Beskrivning Radar PS-46/A

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Radar PS-46/A for Aircraft JA37

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Radar PS-46/A for aircraft JA37 was developed by Ericsson during the years 1970-1978. Since 1978 the system has been in series production for the Swedish Air Force. PS-46/A is a pulse Doppler radar which makes it possible to detect targets and measure the distance even when the ground return is much larger than the target echo. In this article the basic physical relations and the special problems concerning airborne pulse Doppler radar are considered. The overall requirements of a radar system for modern fighter aircraft and methods for satisfying these requirements are discussed. Finally the design, structure and function of radar system PS-46/A are described.

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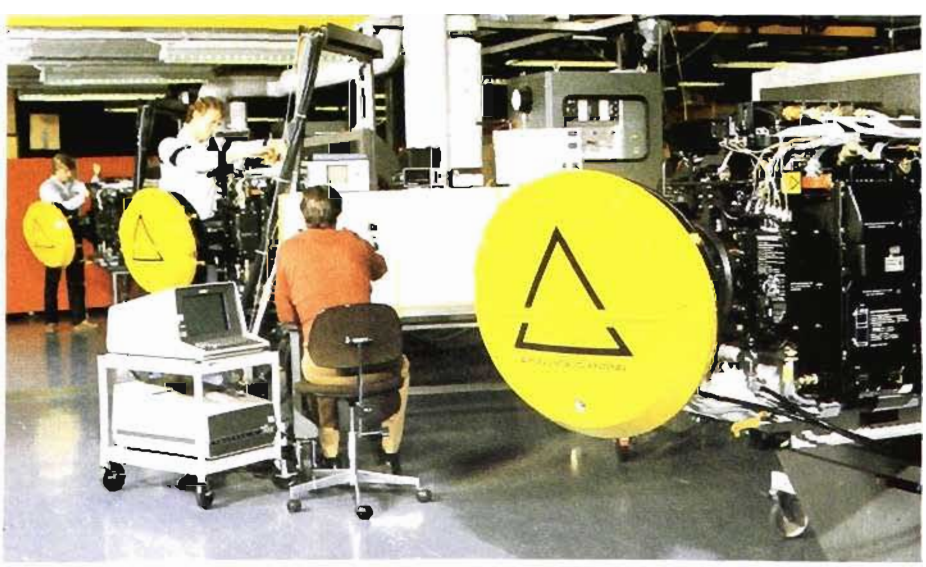
The aircraft 37 project was initiated at the end of the 1950s. It was intended as a multi-purpose aircraft, which could be equipped in different ways for use in different roles in the Swedish Air Force, such as attack, reconnaissance and fighter aircraft. A common basic aircraft would greatly reduce the overall acquisition cost and the capital cost for the Air Force. The attack version, AJ37, came first, quickly followed by the reconnaissance versions SF37 (photo reconnaissance) and SH37 (radar reconnaissance). The studies and preliminary planning for the fighter version, JA37 started at the end of the 1960s. On the part of Ericsson this meant that the Division for Defence and Space Electronics carried out radar studies and SRA Communications AB investigated display equipment. Both units are now parts of Ericsson Radio Systems AB

Fig. 1
Acceptance testing of radar PS-46/A. This final test is mainly stored program controlled and comprises a four-day burning-in stage, functional tests and performance tests



A modern fighter requires advanced radar equipment in order to extend the pilot's ability to see and estimate distances in any light and type of weather. Conventional radar, also called pulse radar, cannot meet the increasingly important requirement of being able to look down and distinguish flying targets against the background, i.e. the ground. Doppler radar can meet this requirement, but on the other hand it makes new demands on the design of the radar equipment.

Studies of Doppler radar for military aircraft were initiated by the Royal Swedish Air Force Materiel Administration in about 1960 with the participation of the Swedish electronics industry, including Ericsson. The studies provided the basic insight regarding the special requirements of Doppler radar, such as

- the spectral purity of the transmitted signal
- the high stability of the receiver
- the absence of disturbing modulation products from, for example, power supply units
- the dynamic requirements of the frequency filtering etc.

The first experimental Doppler radar system, a pulse Doppler radar with a high pulse repetition frequency, PRF, (HPD radar), was gradually developed during the years 1963–1965.

The second experimental Doppler radar system, a pulse Doppler radar with low PRF (LPD radar), was developed during the years 1965–1967

The studies and experimental work during the 1960s formed the basis for Ericsson's extensive know-how in the field of Doppler radar, a basis on which the expanding business activities during the 1970s were largely built. The radar for the fighter version of aircraft 37 constitutes a milestone in this development.

