CHAPTER 6

INFRARED

The term *infrared is* a Latin word meaning *beyond the red.* Infrared is commonly shortened to IR. The process of detecting or sensing infrared radiation from a target without being in physical contact with that target is known as *remote sensing.* Active and passive systems are used for remote sensing.

Active systems send a signal to the target and receive a return signal. Radar sets are examples of active systems. Passive systems detect a signal or disturbance originating at the target. The signal may be emitted either by the target or another source. Photography using natural light is an example of a passive system.

Humans can see only a small part of the entire electromagnetic spectrum. However, even though we cannot see them, other parts of the spectrum contain useful information. The infrared spectrum is a small portion of the entire electromagnetic spectrum. IR radiation is a form of electromagnetic energy. IR waves have certain characteristics similar to those of light and RF waves. These characteristics include reflection, refraction, absorption, and speed of transmission. IR waves differ from light, RF, and other electromagnetic waves only in wavelengths and frequency of oscillation.

The IR frequency range is from about 300 gigahertz to 400 terahertz. Its place in the electromagnetic spectrum (fig. 6-1) is between visible

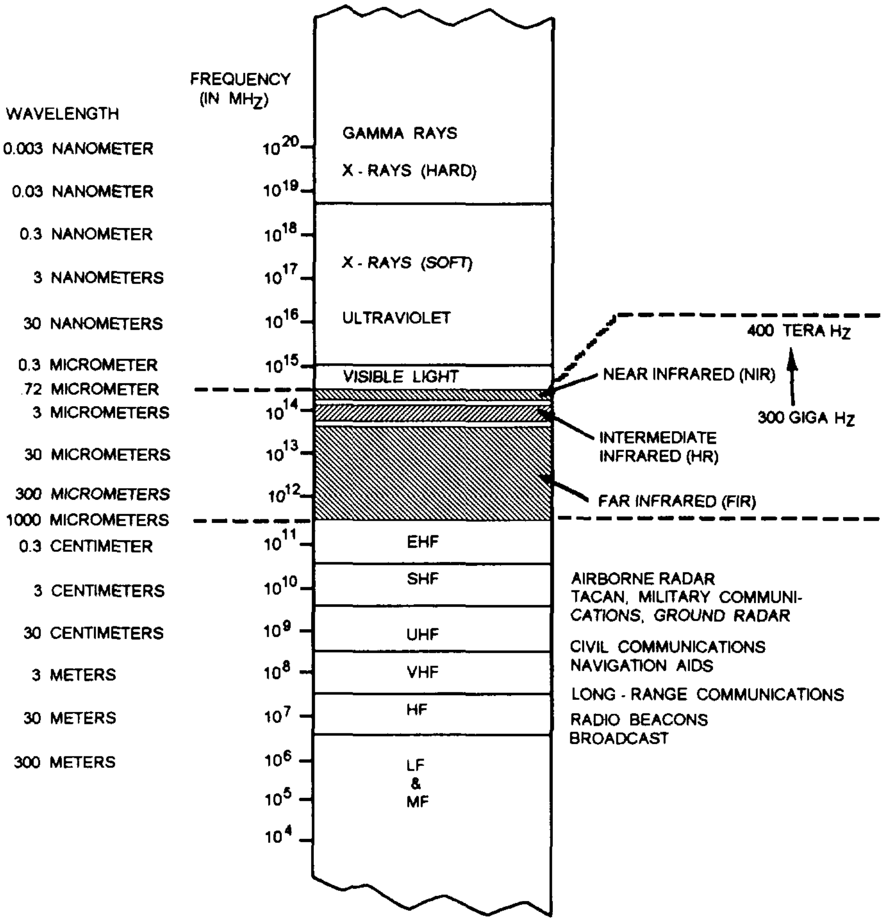


Figure 6-1.-Electromagnetic spectrum.

light and the microwave region used for high-definition radar. The IR region of the electromagnetic spectrum lies between wavelengths of 0.72 and 1,000 micrometers. Discussion of the IR region is usually in terms of wavelength rather than frequency.

> **NOTE:** A basic knowledge of IR detection principles is essential to understanding thermal imaging and the FLIR system as discussed in this chapter. If needed, you should review IR detection principles in *Aviation Electronics Technician 3*, NAVEDTRA 12329, before reading this chapter.

THERMAL IMAGING

> Learning Objective: *Recognize functions, characteristics, components, and operating principles of thermal or infrared imaging.*

Infrared radiation is also known as *thermal* or *heat* radiation. Most materials emit, absorb, and/or reflect radiation in the IR region of the electromagnetic spectrum. For example, an aircraft parked on a sunlit runway absorbs and radiates varying amounts of IR radiation. After the sun sets, the aircraft continues to radiate the absorbed heat, making detection at night possible. Even if the aircraft is moved, detection of the aircraft is possible because the runway surface, which was directly below the aircraft, will be cooler than the surrounding runway.

Thermal imaging is referenced in terms of temperature instead of reflectivity (radar) or color (visible light). Variations of the temperature in a scene tend to correspond to details that can be visually detected. The IR imaging system processes this information and converts it into information that the system operator can use. Currently, the types of imaging systems generally used are mechanical-scanning, fast-framing devices. They use the frame rate (information update rate) that is similar to television. They are known as forward-looking infrared (FLIR) devices.

Before a target can be detected, it must exchange energy with its environment, be self-heating, have emissivity differences, and reflect other sources. Look at figure 6-2. Notice the atmosphere between

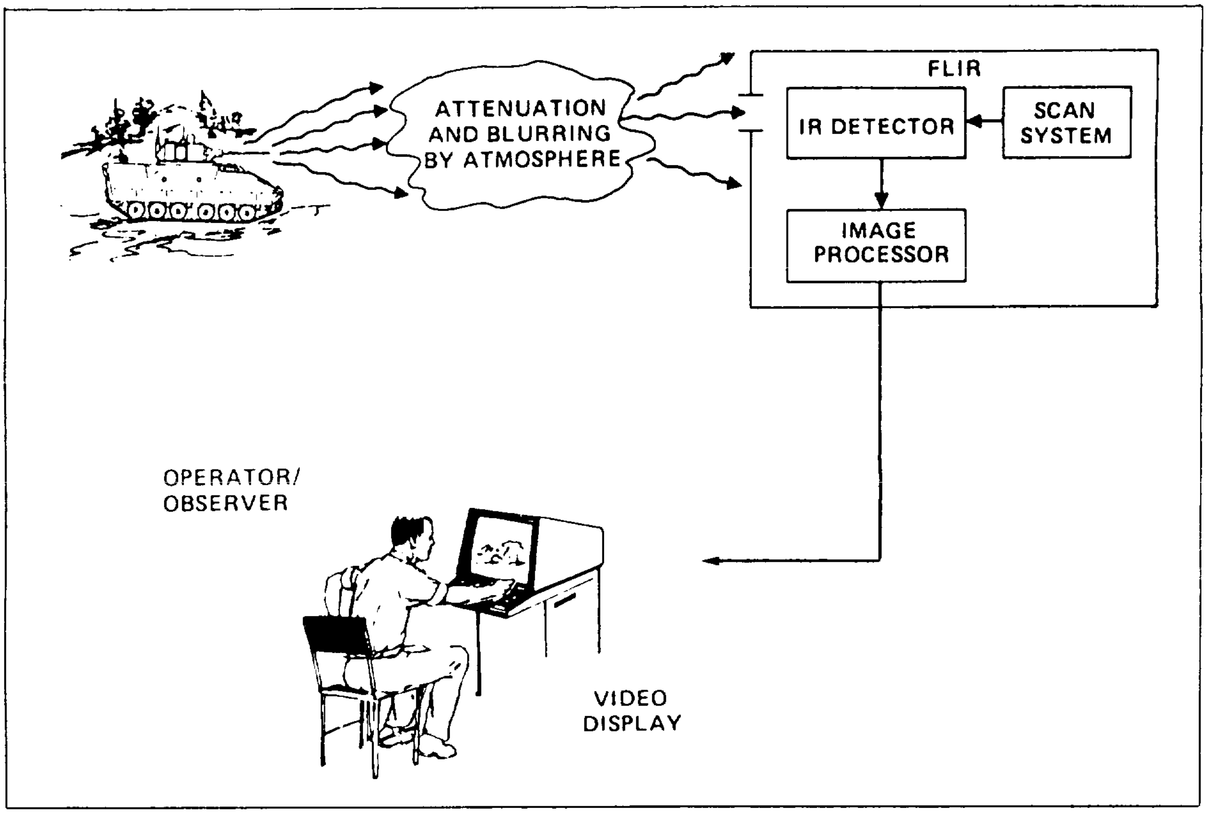


Figure 6-2.-Thermal imaging.

Table 6-1.-Characteristics of IR Radiation

NAME		WAVELENGTH (µM)	FREQUENCY (HZ)
NEAR INFRARED	NIR	0.72 µM – 3 µM	4.3 ö $10^{15} - 1 \times 10^{14}$
MIDDLE INFRARED	MIR	3 µM – 6 µM	3.0 ö $10^{14} - 5 \times 10^{13}$
FAR INFRARED	FIR	6 µM – 15 µM	5.0 ö $10^{13} - 2 \times 10^{13}$
EXTREME INFRARED	XIR	15 µM – 1000 µM	2.0 ö $10^{13} - 3 \times 10^{11}$

the target and the FLIR attenuates and blurs the target signal. The FLIR operator aims the limited field of view FLIR to search the scene for targets, using a search pattern and clues, such as radar targets or laser designators.

The FLIR system uses thermal sensitivity, image sharpness, spectral response, contrast, and magnification to produce a visual image of the thermal scene. The operator uses training, experience, and image interpretation skills to detect and identify targets.

INFRARED RADIATION

The atmosphere is a poor transmitter of infrared radiation because of the absorption properties of CO_2 (carbon dioxide), H_2O (water), and 0_3 (ozone). Infrared radiation is broken into four regions, as can be seen in table 6-1. Only the first three are used with this system. Figure 6-3 shows the transmission spectrum of the atmosphere. You can see that the best transmission is between 3 µm and 5 pm, and between 8 µm and 14 µm. The range between these wavelengths is known as a window. Infrared imaging devices are designed to operate in one of these two windows, usually the 8 µm to 14 µm window.

Infrared Radiation Sources

All matter whose temperature is above -273°C (absolute zero) emits IR radiation. The amount of the radiation emitted is a function of heat. Theoretically, a perfect emitter is a black body with an emissivity of 1. Realistically, the best emissivity is somewhere around 0.98. The emissivity of various objects is measured on a scale of 0 to 1.

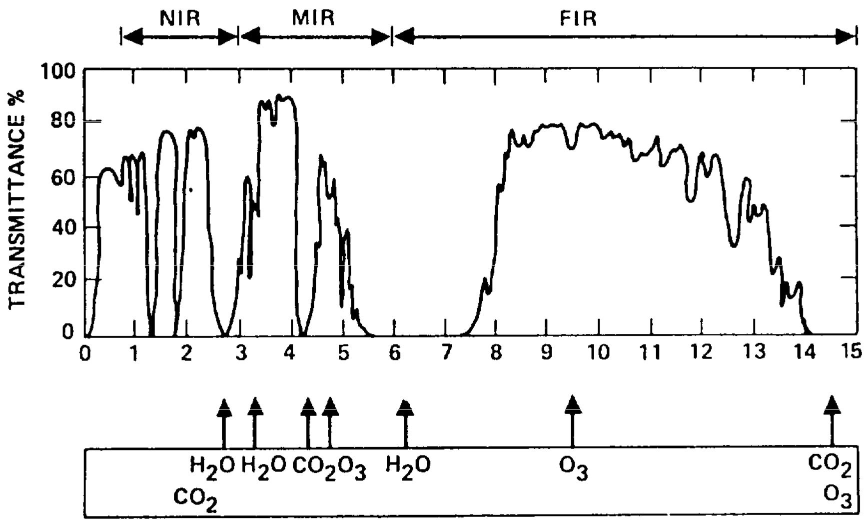


Figure 6-3.-Transmission spectrum of the atmosphere.

The total energy emitted by an object at all wavelengths is directly dependent upon its temperature. If the temperature of a body is increased 10 times, the IR radiation emitted by the body is increased 10,000 times. If the energy emitted by a black body and its wavelengths is plotted on a graph, a hill-shaped curve results (fig. 6-4). By looking at this graph, you can see that the energy emitted by short wavelengths is low. As the wavelengths get longer, the amount of energy increases up to a peak amount. After the peak is reached, the energy emitted by the body drops off sharply with a further increase in wavelength.

Infrared Optics

Many of the materials commonly used in visible light optics are opaque at IR frequencies. For this reason, they cannot be used in IR imaging systems. The optical material used in IR imaging systems should have a majority of the following qualities:

- Be transparent at the wavelengths on which the system is operating
- Be opaque to other wavelengths
- Have a zero coefficient of thermal expansion to prevent deformation and stress problems in optical components

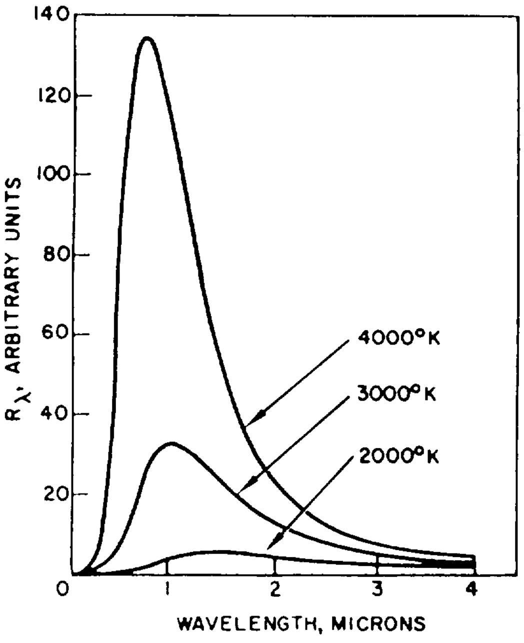


Figure 6-4.-Black body radiation.

- Have high surface hardness to prevent scratching the optical surfaces
- Have high mechanical strength to allow the use of thin lenses (high-ratio diameter to thickness)
- Have low volubility with water to prevent damage to optical components by atmospheric moisture
- Be compatible with antireflection coatings to prevent separation of the coating from the optical component

None of the materials currently used for IR optics have all of these qualities. However, silicon, germanium, zinc selenide, and zinc sulfide have many of them.

