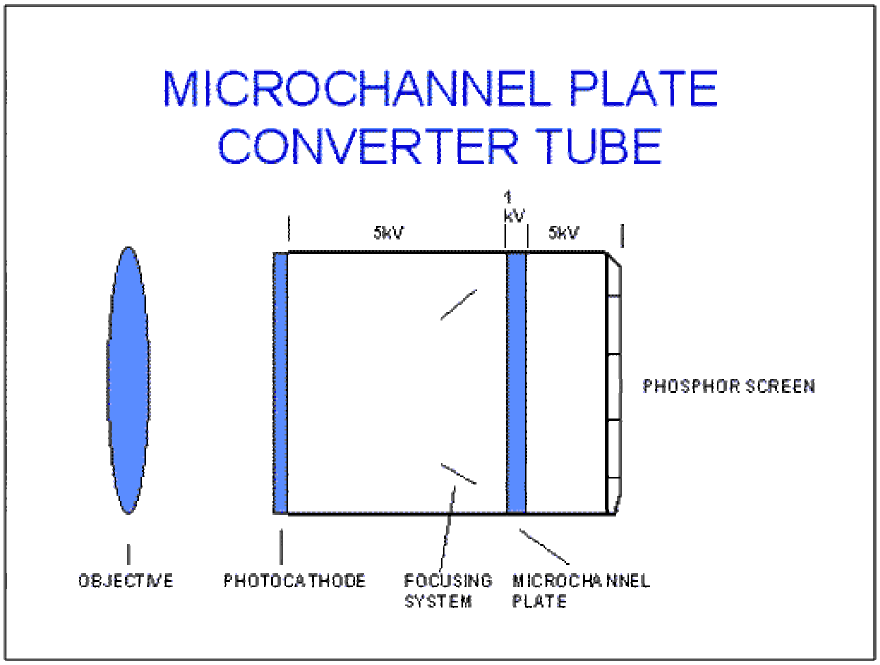


Figure 10 – Micro Channel Plate Converter Tube for Second Generation II

69. A Third Generation tube differs from a Second Generation tube by having a Gallium Arsenide photo-cathode that is particularly responsive to starlight radiation, thereby providing improved performance.

70. There are a number of II devices in the Canadian Forces (CF) inventory. Some examples are:

a. AN/PVS-502 - Night Vision Set, with a range of 300-500 m;

b. AN/PVS-503 - Second Generation Night Vision Set;

c. AN/YVS 502 - Medium to long range Night Observation Device mounted on crew-served weapons, with a range of 2,000 m; and

d. AN/VVS 501 - Second Generation Viewer for Night Driving and Observation.

71. Figure 11 shows the spectral response of the IIs according to the detected wavelength and the level of II generation.

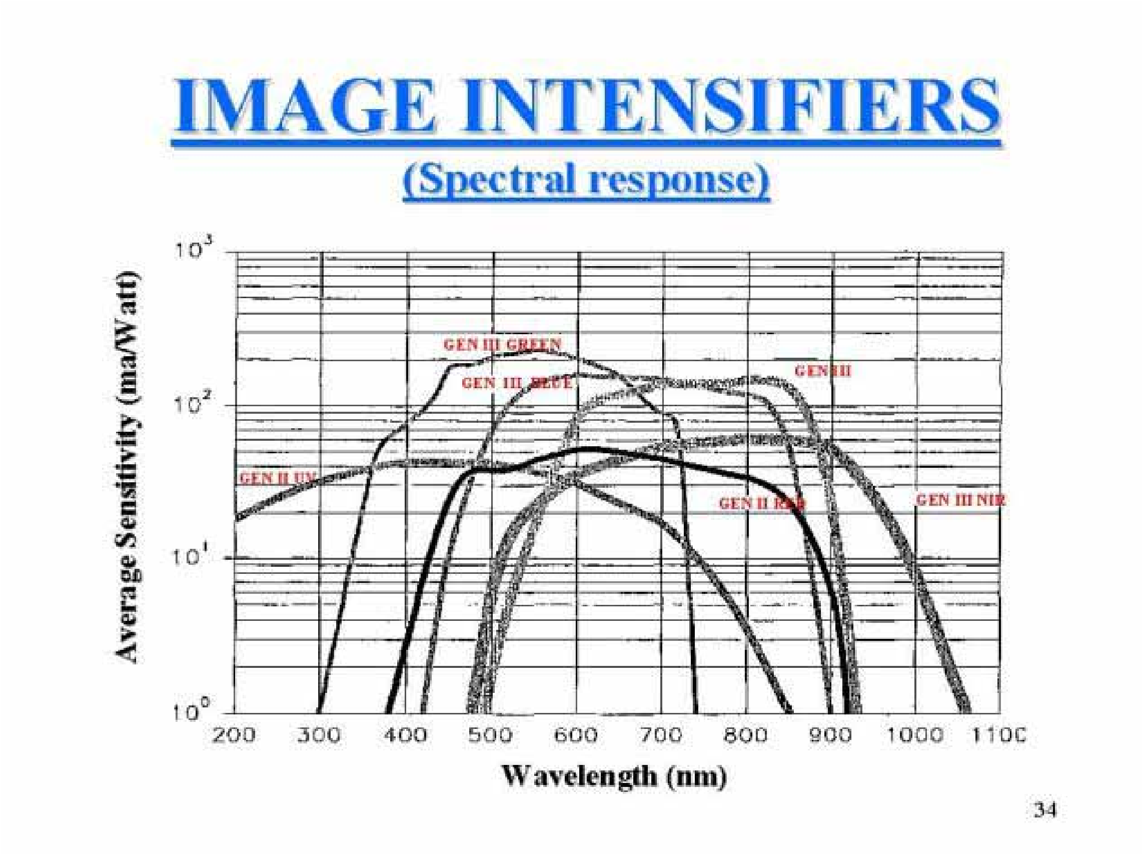


Figure 11 – II Spectral Response

72. We have mentioned two limitations of the cascade system, namely bulk and 'white-out'. All II systems have two further limitations. They are prone to the same poor weather limitations as the eye. To achieve longer ranges, very large objective lenses are required to gather the available light.

73. However, II devices have the merit of being passive and they are relatively small. Therefore, they can be used as small arms weapons sights. The Common Weapon Sight (CWS) weighs 1.1 kg and will recognize a man at 600 m in clear starlight.

THERMAL IMAGING

74. Emissivity Equation

$$M=gT^4$$

$$M=egT^4$$

75. Radiation emitted by an object is proportional to its temperature to the fourth power. The radiant emittance for a black body (perfect emitter) is given by the first equation shown here, where "**g**" is a constant (5.6697x10 to the 12th) and **T** is temperature in degrees Kelvin (K).

76. Since real emitters are not perfect emitters, their emittance is given by **M=egT** to the fourth, which is the second equation, where "**e**" equals the effective emissivity for that material. This tells us that the amount of energy radiated or emitted by a material depends on the type of material. Even if your temperature is equivalent to the ambient temperature or your background, the difference in emissivity of the materials can be enough to get you detected. Selection of the most appropriate materials consistent with the role and mission of the object in question is necessary.

77. TI systems are used in fighter aircraft, patrol aircraft (CP140) and helicopters in an application known as FLIR or Forward Looking Infrared. They are also used in tanks, LAVs, air defence, aboard ships and as part of the guidance system in weapons systems such as second generation TOW especially in poor weather conditions and night-time firing. The system detects the differences in levels of IR radiation radiated by all objects above absolute zero in temperature. The hotter the object, the more the radiation emitted. A body at 700 degrees Celsius (973 degrees Kelvin) peaks in radiation at the radiated wavelength 3 micrometres (or in the near IR band), while the human body at 20 degrees Celsius (293 degrees Kelvin) emits most strongly at the wavelength of around 10 micrometres or in the far IR band.

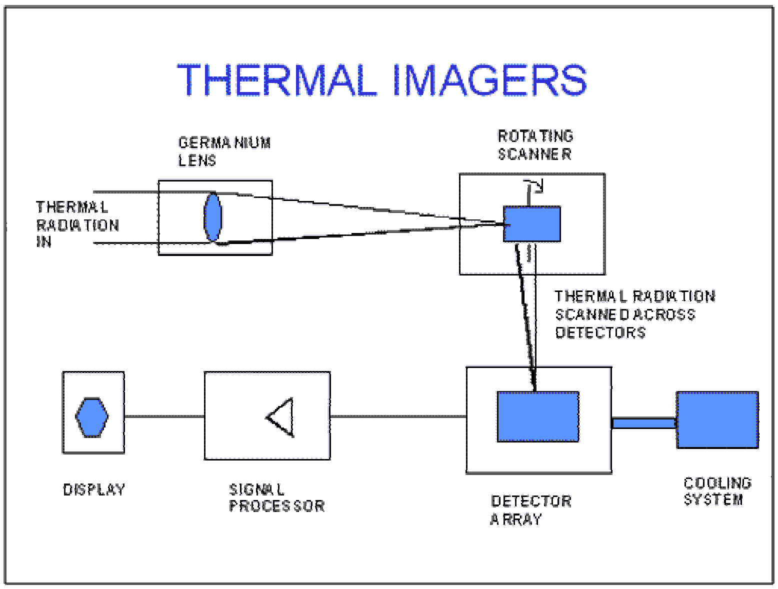
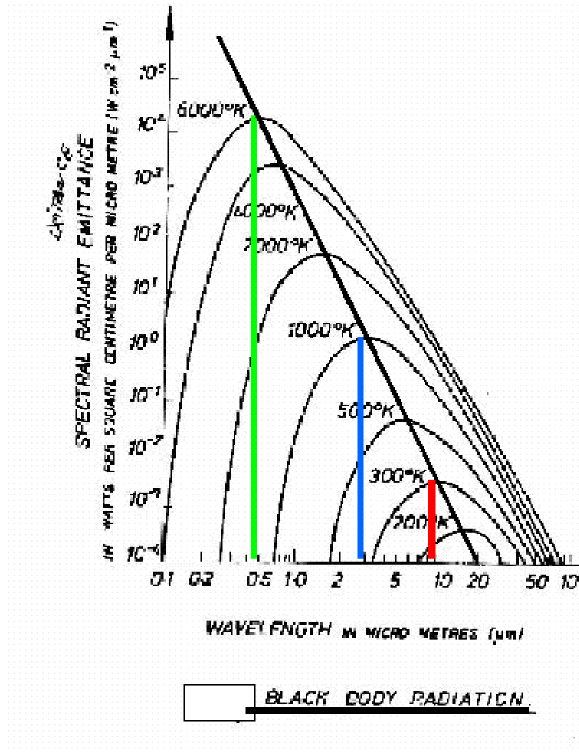


Figure 12 – TI (Note)

78. Figure 13 shows that, as the temperature of the radiating body increases, the peak frequency of radiated electromagnetic energy increases and the wavelength decreases. The sun peaks at the visible waveband.

NOTE: Some detectors are now uncooled (explained in paragraph 81).