The demands made on radar for a modern fighter aircraft are based on the behaviour of the defender and the attacker, the expected weapons and the electronic environment of the "battlefield". During the 1960s the previous high altitude mode of behaviour of attacking aircraft was changed to one of low altitude, making use of the features of the terrain for protection against de-

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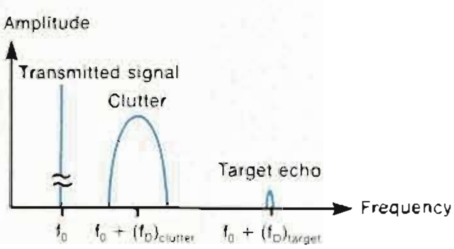


Fig. 3
The frequency diagram for the situation illustrated in fig. 2. The target echo will have a higher frequency than the clutter because the target is flying towards the radar

Fig 2
The geometry of the fighter and target aircraft

V_J speed of the fighter
V_M speed of the target
β the angle between the fighter velocity vector and the line-of-sight fighter-target
θ the angle between the target velocity vector and the line-of-sight fighter-target

The small echo from the target is masked by the ground return. The power ratio between clutter and target echo is dependent on a number of factors, such as target size, the reflecting power of the ground, the range resolution of the radar, the coverage area of the main beam etc. 10^4 (40 dB) is a typical value for this ratio

tection and attack. The defender is forced to fly higher in order to be able to survey larger areas. Thus the defender's radar must be able to look down and detect an enemy aircraft against a solid radar background. The Doppler radar offers the possibility of separating the target from the background or, in other words suppressing the background by means of selective frequency filtering.

Radar system PS-46/A for aircraft JA37 was developed by Ericsson during the years 1970–1978. The development work comprised three prototype generations with different stages of testing on the ground and in the air. The first series produced system was delivered on April 26, 1978.

Doppler radar

Like all other radar systems Doppler radar utilizes the simple principle of transmitting an electromagnetic wave and then analysing the reflected signal in order to extract the desired information. Older types of radar equipment used only the signal amplitude to detect and measure the distance to isolated targets, for example aircraft at a high altitude. A Doppler radar also utilizes the frequency information, for example to distinguish between the signal from a small moving target and a much larger background signal.

Fig. 2 shows a situation with a fighter whose radar beam covers both the target aircraft and the ground below it. Since the radar is mounted on a moving platform the signals reflected by the ground, the clutter, will have a Doppler shift

$$(f_D)_{clutter} = \frac{2\,V_J}{\lambda}\cos\beta$$

where λ is the wavelength of the radar signal.

The signals from the target have the Doppler shift

$$(f_D)_{target} = \frac{2\,V_J}{\lambda}\cos\beta + \frac{2\,V_M}{\lambda}\cos\theta$$

Fig. 3 shows the signals at their relative frequencies. The clutter can be suppressed and the target echo detected by suitable filtering.

Some basic problems should be mentioned. The Doppler effect, i.e. the frequency shift generated by a moving target, is very small relative the carrier and is extremely difficult to measure with an instrument mounted in a shaking and vibrating aircraft. If the target in fig. 2 has a speed of 150 m/s along the line of sight to the fighter, the radar senses the Doppler shift of the target as

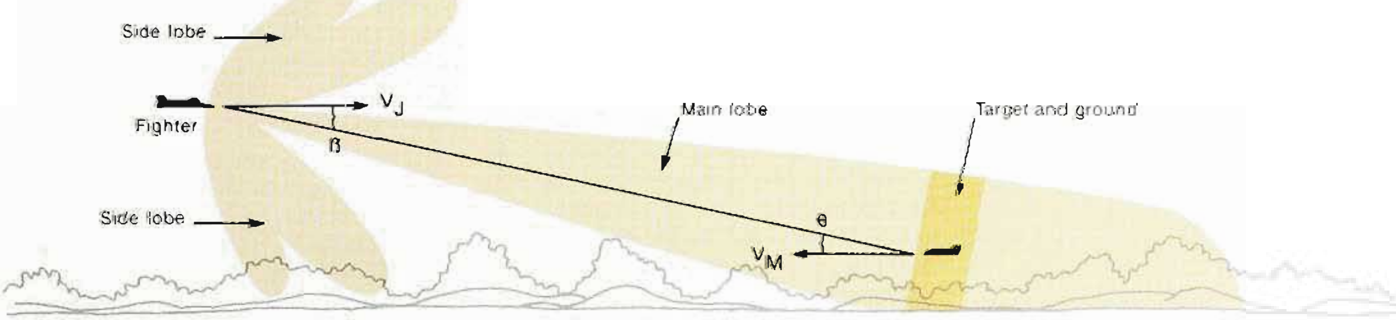
$$(f_D)_{target} = \frac{2\cdot 150}{\lambda}$$

But $\lambda = c/f_0$ (where c is the speed of light and f_0 is the radar transmit frequency), i.e.

$$\frac{(f_D)_{target}}{f_0} = \frac{2\cdot 150}{c} = 10^{-6}$$

The difficulties are even greater if targets with lower relative speeds have to be detected, or if frequency resolution is required for targets with different Doppler shifts ($10^{-7} - 10^{-9}$).