Infrared Detectors

The detector is the most important component of the IR imaging system. There are many types of detectors, each having a distinct set of operating characteristics. Bolometers, Golay cells, mercury-doped germanium, lead sulfide, and phototubes are the most commonly used types of detectors. Detectors can be characterized by their optical configuration or by the energy-matter interaction process. There are two types of optical configurations—elemental and imaging.

ELEMENTAL DETECTORS.— Elemental detectors average the portion of the image of the outside scene falling on the detector into a single signal. To detect the existence of a signal in the field of view, the detector builds up the picture by sequentially scanning the scene. The elemental detector requires time to develop the image because the entire scene must be scanned.

IMAGING DETECTORS.— Imaging detectors yield the image directly. An imaging detector is considered a myriad of point detectors. Each of the detectors responds to a discrete point on the image. Therefore, the imaging detector produces the entire image instantaneously. A good example of an imaging detector is photographic film.

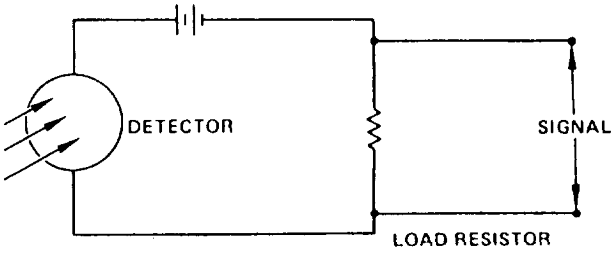


Figure 6-5.-Photoconductive detector circuit.

Energy-Matter Interaction

There are two basic types of energy-matter interaction. They are the *thermal effect* and the *photon effect.*

THERMAL EFFECT.— The thermal effect type of energy-matter interaction involves the absorption of radiant energy in the detector. This results in a temperature increase in the detector element. The radiation is detected by monitoring the temperature increase in the detector. Both the elemental and imaging forms of detectors use the thermal effect.

PHOTON EFFECT.— In the photon effect type of energy-matter interaction, the photons of the radiant energy interact directly with the electrons in the detector material. Usually, detectors using the photon effect use semiconductor material. There are three specific types of photon effect detection. They are *photoconductivity, photoelectric,* and *photoemissive.*

1. Photoconductivity. Photoconductivity is the most widely used photon effect. (See figure 6-5.) Radiant energy changes the electrical conductivity of the detector material. An electrical circuit is used to measure the change in the conductivity.

2. Photoelectric (also referred to as photovoltaic). In the photoelectric effect (fig. 6-6), a potential difference across a PN junction is caused by the radiant signal. The photocurrent (current generated by light) is added to the dark current (current that flows with no radiant input). The total current is proportional to the amount of light that falls on the detector.

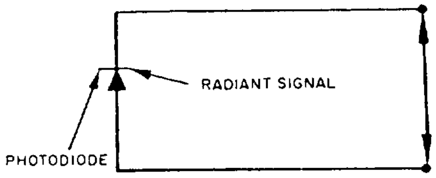


Figure 6-6.-Photoelectric effect.

3. Photoemissive. The photoemissive effect (fig. 6-7) is also known as the *external photo effect.* The action of the radiation causes the emission of an electron from the surface of the photocathode to the surrounding space. The electron is photoexcited from the Fermi level above the potential barrier at the surface of the metal.

INFRARED IMAGING SYSTEMS

An infrared imaging system has the following components: detectors, a scene dissection system, front end optics, a refrigeration system, and an image processing system.

Detectors

Detectors convert the IR radiation signal into an electrical signal that is processed into information used by the operator. Detectors can be arranged in many different configurations for their use in an IR imaging system.

DETECTOR ARRAY.— Only a small portion of the image scene is taken by a detector (or detectors) to

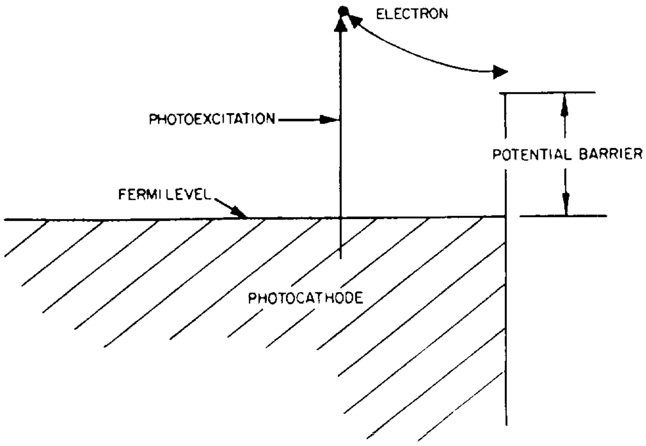


Figure 6-7.-Photoemessive effect.

achieve maximum resolution. A large number of detector elements can be grouped together to form an array (fig. 6-8, view A). The elements of this array are packed closely together in a regular pattern. Thus, the image of the scene is spread across the array like a picture or a mosaic. Each detector element views a small portion of the total scene. The disadvantage of this type of system is that each detector element requires a supporting electronic circuit to process the information that it provides. Also, each detector element requires a preamplifier to boost the signal to a usable level.

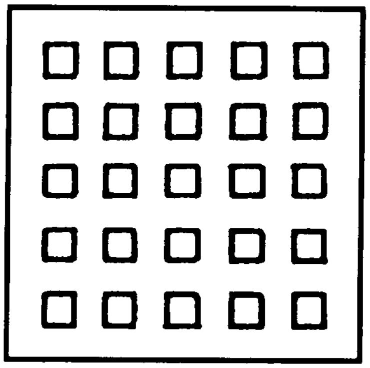
SINGLE DETECTOR.— Another method that is used to provide the operator with information is the single detector (fig. 6-8, view B). Here, there is one detector requiring one set of supporting circuitry. In this type of system, the detector is scanned across the image so that the detector can see the whole image. An optical system is required that can supply the scanning. This type of system is adequate if real-time information is not needed, or if the object of interest is stationary or not moving quickly.

Scene Dissection System

The scene dissection system is used to scan the scene image. There are many types of scanning-one associated with each type of detector array. When a single detector with one axis of fast scan and one axis of slow scan is used, the scene is scanned rapidly in the horizontal direction and slowly in the vertical direction. As a result, the line is scanned horizontally; then the next line is scanned horizontally, etc.

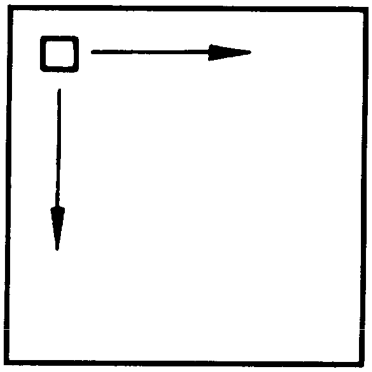
A vertical linear array is scanned rapidly in the horizontal direction (fig. 6-8, view C). One detector element scans one line of the image. In the linear array, there is a space, one element wide, between each element. The scan is one axis with an interlace being used. A vertical linear array is scanned rapidly in the horizontal direction. After each horizontal scan, the mechanism shifts the image upward or downward one detector element width so that on the next scan, the lines that were missed are covered.

Each system has an optimum configuration of detector array and image dissection. If the number of elements in the detector increases, the system becomes more complicated. Also, the cost of the



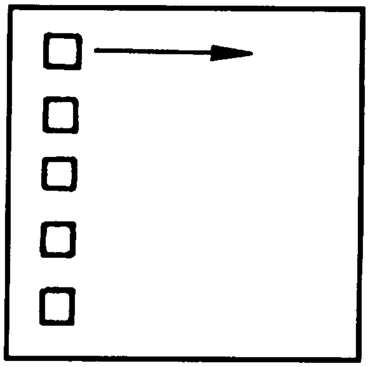
MOSAIC ARRAY WITH NO SCAN

A



SINGLE DETECTOR WITH VERTICAL SLOW SCAN AND HORIZONTAL FAST SCAN

B



PARALLEL ARRAY WITH SLOW SCAN HORIZONTALLY INTERLACE, VERTICALLY

C

Figure 6-8.-Detector arrays.

system increases, and the reliability of the system decreases. If the number of detectors decreases, the amount of information that can be processed is reduced. A compromise between a large number of elements (increased cost) and a smaller number of elements (reduced information) is the linear array that scans in one direction only. Each detector scans one line of the scene image. The complexity of the electronics is reduced, and the amount of information that is processed is increased. Thus, the size of the scene to be viewed and the detail of the scene is increased.

There are many types of mechanisms that can be used to scan the scene. When you scan with two axes, the two scanning motions must be synchronized. The electronic signal that controls the sampling of the detectors must also be synchronized with the scanning motions.

Front End Optics

The front end optics collect the incoming radiant energy and focus the image at the detectors. The optics may be reflective or refractive, or a combination of both. Many systems offer a zoom capability, allowing a continuous change in magnification of the image without changing the focus. Spectral filters are used to restrict the wavelength of light entering the system. This prevents unwanted wavelengths of light from reaching the detector and interfering with the imaging process.

Refrigeration System

A refrigeration system is needed in imaging systems because many types of infrared detectors require low temperatures if they are to operate properly. The two types of detector cooling that are used are the *open-cycle* and the *closed-cycle* types.

In the open-cycle type of cooling, a reservoir of liquified cryogenic gas is provided. The liquid is forced to travel to the detector, where it is allowed to revert to a gas. As it changes from a liquid to a gas, it absorbs a great deal of heat from the surrounding area and the detector.

In the closed-cycle type of cooling, the gas is compressed, and the heat generated by the compression is radiated away by the use of a heat exchanger. The gas is then returned to the compressor and the cycle repeats itself.

Image Processing Systems

The image processing system is used to convert the data collected by the detectors into a video display. Data from the detectors is multiplexed so that it can be handled by one set of electronics. Then it is processed so that the information coming from the detectors is in the correct order of serial transference to the video display. At this point, any other information that is to be displayed is added.

In other image processing systems, the signals from the detectors are amplified and sent to an LED display, or they are optically amplified by photomultiplier tubes and projected on a phosphorescent screen.

FORWARD-LOOKING INFRARED SYSTEM

Learning Objective: *Recognize components and operating principles of a typical FLIR system.*

A forward-looking infrared system is an infrared detecting set (IRDS). The IRDS is a passive device that operates on the IR principles of emissivity. The terms *FLIR* and *IRDS* are synonymous so far as system operation is concerned. Only the azimuth coverage differs. The FLIR system scans an operator-selected portion of the terrain along the aircraft's flight path and displays a televised image of the IR patterns of the terrain. The primary function of the FLIR system is to give the operator an improved capability to detect, identify, and classify targets of interest that would otherwise be concealed from either visual observation or radar detection. The visual concealment could be due to darkness or camouflage. The radar concealment could be due to extreme scope clutter caused by inclement weather, rough seas, or electronic jamming. Additionally, the FLIR system emits no transmission for detection by an enemy. Although there are various types of FLIR systems

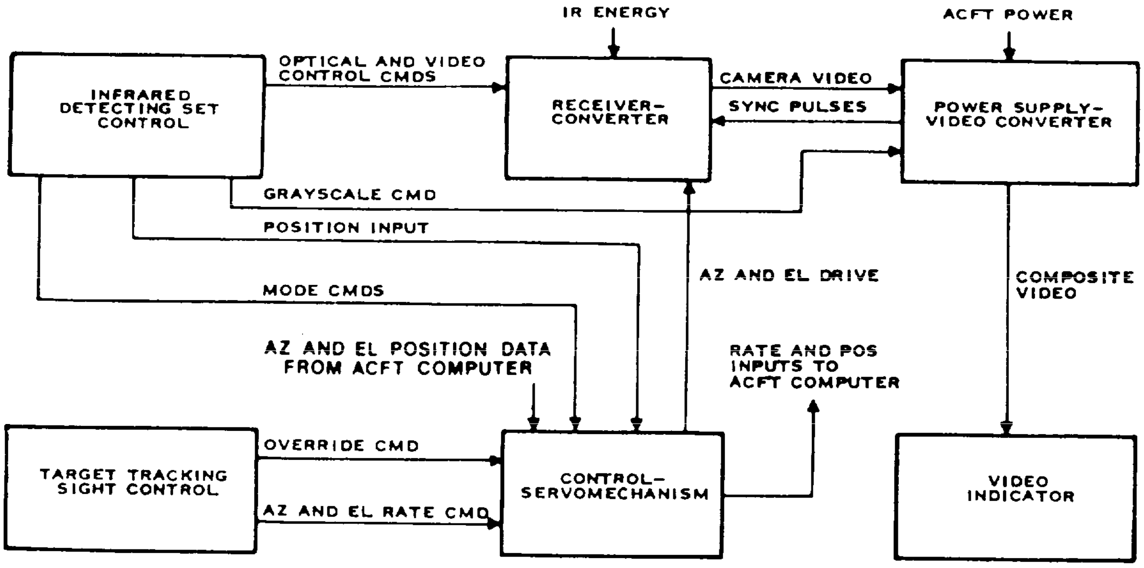


Figure 6-9.-FLIR system block diagram.