This chart demonstrates the relationship between the radiation temperature of a perfectly radiating body (Called black body) and the peak wavelenght at which it radiates.

A body at 300 K (your own body per example) radiates energy at wavelenghts varying from 3 microns up to about 50 microns, with the peak at about 9 microns. This is in the far infra red where your thermal imagers operate.

At 1000K, the exhaust of an aircraft, the radiation peaks at about 3 microns, the near infra red. Side Winders missiles work in that band.

Finally, the sun at 6000K peaks at about 4 microns. The colour green.

To find the peak wavelenght, use this relationship:

Temp (K) X Peak wavelenght = 2897

Figure 13 – Relationship Between Temperature and Radiated Wavelength

79. The atmosphere absorbs most of this radiation, but there are two transmission windows in the 3-5 micrometre and 8-13 micrometre bands. Detectors working in the 3-5 micrometre band are more suitable for the detection of hot bodies such as jet engines and vehicle exhausts, while relatively cold targets such as people and cold vehicles can be detected in the 8-13 micron band. An explanation of this phenomenon is given below.

80. Cadmium Mercury Telluride (CMT) is the most useful material for high-resolution TI because it is sensitive to a broadband of IR wavelengths (from 2-14 micrometres) and can detect very small differences in temperature. Because CMT is so sensitive to IR, it must be cooled to 77 degrees Kelvin to eliminate thermal noise, that is the background heat that would generate a current in the detector, swamping the picture of the scene. Cooling is achieved by liquid nitrogen.

81. There are now uncooled detectors. These detectors operate at or near room temperature. When IR radiation from night-time scenes are focused onto uncooled detectors, the heat absorbed causes changes to the electrical properties of the detector materiel. These changes are then compared to baseline values and a TI is created. Although uncooled detectors produce lower image quality than cooled detectors, uncooled technology has resulted in smaller and less costly detectors.

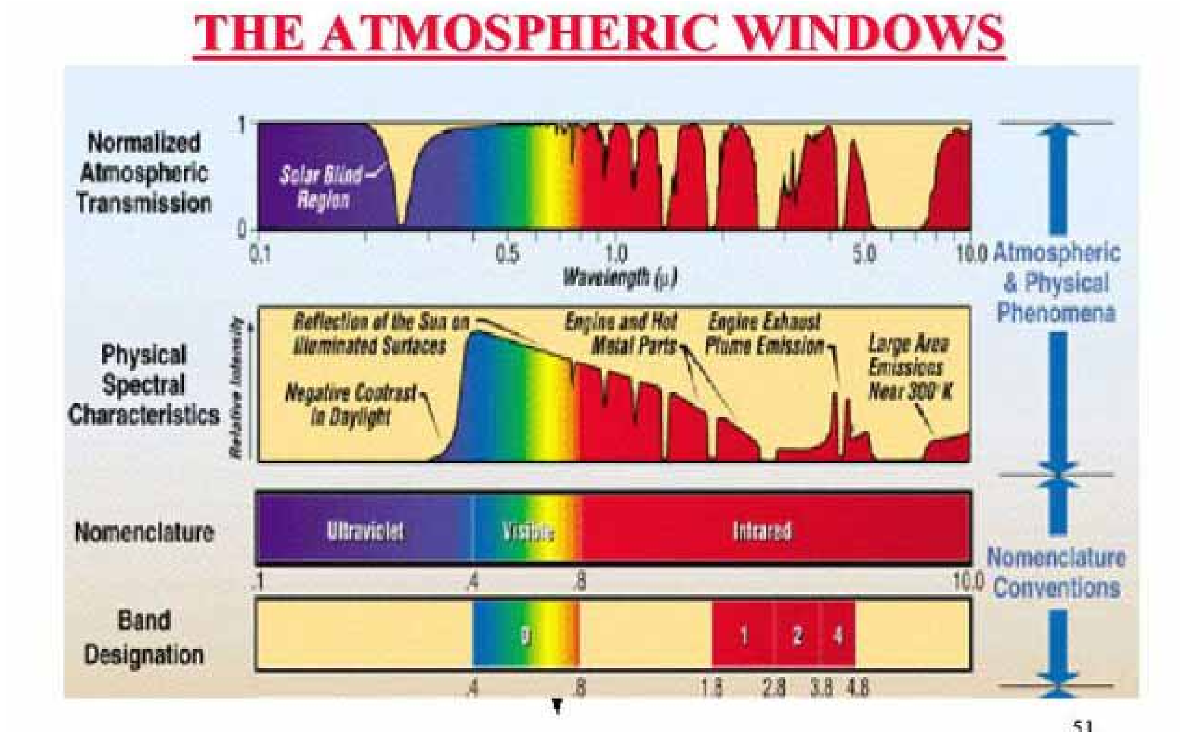


Figure 14 – Atmospheric Windows

82. **Absorption**. Earlier, we made reference to the two useable bands of IR for TI. This occurs because the molecules of the atmosphere absorb electromagnetic radiation at characteristic wavelengths. In the case of the atmosphere, the chief constituents which absorb strongly in the IR bands are carbon dioxide, water vapour and, to a lesser extent, ozone. There are certain bands where the atmosphere is very absorbent. In Figure 14, the higher the coloured section at a given frequency, the better the wave propagates in the atmosphere. One peak comes in the visible spectrum and two in the IR, approximately from 3-5 microns and from 8-13 microns.

83. Clearly, any thermal system must operate in one of these windows for efficient transmission. In the context of transmission, it is vital to use components such as lenses that are transparent over the wavelength range used. It is worth noting that glass is of no use at all since it is completely opaque to radiation of wavelengths greater than 2.7 microns. There are, however, a number of materials that are transparent to IR radiation. The most commonly used is germanium, which is also very expensive. Detectors were first developed which operated in the 3-5 micron band and it is only recently that the use of CMT has allowed the exploitation of the 8-13 micron band. TI devices working in the 3-5 micron band need cooling to temperatures that can be achieved by electrical methods. However, TI devices for battlefield use in the 8-13 micron band require cooling to very low temperatures. This is achieved by immersing the back of the detector in a liquid gas, which is allowed to boil to ensure a steady temperature.

84. The lenses that collect and focus radiation on the scanner are made of germanium, because glass is a poor transmission medium for IR radiation in the useful band. The scanner is a rotating polygonal mirror that scans across the target and reflects the image of the target onto the detection array. The ideal detector is one consisting of a mosaic of elements. Attaining a resolution of 0.5 milliradians and a FOV of 20 degrees requires about half a million detectors,

each with its own preamplifier. A typical cooled CMT detector includes 150 elements, each 50 micrometres square.

85. During scanning, the signal from each element is preamplified, delayed and added to the signal in the following element. When the last element is reached, all the signals are added together, further amplified and visually displayed. Each line on the display is made up of several hundred scans of the detector. With this type of detector, the preamplication, delay and summation circuits are external, so leads from each of the elements have to come out of the detector. This produces complex and bulky circuitry.

86. SPRITE (Signal Processing In The Element) detection is a concept replacing the detecting array and its external processing circuitry. In place of the many separate elements of CMT (each with its own output wire, preamplifier and delay unit), there is on each a single, much larger strip with a single output wire and preamplifier leading to the visual display.

87. Staring arrays are weapons guidance sensors (usually IR light sensing) that have a fixed pointing direction and optical system. They are now the norm for IR detectors. These allow for a complete image to be captured in one view by the multiple sensor arrays involved in the detection process. Mosaics called Large Format Emitter Arrays of 1024 x 1024 sensors are already available and 1024 x 2048 format sensors will be available in the future.

88. TI devices are passive, in the sense that they do not emit a signal. However, they do have a signature that can be picked up by another TI. The cold spot of a cooled photon detector can be detected against the normal background level of radiation.

89. Unlike II, TI devices do not depend on ambient light, so they can operate by day or night. Therefore, they can be used to see through obscuration such as smoke or camouflage designed to defeat visible light devices.

90. Typically, a man portable TI device should allow recognition of a tank at about 2 km and larger systems might achieve the same to 4 km.

LOW LIGHT TELEVISION

91. Low Light Television (LLTV), while still used, is not competitive with more advanced sensors utilizing TI technology. The system consists of a high resolution TV camera that is attached to a light intensification device (II device). Some systems also use active laser illumination to enable the camera to ‘see’ the target. TV images are transmitted to the control/display unit via wire or radio.

92. LLTV systems are generally good in low illumination environments down to starlight. The difficulty is that they can be defeated by anything that can defeat the human eye. Therefore, their utility on the battlefield in all conditions and subject to normal obscuration is quite limited.

93. **Long Range Sensors**. The modern battlefield commander has a vision of a knowledge-based and command-centric organization capable of continuous adaptation and task-tailoring across the spectrum of conflict. This is made possible by concepts such as Network Centric Warfare, an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers and shooters to achieve shared

awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization.

94. Given the limits of the human senses and those imposed by ground and vegetation, there is a requirement for a range of systems and concepts to provide full coverage of a commander's area of interest. We will examine the following sensors:

a. trip wires,

b. acoustic sensors,

c. electromagnetic sensors,

d. motion detectors, and

e. unmanned aerial vehicles (UAVs).

TRIP WIRES

95. At the low-tech end, the trip wire remains a very simple yet effective method of detecting an intruder. Today's trip wire systems, such as the "mini-break wire detector" incorporate an electrical circuit that transmits an audible signal when the deployed wire is disturbed. Trip wires can also be attached to lighting systems or a range of pyrotechnics to help alert friendly forces to intrusions.

REMOTE GROUND-BASED SYSTEMS

96. A remote ground-based system (RGS) consists of three elements:

a. a sensor,

b. a communication link, and

c. a control station.

97. The sensors are a combination of:

a. acoustic,

b. electromagnetic,

c. IR radiation,

d. seismic, and

e. magnetic.

98. Sensors can be designed to detect energy in any part of the EMS. Advances in computing power and miniaturization have allowed the design of intelligent sensors that can switch on or off, on command or on a timed basis. They can discriminate between signals to recognize specific targets, trigger other sensors and count targets. An example is shown in Figure 15.

