Defence School of
Aeronautical Engineering

No 2 School of Technical Training

Academic Principles Organisation

AVIONICS PART 2 PHASE 3
Radar

BOOK 5
Identification & Surveillance

WARNING

These course notes are produced solely for the purpose of training. They are not subject to formal amendment action after issue, and they must NOT be used for operating and maintaining the equipment described. Operation and maintenance of equipment is governed by the limitations and procedures laid down in the authorised publications and manuals which must be complied with for these purposes.

IDENTIFICATION & SURVEILLANCE

AIRCRAFT IFF SYSTEM

Objectives

T.O.s – 42.6.1, 42.7.1, 12.8.1, 43.5.1, 46.5.1, 46.2.1, 46.3.1

E.O. - **AR 03 Describe Aircraft Surveillance Systems**

KLP Ref – AR.03.01 Describe IFF System.

Performance - Describe IFF System.

FORWARD LOOKING INFRA RED (FLIR)

Objectives

T.O.s - 42.6.1, 42.7.1, 12.8.1, 43.5.1, 46.5.1, 46.2.1, 46.3.1

E.O. - **AR 03 Describe Aircraft Surveillance Systems**

KLP Ref – **AR.03.02**– Describe the IR navigation aids (FLIR).

Performance - Describe the IR navigation aids (FLIR).

Objectives

T.O.s - 42.6.1, 42.7.1, 12.8.1, 43.5.1, 46.5.1, 46.2.1, 46.3.1

E.O. - **AR 03 Describe Aircraft Surveillance Systems**

KLP Ref – **AR.03.03 –** Describe the reconnaissance video recording system.

Performance - Describe the reconnaissance video recording system.

CONTENTS:

IDENTIFICATION FRIEND OR FOE / SECONDARY SURVEILLANCE RADAR (IFF/SSR)

Introduction

1. In the Introduction to radar phase the basic principles of Primary and Secondary radar were discussed.

   a. A primary radar system depends on receiving a radar echo reflected passively from a target aircraft.

   b. In a secondary radar system, a transmitted radar signal is used to trigger a response from radar equipment in the target aircraft.

2. The military system, Identification, Friend or Foe (IFF), and the equivalent civilian system, Secondary Surveillance Radar (SSR), are examples of secondary radar systems.

3. In the earliest days of air defence radar, it was realised that there was a need to distinguish the radar plots of friendly aircraft from those of hostile ones. Basic primary radar could not distinguish between friendly or hostile echoes.

4. This problem was solved by equipping friendly aircraft with a transmitter/receiver in the aircraft known as a transponder. When the system is used, the interrogating radar sends out the interrogation “question” in a series of pulses depending on selected mode (see Table 1). The aircraft transponder will automatically respond to an interrogating radar code by transmitting a recognisable return signal in the correct coded pulses for that mode. The reply is received by the interrogating radar and will be displayed as a “friendly” target. If the reply is incorrect or no reply is received, the aircraft is unknown and could be hostile.

5. Although IFF and SSR have a number of differences, the operating principles of each are basically the same. RAF aircraft are fitted with transponders which can operate with both systems, this is due to the fact that military aircraft will often come under the control of civil air traffic control, military aircraft have Civil SSR incorporated into their identification systems. Civilian aircraft have the SSR system only. From the view point of ground-based systems, the secondary radar operates in conjunction with a primary radar. The primary radar provides the radar operator with the target return and location, while the associated secondary radar provides the identification information.

6. Many Air Intercept aircraft are fitted with IFF interrogator systems, these are usually incorporated into complex Airborne Intercept radar systems, where interrogations may also be carried out in Track While Scan mode (TWS).

7. Some Military ships and land-based ground to air missile systems also have IFF interrogation capabilities. In fact, the importance of reliable IFF systems on aircraft is paramount, as without the correct reply to IFF interrogations in a combat

zone, the aircraft could be engaged mistakenly as an enemy and could result in loss of both crew and aircraft. These events are known as “blue on blue incidents. However, it is hoped with improvements in technology these incidents are eliminated.