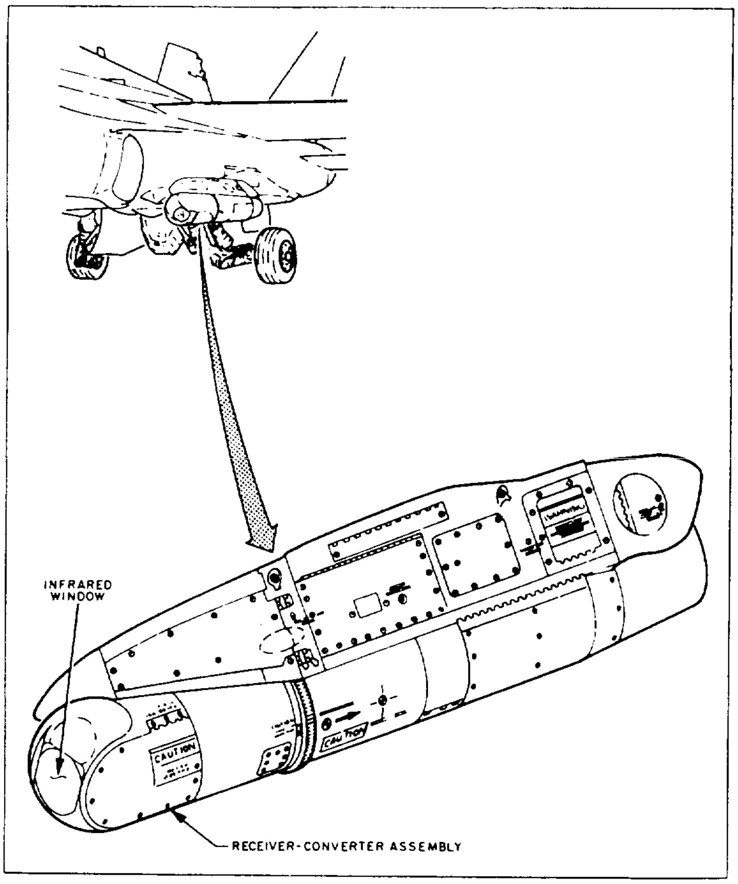


Figure 6-10.-Station-mounted FLIR pod.

used in the Navy, their principles of operation are basically the same.

A typical FLIR system contains several weapons replaceable assemblies (WRAs). These WRAs are as follows: receiver-converter, power supply-video converter, control servomechanism, target tracking sight control, infrared detecting set control, and video indicator. Figure 6-9 shows the block diagram of a typical FLIR system. You should refer to the block diagram as you read about the FLIR system components.

RECEIVER-CONVERTER ASSEMBLY

The receiver-converter assembly contains all of the optics and electronics used to detect and convert IR energy into a single-channel video output to be processed by the power supply-video converter assembly. The processed video output is applied to the video indicator. The receiver-converter assembly contains gyros, gimbals, and drive motors to aim and stabilize the receiver section in azimuth and elevation. It also contains a heat exchanger to circulate conditioned air throughout the assembly and a refrigerator unit to keep the IR detectors cooled to cryogenic temperatures. The receiver-converter assembly is housed in either the forward section of a station-mounted FLIR pod (fig. 6-10) or in its own pod, mounted on the forward lower part of the aircraft's fuselage (fig. 6-11). The housing used is dependent on the aircraft model.

Functionally, the receiver-converter breaks down into four subsystems as follows:

- IR to composite video conversion
- Temperature control
- Positioning and stabilization
- BITE (built-in test equipment)

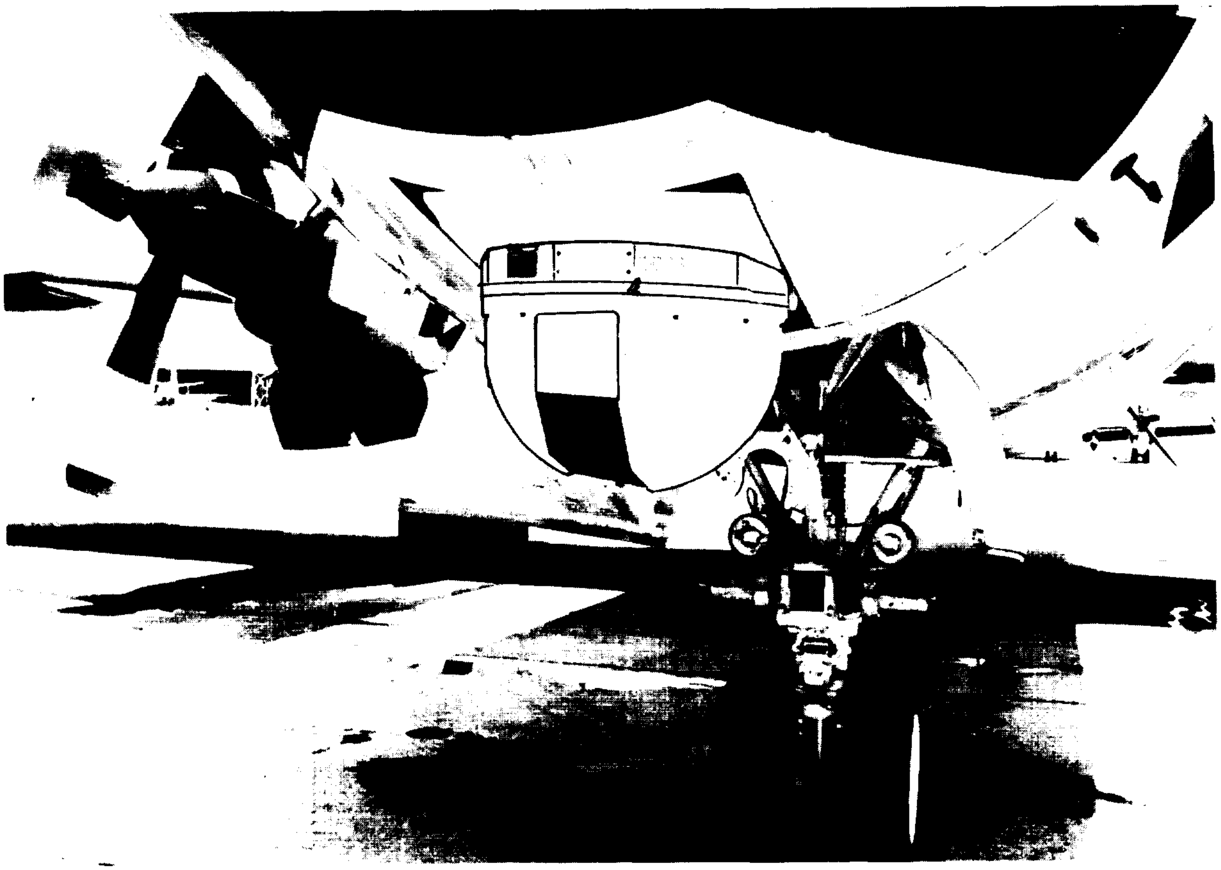


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Figure 6-11.-Receiver-converter pod shown in operating position.

IR to Composite Video Conversion

Figure 6-12 is a diagram showing the optics and electronic components of a typical receiver-converter required to perform IR detection and conversion into a useable video signal. Although the signal optical path and conversion coincide, each path is discussed separately for simplicity. You should refer to figure 6-12 as you read the following paragraphs.

SIGNAL OPTICAL PATH.— Incoming IR energy from a target enters the receiver through a window and strikes one side of a double-sided scan mirror. This mirror is controlled by a seamer module. The IR signal either strikes the mirror directly or is focused onto the mirror by optical lenses contained in what is called an afocal optics unit. The operation of the afocal unit is governed by a field of view (FOV) switch on the operator's infrared detecting set control (IRDSC). In the wide FOV mode of operation, the afocal optic lenses are not in the signal optical path. In the narrow FOV mode of operation, the lenses are in the path shown in figure 6-12. The lenses are focused by a motor that is controlled by a focusing module in the receiver-converter assembly. The focusing module has two inputs to control the operation of the focusing motor. One input is a target range scale set by the operator on the IRDSC. The other input is a feedback signal from a temperature-sensing circuit in the afocal optics unit. Because the index of refraction of an optical lens changes with changes in temperature, the focusing module monitors the temperature of the lens and maintains proper focusing of the IR signal onto the scan mirror.

The scan mirror is controlled by a scanner module. It is also positioned in line-of-sight (LOS) position, along with the entire receiving head, by

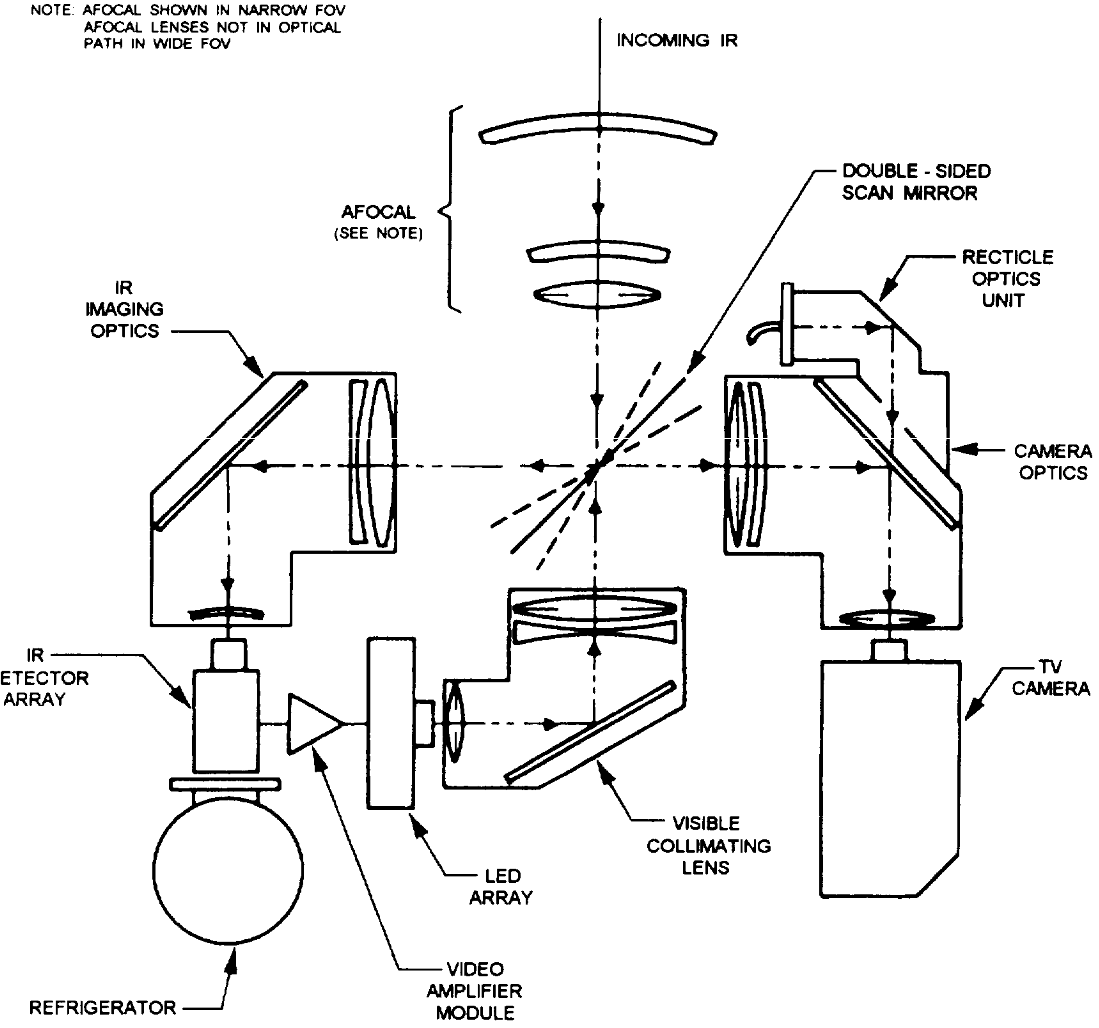


Figure 6-12.-FLIR optical path and IR processing.

signals from the control servomechanism. As shown at the top of figure 6-12, one side scans the incoming IR energy and reflects the signals into the IR imaging optics, while the bottom side simultaneously scans visible light signals from the collimating lens and reflects the signal into the TV camera optics. The mirror scans the horizontal axis, and is indexed in the vertical axis to provide a 2:1 ratio interlace scan. The mirror scan is synchronized to the TV camera by sync signals.

IR TO VIDEO PROCESSING.— The IR signals reflected from the scan mirror into the imaging optics are focused onto an IR detector array located behind an imaging lens. The lens is kept in focus much the same as the afocal lenses. The IR detector array consists of approximately 180 individual detectors arranged in a linear array with a space between each to allow for 2:1 interlacing. The scan mirror scans the image across the detectors, and each detector produces a single horizontal line of IR video. The scan mirror is indexed one line width in the vertical direction, making a total of 360 lines of video with only 180 detectors and amplifier channels. Because of the 2:1 interlacing, two full scans of the mirror are required to reproduce the entire image. Each detector conducts according to the amount of IR energy impressed on it from the scan mirror. The resultant output of the IR detector array is 180 parallel signals representing 360 video lines of IR energy scanned by the scan mirror.

The IR detectors are kept at cryogenic temperatures by the refrigerator unit. The detectors are biased to process the incoming IR energy into a useable multichannel IR video signal. The low-level output of the detector array is fed to a video amplifier module. The module consists of one preamplifier and three postamplifiers for each of the IR detectors in the array. This is required to increase the IR signal to a useable level. The output of the postamplifiers is controlled by a dc level (+ or –) whose polarity is controlled by a polarity switch on the IRDSC. The purpose of the dc polarity is to have “hot” targets appear either white or black on the video indicator. Also, the outputs of the video amplifiers are gated on or off in synchronization with the scan mirror and the TV camera sweep.

Each video amplifier feeds a light-emitting diode (LED) of the LED array. The LED array duplicates the IR detector array. The visible light intensity output of one LED is proportional to the IR output of the corresponding IR detector in the detector array. The resultant output of the LED array comprises 180 parallel visible light beams (signals) representative of the IR energy scanned by the scan mirror. In other words, the resultant output of the LED array represents the terrain or targets scanned.

The output of the LED array is applied to the collimating lens unit. This unit focuses the visible light while maintaining the light beams parallel to each other rather than converging them to a focal point, as shown in figure 6-13, views A and B.

The output of the collimating lens unit is scanned by the back side of the scan mirror and is reflected into the camera optics unit that focuses the light for the TV vidicon camera. Also, a reticle light signal from the reticle optics unit is applied simultaneously to the TV camera to give an indication of the position of the receiving head. The TV vidicon camera processes the visible light signals into a single channel video signal. The video output of the camera is fed to the power supply-video converter assembly for further processing.