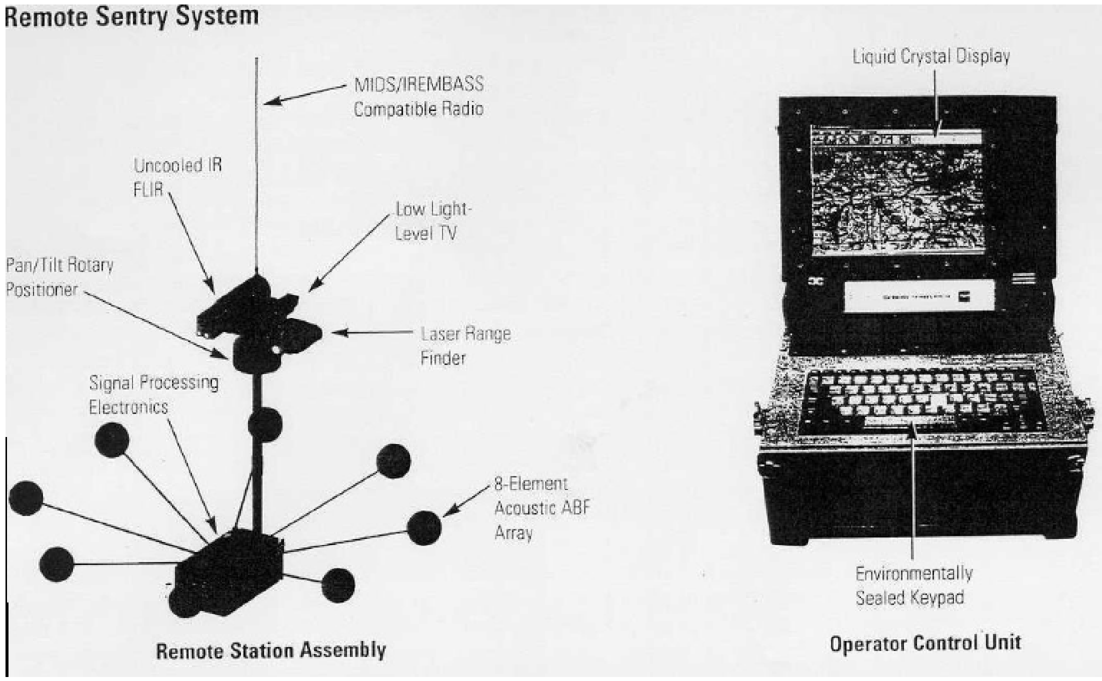


Figure 15 – REMBASS Remote Ground Sensor

99. The communication links may be line or radio. The communication links are used to transmit data from the sensors to the ground station, and the other way around. The link can be used to set the sensors on or off, to transmit information to make a decision at the ground station and to keep track of the sensors operational status. This link can be analog or digital and can transmit information from simple bits to a real-time video clip.

100. Modern control stations have the ability to control a number of different sensors and to use the data they provide to present information in a readily useable form.

ACOUSTIC SENSORS

101. **Sound Ranging**. There is a wide range of acoustic sensors that can be employed either individually or in conjunction with other systems. Examples of unattended multi-sensors incorporating acoustics are the wide area munition and REMBASS. An array of acoustic sensors can be set up to detect and locate activity such as firing artillery or moving vehicles.

102. In this application, three or more sensors along the sensor line are used to triangulate and locate the object producing the noise. The CF has one such acoustic sensor array, illustrated in Figure 17, with the artillery in CFB Gagetown.

103. Because the Doppler shift in frequency produced by moving objects can be readily converted to audible sound (see example below), acoustic devices can also be incorporated in radar sensors. Different moving objects have distinct Doppler signatures and therefore trained operators are able to identify moving personnel, wheeled and tracked vehicles. An example of this technology would be the Man Portable Surveillance and Target Acquisition (MSTAR) radar in the COYOTE.

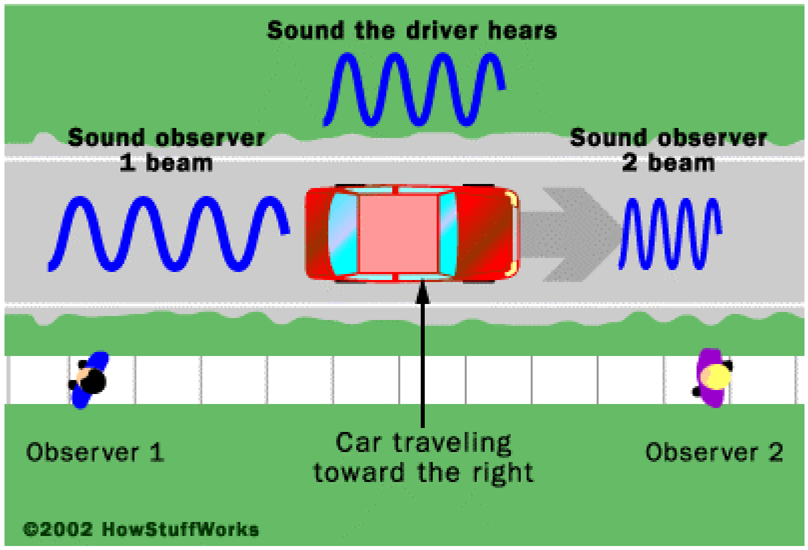


Figure 16 - Explanation of the Doppler Shift

ELECTROMAGNETIC SYSTEMS

104. There are a wide variety of sensors utilizing the electromagnetic principle. Basically the sensor cable is buried around the perimeter of the site and connected to a detection unit. The detection unit generates a radio frequency signal. The result is an electromagnetic detection field that goes along the length of the cable, to create a zone of detection above and below ground up to approximately three feet in height. If an object with a large enough mass, i.e., humans or vehicles, enters the field, the signal is changed. The detection unit then generates an alarm. Common nuisance alarm sources such as small animals are ignored.

105. The Racal CLASSIC Unattended Ground Sensor (UGS) System will be used to familiarize you with seismic, IR and magnetic UGSs, since one of these systems has been purchased by the CF.

106. The CLASSIC remote sensor system consists of eight sensors which report via burst radio signals to a monitor. The standard sensor has a detachable geophone that picks up vibrations in the ground and passes signals to a processing unit. The processing circuit recognizes from the type of signal whether the intruder is human or vehicle. An external IR sensor is also available. This detects heat from the target. It has two FOVs, which allows both

Figure 17 – SORAS 6 Sound Ranging System

detection and direction. A magnetic sensor is part of the system and detects variations in the local magnetic field caused by the passing of metal objects.

107. The seismic geophone is a single axis device to detect vertical ground motion. The unit consists of a coil suspended between the poles of a permanent magnet. Ground vibrations move the case assembly, while the coil remains stationary. This relative motion induces a voltage in the coil. Its range is 5-10 m. The IR transducer detects the passing of personnel and vehicles by passively assessing the temperature difference between the object and the background. This is done in the 3-5 micron band. The range of the seismic sensor is 3-30 m. The magnetic detector functions by detecting changes in the local magnetic field caused by metallic objects. Its range is 5-15 m. Information on intruders detected by the sensors is relayed to a monitor, which can handle up to two messages from each of the eight sensors simultaneously. Sensor configuration can consist of any combination of types, to a maximum of eight.

TETHERED PLATFORMS

108. There are a wide variety of tethered platforms. A generic example is a rotor powered tethered vehicle that mounts a variety of sensors including radar, LLTV, IR, TI and electronic warfare (EW). Such platforms can be flown in steady winds. They generally have impressive endurance, since fuel is supplied through the tethering cable, which is also used for transmission of control, monitoring and sensor signals. A common method of driving the rotors is the ejection of compressed air at the blade tips of the rotors. This reaction propulsion system eliminates the need for a tail rotor. The platform is flown at altitudes up to 300 m that gives a radar range of about 50 km depending on the terrain.

109. Another example of an in-service system is the United States (US) Aerostat Radar System. The tethered Aerostat Radar System is a balloon-borne radar system that is in use to provide low-level radar surveillance data in support of federal agencies involved in the drug interdiction programme. The Aerostat general characteristics are:

a. function - low-level radar aircraft detection;

b. tether length - 25,000 feet;

c. payload weight - 1,200-2,200 pounds;

d. maximum detection range - 200 nautical miles; and

e. winds - can be used in winds below 65 knots.

110. This low cost radar system is generally only limited by the weather (US experience is 60 per cent availability).

UNMANNED AERIAL VEHICLES

111. Two recent developments, namely the Global War on Terror and the dramatic change in battlefield concepts have resulted in changes to weapons and equipment. One area of dynamic change is that of UAVs. The future battlespace is envisioned as having characteristics such as: operations expanded in speed and space, non-linear and dispersed, linked sensor, manoeuvre and shooter platforms, common data, operational picture, decisive information operations, faster decision making and combat, simultaneous and compressed in time. One equipment that has had

growing success in the Global War on Terror and can greatly assist operations on the future battlespace is the UAV.

112. UAVs are becoming more capable and effective, with ever expanding mission sets. UAVs were originally limited to peripheral roles on the battlefield. They are now being seen as viable or preferred alternatives to manned missions. The UAV is being used for long-endurance patrols and are continually creating new and specialized roles from target acquisition for strike aircraft to real-time surveillance for task forces such as the Canadian Sperwer in Afghanistan.

113. There are many sizes and differing capabilities amongst the current range of UAVs being employed by military forces. There are five generally acknowledged classes of UAVs. They are:

a. High Altitude Long Endurance (HALE), i.e., US Global Hawk;

b. Medium Altitude Long Endurance (MALE), i.e., US Predator;

c. Tactical Unmanned Aerial Vehicles (TUAV), i.e., Canadian Sperwer;

d. Mini UAVs, i.e., US Silver Fox; and

e. Micro UAVs, i.e., Israeli Mosquito.

114. The Canadian Army does not have the roles or requirements that would justify HALE and MALE UAVs, but our current concepts and requirements would see us using TUAVs in support of Task Forces, and Mini UAVs for reconnaissance detachments. One of the key aspects of the ISTAR Project was the procurement of the CU-161 Sperwer TUAV system, that was subsequently used in Afghanistan. Additionally, Canada is looking at acquiring some form of mini UAV for battlefield applications.

115. A UAV system is composed of four main components: a control system, communications system, payload and one or more air vehicles. The control systems for UAVs vary according to the size and role of the vehicle. It may be as small as a laptop computer with a control program to shelters or vehicles with large displays to track and control the aircraft.

116. One of the critical aspects of UAV operation is the communications architecture. This system is responsible for not only the command and control (C2) of the aircraft but also the relay of imagery or sensor information. The capabilities of the UAV platform will determine what type of communications are required. For short range, line of sight (LOS) radio communications will normally suffice, but for long range, beyond line of sight (BLOS) communications, satellite or radio relay will be required. In fact, for BLOS UAVs, there may be a very complex communications structure, especially if data, or imagery is being sent from the UAV to a ground station in theatre, strike aircraft in the air and back to a national headquarters.

117. One of the major operational difficulties of UAV operations is the maintenance of useable or sustainable data links. The higher the frequency of this link, the more critical is the requirement for an unobstructed path between them. The choice of frequency is governed by the amount of information that the link is required to carry. TV and TI sensors require a broadband or high information link and therefore a higher frequency than IR or moving target indicator (MTI) radar sensors. Clearly, the lowest possible frequency consistent with the required data rate should be chosen to reduce this problem.

118. As much as the variety and performance of UAV platforms is expanding, so are the types of missions that they are employed on. Traditionally, UAVs were tasked with standard missions such as long range surveillance, monitoring hazardous conditions or target acquisition. As a result of the changes brought about by the end of the Cold War, the changing makeup of western militaries and the ongoing Revolution in Military Affairs, UAVs became much more capable at a very opportune time. Since the 1990s, there has been a widespread increase in the roles and use of UAVs in western militaries.