Basic IFF/SSR Primary and Secondary Radar Arrangement

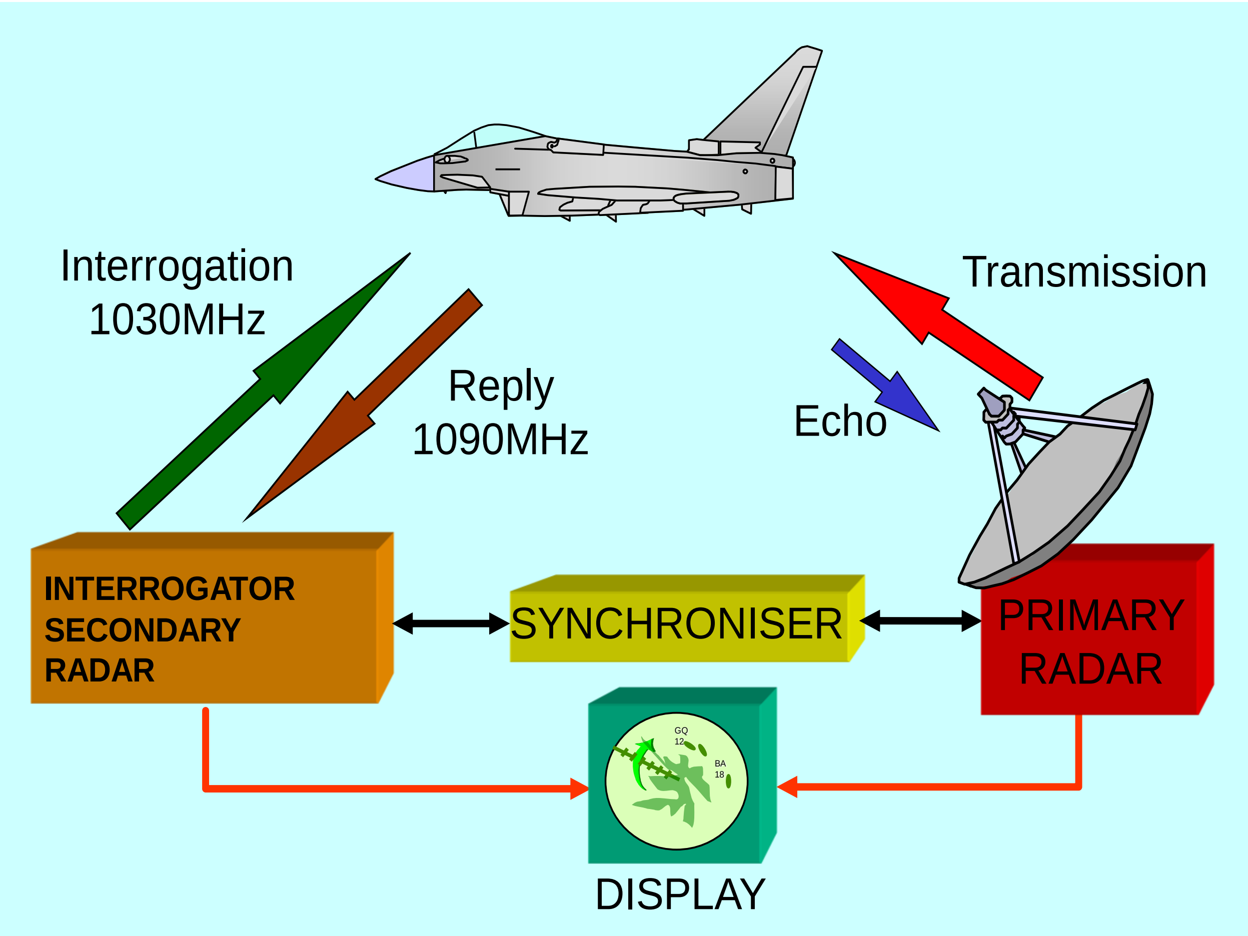

Figure 1 - Secondary Identification and Primary Radar Systems

8. **Primary Radar** The primary radar will detect the target aircraft by transmission and reception of a pulsed radar signal. The received energy is processed and displayed on to a radar screen for to display the location of the aircraft.

9. **Interrogator** This is the secondary radar that interrogates the aircraft. The Interrogator signal is transmitted at a frequency of 1030 MHz and consists of a pair of pulses the spacing between these pulses determines the mode of interrogation as shown in Table 1.

10. **Replies** The interrogator signal is received and decoded and then replies are transmitted from the aircraft Transponder. Replying on a frequency of 1090 MHz and consisting of pairs of pulses known as the framing pulses, these have up to 12

information pulses in between, giving the ability to transmit up to 4096 codes. So, in short, within the modes there are numeric codes.

11. **Synchroniser** The purpose of the Synchroniser is to ensure the Primary Radar and Interrogating radar operate and target the aircraft at the same time, achieving the simultaneous presentation of secondary and primary information; this is achieved by the use of a synchroniser and situating the Interrogator on top of the primary radar ensuring both rotate together.

12. **Radar Display** The radar display will allow the ground station's operator to visualise where a specific target is within his airspace. By the use of the IFF system the operator will also be able to view a multitude of information about specific aircraft including flight number, altitude, speed etc.

13. **IFF Modes** The modes have different uses which are determined by pulse spacing and secure transmission techniques in some military modes. See Table 1.

User	Mode	Spacing	Codes Available	Further Detail
Military	1	3µs	32	Pool of 32 Mission Codes
Military	2	5µs	4096	Pool of "Platform Numbers" to distinguish between friends.
Military & Civilian	3/A	8µs	4096	ID,4096 codes changed periodically. Set in the cockpit but assigned by air traffic areas
Military & Civilian	C	25µs	Auto reply	Provides Automatic transmission of Altitude
Military	4		No Longer Used	
Military	5	Crypto	16384	Encrypted Secure positive ID, PIN, Lethal Interrogation.
Civilian	S	Random	16,777,214	Selective interrogation, individual aircraft address, unique ICAO 24-bit identifier, upon registration the address becomes aircrafts certificate of registration.

Table 1- Modes of Interrogation

14. **Operating modes** SSR has 3 operating modes: A, C and S. IFF has 4 modes: 1, 2, 3, and 5. Mode 4 is no longer used. IFF Mode 3 and SSR Mode A are identical and normally referred to as Mode 3/A. Mode 5 is a secure military mode replacing mode 4. Mode S is the latest Civilian mode.