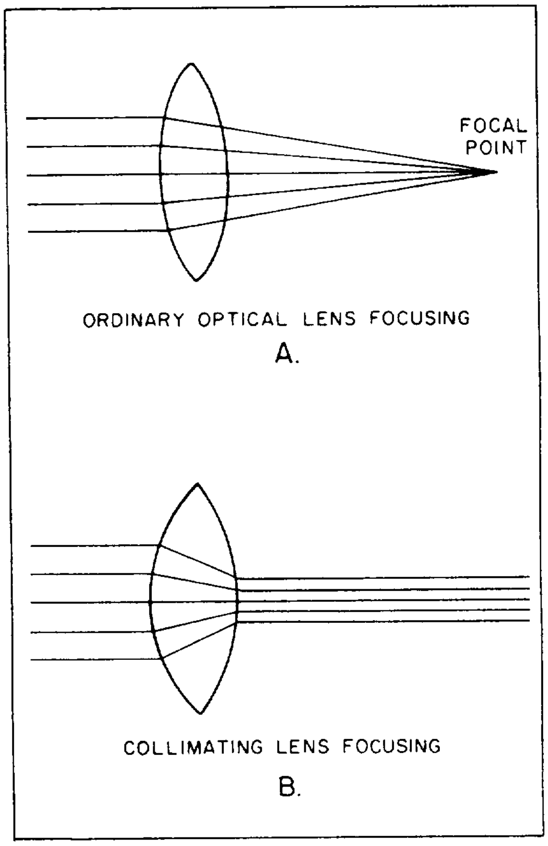


Figure 6-13.-Lens focusing patterns.

Temperature Control

Figure 6-14 is a block diagram of a receiver-converter heat exchanger. The heat exchanger supplies conditioned air to the receiver-converter assembly for environmental control. The exchanger shown consists of two blowers, six heaters, three temperature-sensitive switches, and an air-to-air heat exchanger. Three of the heaters are connected in a wye configuration, and the other three are connected in a delta configuration. The three temperature-sensitive switches are usually mounted on the receiver casting. Blowers B1 and B2 circulate cooling air and heating air within the receiver-converter. Internal blower B1 operates whenever the FLIR system is turned on. If the temperature of the assembly compartment goes above approximately 77°F (25°C), thermal switch RT3 operates relay K3, applying power to external blower B2. Blower B2 draws cool external air through the air-to-air heat exchanger. Internal blower B1 circulates the cool air and cools the compartment. If the temperature in the compartment goes below 68°F (20°C), thermal switch RT2 operates relay K1, applying power to the wye-configured heaters. The heaters operate at approximately 365 watts. If the compartment temperature drops below 50°F (10°C), thermal switch RT1 operates K2, applying power to the delta-cordigured heaters. This increases the wattage used by the heaters to approximately 1,200 watts. Thus, the heat exchanger is able to maintain the receiver-converter compartment at a temperature between 68°F and 77°F at all times.

Positioning and Stabilization

The function of the stabilized gimbal subsystem of the receiver-converter is to allow the operator to select the line-of-sight (LOS) desired to the receiver unit. Another function is to maintain a steady image of the IR patterns of the areas viewed regardless of aircraft movement. This critical stability is obtained by means of gyros mounted on the receiver assembly. There is one azimuth and one elevation gyro. Figure 6-15 is a simplified block diagram of a typical FLIR positioning and stabilization subsystem.

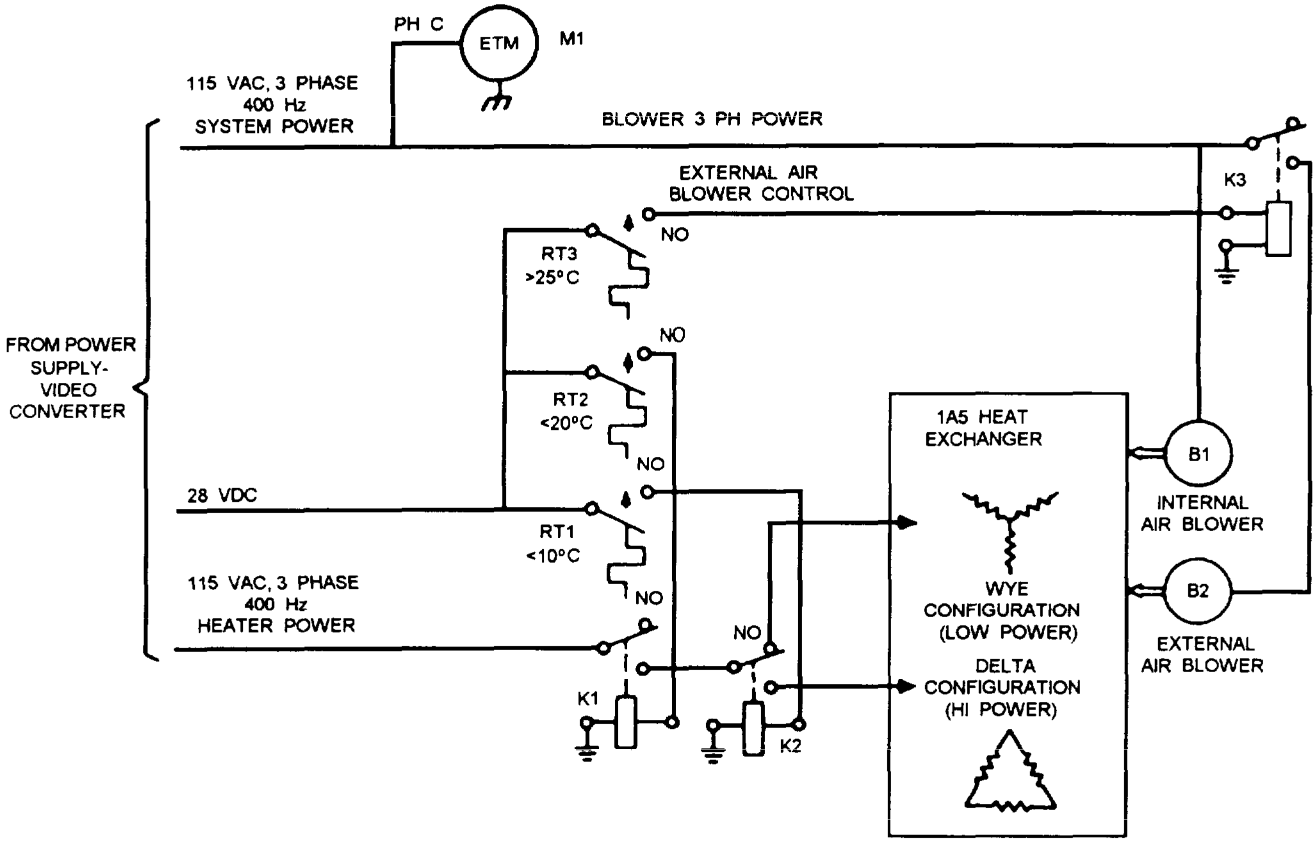


Figure 6-14.-Receiver-converter heat exchanger block diagram.

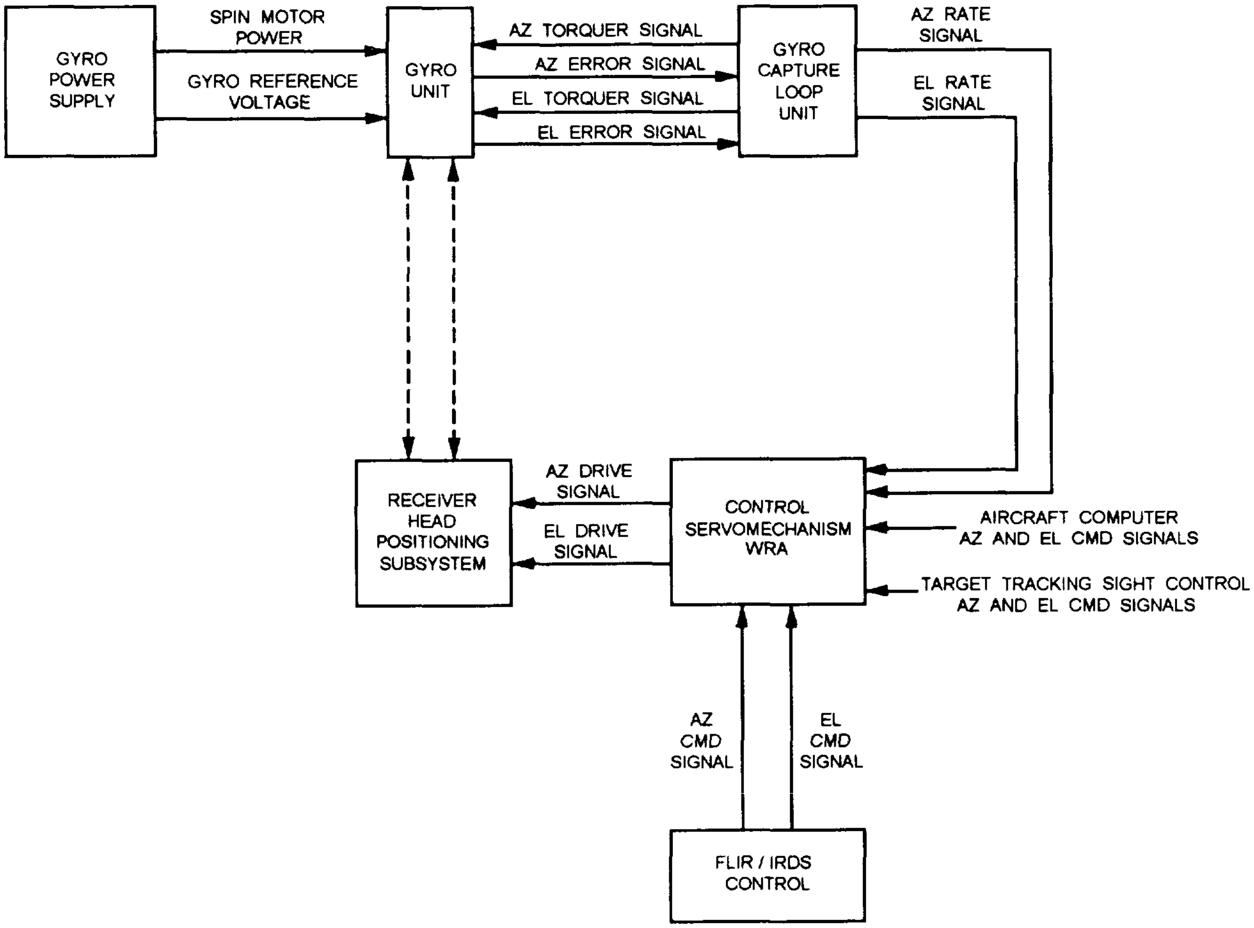


Figure 6-15.-FLIR positioning/stabilization block diagram.

The LOS of the receiver is selected in one of three ways:

- By a program in the aircraft's computer (or a video tracking computer when the system is used with a laser system)
- By inputs from the target tracking sight control
- By operator adjustment of the azimuth and elevation controls on the control box

The control servomechanism WRA processes these azimuth and elevation commands, no matter from which source they come. This WRA will then apply drive signals to the receiver head positioning motors and gimbals. The receiving head is aligned to the desired LOS. If the aircraft should pitch or roll, the gyros (mounted on the receiver head) initiate error signals to a capture loop. This loop creates azimuth and elevation rate signals. The rate signals are fed back to the control servomechanism (CS). The CS will then process these rate signals and apply them to the receiver head as drive signals to maintain the correct LOS. In the manual mode (which uses the target tracking sight control), the stabilization system is inhibited in the control servomechanism assembly.

BITE System

Most FLIR systems are equipped with a built-in test equipment (BITE) system. The receiver-converter BITE subsystem monitors status signals from the following subassemblies:

- Camera video
- Refrigerator unit
- Gimbals from the control servomechanism assembly
- Scan mirror and TV camera scan
- Focus drive of the lenses
- Heat exchanger

- Afocal optics assembly

- IR detectors

Figure 6-16 is a simplified block diagram of a receiver-converter BITE system. The BITE signals go to a BITE logic module in the power supply-video converter WRA. In this WRA, they are combined and sent to the IRDSC to light the various indicators.

POWER SUPPLY-VIDEO CONVERTER ASSEMBLY

Functionally, the power supply-video converter assembly breaks down into three subsystems. These subsystems are the power supply, the video processing, and the BITE system.

Power Supply

The power supply subsystem is a typical power supply. It filters aircraft power for use by the receiver-converter assembly. It also develops all the operating voltages for both the receiver-converter and the power supply-video converter circuits.

Video Processing

The video processing subsystem generates the synchronizing drive and timing signals for the receiver-converter. It also converts the TV camera video from the receiver-converter assembly into a composite video format. This format consists of camera video and receiver position information for presentation on the video indicator.

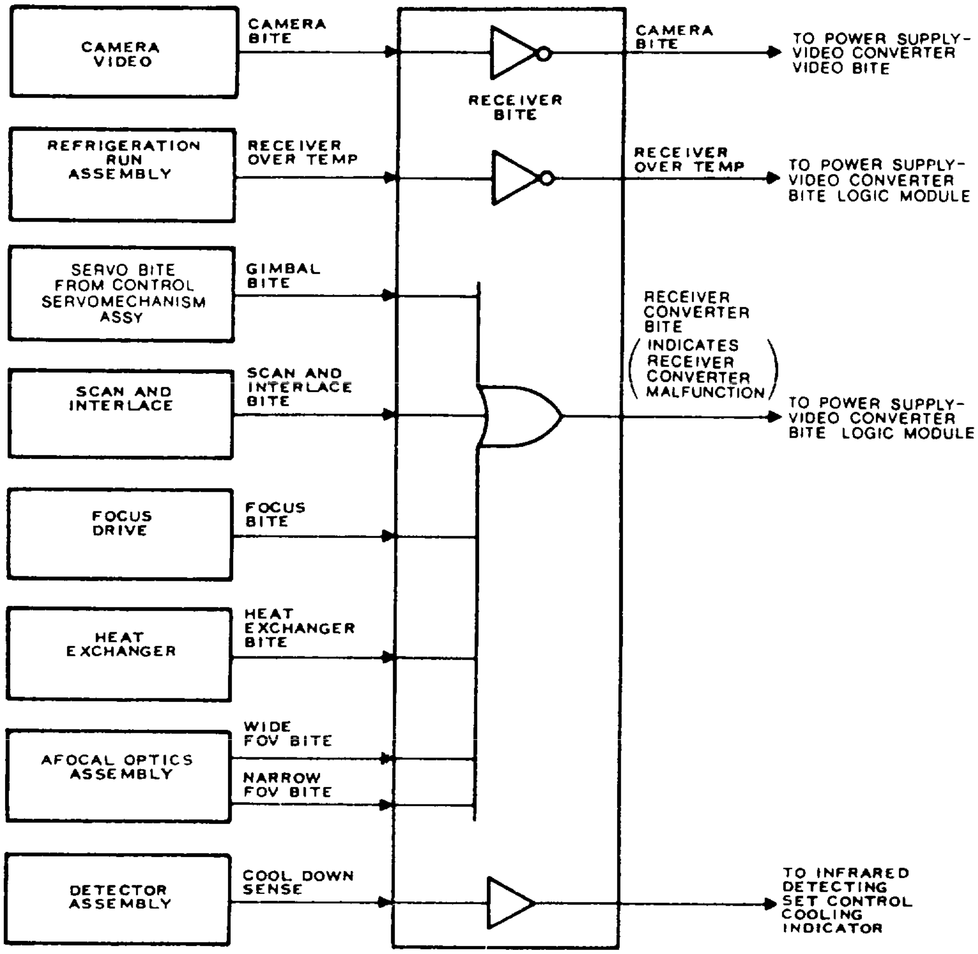


Figure 6-16.-Receiver-converter BITE block diagram.