119. The following list, although not exclusive, does illustrate a growing list of UAV missions:

a. reconnaissance,

b. signals intelligence,

c. mine countermeasures,

d. target acquisition/designation,

e. battlefield management,

f. chemical/biological reconnaissance,

g. EW,

h. combat SAR,

i. communications/data relay,

j. information warfare,

k. digital mapping, and

l. bomb/missile delivery(Predator/Global Hawk).

120. As mentioned in paragraph 112, there are five general classes of UAV. The following is a listing of characteristics of specific UAVs in each of the five classes:

a. **HALE - US Global Hawk**.

(1) wingspan - 35.3 m and is 13.4 m long;

(2) flight weight - 11,612 kg;

(3) maximum altitude - 65,000 feet;

(4) range - 12,000 nautical miles (NM);

(5) speed - approximately 340 knots;

(6) endurance - 35 hours; and

(7) payloads - Synthetic Aperture Radar (SAR)/Ground Moving Target Indicator, electro-optical and IR sensors. Global Hawk can image an area

the size of the state of Illinois (40,000 square miles) in just 24 hours. Through SATCOM and ground systems, the imagery can be relayed in near real-time.

b. **MALE - US Predator**.

(1) wingspan - 49 feet, length 27 feet;

(2) maximum altitude - 25,000 feet;

(3) range - 400 NM;

(4) speed - aproximately 70 knots;

(5) endurance - 40 hours; and

(6) payloads - 450 pounds electro-optical and IR cameras and a SAR. The two-colour DLTV is equipped with a variable zoom, 19 mm to 560 mm. For comunications, the air-vehicle is equipped with ultra-high frequency (UHF), very high frequency (VHF) radio links, a C band LOS data link (range 150 miles) and UHF and Ku band satellite data links.

c. **TUAV - Canadian Sperwer**.

(1) wingspan - 4.3 m;

(2) length - 2.7 m;

(3) maximum altitude - 16,500 feet;

(4) range - 90-150 km radius;

(5) speed - 90-127 knots;

(6) endurance - 4-5 hours; and

(7) payloads - digital payload and data link, electro-optical and IR.

d. **Mini UAVs - US Silver Fox**.

(1) wingspan - 2.4 m;

(2) length - 1.47 m;

(3) weight - 10 kg;

(4) maximum altitude - 12,000 feet;

(5) range – C2 range 36 km;

(6) speed - 38-110 knots;

(7) endurance - 8-10 hours; and

(8) payloads - 5 pounds electro-optic, IR (uncooled) C2 Radio 2 watt Frequency Agile Military Band. Video Transmitter 2 watt S Band FM video TX with optional 19.2 kbps Data Carrier.

e. **Micro UAV - Israeli Mosquito**.

(1) wingspan – 30 cm;

(2) maximum altitude - tree top;

(3) range - typical operational area 1 km x 1 km;

(4) endurance - 40-60 minutes; and

(5) payload - real-time imagery of restricted urban areas.

121. Although the majority of UAVs are fixed wing there are a growing number of rotary wing UAVs in several of the classes mentioned above. One example is the US Eagle Eye System which has a speed of up to 200 knots, range of over 800 NM, altitude up to 20,000 feet, endurance of 3-6 hours and payload of 200 pounds. There are also a number of rotary mini UAVs in development. In addition, there are also developments with regard to Unmanned Ground Vehicles (UGVs). One of the more recent applications of this technology was in the caves of Afghanistan.

122. UAVs continue to evolve and have enormous potential for the future. Improvements in sensor capability, data fusion and transfer, improved communications and power systems will allow future UAVs to do more, go further and loiter longer. With regard to the larger UAVs such as Predator, the US has developed a Predator B with internal payload of 800 pounds and external payload of 3,000 pounds. This has allowed them to fly Predator B with up to 14 Hellfire II anti-armour missiles and, in fact, they have also dropped a Paveway II (GBU-12) laser-guided bomb onto a stationary target. On the other end of the scale, Israel is developing mini UAVs weighing only .65 kg with a payload of .5 to .8 kg miniature camera that has a 25 X zoom and day and night capability. There is also crossover activity with regard to UAV missions. Trials are being carried out with MALE UAVs carrying and deploying mini UAVs on various missions.

RADAR (RADIO DETECTION AND RANGING SYSTEMS)

123. Although radar has been widely used by air and maritime forces for years, land forces have only recently begun to exploit its full potential. Today its main applications are:

a. detection of small fast air targets,

b. tracking and provision of range data,

c. long range surveillance,

d. day/night operations,

e. visibility through smoke, rain and fog,

f. fusing,

g. meteorology,

h. muzzle velocity indication,

i. detection of vehicles and personnel,

j. weapons locating, and

k. artillery adjustment.

124. Radar, just as radio, is divided up into radar designation bands. These traditional bands originated as code names during The Second World War and still in military and aviation use throughout the world today. The radar frequency bands are:

a. High Frequency (HF) Band, 3-30 MHz. This band is used by coastal radar and over the horizon (OTH).

b. P Band, 30-300 MHz. This is for "previous" and is applied retrospectively to early radar systems.

c. VHF Band, 50-330 MHz. This is for very long range and ground penetrating.

d. UHF Band, 300-1,000 MHz. This is very long range (e.g., ballistic missile early warning), ground penetrating, foliage penetrating.

e. L Band Radar - operates on a frequency of 1-2 GHz. These radars are used mostly for clear air turbulence studies.

f. S Band Radar - operates on a frequency of 2-4 GHz. Because of the wavelength and frequency, S band radars are not easily attenuated. This makes them useful for near and far range weather observation. The drawback of this band is that the antenna dishes are large, it is not uncommon for an S band dish to be 25 feet in size.

g. C Band Radar - operates on a frequency of 4-8 GHz. C band radar dishes do not have to be very large. This makes C band radars affordable for TV stations. The C band signal is more easily attenuated so this type of radar is best used for short range weather observation.

h. X Band Radar - operates on a frequency of 8-12 GHz. X band radars attenuate very easily so they are used only for short range weather observation. Also, due to the small size of the radar, most airplanes are equipped with X band radar to pick up turbulence and other weather phenomenon. This band is also used for space applications and some police radars. Because of overcrowding in other bands there are more military users moving into this band.

i. K Band Radars are split into Ku 12-18 GHz, K 18-27 GHz and Ka Bands 27-40 GHz. This split is due in part to the strong absorption line in water vapour. This band is much more sensitive than X band. This band is very crowded and has many civilian and military users.

TYPES OF RADAR

125. **Primary and Secondary**. In a primary radar, the radar transmits a signal that reaches the target, is reflected and travels back to the receiver of the primary radar.

126. In a secondary radar, the transmitted signal is received by a transponder in the target. This then triggers a reply that is received by the original radar. This reply can contain information about the target such as position, speed and target type. An example would be an air traffic control radar. This type of radar is also known as a secondary surveillance radar and relies on the cooperation of the target to be successful. Such radar forms an excellent basis for an identification friend or foe (IFF) system.

127. **Monostatic and Bistatic**. In monostatic radar, the transmitter and receiver are located in the same location, and use the same antenna. In bistatic radar, the transmitter and receiver are separated. As the receiver is purely passive, it is less susceptible to detection, jamming and anti-radiation missiles. This is also the arrangement used in semi-active radar homing missiles, where the transmitter is ground based and the receiver is in the missile nose.

128. **The Radar Task**. The main radar tasks are:

a. detection,

b. range determination,

c. bearing or direction, and

d. velocity estimation.

129. To detect, the radar senses the low-energy radio echo of the original signal. The range is determined by measuring the time taken for radiated (remember that they travel at the speed of light) pulses to go to and return from the target. Location of the target is obtained by forming the radar wave into a narrow beam, and measuring the direction in which the antenna points at the time of detection. Radars must make a compromise between the rate the radar can scan and the maximum range at which you wish to conduct surveillance.

130. Target radial velocity (the portion of the target velocity which is coming straight towards the radar) is obtained by measuring the change in frequency between the transmitted wave and received wave, the so-called Doppler Shift. This very important technique allows the target velocity to be estimated, but perhaps more significantly, it means that returns from unwanted stationary objects such as ground vegetation and clouds can be filtered out since they have no velocity of their own. This process of clutter rejection is a powerful one and leads to the radar's strong capability to detect moving targets. The very different characteristic Doppler signature of various types of target, such as marching men, wheeled or tracked vehicles, helicopters and aircraft also allows target classification to be carried out. For a target moving circumferentially around the radar, with no radial velocity component towards the radar, the Doppler frequency is zero.

131. The Doppler frequency is given by the formula shown here:

$$\mathbf{f_d} = \frac{2v}{\lambda}$$

where **fd** is the Doppler shift frequency, **v** is the target velocity radially inwards (or outwards) and Lambda (λ) is the radar wavelength. Since the radar wavelength λ is known and the Doppler shift frequency **fd** can be measured, the target speed information **v** can be calculated. Two examples of platforms that use Doppler Shift are the US airborne E-8C Joint Surveillance Target Attack Radar System (JSTARS) and the United Kingdom (UK) land-based MSTAR.

132. **Pulse Radar Operation**. We will examine how pulse radar operates. These radars emit short, high-energy pulses at the radar frequency. For example, a one millisecond pulse at 15 GHz.

133. At the same time, a switch connects the oscillator to the antenna to radiate the pulse energy. The receiver is disconnected, preventing burnout of the sensitive detector in the receiver. This is known as duplexing. It is required because the return pulse is much weaker than the outgoing one. After the pulse is sent, the switch goes back to the receive mode.

134. The radar energy travels to the target and back in time T, which is measured electronically. The computer estimates the range derived from T, and determines the direction to the target by looking at the antenna direction.

135. Since there may be many targets in the path of the radar range capability, the range is gated in time intervals. The Receiver 'dumps' its signals into a different range gate at predetermined specified time periods. At the end of one transmit and receive period, the switch goes back to transmit in order to send out another pulse. The range gates are emptied into the computer for processing.

136. The radar does not send out a single pulse but repeats the above sequence many times a second. The rate of repetition is called the pulse repetition frequency (PRF). The PRF, together with the radar frequency and antenna scan rate, are important characteristics that can be monitored in order to 'fingerprint' a radar.

137. **Radar Performance**. The key parameters that allow evaluation of radar performance are:

a. range capability in varying weather conditions; and

b. resolution.

138. These are established through:

a. antenna design,

b. detection methods and techniques, and

c. the frequency of operation.

139. The radar antenna features in both key parameters stated in paragraph 134 above. It defines the main beam characteristics and the number and size of the side lobes. The degree to which the antenna concentrates power in a given direction is expressed as "gain". This is not gain in the sense of amplifying the original power input. In fact, the radiated beam will always be less than the original total power input. Rather, it is an expression of the increase in power in the main beam relative to the amount of power that would propagate in the desired direction if the power

were transmitted equally in all directions. The more efficient the antenna, the smaller the side lobes and the greater the 'gain'.