15. **Mode 5 -** Introduced in the early 90s, Mode 4 was the NATO minimum theatre entry standard. First introduced in 2008, Mode 5 has now completely replaced Mode 4, which is no longer supported. In time, Mode 5 should completely replace military modes 1,2 & 3. Today, both Civilian and Military aircraft flights can easily be tracked

with Apps such as Flight Tracker or with simple commercially available surveillance equipment, therefore, information on position, altitude etc could easily be obtained. This would give the enemy an extreme tactical advantage.

16. **NATO minimum theatre entry standards** Mode 5's enhanced security is required to meet the NATO minimum theatre entry standards for basic interoperability. Without a serviceable Mode 5 the platform simply cannot enter the theatre of operations.

17. **Encryption (Crypto)** The security of Mode 5 is enhanced by using new cryptographic computers and algorithms, and enhanced data Comsec capabilities, such as key authentication and use of spread spectrum modulation techniques. Mode 5 will only reply to a correctly configured interrogation signal.

18. **Loading Codes** The Mode 5 (Crypto code) is loaded into the aircraft Transponder of the aircraft by a key fill device, this must be kept in a secure environment and only handled by Crypto authorised Avionics Technicians.

19. **Operational benefits of encrypted Mode 5**

- Resistant to spoofing or deception
- Anti-jamming improved
- Reduced operator workload
- Reduced likelihood of blue-on-blue incident

20. **Mode 5 interrogation levels 1 & 2** There are 2 levels of information.

- **Level 1:** Provides Basic ID & height data.
- **Level 2:** Provides Reports containing data and encrypted GPS position. This can be triggered by interrogation or sent directly.

21. **Lethal Interrogation** Historically, aircrew may have turned transponders off in operationally sensitive areas. However, this meant there was an increased risk of forgetting to turn them back on when returning from the mission. Without IFF replies, this could cause a blue-on-blue incident. As part of an engagement sequence the Transponder can be in Standby with M5 selected on. On return from the Emission Control (EMCON) zone, defending friendly forces can transmit a Lethal Interrogation “a wake-up pulse” and the transponder in standby would reply. Hence preventing a possible blue-on-blue incident. (See Figure 2).

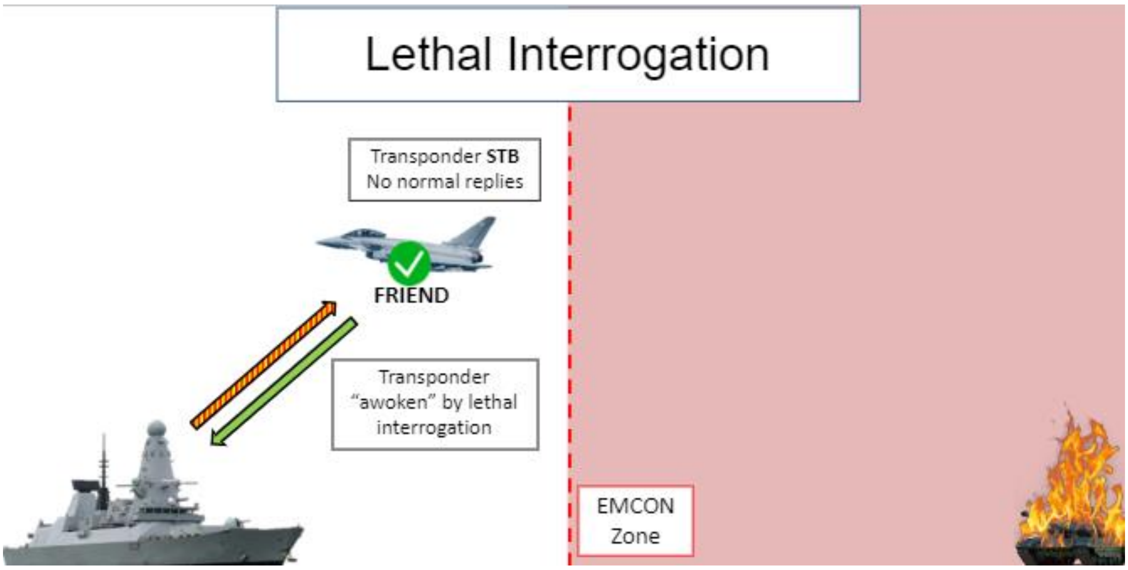

Figure 2 Lethal Interrogation Wake up

One issue however, is that any transponders on Standby in the EMCOM zone will also respond to the lethal interrogation pulse (see Figure 3) this could possibly alert enemy forces. Therefore, to use mode 5, all aircrew and interrogating friendly forces are thoroughly aware and correctly trained for the combat scenario.