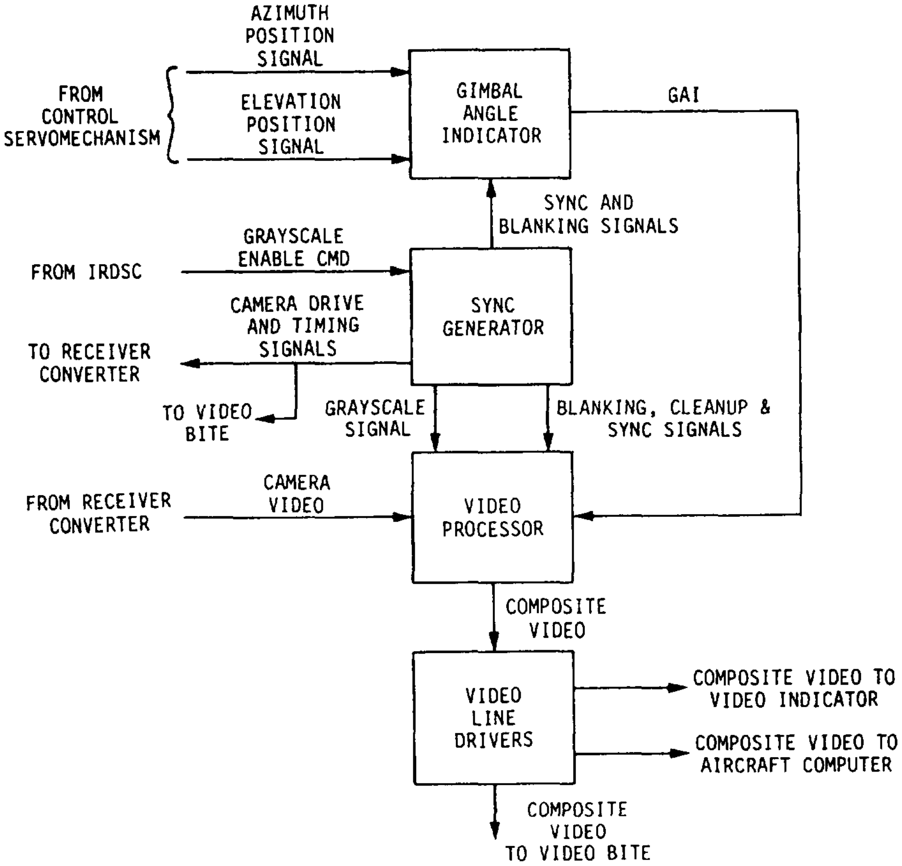


Figure 6-17.-Video converter video processing block diagram.

Figure 6-17 is a simplified block diagram of the video processing sections found in a typical FLIR power supply-video converter WRA. The gimbal angle indicator unit receives linear signals from the control servomechanism azimuth and elevation gimbal potentiometers. These potentiometers receive inputs from the gimbals in the receiver-converter. The potentiometers then generate synthetic video signals. The signals present short, bright-line segments along the calibrated scales on the video indicator to show receiver head position. An example of this is shown in figure 6-18.

The sync generator module contains a crystal-controlled clock. The module generates all timing (sync), clamping, and drive signals for the receiver-converter and the TV camera. It also generates all timing, gating, clamping, and blanking signals for the video processor and gimbal angle

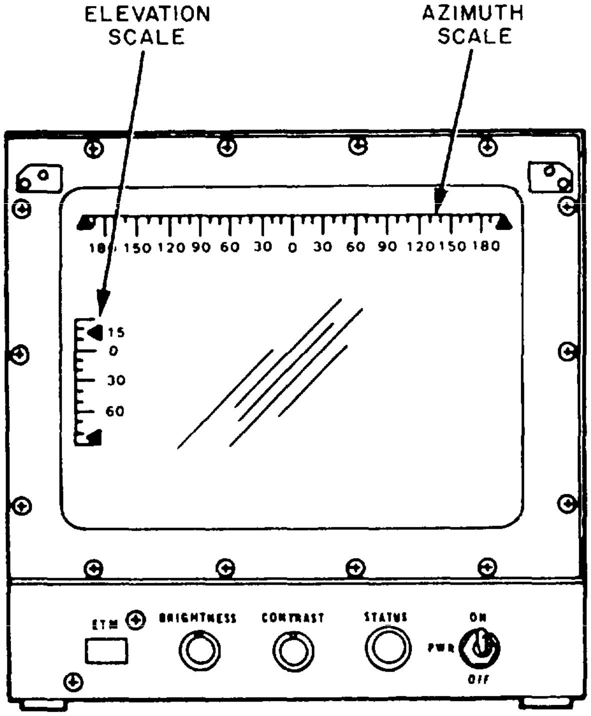


Figure 6-18.-Azimuth/elevation scale on a video indicator.

Table 6-2-Sync Generator Outputs

SYNC GEN OUTPUT	UNIT SUPPLIED
Beam gate only	TV camera
Cathode drive	TV camera
Dark current drive	TV camera
Horizontal current drive	TV camera
Vertical deflection drive	TV camera
Composite clamping	TV camera
Scanner sync	Scanning optic unit
Horizontal sync	Gimbal angle indicator (GAI)
Composite blanking	GAI, video processor
Vertical blanking	Gimbal angle indicator
Composite sync	Video processor
Gray scale signal	Video processor
Horizontal clamping	Video processor

indicator (GAI) modules. These signals are listed in table 6-2.

The sync generator module also generates a gray scale signal upon receipt of a gray scale command signal from the IRDSC. The IRDSC generates this command whenever the gray scale switch is turned on. The gray scale signal presents a gray scale pattern (fig. 6-19) on the video indicator. The pattern serves to aid the operator in adjusting the level and gain controls on the IRDSC. There is a total of ten different shades. Each shade represents a different IR temperature range to which the operator can compare the target intensity and estimate the temperature of the target. The temperature is an indication of the type of target material.

The video processor receives raw video signals from the TV camera. It also receives gimbal angle Indicator synthetic video, gray scale signals, composite sync, composite blanking, and horizontal

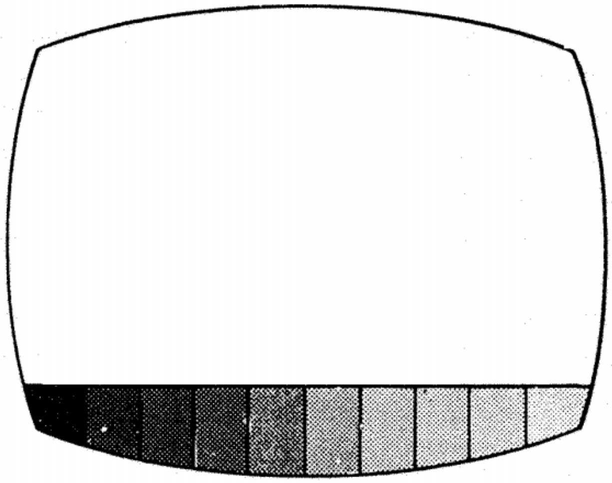


Figure 6-19.-Gray scale video indicator presentation.

clamping signals from the sync generator. The video processor combines all of these signals into a composite video signal, which is fed to the video line drivers. The video line drivers amplify the composite video and provide three separate outputs. One output goes to the video indicator, one goes to the aircraft computer, and one goes to the video BITE module.

BITE Subsystem

Figure 6-20 shows a simplified block diagram of the BITE subsystem of the power supply-video converter. The BITE logic module receives an initiation command signal from the IRDSC. This command is generated whenever BITE is selected on the IRDSC. The signal causes the BITE logic module to generate and send a gray scale enable signal to the sync generator. This signal overrides the gray scale switch on the IRDSC, and causes the sync generator to output a gray scale signal in addition to the sync, blanking, clamping, and drive signals. BITE logic also sends a BITE initiate signal to the control servomechanism to initiate servo BITE. A BITE ON signal is sent to the IRDSC from the BITE logic module to light the BITE ON indicator. This indicator shows that the BITE mode is operating.

The TV video BITE module monitors the output of the sync generator, the video line drivers, and the camera BITE from the receiver-converter. If a failure occurs in any of these circuits, the video BITE module generates and sends a TV fail signal to the power supply BITE module.

The power supply BITE module monitors all of the power supply voltages. If any voltage is not correct, a power supply malfunction signal is generated and sent to the BITE logic module. This signal causes the logic module to send a power supply fail signal to the IRDSC to light the power supply fail light. If the power supply receives a TV fail signal

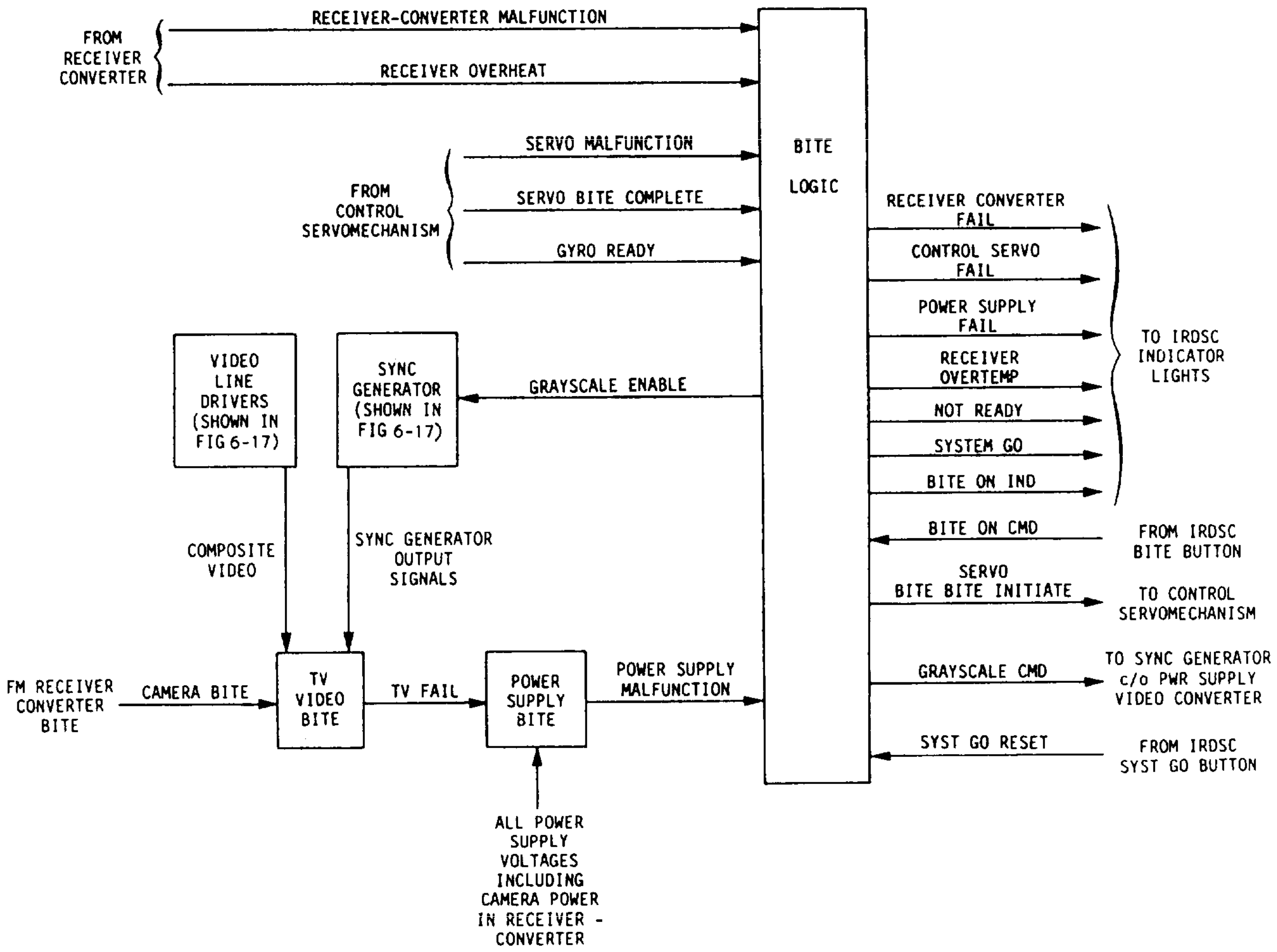


Figure 6-20.-Power supply-video converter BITE block diagram.

from the video BITE, it will send a power supply malfunction signal to the IRDSC to light the power supply fail light.

BITE logic also monitors incoming signals from the receiver-converter and control servomechanism. The logic module will initiate signals to the IRDSC to operate the various indicator lights based on these signals.

CONTROL SERVOMECHANISM ASSEMBLY

The control servomechanism assembly processes line-of-sight (LOS) position and rate commands from the IRDSC, the target tracking sight control (TTSC), or the aircraft computer. The source of these commands depends upon which operational mode the system is operating in. These commands are processed as analog drive signals for slewing (steering) the receiver-converter drive motors and gimbals to position the receiver head. Functionally, the control servomechanism assembly breaks down into four subsystems. These are the power supply, azimuth drive, elevation drive, and the BITE subsystems.