140. An ideal radar would have a very narrow beam width in the desired direction. This would allow for less power to be transmitted and a more precise azimuth determination. It would increase the resolution and allow deconfliction of targets that are very close to each other.

141. **Radar Range Equation**. This complicated looking equation demonstrates the factors accounting for the final power, **Pr**, ultimately returning to the receiver.

$$\mathbf{Pr} = \frac{\mathbf{P_t GgA}}{\mathbf{16}\pi^2 r^4 \mathbf{L}}$$

142. $\mathbf{P_t}$ is the original power generated by the oscillator, in watts. The majority of the original power will be dissipated through the distance (range) to and back from the target. This is accounted for by the $\mathbf{r^4}$ expression.

143. The amount of power reflected by the object is a function of its radar cross section (RCS) and is represented by gA. You can see, therefore, that reduction of the RCS by using absorbent materials will reduce gA, thus reducing returned power to the receiver and therefore reducing the chances of detection. The **G** in the equation is a measure of the 'gain' associated with the radar. Finally, **L** is a measure of atmospheric losses and losses through cables. $\mathbf{16\pi^2}$ is a constant that takes account of the three dimensional radiation of the power.

144. **Radar Resolution**. This is the ability to distinguish between two closely located targets. The resolution can be established in range, azimuth, elevation and velocity. The main criterion for enhanced resolution is the "pulse width". This is somewhat of a misnomer since it actually determines the length of the pulse. It can be simply computed by counting the time it takes to send the pulse. Since you know that the wave travels at the speed of light (300,000 m per second), you simply multiply the speed with the time to determine the "pulse width".

145. The angular resolution in azimuth and elevation is determined by antenna beam width, while the velocity is measured by using the Doppler shift.

146. **Scanning Radar**. In order to cover wide angular areas with narrow beams, radars must incorporate some form of scanning. Here the beam is moved across the area of interest by either moving the antenna or by using a fixed phased array. The former is obviously done by physically turning the antenna, the latter is done electronically by energizing different beams in a fixed sequence. Alternatively the antenna may have multiple beams. Examples are the Coyote MSTAR and the air defence anti-tank system (ADATS) surveillance radars.

Figure 18 – CF ADATS (Its radar is used for both surveillance and tracking targets)

147. **Tracking Radars**. Tracking radars use multiple beams along the antenna axis. By detecting the different arrival times of the target signal at the four antenna points, the antenna system is adjusted in the direction of the movement of the target and continues to be focussed on it. The Air Defence Skyguard radar combines surveillance and tracking techniques.

148. **SAR**. SAR is capable of very high resolution at very long range. An aircraft with sideways looking radar flies a path parallel to the area of target detection. As it detects a target, it keeps the location in memory and compares it with the following signal returns. This computation represents a virtual representation of a large antenna, which is the distance travelled by the aircraft as long as it receives echoes from the same target. It also has the effect of producing a synthesized very narrow beam. In fact, the aperture is much smaller and this gives rise to the term SAR. SAR is optimized to detect static targets, since the movement of the target is the actual speed of the aircraft.

149. **CP 140M AURORA Incremental Modernization Project (AIMP)**. This project will see CP140 aircraft fitted with APS-143 Ocean Eye, Inverse SAR and a replacement electro-optical IR imager (MX-20). The Ocean Eye radar is an X Band Radar (9.25-9.70 GHz) that will give the Aurora a radar surveillance capability up to 200 NM. This radar has a detection performance of one square metre target beyond 30 NM in sea state 3 from low altitude. Because of its nature, SAR can accomplish medium resolution strip mapping for uninterrupted ground-surveillance images or very high-resolution spot-light mode – used to identify ground targets or ships at sea.

LONG RANGE AND BATTLEFIELD SURVEILLANCE RADARS

150. The requirement for timely information about enemy deployments and movement is vital for the battlefield commander. Radar plays an important role in satisfying the need as it provides day and night surveillance in all weather out to long ranges. There are two distinct types of such radar.

Figure 19 – Coyote LAV Reconnaissance with MSTAR Battlefield Surveillance Radar on Ground Mount (Object on Tripod to Extreme Right)

151. Short-range radars operate out to 30 or 40 km. They may be man portable or vehicle mounted, depending on range and may be used for surveillance of moving targets, target acquisition and correction of fall of shot. The Coyote LAV Reconnaissance mounts the MSTAR Battlefield Surveillance Radar, shown in Figure 19. The radar is either mounted on an extendible mast or on a tripod that can be deployed up to 200 m from the vehicle. In this configuration, it is linked to the operator with a fibre optic cable. The MSTAR operates in the Ku Band between 16.94 and 17.083 GHz. It has a peak power of 4 watts. The radar can detect moving vehicles at 24 km and a moving man can be detected at 3,100 m. Radars for surveillance beyond the front line, at ranges up to 300 km and beyond, are normally carried in aircraft and helicopters and are able to detect moving targets or to provide radar photographs.

MANNED AIRCRAFT

152. Manned surveillance aircraft can be divided into those which fly over or relatively near to the target and those that stand well back and use long-range sensors. The former are generally non-real-time systems. Their payload is collected after the mission, analysed and used. Their product however has very good resolution and high accuracy. The latter are known as Stand-off systems, which in general have poorer resolution and accuracy but in addition to providing information about enemy movements, they may be used to cue other sensors to provide precise targeting.

153. Airborne platforms carry three basic types of sensors:

a. Cameras provide high-resolution film of the target area. They can be used at night using flare dispensers.

b. The two main types of IR are Infrared Line Scan (IRLS) and Sideways Looking Infrared (SLIR). IRLS produces a thermal picture of the target area. It is effective by day and night but its performance is degraded by fog, mist and cloud. SLIR, an airborne TI system, can be used to supplement IRLS coverage in areas of picture distortion, say close to the horizon.

c. A radar must be used if Stand-off systems are to give both long range and all-weather capability. The radar payload can weigh in the vicinity of 500 kilograms. The aircraft will normally operate 10-100 km behind the forward line of our own troops (FLOT) and at altitudes of 500-15,000 m. These factors are crucial in determining the area coverage, resolution and accuracy achievable. Although some of the signal processing may take place in the aircraft, a ground control station is likely to be used for this purpose. Analysed information is then passed from the Ground Control Station to tactical users.

Figure 20 – The CF-18 is an Example of a Manned Aircraft that Can Carry a Surveillance Pod

154. The United States Air Force (USAF) JSTARS is an airborne ground surveillance system with a multi-mode radar system, including wide area surveillance (WAS) MTI radar to detect moving vehicles and a SAR for high-resolution imagery of stationary targets, including mines.

155. Figure 21 shows a typical radar display from a MTI, taken from a JSTAR towards the end of the Gulf War in 1991. Notice the traffic patterns as the opponents were fleeing Kuwait.

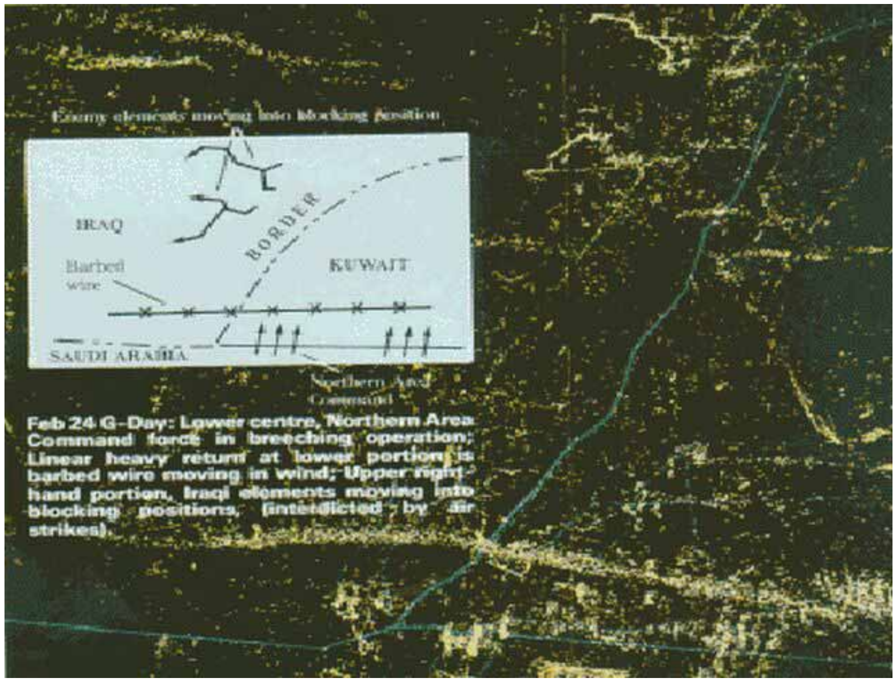


Figure 21 – JSTARS MTI Radar Image of Fleeing Iraqi Troops, 1991

156. **UK SENTINEL R1 Airborne Stand-off Radar (ASTOR)**. The UK is fielding a stand-off radar system called ASTOR. This system, which will be mounted in Bombardier Global Expess Jets, is an airborne battlefield or ground surveillance system for operation with the RAF and British Army. The radar in this system is an upgrade of Raytheon's ASARS-2 side looking airborne radar. This radar can provide images of the battlefield at ranges of 160 km at altitudes up to 47,000 feet. The radar has SAR spot mode and SASR swath with an MTI capability. The aircraft will normally fly at 15,000 feet in order to achieve maximum ground radar coverage. The aircraft has a range of 6,500 NM and an endurance of 14 hours. The vast amount of data collected by ASTOR will eventually be fused with data from the Nimrod R1, E-3D AWACS, Watchkeeper UAV and even satellite imagery to provide a comprehensive view of the battlefield.

WEAPON LOCATING RADARS

157. The purpose of a weapon locating radar (WLR) is to detect the launch of an enemy projectile or missile and to establish a segment of the trajectory of the projectile of sufficient length and positional accuracy to enable a computer to determine the location of the launcher. This technique is known as backtracking location or back extrapolation, because the computer follows back along the measured portion of the projectile path to the point where it intersects the ground. The main targets for WLRs are mortars, free flight rockets and guns.

158. A radar target with a small RCS and high speed may appear at any time, so the radar must cover the whole possible volume of target space in the acquisition mode. Therefore the radar operates with a high repetition rate scan beam, or with a floodlight antenna system. The data acquired here, together with the weapon trajectory in the WLR computer memory, enable the computer to find the point at which the trajectory meets the ground. The expected point of impact

may also be determined, but with less accuracy because of the much longer length of extrapolation required.

Figure 22 – Arthur Weapons Locating Radar Mounted on a Bv 206 Vehicle

159. ARTHUR (ARTillery HUnting Radar) is Weapons Locating System developed by the Norwegian and Swedish MODs. It operates in the 5.4-5.9 GHz range (C Band Radar) and has a maximum tracking range of 40 km with a Passive Phased Array Antenna. This system can track up to 100 targets per minute simultaneously. ARTHUR can also locate enemy firing units and register own fire simultaneously.