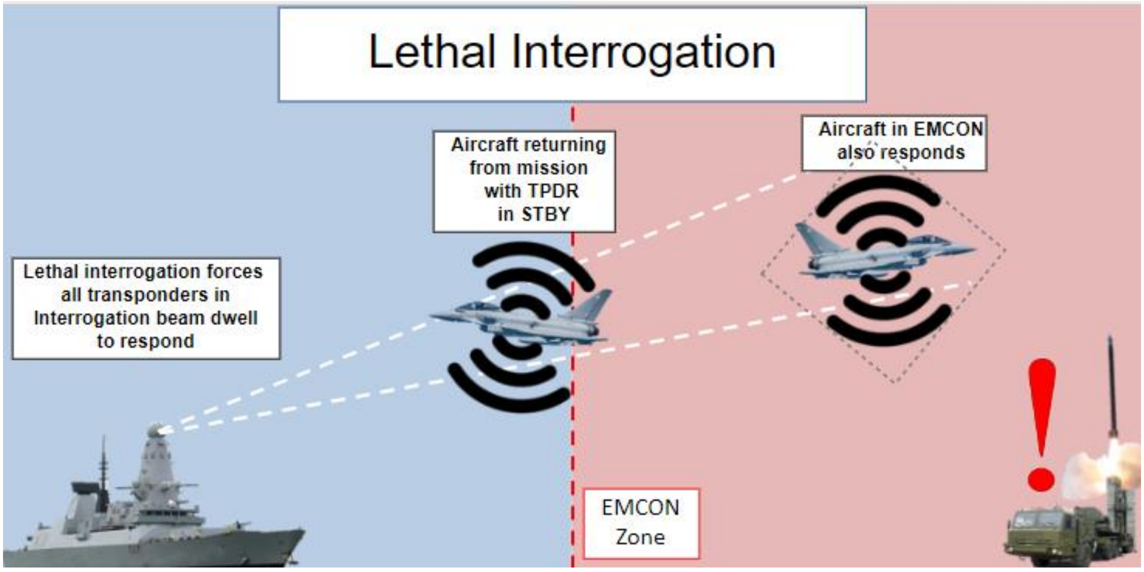

Figure 3 Lethal Interrogation in EMCON Zone

22. **Mode S system -** During the 1990's a new addressable secondary radar transponder system was installed throughout the world to replace the old system. This new system is called "Mode S" (the S means selective). Unlike the old transponders that replied to any interrogation the mode S transponder can be made to reply only when that specific transponder is interrogated. This reduces the amount of interference in the air traffic radar system and allows for more aircraft to be under surveillance. A very useful feature is the military aircraft is operating in a war zone as the IFF system will not reply to enemy interrogators and so protect the aircrafts' location.

23. The mode S system was an entirely new concept and although the operating frequencies are unchanged, the method of modulation and interrogation are completely different. An important characteristic of the mode S system is that each aircraft has a unique identity permanently assigned to it.

24. Each aircraft is allocated with a unique International Civil Aviation Organization (ICAO) address in Hexadecimal Code which is hard coded into the airframe.

25. The mode S secondary radar system has enormous capacity and can have more than 16 million different identities. Enough for each aircraft in the world to have its own identity. Mode S transponders will automatically transmit an aircraft's registration and type whenever it is interrogated by ground-based radar. The Transponder will Auto transmit aircraft registration rather than ATC assigned "Squawk" codes. Therefore, an air traffic controller can identify an aircraft without having any previous contact with that aircraft to assign a transponder code.

26. The main justification for the adoption of Mode S is the value of the data link in supporting a greater degree of automation in the air traffic management system. The use of the data link would permit the flight of aircraft in increasingly dense airspace with improved safety.

27. **Associated Systems.** **T**raffic Advisory and **C**ollision **A**voidance **S**ystem (TCAS). This is an airborne system used to communicate avoidance information between aircraft. This can only be done between aircraft that are equipped with a mode S transponder.

28. **Emergency codes.** The following codes may be used to warn the ATC that there is a problem with the aircraft without alerting the hijacker:

a. 7700 emergencies,

b. 7600 radio failure

c. 7500 interference/ hijack.