The azimuth and elevation drive signals are processed simultaneously in a given module. For simplicity, we will discuss each subsystem separately. Notice the modules are labeled in their respective block diagrams as azimuth (fig. 6-21) or elevation (fig. 6-22) as appropriate. Keep in mind that, in actual practice, a module (such as mode logic) is

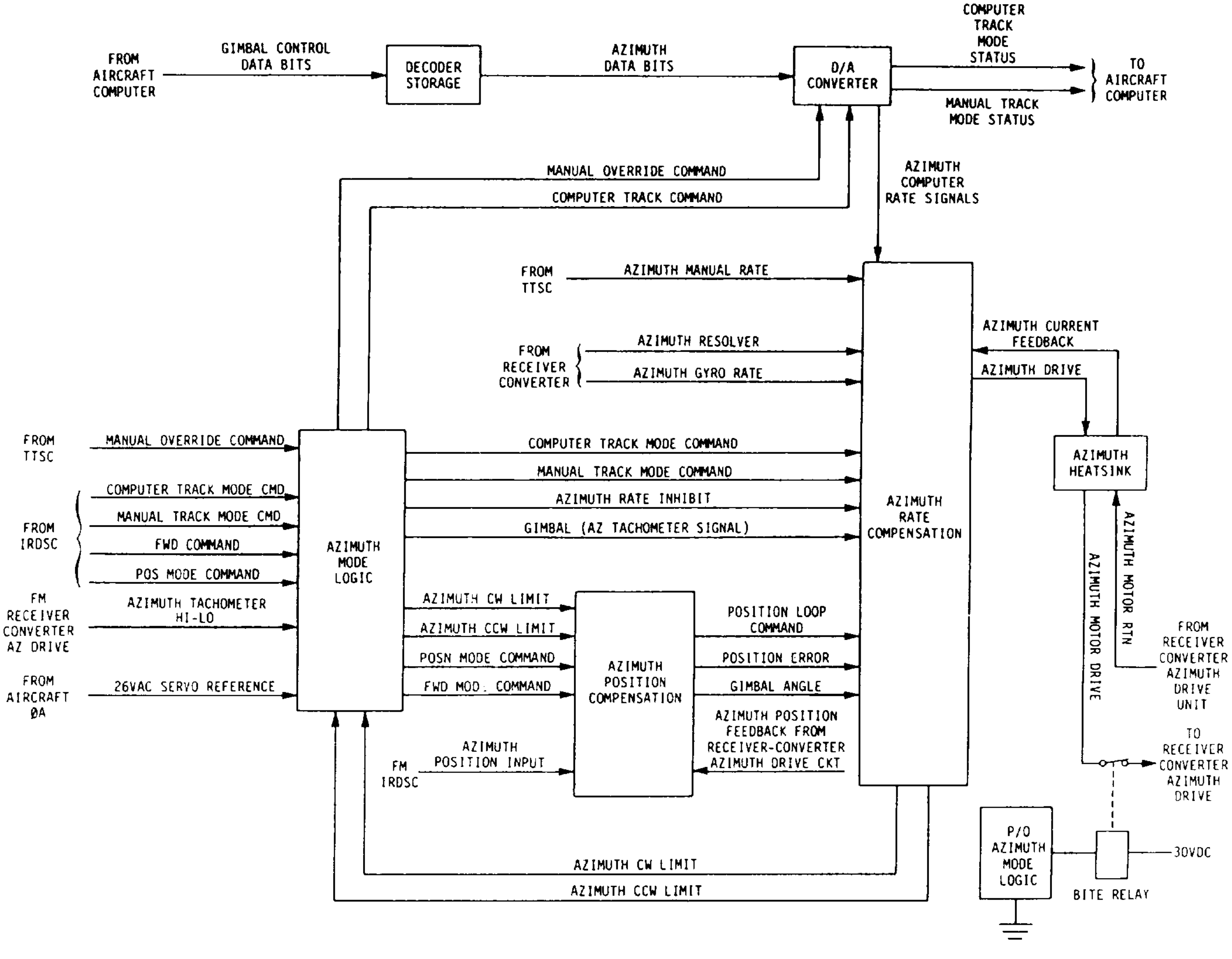


Figure 6-21.-Azimuth drive subsystem block diagram.

shared by both azimuth and elevation drive signals. The following discussion will refer to that module as the azimuth mode logic module or the elevation mode logic module, as appropriate.

Power Supply

The power supply is a typical power supply. It filters aircraft power and develops all of the operating voltages for the control servomechanism assembly and the TTSC assembly circuits.

Azimuth Drive Subsystem

Figure 6-21 is a simplified block diagram of a typical azimuth drive subsystem used in a control servomechanism assembly. The azimuth mode logic module receives one of four operational commands from the IRDSC. These mode commands are for either the position, the forward (FWD), the manual track, or the computer track modes. The operator selects the mode on the IRDSC.

POSITION MODE.— The position mode command signal is processed by the mode logic module, which sends a position (POS) command signal to the azimuth position compensation module. This module processes the signal, enabling it to receive azimuth position (LOS) information from the IRDSC azimuth control. It outputs position loop command and gimbal angle signals to the azimuth rate compensation module. The azimuth rate compensation module sends an azimuth drive signal to the azimuth heat sink module. This module

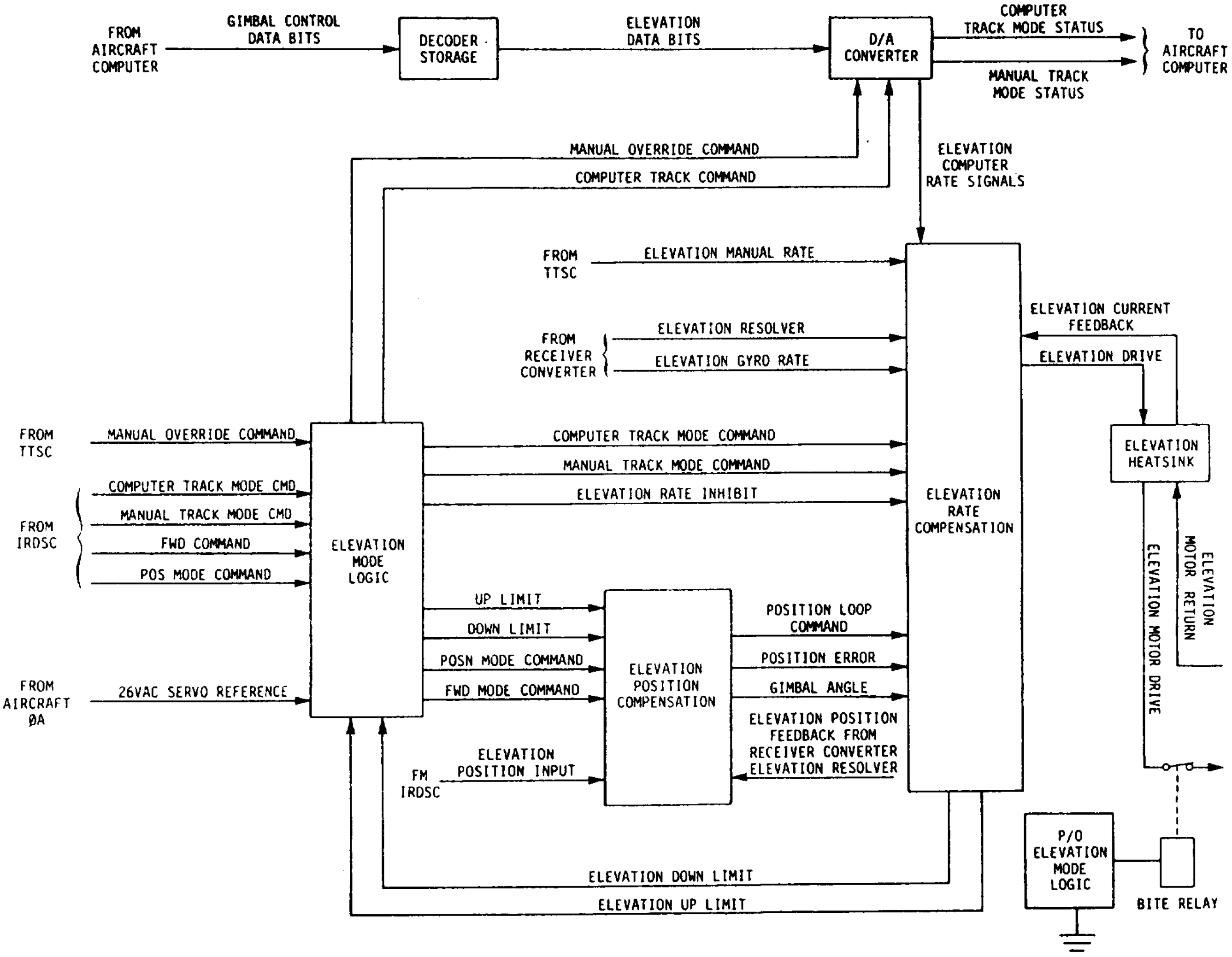


Figure 6-22.-Elevation drive subsystem block diagram.

amplifies the signal to develop enough motor drive power to steer the receiver head to the azimuth bearing selected on the IRDSC by the operator.

Four feedback signals are involved in ensuring the receiver head maintains the correct LOS. An azimuth tachometer signal from the receiver-converter azimuth drive unit is fed back to the mode logic module. The mode logic module produces a gimbal rate signal for the azimuth rate compensation module. An azimuth position signal from the same azimuth drive unit is fed back to the azimuth position compensation module. The mode logic module compares the azimuth position signals with the IRDSC azimuth input and, as applicable, outputs a position error signal to the azimuth rate compensation module. An azimuth gyro rate signal from the receiver-converter's gyro unit is fed to the azimuth rate compensation module. Also, an azimuth current drive signal is fed back to the rate compensation module. The rate compensation module processes all of the feedback signals (position error, gimbal rate, gyro rate, and current drive signals) and develops an output signal. This output signal, if necessary, maintains the receiver head at the correct selected heading.

FORWARD MODE (FWD).— The FWD mode command is processed by the azimuth mode logic module. This module outputs a FWD mode command signal to the azimuth position compensation module. This module will process the command signal. It then outputs a position loop command and a gimbal angle signal to the azimuth rate compensation module. This module then sends an azimuth drive signal to steer the receiver head to 0° azimuth. The azimuth drive signal is amplified by the azimuth heat sink module to produce the motor power to drive the motors in the receiver-converter. The stabilization/positioning feedback circuits work the same as the circuits in the position mode previously explained.

MANUAL TRACK MODE.— The manual track mode command signal is processed by the mode logic circuit. This circuit sends a manual track command signal and an azimuth rate inhibit signal to the azimuth rate compensation module. These signals cause the circuits to accept only azimuth rate signals from the target tracking sight control assembly. The TTSC assembly is a pistol grip unit. The operator uses the thumb control on the pistol grip unit to aim the receiver head to the desired LOS. The azimuth drive output signal from the circuit is controlled by the TTSC, and no feedback is used for stabilization.

Action of a comparator circuit in the azimuth rate compensation module determines when the receiver-converter gimbals reach their electrical limits and produce limit signals (CW and CCW). These limit signals prevent the manual track mode and computer track mode commands from developing the azimuth drive signal. The limit signals are fed back to the mode logic module that outputs a CW or CCW signal to the azimuth position compensation module. This signal causes the module to develop an error signal that, in turn, develops appropriate azimuth drive.

COMPUTER TRACK MODE.— The aircraft computer supplies gimbal control data bits (azimuth and elevation position rate commands) from its program to the decoder storage module. This module demultiplexes and stores 12-bit azimuth and elevation rate commands. It also provides azimuth and elevation data outputs to the digital-to-analog (D/A) converter module. The purpose of storage is to allow the decoder to output data bits to the D/A converter, while the computer updates itself from feedback information before issuing new gimbal control signals to keep the receiver head at the programmed LOS.

When the computer track mode is selected on the IRDSC, the computer track command is processed by the mode logic module. This module will send a computer track mode command to the D/A converter and to the azimuth rate compensation module. The signal enables the D/A converter to process azimuth data bits into analog azimuth position rate signals, which are fed to the azimuth rate compensation module. The D/A converter also sends a computer track mode status signal to inform the aircraft computer that the D/A converter is operating in the computer mode. The computer track command signal enables the azimuth rate compensation module to accept azimuth position rate signals from the D/A converter only. The azimuth rate compensation module disables inputs from the azimuth position compensation module. This means no feedback information can be processed in the computer mode. The rate compensation circuit processes the azimuth position rate signal from the D/A converter and outputs an azimuth drive signal. This signal goes through the azimuth heat sink circuit to slew the receiver head to the azimuth position programmed into the computer.

An azimuth resolver in the receiver-converter feeds back four-wire resolver position information signals to the azimuth rate compensation module where they are converted into three-wire syncro information signals. These signals are fed back to the aircraft computer logic circuits to update the computer and develop gimbal control data bits to maintain the receiver head at the correct LOS.

If the system is operating in the position mode, FWD mode, or computer track mode, and the operator wants to quickly shift to the manual track mode, the operator is able to do so by use of a manual override function on the TTSC. When manual override is initiated, a manual override command signal from the TTSC is processed by the azimuth mode logic module. This module sends a manual override signal to the D/A converter. It also sends out manual track command signals, as explained previously for manual track mode. The FLIR system functions in the manual track mode regardless of the position of the control box mode select switch.

The manual track override signal disables the D/A converter. It also sends a manual track mode status to the aircraft computer logic to prevent the computer from operating should the control box have computer track selected.

Elevation Drive Subsystem

Figure 6-22 is the simplified block diagram of an elevation drive subsystem. Compare figures 6-21 and 6-22. Notice they are the same except for the elevation and azimuth labels on the modules. The subsystems are the same because the servomechanism elevation drive circuits operate the same and process the same signals and develop the same drive signal as the azimuth drive subsystem. The only difference is that no tachometer feedback is used in the elevation circuits, and all signals come from or go to elevation circuits vice azimuth circuits.

In the FWD mode of operation, the elevation circuits slew the receiver head to –4° (down tilt) elevation. The azimuth circuits slew the receive head to 0° azimuth. All other modes operate the same except the receiver head is slewed in elevation instead of in azimuth.