OTHER BATTLEFIELD RADAR

160. The following systems use radar technique to operate, but will not be discussed in detail:

a. muzzle velocity measurement or chronographs are small radars placed near gun positions to measure the muzzle velocity of rounds using Doppler. This allows corrections to reduce the random scatter of rounds at the target;

b. weather balloon tracking radar tracks reflectors fitted to meteorological balloons to allow the calculation of wind profiles; and

c. anti-tank or anti-aircraft homing radar is MMW radar located in the nose of a projectile.

SPACE OPERATIONS

161. **Joint Space Support Project (JSSP)**. The JSSP's objective is to develop and implement specific space-related capabilities to enhance the operational effectiveness of the CF for domestic and/or international operations. This project has two elements: Surveillance and Reconnaissance (S&R) and Space Situational Awareness (SSA).

162. The theatre-level capabilities to be fielded include commercial space-based S&R imagery and SSA. These capabilities will allow for direct in-theatre download of commercial satellite imagery via a Ground Receive Terminal (GRT) for mission planning, tactical reconnaissance, target acquisition and Battle Damage Assessment (BDA). It will also allow for the acquisition

and dissemination of satellite capabilities, threat and overflight awareness (SSA). Initial Operating Capability (IOC) for this project is expected in the fiscal year (FY) 08/09 timeframe.

SATELLITES

163. **The Protected Military Satellite Communications Project (PMSC)**. This project will provide the CF with a protected, guaranteed military satellite communications (MILSATCOM) capability by cooperating with the US Department of Defense (DOD) on their Advanced Extremely High Frequency (AEHF) military communications satellites and by acquiring AEHF terminals. There are four nations involved in this project (US, Netherlands, UK and Canada. Current plans call for an IOC of 2010.

Figure 23 – Surveillance Satellite

164. Satellites use some very sophisticated technology and offer the greatest potential for large area surveillance for protracted periods. In peace, crisis and war, they can give excellent strategic indications of what is happening in areas that cannot be covered by other means. Satellites can carry a variety of sensors. If a satellite's FOV can be optimized for detail, excellent resolution can be achieved. As you are no doubt aware, satellites have been used to very good effect in places like Bosnia to monitor adherence to weapons restriction policies and in Rwanda to monitor the movement of refugees.

LASERS

165. Laser stands for Light Amplification by Stimulated Emission of Radiation. A laser works by amplifying light or other electromagnetic radiation of the same wavelength in a resonating cavity. A cavity is a volume containing the atoms that will be excited. It can be a solid, like ruby, or a gas, like carbon dioxide (CO2). It could technically be a liquid. Most modern lasers use gases. The wavelength of the radiation depends on material used in the cavity. Light is then emitted from the cavity, either as a pulse or as a continuous beam. The radiation is intense, directional and coherent. How and why this actually happens will be described below. Two limitations of lasers in their applications to land operations are:

a. they are active. The laser is an active device and is therefore very susceptible to detection and counter-surveillance; and

b. in terms of power efficiency, lasers remain very low. Early lasers were highly inefficient, producing only about 1 per cent coherent light and 99 per cent heat. Today efficiencies of 20 per cent are not uncommon and the near future should bring ever-higher percentages.

166. **Coherence**. A laser's special properties derive from the fact that the light beam possesses frequency and spatial coherence. Frequency coherent light has only one frequency. In practical terms, in the visual spectrum this means that the light is of only one colour, not just, say, red, but of a specific red from the thousands possible. Frequency coherent light thus lends itself to easy frequency multiplication. Therefore, a visual frequency can be raised to a higher invisible frequency very efficiently.

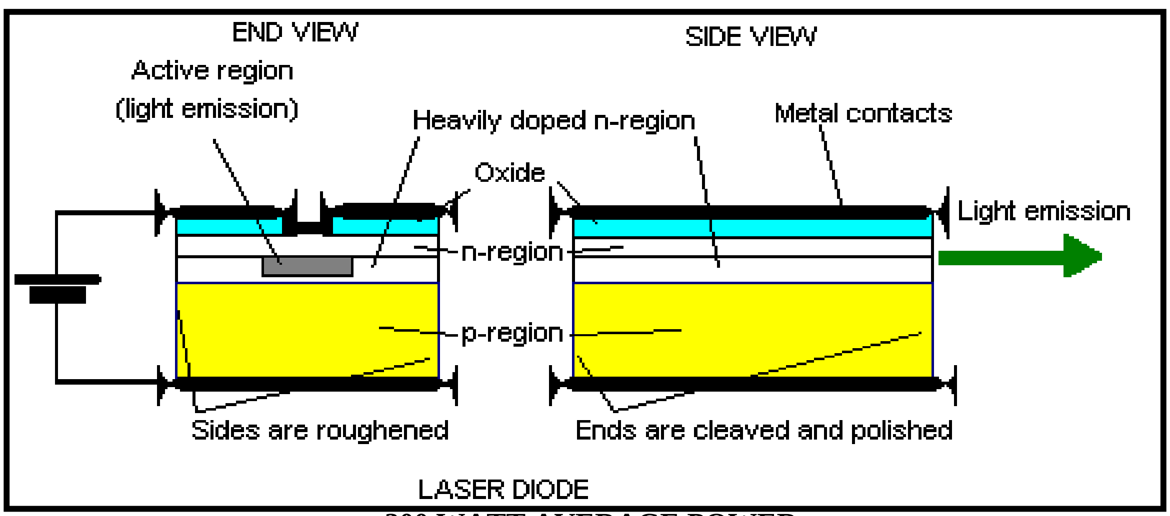
167. These are the three main types of lasers:

a. optically pumped lasers, which may be crystalline, glass, liquid, gaseous or synthetic;

b. radio frequency or direct current pumped gas lasers; and

c. semiconductor diode lasers pumped by injection of high current.

168. **Diode Pumped Lasers**. The third type of laser is a solid state laser similar to the optically pumped ruby laser or the more modern optically pumped titanium sapphire. Originally called an injection laser, they are now known as solid state diode pumped lasers using neodymium. This laser emits coherent light by passing an extremely high current between the terminals of the semiconductor diode. These lasers have 40 per cent efficiency, compared to the original lasers that were only efficient at one per cent. Higher efficiency levels can be achieved when you use a laser diode to pump another laser diode. The most important tactical impact is the ability to tune the output frequency of your laser. This implies that lasers can now be manufactured to operate at any wavelength, rending the usage of laser goggles almost obsolete! A sample is shown below.



300 WATT AVERAGE POWER
10 PER CENT EFFICIENCY
1,000,000,000 SHOTS

Figure 24 – Diode Laser

169. Since the mid-1980's important advances have been made in this field. The neodymium laser is 300 watts, about 10 per cent efficiency, which is 90 per cent of input energy, goes to heat, and has a lifetime of about 1,000,000,000 shots. In contrast to the historical method of pumping solid state lasers, diode lasers have a much-reduced thermal load. This technology is now fielding laser radars, anti-sensor lasers and high bandwidth communications from satellites to theatre and battlefield commanders.

170. The introduction of lasers brought two immediate effects to the battlefield. Rangefinding became much more accurate. In fact, today we are talking + or - 5 m at 10 km. Range is calculated by measuring the time for a laser pulse to return to the rangefinder equipment, having been reflected off the target.

171. At these short ranges, the fixed frequency of laser light is significant. It permits counting of the cycles between emission of the light beam and its reflection. The number of cycles, in effect, measures the distance the light has travelled. Dividing by two provides the range to the high accuracy mentioned above. Very accurate target marking is now also possible. A coded laser beam is used to illuminate the target and the reflection from the target can be picked up by specially designed guidance systems in artillery shells, bombs, missiles and aircraft. The CF ADATS also uses laser technology. In this case a coded patterned beam is sent and the detector in the missile tail cues the steering mechanism so the missile literally flies down the laser beam to the target, hence the name laser beam rider. Thus the missile does not care where the laser beam is pointed, making ADATS very effective against both air and ground targets. Table 3 lists lasers in use in the Canadian land forces.

172. Depending on the wavelength, lasers have the ability to penetrate smoke and they can also provide illumination for II devices.

LASER USE IN THE CANADIAN LAND FORCES		
SYSTEM	USE	EYE SAFE
ADATS	MISSILE GUIDANCE	YES
FOO	RANGEFINDER	NO
COYOTE	RANGEFINDER	NO
LEOPARD	RANGEFINDER	NO
CH-146 GRIFFON	SELF DEFENCE WARNING	YES

Table 3 – Laser Use in the Canadian Land Forces

173. When we talk of laser weapons, we mean devices capable of disrupting or damaging various electromagnetic devices and of course damaging the unprotected human eye. Lasers powerful enough to actually destroy major weapons systems are not yet fielded. Some advantages and disadvantages of current laser weapons are shown in Table 4. Table 5 lists laser weapons in service and under development worldwide.

LASER WEAPONS	
ADVANTAGES	DISADVANTAGES
High Directionality Speed of Light Fast and Silent Ammunition Logistics Simplified Laser beam may be Invisible	Atmospheric Effects Efficiency of Energy Conversion Kill Assessment Difficult Bulky, Heavy, Expensive

Table 4 – Advantages and Disadvantages of Laser Weapons

TACTICAL				
SYSTEMS	ENERGY OR POWER	TARGETS	EFFECTS	STATUS
COBRA DAZER STINGRAY	E≤10J	EYES AND EO SENSORS	DAMAGE	OPS
(CO, COIL, DIODES, ETC.)	P≤1 KW	EYES AND EO SENSORS	DAZZLING+ DAMAGE	R & D
MIRACL (US) LATEX (FR)	E>100 KJ OR P>100 KW	AIRCRAFTS AND MISSILES	DAMAGE	R & D
STRATEGIC				
SDI	P>100 KW	MISSILES, SATELLITES	DAMAGE	R & D

Table 5 – Laser Weapon Status

EXAMPLES OF OPERATIONS HAZARDS			
LASER DEVICES	WAVELENGTH (MICRONS)	OUTPUT ENERGY	SENSORS AT RISK
M60-TANK	0.69	40mJ	EYES, II, TV
M-1-TANK	1.06	40mJ	EYES, II, TV
GLLD	1.06	100mJ	EYES, II, TV
TADS (AH-64)	1.06	100mJ	EYES, II, TV
LTD	1.06	50mJ	EYES, II, TV

Table 6 – Examples of Laser Operations Hazards

174. Table 6 lists some examples of operations hazards caused by lasers. The following factors affect laser hazards:

a. the electro-optic devices themselves;

b. the atmospheric attenuation in the travelling path;

c. the ambient light level;

d. the repetition rate of the laser; and

e. the viewing mode in usage.