Aircraft IFF System layout

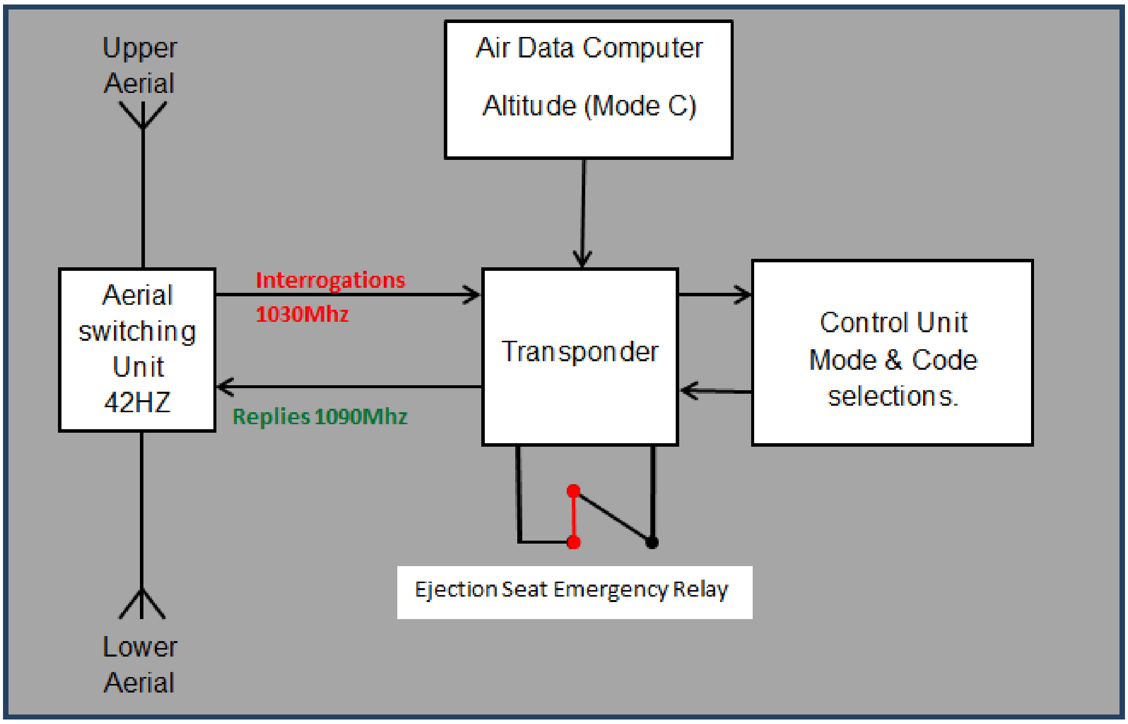

Figure 4 - IFF Aircraft System Layout

29. **Aircraft IFF System** A conventional Aircraft system consists of the following:

a. **Aerial system -** 2 surface mounted aerials one on the upper fuselage on the lower providing all round coverage for the reception of interrogation signals and transmitted replies. A 42 Hz Aerial switching unit alternates the transponder signal to the upper and lower aerials.

b. **Altitude Mode C -** Height information is automatically fed to the transponder by the Air Data Computer or other height information source.

c. **Transponder unit -** This contains the main transmitter and receiver modules. The incoming interrogation pulses are decoded by the receiver and the coded reply set up on the control panel is triggered and sent back by the transmitter module.

d. **Emergency Relay -** On aircraft fitted with ejection seats when an ejection occurs an electrical connection on the seat will be disconnected which will activate the transponder in emergency mode

e. **Control Unit -** This can consist of a separate unit but, is often integral with the transponder. This switches the system off/on, in Normal or emergency mode (emergency replies to all interrogations). It is also where the individual codes for mode 1 and mode 3/A are entered. The pilot also selects what modes are to be replied to by the transponder.

30. On the control unit there is an Identification of position Switch (I/P). Usually a two-position toggle switch which will produce an identification of position pulse. This will show up on the Interrogators (ATC) display screen giving an enhanced symbol to identify that particular aircraft, this will aid the operator to see that specific aircraft in a plot with many aircraft in one sector of radar returns.

31. There is also an interruptive BITE test button with a green for serviceable indicator light.

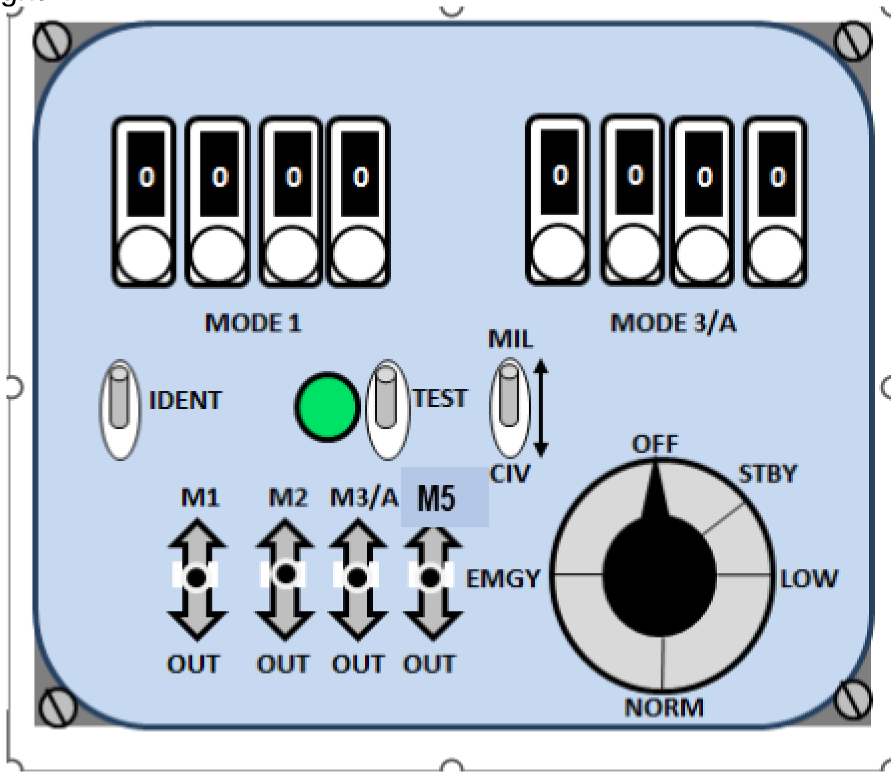

Figure 5 - IFF control Unit.

Three-pulse Side lobe Suppression The radiation pattern from all aerials contains side lobes. In secondary radar, sidelobes are effective at greater ranges than in primary radar since transponder transmissions are detected rather than target echoes. This causes confusion on the interrogator's display.