CS BITE Subsystem

The control servomechanism BITE subsystem automatically determines whether a servo-system failure is in the CS WRA or in the receiver-converter WRA. Figure 6-23 is a simplified block diagram of the CS BITE subsystem. For ease of signal tracing, some of the modules have been duplicated at various locations on the diagram. These modules, such as the mode logic, have alphanumeric designators (A1, A2, A3, etc.). However, the modules are all part of one logic module. The alphanumeric numbers are used to show where signals enter/leave a particular module.

A temperature sensor in the receiver-converter monitors the gyro operating temperature. When the gyros are operating properly, the sensor develops a temp ready signal, regardless of which operational mode is selected on the control box. The temp ready signal is fed to the mode logic module (A1) of the CS. The mode logic circuit outputs a rcvr ready signal to the servo BITE module (B1). The rcvr ready signal enables servo BITE (B1). When BITE is initiated on the control box, a BITE initiate signal is received by the servo BITE (B1) module from the power supply-video converter BITE logic module. The BITE initiate signal initiates a series of four test sequenced as follows: fault isolate, BITE 1, BITE 2, and BITE 3. All tests are controlled by a 10-HZ clock in the servo BITE module. Each test sequence takes 10 to 12 seconds to complete.

FAULT ISOLATE TEST.— Initially (when rcvr ready and BITE initiate are received), the servo BITE module (B1) generates a BITE fault isolate signal and a digital computer interface (DCI) fault isolate signal. The BITE fault isolate signal goes to the following modules: azimuth position compensation (C1), elevation position compensation (D1), mode logic (A3), azimuth rate compensation (E1), and elevation rate compensation (F1). The signal enables all of these modules and causes the azimuth position compensation module (C2) and elevation position compensation module (D2) to generate BITE motor drive signals.

The DCI fault isolate signal goes to the decoder storage module (for use in the BITE 3 test) and to mode logic (A2). The DCI signal causes mode logic to open the BITE relay drive line, de-energizing the BITE relay (shown in the de-energized position). Opening the relay removes azimuth and elevation motor drive from the motors in the receiver-converter. Instead, the azimuth and elevation heat sink motor drive output is routed to the azimuth position compensation module (C1) and the elevation position compensation module (D1). The BITE motor drive signals generated by the azimuth position compensation (C2) and elevation position compensation (D2) are routed by way of AZ POSN and EL POSN lines to the azimuth rate compensation (E1) and elevation rate compensation (F1), respectively. The drive signals out of these modules

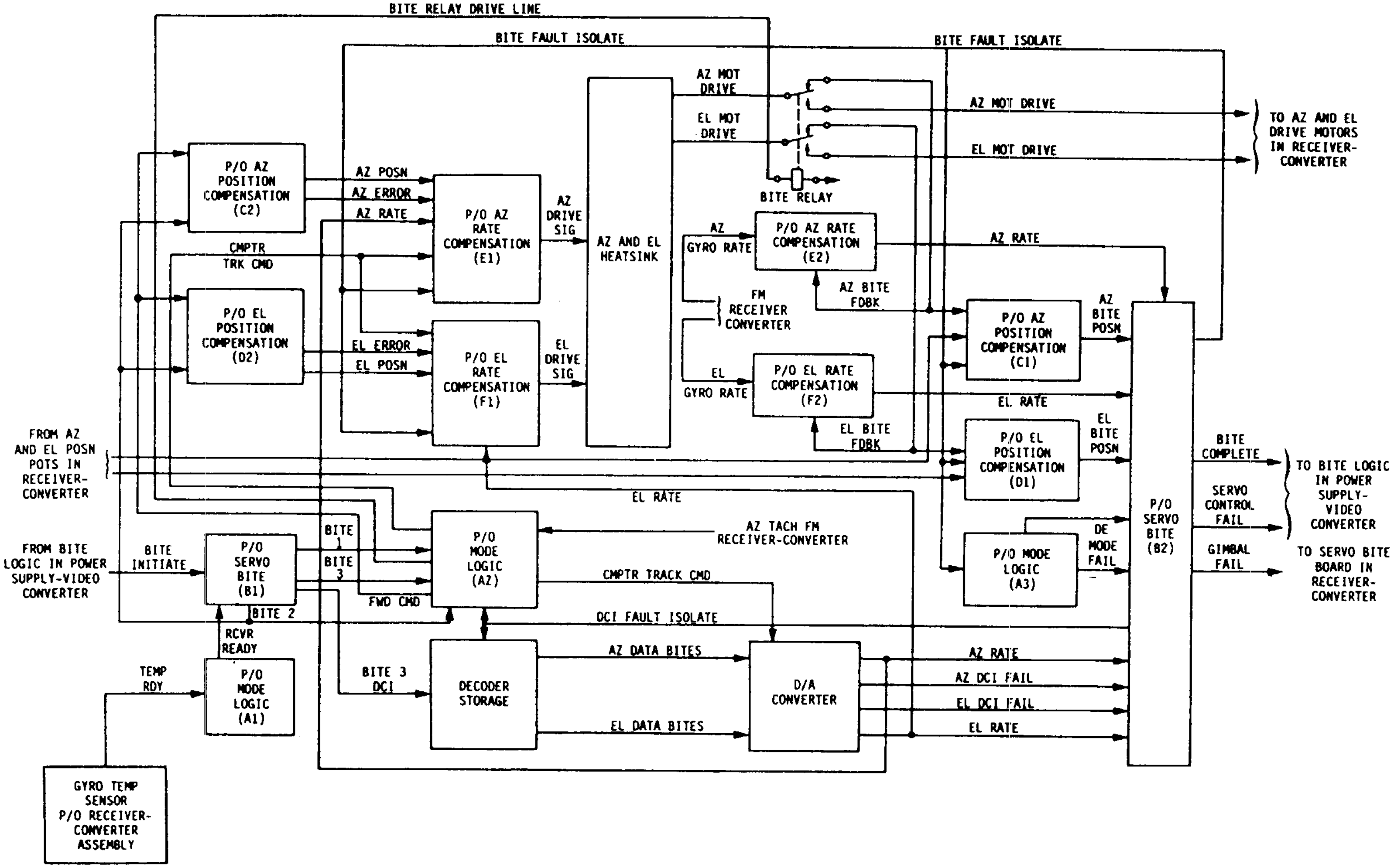


Figure 6-23.—Control servomechanism BITE block diagram.

go to the azimuth/elevation heat sink module. From this module, the signals go through the BITE relay and back into azimuth position compensation module (C1) and elevation position compensation module (D1). Modules C1 and D1 output azimuth and elevation BITE position signals to servo BITE (B2). The servo BITE module (B2) outputs a servo control fail signal to the power supply-video converter BITE logic circuit, which is labeled a servo malfunction in figure 6-20. This logic circuit, in turn, outputs a not ready signal to light the NOT READY light on the control box.

With the BITE relay de-energized (as shown), an azimuth loop is formed. This loop consists of the azimuth position compensation (C2), azimuth rate compensation (E1), a heat sink module and BITE relay, azimuth rate compensation (E2), and azimuth position compensation (C1). Likewise, an elevation loop is formed. This elevation loop consists of elevation position compensation (D2), elevation rate compensation (F1), a heat sink module and BITE relay, elevation rate compensation (F2), and elevation position compensation (D1). This allows the BITE motor drive signals (developed in C2 and D2) to continue around the loop. The BITE motor drive signals are monitored by frequency and amplitude detectors in servo BITE (B2). The inputs to these detectors are the azimuth and elevation BITE position signals from C1 and D1, which represent the signals in the loops. If an error or failure occurs, servo BITE (B2) generates a servo control fail signal. This signal is sent to the power supply-video converter BITE logic, labeled servo malfunction in figure 6-20. From here a control servo fail signal is sent to the control box to light the CONTROL SERVO FAIL light.

If no errors or failures are present during the fault isolation test, which takes approximately 10 to 12 seconds, a BITE 1 signal is generated by servo BITE (B1). This signal terminates the fault isolation test and initiates the BITE 1 test.

BITE 1 TEST.— When servo BITE (B1) generates a BITE 1 signal, the signal is fed to mode logic (A2). This causes module A2 to energize the BITE relay (via the BITE relay drive line), reconnecting the heat sink module output to the drive motors in the receiver-converter WRA. This also opens up the azimuth and elevation loops. Mode logic (A2) also generates a FWD command signal. This signal is fed to the azimuth position compensation module (C2) and elevation position compensation module (D2). These two modules generate BITE motor drive signals. These signals are fed through the azimuth and elevation rate compensation modules (E1 and F1) to the heat sink module and the now energized BITE relay. This positions the receiver head in the receiver-converter to 0° azimuth and -4° elevation. Position feedback signals from the receiver-converter are fed to the servo BITE (B2) module where they are monitored. If there is an error/failure, a gimbal fail signal is generated and fed to the servo BITE board in the receiver-converter. This action causes the receiver BITE circuit to generate and send a receiver-converter malfunction signal to the control box to light the RCVR CONV FAIL light.

If the feedback signals to B2 are correct (for 10 to 12 seconds), a BITE 2 signal is generated by servo BITE (B1). The BITE 2 signal terminates the BITE 1 test and initiates the BITE 2 test.

BITE 2 TEST.— When servo BITE (B2) generates a BITE 2 signal, the signal is fed to the mode logic module (A2) to cancel the FWD command signal. The BITE 2 signal is also fed to the azimuth position compensation module (C2) and the elevation position compensation module (D2). The BITE 2 signal causes these modules to develop and send error motor drive signals to the receiver head by way of the same signal path as the BITE 1 signal. These signals drive the receiver head to 130° azimuth and -60° elevation. Feedback signals are monitored by servo BITE (B2). If an error is present, B2 generates a gimbal fail signal to light the RCVR CONV FAIL light on the control box. This fail signal uses the same path as in BITE 1 testing. If the feedback signals are correct, servo BITE (B1) generates a BITE 3 signal. This signal terminates BITE 2 testing and initiates the BITE 3 test.

BITE 3 TEST.— When servo BITE (B1) generates a BITE 3 signal, the module B1 also generates a BITE 3 DCI signal (simulated computer data bit). This signal is sent to the decoder storage module. Simultaneously, a BITE 3 signal is sent to mode logic (A2). This module initiates a computer track command signal and sends it to the azimuth position compensation module (C2), the elevation position compensation module (D2), and the D/A converter module. The computer track command signal enables these modules for the computer track mode.

The BITE 3 DCI signals from the decoder storage module are processed by the D/A converter. The D/A converter outputs azimuth and elevation rate signals. A circuit in the D/A converter monitors the amplitude and frequency of these rate signals. If the amplitude and frequency are incorrect, the D/A converter generates a DCI fail (either azimuth or elevation) signal to the servo BITE (B2). This module outputs a servo control fail signal, which, in turn, lights the

CONTROL SERVO FAIL light on the control box. If the signals are correct, they are fed to the azimuth and elevation rate compensation modules (E1 and F1) to develop motor drive signals to slew the receiver head gimbals maximum CW and up. The rate feedback signals (gyro rate to E2 and F2 and azimuth tachometer to mode logic A2 and A3) are fed to servo BITE (B2). These signals are compared to the signals (azimuth/elevation rate) from the D/A converter. Should an error exist, a DCI fault isolate signal is generated by servo BITE (B2) and fed to mode logic (A2). Mode logic (A2) sends a known tachometer signal to the tachometer demodulator. If the demodulator is bad, a DEMOD fail signal is generated and sent to B2 that causes a control servo fail output. If the demodulator is good, but a rate error still exist, B2 outputs a gimbal fail signal that signifies the receiver-converter is bad. If the rate comparison shows no error, a BITE complete signal is generated by servo BITE (B2) and sent to the power supply-video converter. If no error has occurred during BITE, the BITE logic module initiates a system go signal. This signal is sent to the control box to light the SYS GO light.

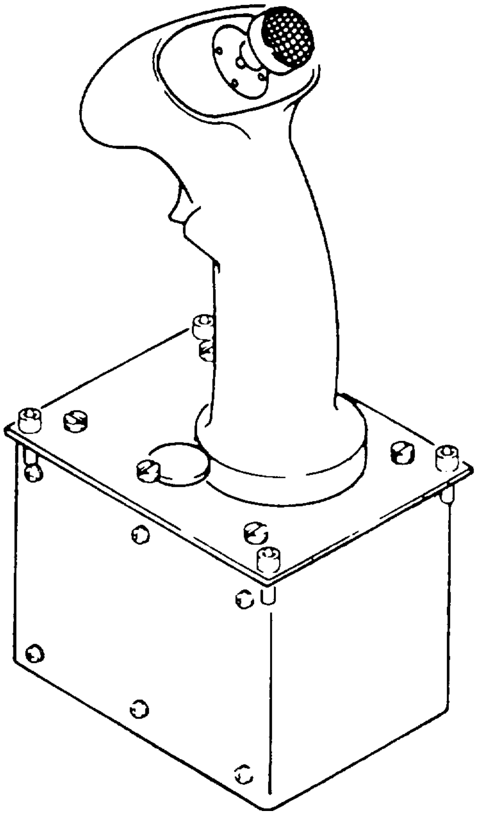


Figure 6-24.-Target tracking sight control.