175. How effective a given laser will be in causing damage to eyes or electro-optic devices depends on a number of factors. Obviously the type and power of the device is critical. Even though lasers are extremely coherent light, the atmosphere will nonetheless cause some diffusion or deflection in the beam. The repetition rate of the laser bursts is a factor, since this is a measure of the amount of energy actually impacting on the target in a given time. Whether or not the viewing device is constructed to inhibit the effects of lasers is a factor as well.

176. The following laser effects can occur to optical sensors (see Table 7 for laser effects on II devices):

a. **Dazzling or Jamming**. A system overload renders the eyes or an electro-optic device incapable of performing its mission while the overload is occurring. Either continuous waves or pulsed laser sources can cause these effects. Recovery time for the victim can be counted in seconds or days.

b. **Damage**. A system overload causes a permanent degradation in electro-optic device performance. Usually, the system needs repair, or the eyes need health care.

177. Types of damage to the eye from visible and near IR lasers include:

a. hemorrhagic lesion;

b. severe retina burns with bleeding. Loss of vision can be permanent;

c. temporary blinding;

d. intermediate retinal burns;

e. severe degradation of visual acuity; and

f. dark spots in the FOV.

LASER EFFECTS ON IMAGE INTENSIFIERS		
EFFECTS	**DESCRIPTION**	**COMMENT**
SCENE WASHOUT	LOSS OF SCENE CONTRAST	TEMPORARY DEGRADATION WAVELENGTH DEPENDENT
BLOOMING	BRIGHT SPOT COVERING PART OR ALL OF SCENE	TEMPORARY; CONTINUED EXPOSURE; WAVELENGTH DEPENDENT; FIRST GENERATION
BLACKOUT	ELECTRONIC OVERLOAD	FIRST GENERATION ONLY; BRIGHTNESS CONTROL IMPORTANT
ARC DISCHARGE	ARCING FOLLOWED BY TUBE BLACKOUT	NOT NECESSARILY PERMANENT; INSUFFICIENT DATA
PHOTOCATHODE DAMAGE	PITTING	PERMANENT DAMAGE IN LOCALIZED TUBE AREA

Table 7 – Laser Effects on IIs

178. Table 8 demonstrates the various laser threats expected on the battlefield.

SOME LASER THREATS ON THE MODERN BATTLEFIELD

LASER TYPE	WAVELENGTH (µm)	APPLICATIONS
Nd:YAG (Doubled)	0.532	Weapons
Ruby	0.694	LRF
GaAs	0.8 - 0.95	LBR
YAG	1.064	LRF/LTD/LBR
Erbium/NdYAG (Raman shift)	1.54	LRF
Alexandrite	0.75 (tunable)	Weapons
CO_2	10.6	LBR/LRF

LRF: Laser Rangefinder
LTD: Laser Target Designator
LBR: Laser Beamrider

38

Table 8 – Some Laser Threats on the Modern Battlefield

179. Laser hazards have been categorized by industry to identify the level of protection required by personnel. These classifications have been adopted by Department of National Defence (DND) and are shown in Table 9. It must be noted that all lasers have the potential to be hazardous for the eyes.

INDUSTRIAL LASER CLASSIFICATION	
Laser Classification	**Characteristics**
Class 1	Not hazardous even when collected by 50 mm optics and concentrated into eye pupil Low-power semiconductor and enclosed lasers
Class 2	Operate in visible range of the spectrum Viewing for longer than 0.25 seconds may be hazardous, but protection is afforded by the eye's natural aversion to bright light No increase in hazard when a viewing aid is used
Class 3A	Unaided intra-beam viewing is protected by the eye blink reflex Use of aids outside the visible range may be hazardous Class 3A lasers have an output power up to 5x the Class 1 levels
Class 3B	Intra-beam viewing is unsafe Viewing of diffuse reflections is not a hazard
Class 4	Serious injury will result from viewing - either direct or diffuse radiation Combustion is possible

Table 9 – Industrial Laser Hazard Classification

THE FUTURE

180. The development of low powered eye safe lasers has led to their adoption into a family of direct fire simulators. This has increased training realism and has decreased training costs.

181. A laser tracker operates on the same principles as radar. However, the short wavelength and the highly directional beam give laser trackers a higher resolution and make them less susceptible to interference than radar. These developments are still in their early stages, but are likely to have significant applications in the future.

182. Communications lasers have the potential to provide high capacity, point-to-point communications links.

183. Major efforts are being placed in the research of better methods to use lasers on the battlefield. A promising technique uses laser range gating. This concept reduces the blinding effect from early reflection of the laser beam from perturbations encountered along the flight path.

184. The concept, shown in Figure 25, synchronizes the projection of the laser pulse with the opening of the optical receivers, in order to only receive the light that has travelled to the target and come back from it. This eliminates any light returned to the sensor from objects between the laser projector and the target.

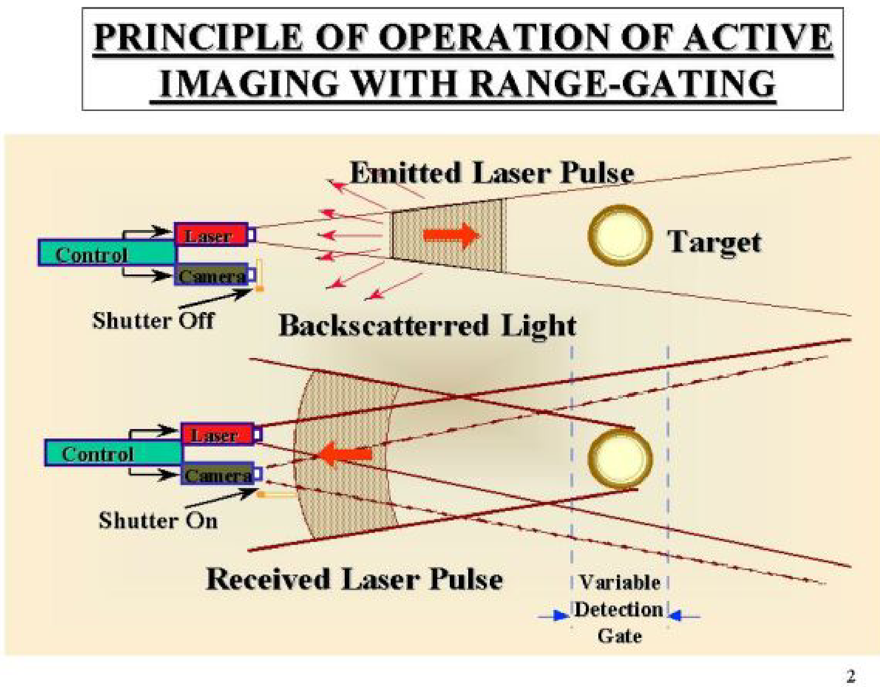


Figure 25 – Radar Range Gating

185. High powered lasers used as Directed Energy Weapons (DEWs) that are capable of physical kills of vehicles are possible, but are unlikely to be feasible for the next 15-30 years. The problems in this area are the provision of sufficient power, combined with the ability to maintain a coherent beam.

SECTION 3 - COUNTERMEASURES

INTRODUCTION

186. This section will concentrate on reducing the soldier's vulnerability to detection from the sensors discussed in the previous section. Even though sensor technology is rapidly advancing and appears to reduce the ability for a soldier to hide on the battlefield, that technology can be defeated if you know and take advantage of its physical properties.

187. The general approach to survival on the battlefield follows this thought process:

a. avoid detection, or being seen by your opponent;

b. avoid acquisition, or getting caught in the firing loop of a hostile weapon system;

c. avoid being hit by the projectile;

d. avoid being penetrated; and

e. avoid being killed if the projectile makes it through.

188. This section will cover the first two levels of survival, avoiding detection and avoiding acquisition. This will be discussed under two major aspects of countermeasures:

a. camouflage; and

b. radar signature reduction, or stealth.

189. The section will conclude with a discussion on Defensive Aids Suites (DAS), which should be read in conjunction with the Protection and Fire Control System sections of the armoured fighting vehicle (AFV) Technology chapter of the Technology Handbook.

CAMOUFLAGE

190. Camouflage can be thought of as the process of making a person or object blend into the environment. It requires an awareness of one's surroundings and the ability to visualize those characteristics that enemy sensors will detect. Despite the range of sophisticated surveillance devices, it is believed that up to 75 per cent of the information gained on the battlefield will be in the visual band, aided by surveillance sensors.

191. Movement will always be the largest method of detecting targets. This section will concentrate on the basic parameters that will help you reduce your optical signature.

192. Common sense tells us that the easiest way to detect an object is to be able to discern the contrast and differences between an object and its background. The most important parameters are:

a. colour;

b. shape;

c. size;

d. near infrared reflectance (NIR) (the brightness of an object when viewed through night vision devices); and

e. contrast.

193. **Colour**. For anyone with average colour vision, differences in colour (brightness will be considered part of colour) is the first clue that an object is different from its background. This is easily demonstrated in the photo in Figure 26, where a red brick is inserted into a grey wall.

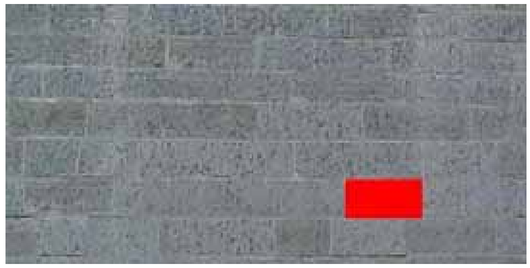


Figure 26 - Colour

194. An example of how the eye is drawn to the difference in brightness (of the same colour) between two objects is shown in Figure 27.

Figure 27 – Brightness

195. **Size and Shape**. Size and shape are linked together. In order to demonstrate this point, a composite image has been created in Figure 28 below. The image is of the Indian Navy Marine urban pattern. The four colours that make up the pattern have been used to create a digitized portion of the photo using straight edges, to demonstrate the effect that changing the shape has on drawing the eye to the difference between an object and its background.

Figure 28 – Shape

196. Changing the size of the shapes that are found in a background also has a profound impact on drawing the eye to the difference between an object and its background. A pattern that is too large compared to its background generally increases the shape clues, as shown in Figure 29 below, while a pattern that has smaller shapes than its background generally increases contrast cues and draws the eye to the object.

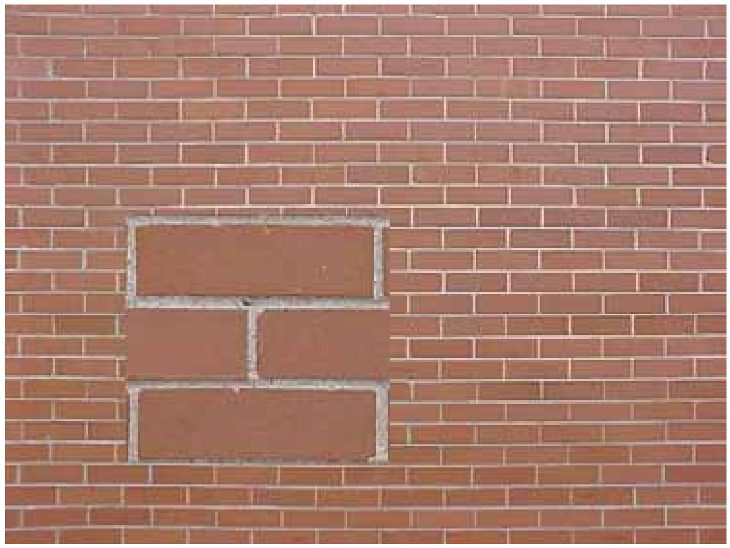


Figure 29 - Size

197. **NIR**. All modern militaries, and many other groups involved in armed conflict, are equipped with II devices (a.k.a., Night Vision Devices) that magnify the available light in the NIR portion of the spectrum (approximate wavelengths of 750 to 1,200 NM). This portion of the spectrum is invisible to the unaided eye, but with the aid of a night vision device is highly useful in detecting objects in low light conditions.