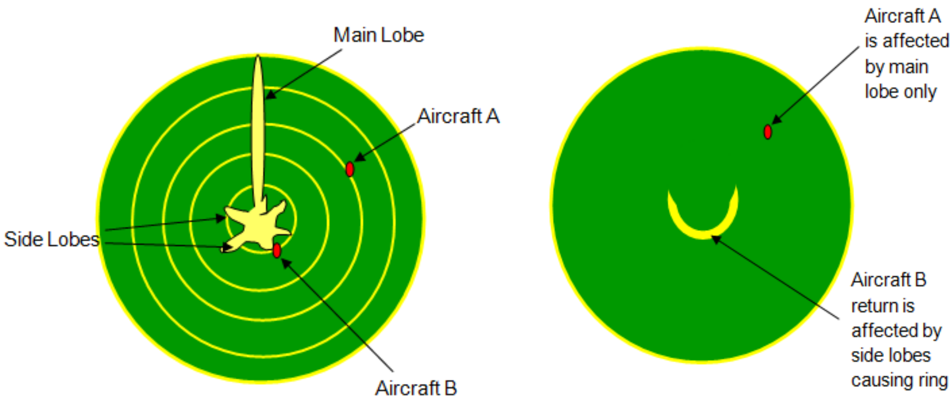

Figure 6 - Side lobe effect on display

32. It is thus necessary to suppress any interrogator sidelobes which would be capable of triggering responses and the 3-pulse sidelobe suppression system has been adopted as the international standard technique. Each interrogation consists of a group of three pulses denoted P1, P2, and P3. The spacing of the pulses is shown in Fig 9; P2, known as the control pulse, is spaced at a constant 2 µs from P1, and the spacing between P1 and P3, the interrogation pulses, is according to the mode as listed in Table 1. The interrogation pulses P1 and P3 are transmitted from a rotating interrogator aerial, and the interrogation pulse P2 is transmitted from the control aerial, producing radiation patterns as shown in Fig 9. The interrogator aerial produces a high-power, narrow beam with lower-power sidelobes. The control aerial radiates an omnidirectional signal which is modified to produce a radiation pattern trough in the direction of propagation.

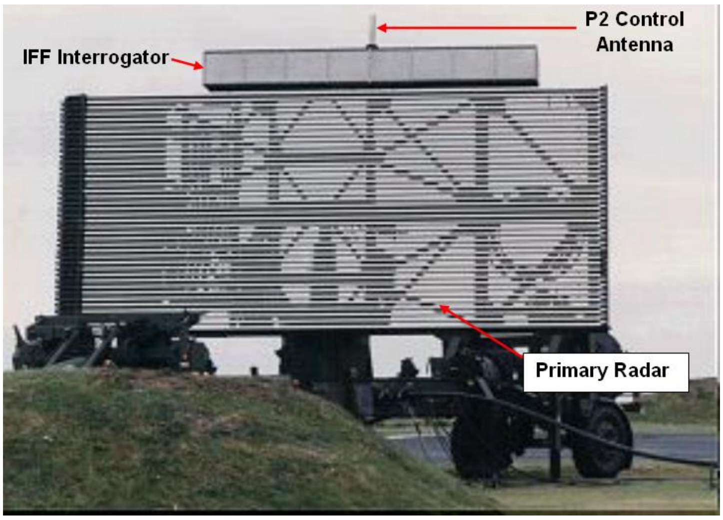

Figure 7 - IFF Interrogator Aerial Assembly

33. By comparing the relative amplitudes of the control and interrogator pulses, the transponder determines whether the interrogation is a correct, main lobe one, or due to a Sidelobe. P1 and P3 amplitudes are greater than a P2 amplitude only (Fig 9) for a correct main lobe interrogation and the transponder will then reply; if P2 is greater than P1 and P3 the transponder is suppressed. The discrimination levels are indicated on Fig 9 which shows that there is a 'grey area' where the transponder may or may not reply.

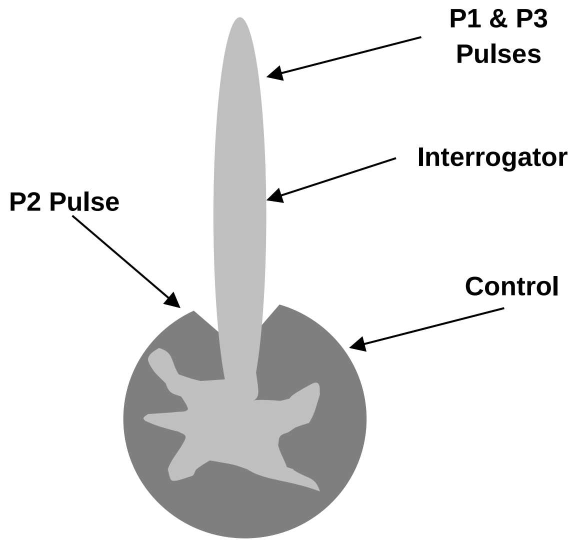

Figure - 8 Pulse aerial polar diagram

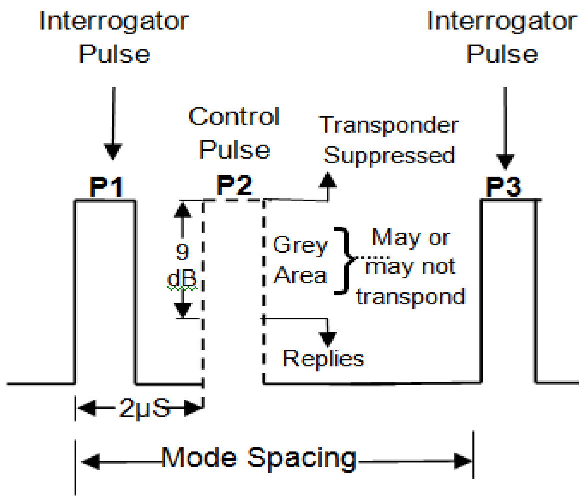

Figure 9 - 3 Pulse Side lobe Suppression pulse spacing

FORWARD LOOKING INFRA-RED (FLIR)