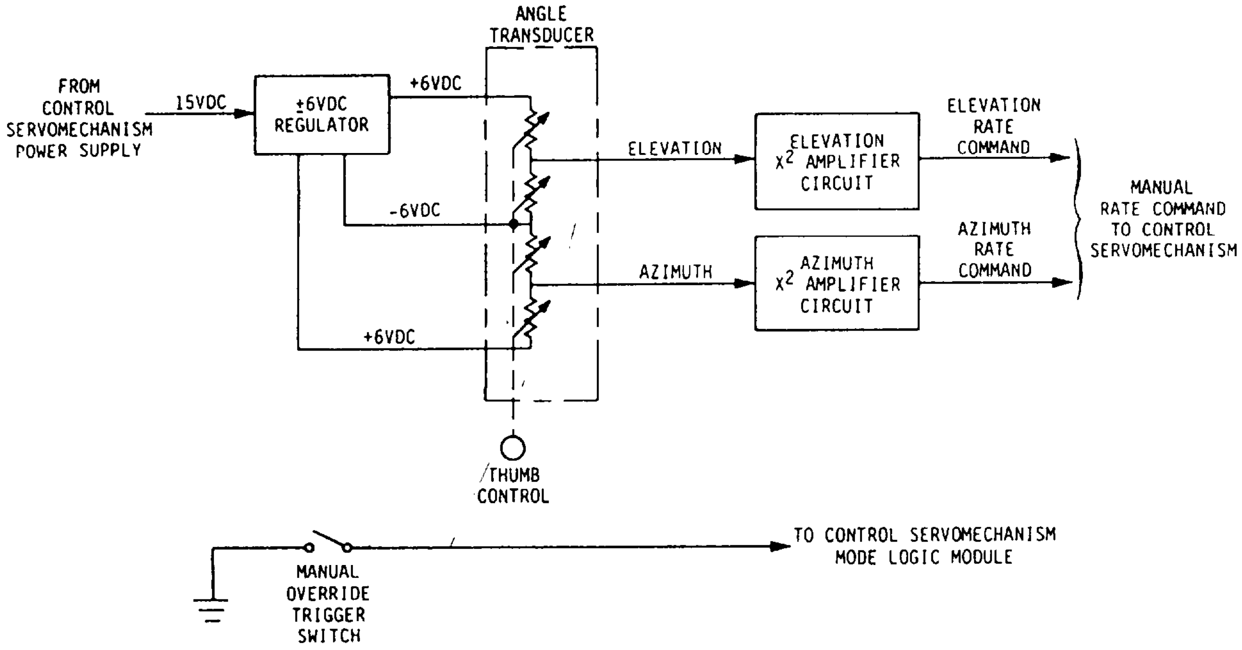


Figure 6-25.-TTSC block diagram.

TARGET TRACKING SIGHT CONTROL

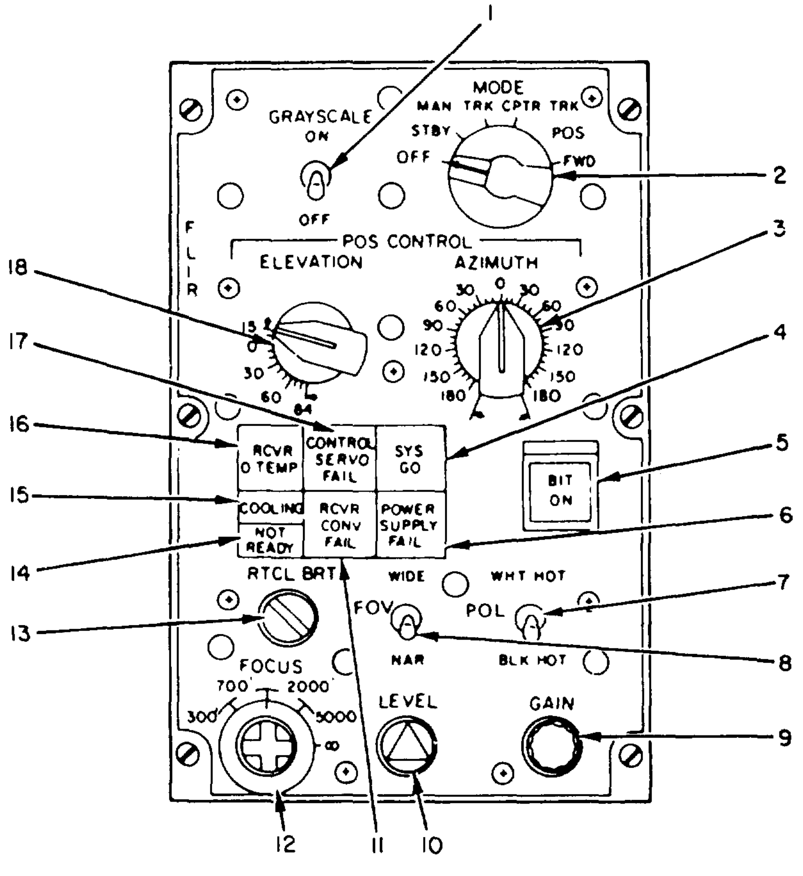
As mentioned earlier in this chapter, TTSC is the manual control used in the manual mode of operation to position the receiver-converter to the desired LOS. Figure 6-24 is a drawing of the TTSC. The TTSC consists of a stationary control stick (A) and the electronics for producing azimuth and elevation dc rate command signals. A thumb control (B) is used in conjunction with an angle transducer to steer the receiver head. A trigger-type switch (C) is used to provide manual override.

Figure 6-25 is a simplified block diagram of a TTSC. A voltage regulator regulates the 15-volt dc input from the control servomechanism WRA and provides +6 volts dc and –6 volts dc to an angle transducer. Adjustment of the thumb control produce voltage outputs from the elevation and azimuth angle transducers. These outputs are amplified and sent to the control servomechanism. Here they are processed to position the receiver head to the desired LOS.

Should you select the computer tracking mode, the FWD mode, or the position mode on the control box, depressing the trigger switch initiates a manual override command signal. This signal goes to the mode logic and D/A converter modules. This places the system in the manual track mode of operation.

INFRARED DETECTING SET CONTROL (IRDSC)

Figure 6-26 is a drawing of an IRDSC/FLIR control box. Notice that each control has been



1. GRAY SCALE switch
2. MODE switch
3. AZIMUTH knob
4. SYS GO push button
5. BIT ON push button
6. POWER SUPPLY FAIL indicator
7. POL switch
8. FOV switch
9. GAIN knob
10. LEVEL knob
11. RCVR CONV FAIL indicator
12. FOCUS switch
13. RTCL BRT knob
14. NOT READY indicator
15. COOLING indicator
16. RCVR O TEMP indicator
17. SERVO FAIL indicator
18. ELEVATION knob

Figure 6-26.-IRDSC/FLIR control box.

numbered. Refer to these numbers while you read the following section.

1. The GRAY SCALE switch energizes the circuit in the power supply-video converter WRA, which presents ten shades of gray across the bottom of the video indicator.

2. The MODE switch is a 6-position rotary switch that selects the mode of operation. In the STBY position, the system is maintained in the operational readiness state. The air conditioning and cryogenic cooling of detectors is activated. The receiver head is in the stow position (CCW and up limits).

3. The AZIMUTH knob controls the receiver slew signals (azimuth) in the position mode of operation.

4. The SYS GO push button illuminates to indicate a good system at the completion of BITE. The light can be extinguished by pressing the indicator.

5. The BIT ON push button initiates the BITE test sequence. The push button is lit while BITE is in progress. The light goes out upon completion of BITE.

6. The POWER SUPPLY FAIL indicator illuminates if the power supply-video converter fails BITE.

7. The POL switch is a two-position switch that selects the polarity of video signals from the postamplifiers of the receiver-converter detector array video amplifier circuits. In the WHT HOT position, the hot targets appear white on the video indicator. In the BLK HOT position, the hot targets appear black on the indicator.

8. The FOV switch selects either wide (WIDE) or narrow (NAR) field of view. It does this by switching an afocal lens assembly in or out of the optical path of the receiver.

9. The GAIN knob adjusts the dc level of the video output to the video indicator. This affects the contrast of targets on the indicator.

10. The LEVEL knob adjusts the dc level of the video output of the receiver-converter. This affects the brightness of the background on the video indicator.

11. The RCVR CONV FAIL indicator illuminates if the receiver-converter fails BITE test.

12. The FOCUS switch is a four position rotary switch that selects target range for focusing the afocal lenses in the narrow FOV.

13. The RTCL BRT knob controls the brightness of the reticle that is superimposed on the video signal applied to the video indicator.

14. The NOT READY indicator illuminates when the receiver-converter is not at operating temperature, when gyro spin-up is not complete, or when BITE is in the fault isolation mode.

15. The COOLING indicator illuminates to indicate the IR detectors in the receiver-converter have not reached operating temperature.

16. The RCVR O TEMP indicator shows excessive temperature within the receiver-converter.

17. The SERVO FAIL indicator illuminates if the control servomechanism fails the BITE test.

18. The ELEVATION knob controls the receiver slew signals (elevation) in the position mode of operation.

VIDEO INDICATOR

The typical video indicator (fig. 6-18) is an 875-line, 30 frames-per-second, closed-circuit TV monitor. On the front of the WRA is an ON-OFF power switch, an elapsed time meter, brightness and contrast controls, and a status indicator. Operation of the indicator is similar to that of a TV monitor. Figure 6-27 is a simplified block diagram of a video indicator's signal processing circuits.

Composite video from the video line driver module of the power supply-video converter is applied to the video amplifier/sync stripper module. This module separates the video signals (IR, RETICLE, GAI, and gray scale) from the sync signals (blanking, clamping, and sync). The module amplifies the video signals and provides the video output to the CRT for display. The contrast control is also injected in the video amplifier/sync stripper module. The module also sends the composite sync signals to the vertical, sync, CRT protect, and brightness control module.

The video amplifier/sync stripper module processes the composite sync signal. It provides vertical and horizontal sync signals to the vertical and horizontal sweep module. It also provides blanking and clamping signals to the CRT. The brightness control is injected in this module. The module also monitors the vertical sweep and horizontal flyback signals, removes the 300-volt dc operating voltage from the CRT, and extinguishes the STATUS light when a failure occurs.

The vertical and horizontal sweep module generates the vertical and horizontal sweeps used to drive the CRT yoke. It provides these drive outputs to the sweep heat sink module. The sweep module receives feedback signals from the sweep heat sink module to update and maintain the proper drive outputs.

The sweep heat sink module receives the vertical and horizontal drive signals and provides the proper level of yoke drive to the CRT. The sweep heat sink module also sends feedback signals to the monitor circuits in the vertical, sync, CRT protect, and brightness control module.

The image presented on the video indicator is a TV picture of the IR energy scanned by the receiver. The video indicator is independent of the BITE subsystems of the other WRAs. Only the STATUS light and picture are indicative of a properly operating video indicator.

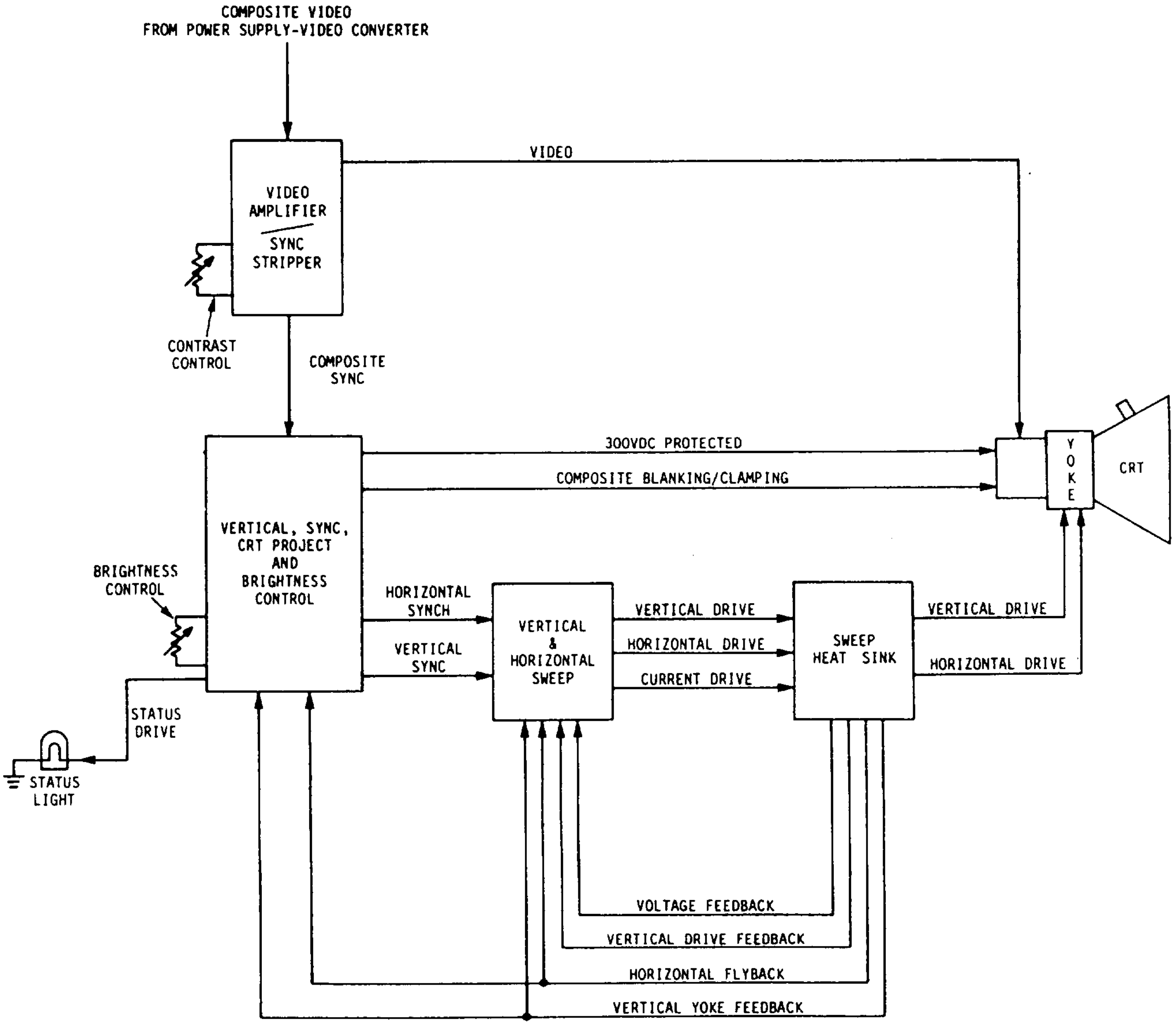


Figure 6-27.-Video Indicator block diagram.

REVIEW QUESTIONS

Q1. Where does the IR frequency range fall in the electromagnetic spectrum?

Q2. How do the IR waves differ from any other wave in the electromagnetic spectrum?

Q3. Realistically, what is the best emissivity of an object?

Q4. What is a good example of an imaging detector?

Q5. What is the major disadvantage of a detector array?

Q6. How wide is the space between the detector elements in a linear array?

Q7. Is a typical IRDS an active or passive system?

Q8. In a typical infrared system, how many detector elements are used to get the 360 lines of video?

Q9. How are the six heaters connected in the heat exchanger?

Q10. What are the four operational modes of operation in the IRDS system?

Q11. True or False. The BITE testing of the system will indicate a video indicator fault.