198. Objects viewed through night vision devices appear as monochrome images. The brighter the object appears, the greater its NIR reflectivity. Thus it is important that the NIR reflectivity of any object that you seek to camouflage must be as close as possible to the NIR reflectivity of its background. It is important to note when observing objects in the NIR part of the spectrum that the brightness of an object in the visual part of the spectrum does not necessarily mean that it will have a similar brightness in the NIR part of the spectrum.

199. The Canadian Land Force Canadian Disruptive Pattern (CADPAT) was designed with these processes in mind. Although heavily criticized in the Afghanistan deployment, it remained very efficient against night vision equipment.

Figure 30 – CF CADPAT Camouflage Clothing

RADAR SIGNATURE REDUCTION (STEALTH)

200. If you recall the radar range equation seen in the previous section,

$$\mathbf{Pr} = \frac{\mathbf{P_t GgA}}{\mathbf{16}\pi^2 r^4 \mathbf{L}}.$$

you will see that the only parameters of the equation which can be exploited for potential signature reduction are:

a. to reduce the dimensions of the RCS that the target projects; or

b. to increase the signal losses when the radar emission reaches the target or in the path between the radar and the target.

201. Figure 31 depicts a representative RCS image projected around an AFV, according to the angle of sight. The larger the signal return, the easier it is for your opponent to detect you with a small amount of projected power. Ideally, you wish to present the lower reflection towards the enemy (called stealth regions on the graph).

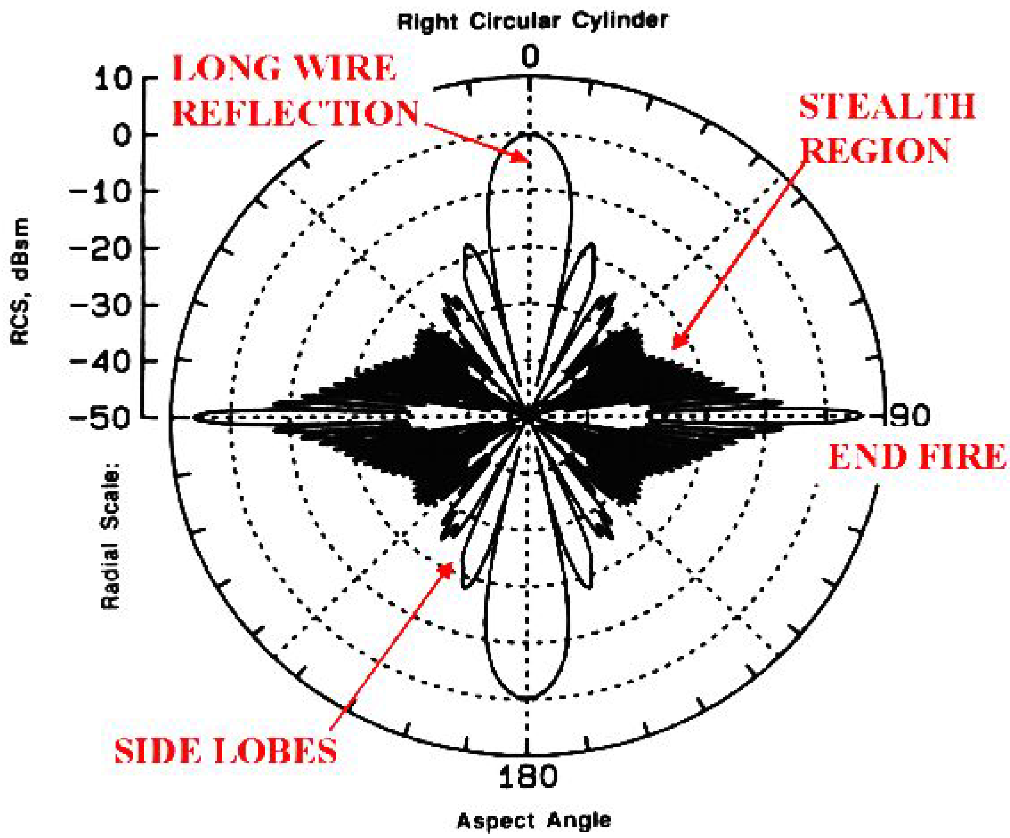


Figure 31 – RCS of an AFV

202. Techniques to reduce the RCS include:

a. design the shape of the vehicle to:

(1) deflect radiation in a direction away from your opponent;

(2) direct travelling waves. These are waves that are transmitted by portions of the vehicle which act like antennas themselves; and

(3) avoid creeping waves. These are radar waves that travel along the vehicle and get retransmitted once it reaches the end; and

b. use material where possible that is:

(1) non-metallic;

(2) radar absorbent, which changes the dielectric properties of the surfaces;

(3) coated; and

(4) covered by radar absorbent netting.

203. In the design, avoid:

a. presenting flat surfaces to the enemy;

b. corner reflectors, where the radio waves get trapped and sent back directly to the radar;

c. cavities, which will modify the overall reflectivity of your surface; and

d. discontinuities such as loose joints.

DEFENSIVE AIDES SUITES

204. The concept of DAS closely follows the discussion on radar signatures, as it concentrates in increasing the signal losses between the attacker and the target, up to the physical destruction of the attacking mechanism.

205. DAS describes a group of sensors and countermeasures integrated with a computer for self-defence of an AFV. A DAS is capable of providing automatic or semi-automatic responds to threats, thereby increasing AFV survivability without the weight burden of additional conventional or reactive armour. Figure 32 summarizes the concept.

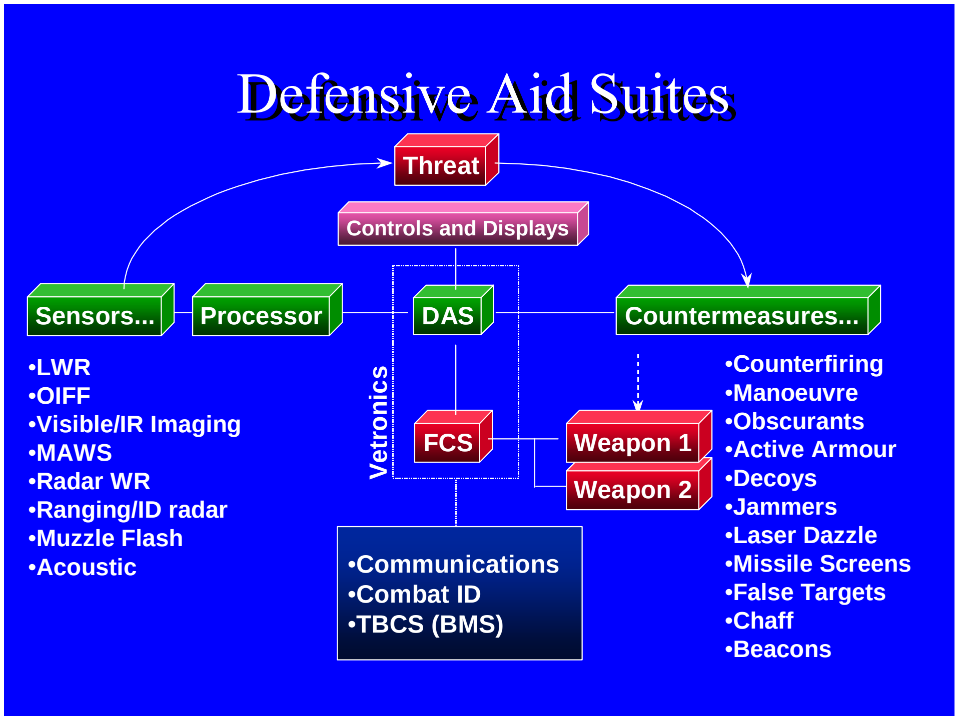


Figure 32 – DAS

206. The sensors can be a combination of:

a. acoustic sensors;

b. radar or optical identification friend or foe (OIFF);

c. visible and IR imaging systems;

d. muzzle blast detectors; and

e. laser warning receivers, which determine the direction and type of laser.

207. Countermeasure techniques include the use of:

a. counterfire from the main armament;

b. manoeuvre;

c. multi-spectral obscurants;

d. decoys;

e. electronic jammers;

f. physical screens;

g. active armour, which physically attacks the projectile; and

h. laser dazzlers, such as the Stingray system shown in Figure 33.

Figure 33 – Stringray Laser Dazzler Mounted on a US Army Bradley Infantry Fighting Vehicle

208. **Multifunction Laser DAS**. This technology builds on basis DAS and involves a multi-wavelength laser which is capable of laser dazzling, false target generation and laser beam rider guidance. This DAS also includes a Missile Approach Warning System and is integrated with the target processing system.

209. **Adaptive Camouflage**. Adaptive elements are being developed which can change their thermal and visual characteristics. The characteristics of the vehicle and background are measured and the characteristics of a group of these elements changed reducing the vehicle signature and detectability.

210. **Active Protection Systems**. An example of an active protection system for AFVs is the Russian Arena E system. This system is designed to protect the tank from attacks by anti-tank guided missiles launched from the ground and by attack helicopter and rocket-propelled grenades (RPGs). The system weighs 1-1.3 tons and uses a fixed omnidirectional radar, that covers a sector of 220-290 degrees around the tank. The protective charges are housed in a belt of 22-26 protective charges (depending on the turret size and shape), each positioned to cover a specific sector.

211. Once an oncoming threat is detected by the radar, the system ejects a charge above and sideways from the tank. As the charges explode, it throws a hail of fragments downward to shutter and destroy incoming projectiles. The system is capable of engaging incoming missiles at speeds ranging from 70-700 m per second. The system creates a virtual cone shaped shield at a radius of 20-30 m from the tank, and its response time, from target detection is .07 seconds. When the system is triggered, a warning signal is activated to warn any nearby infantry.

212. While Arena E provides an effective protection against many types of anti-tank threats such as RPGs, Hellfire and TOW, it cannot defeat fast missiles such as HVM and tank projectiles, such as high explosive anti-tank (HEAT) shaped charge projectiles and armoured piercing fin stabilized discarding sabot (APFSDS) penetrators.

213. This concludes the countermeasures section of Chapter 3.