Introduction

1. The Royal Air Force has always made use of reconnaissance and surveillance in peacetime and battlefield operations. Today the systems employed to obtain information are classed as ISTAR assets; ISTAR stands for Intelligence, Surveillance, Target Acquisition, and Reconnaissance Information is collected on an area using a variety of electronic sensors which carry out Surveillance, Target Acquisition and Reconnaissance. One such sensor is the Forward Looking Infra-Red (FLIR) system.

2. A variety of aircraft equipment and systems use the IR region of the Electro-Magnetic EM spectrum. Forward Looking Infra-Red (FLIR), Infra-Red Line Scan (IRLS) and other Electro-Optical Surveillance and Detection Systems (EOSDS) all operate in the mid to far IR region (8-14□m) which is closer to heat and are therefore classed as Thermal Imaging (TI) systems. Forward Looking Infra-Red (FLIR) is used for thermal imaging as a target designator. The advantage of which is that it is passive and therefore cannot be detected by the enemy.

IR Thermal Imaging Principles

3. Objects with a temperature above absolute zero (-273□C or 0º K) will emit infra-red (IR) radiation and in addition will reflect or absorb incident IR to varying degrees. This means everything in the world is capable of being seen with by IR Thermal Imaging systems. As objects change temperature so does the frequency of the emitted thermal IR radiation. IR Thermal Imaging systems use these variations in emitted and reflected IR to form an image of an object. This is similar to the way that a camera uses variations in visual brightness to form an image. Such systems have the advantage of being independent of natural or artificial illumination and are not easily deceived by camouflage.

4. The EM frequency spectrum has main two windows (frequency ranges) where the atmosphere is especially transparent IR even when fog or smoke obscures normal vision. These two windows occur at wavelengths between:

3 to 5 microns and 8 to 14 microns

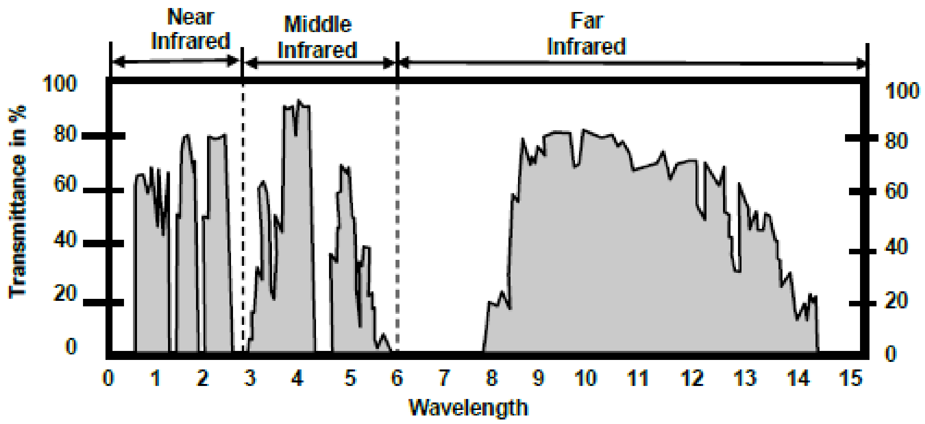

Figure 1 - Atmospheric Effects on IR transmission at Sea Level.

5. The transmission of IR energy through the atmosphere at other wavelengths may be impeded to a greater or lessor extent due to scattering by suspended particles and absorption by its various gasses. If the suspended particles are small as in haze and battlefield smoke an IR system will not be affected even in what appears to be zero visability to the naked eye. If the particles are larger as in cloud, fog, mist and rain then IR absoption is such that it will be no better than the eye and the range of the system will be restricted to the visible range. In addition, some energy in the 8-14□m wavelengths is absorbed by water vapour molecules.

6. The FLIR sensing equipment is usually located in a fairing at the front of the aircraft fuselage.

TORNADO GR4 FLIR (Defence imagery MOD)

Typhoon IRST
Image copyright: 4513407 by Open Government Licence v3.0 Crown Copyright (2015)

7. FLIR System

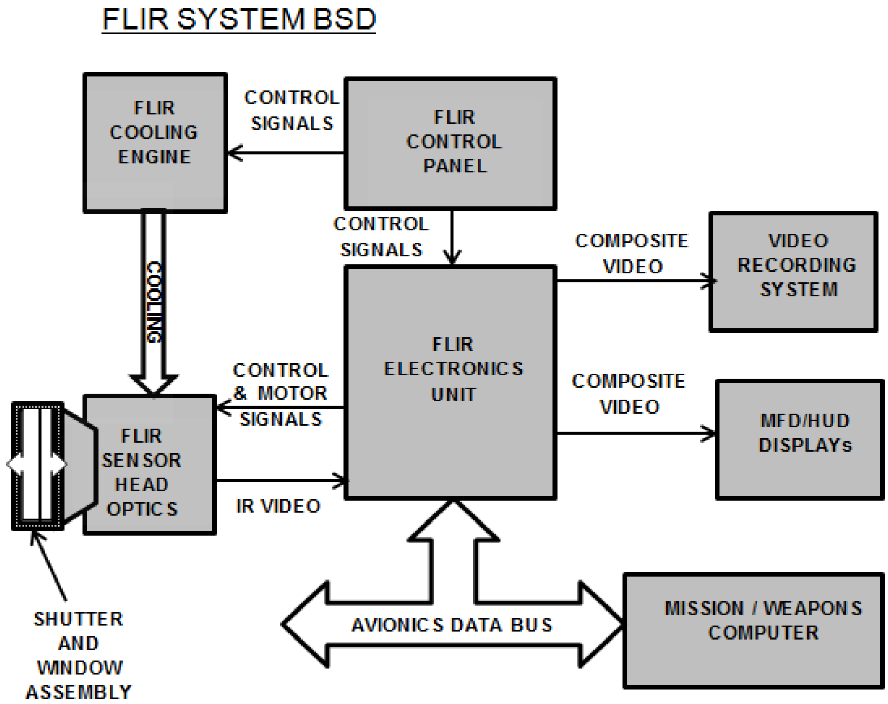

Figure 2 - Simple FLIR Imaging System

8. **Shutter** - The FLIR Shutter protects the FLIR window from damage during weapon firing, in adverse weather conditions.

9. **FLIR Window** - The Window in turn protects the Sensor Head this is made from a special material one example is a low resistivity Germanium window which allow maximum transfer of the IR energy through it.

10. **The Sensor head** - Contains all the electro mechanicals and optical sensors the lenses, mirrors and prism systems. The optical system collects the thermal IR radiation and focuses the image onto one or more IR detectors in a similar way to a standard light camera, however:

a. Conventional glass is essentially opaque (not see through) to IR wavelengths greater than 3 m, so special materials must used for lenses/windows.

b. The difficulties in dealing with IR are mainly due to the Thermal Imaging (TI) systems wide bandwidth, which at 8 – 13 m is much greater than that of visible-light optics at 0.4 – 0.7 m.

c. The combination of a wide bandwidth and special IR optics results in much greater distortions (aberrations) than with visible-light optics.

d. IR optics for airborne military use have to withstand extremes of pressure, vibration, shock and temperature.

11. **IR Detectors -** These are the main sensors. The detectors used in Thermal Imaging (TI) IR systems are made of special semi-conductor materials such as cadmium mercury teluride (CAT), which generate electrical signals proportional to the amount of IR radiation focussed on it. The detectors are complex and delicate assemblies and monitored by BITE. They are also photo conductive

12. **Detector Cooling Engine -** Cooling of the detector is essential for optimum performance of the TI system. Cooling allows small differences or variations in the temperature of the viewed scene are easily recognised. Without cooling the detectors their own heat output would prevent detection of these small temperature variations, reducing its sensitivity to external IR radiation. The Cooling is provided by a cryogenic cooling system/engine. Detectors need to operate in the 60K (- 213 ºC) to 100K (–173 ºC) temperature range for optimum performance.

13. **Control Panel -** This will provide the following controls**:**

- Power on
- Shutter. Open/Close
- Normal/Grey scale switch
- Gain Control
- IBITE

14. **FLIR Electronics unit -** This contains the processing electronics. Converts the detectors electrical signal representing the different IR temperature levels into a form suitable for the various displays display.This unit also interaces with the FLIR control panel and the Avionics Data Bus of the aircraft.

15. **Display -** The FLIR imagery is presented as a real-time raster scan, in a similar manner to TV. The display is usually arranged such that an increase in relative temperature corresponds to a transition from black, through shades of grey, to white. This tonal correspondence can be reversed, if it is considered appropriate for particular applications. The image can be presented on a TV-TAB unit, Multi – Functional Display (MFDs) and/or HUD depending on the aircraft. The Video may also be routed to a Video Recording System (VRS) for post flight analysis.

16. **Interaction with other systems** - The FLIR system is connected to the Avionics Data Bus and aircraft weapon aiming/computer sub-systems as well as the displays onboard the aircraft.

Advantages and Disadvantages of Thermal Imaging IR Sensors

17. **Advantages**:

a. Passive and undetectable in use (everything emits IR radiation).

b. Independent of natural or artificial lighting.

c. Not easily deceived by camouflage.

18. Thermal shadows often are similar to everyday light shadows and are caused by areas being shaded from direct sunlight radiation and depend on how quickly the heat is lost. Thermal shadows in the shape of movable objects (eg aircraft on the ground) can often be seen long after the object has moved.

19. **Disadvantages and Limitations**:

a. Atmospheric Attenuation (absorbs and scatters IR wave lengths).

b. The quality of IR images is generally lower than that of visual images and some detail may be lost.

c. The true size and shape of hot objects may be exaggerated or disguised by thermal blooming (distortions) and halation (blurring) effects.

d. Sensor head / optical systems are made from very expensive, special materials. Some are toxic and even radioactive so extreme care must be taken when handling these.