The equations for the Doppler shift of the target and the clutter only apply to the main radar lobe. Unfortunately the side lobes also give a contribution which has a Doppler shift corresponding to the interval $-V_J$ till $+V_J$ depending on their direction in relation to the velocity vector of the aircraft. The side lobe



The Doppler effect

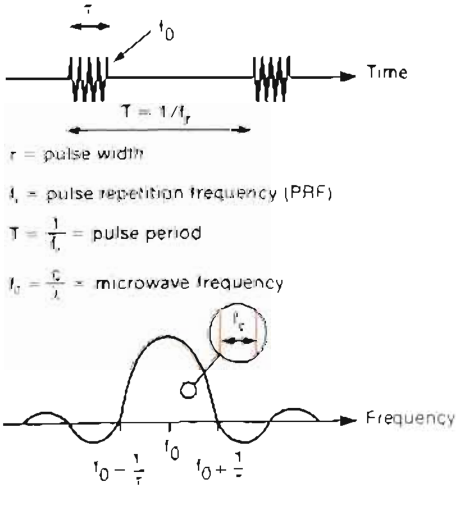
Professor Christian Doppler lived and worked in Austria during the middle of the 19th century. His name is given to the physical effect on which all Doppler radar is based. Professor Doppler explained why a sound source that moves in relation to the observer is sensed as having a higher pitch when the sound source is approaching, and a lower pitch when it is receding. He also found the relationship between the change of frequency, $f_{Doppler}$, the velocity of the sound source towards the observer, V, and the wavelength of the sound, λ:

$$f_{Doppler} = \frac{V}{\lambda}$$

This relationship also applies for electromagnetic waves. It is therefore in principle possible to use radar to separate moving targets from stationary ones by analysing the frequency of the reflected radiation. However, the double propagation path of the signal means that the Doppler shift is

$$f_{Doppler} = \frac{2 \cdot V}{\lambda}$$

Fig. 4
A pulse radar spectrum in the time and frequency domain. In the frequency domain the transmitted (and received) signal is divided into a large number of spectral lines separated (in time) by the pulse repetition frequency. The amplitude envelope is a $\frac{\sin x}{x}$ curve



clutter cannot be filtered out in a Doppler radar having a PRF of less than some tens of kHz. The target echoes can then only be distinguished from the side lobe echoes with the aid of the antenna gain function. This also applies for radar with a high PRF, some hundreds of kHz, if the target Doppler lies within the frequency band of the side lobes. Low antenna side lobe levels are therefore a prerequisite for an airborne Doppler radar.

In pulse Doppler radar clutter signals from the main lobe are present over the whole of the receiver bandwidth in the form of spectrum lines separated by the pulse repetition frequency, fig. 4.

The Doppler filter function must be designed bearing this fact in mind and have stop bands that are repeated at the PRF (comb filter). Targets having a Doppler frequency that differs from the Doppler shift of the ground by an integer multiple of PRF (blind speed) will therefore be suppressed. The problem is accentuated when a low PRF is used if a large unambiguous range is required. In certain cases an acceptable solution can then be obtained by switching between different PRFs. On the other hand, increasing the PRF so that unambiguous distance measurements cannot be carried out directly results in range ambiguity when the distance to the target is a multiple of an unambiguous distance. The target signal is masked by transmit pulse blanking and short-distance clutter.

The equations given above show that the frequency of the clutter is determined by the speed of the aircraft, the angular position of the antenna and the microwave frequency. The clutter frequency must be measured continuously to ensure correct positioning of the Doppler filter stop bands. This function is called clutter tracking.

Another complication, which is caused by the movement of the aircraft, is the spectral widening of the clutter lines. The fact that the main antenna beam has a certain width means that different Doppler shifts for the clutter are obtained within the main beam. The dispersion is proportional to

$$V_r \cdot \sin\beta \cdot \Theta$$

where Θ is the beam width. In the case of wave shapes having a low PRF the stop bandwidth of the Doppler filters must be adjusted accordingly.

The demands made on a modern fighter radar

Detection range suited to tactics and weapons
The fighter radar should help the pilot to detect the target, at a distance that makes possible accurate approach and subsequent combat.

All-weather performance
A fighter must be able to carry out its task under all weather conditions.

Performance against low-altitude targets
The fighter must be able to combat targets at any altitude. The low-flying targets present special difficulties, since they have to be detected against a background that includes large ground returns and returns from targets moving on the ground (cars, hovercraft etc.)

Ability to withstand interference
In a combat situation the intruding aircraft will be equipped with various types of electronic counter measures, ECM. The fighter radar must also function under such circumstances.

Easy to operate
A single-seater fighter requires a radar that the pilot can operate easily.

High availability
Even the most sophisticated fighter aircraft is helpless without radar. The radar must therefore have high availability and short repair times.

In addition to the tactical requirements listed above there are restrictions as regards weight and volume, and also demands for satisfactory operation under adverse environmental conditions (electromagnetic, climatic and kinetic).

Design aspects

The basic requirements for a long detection range are in fact the classic radar requirements
- high transmitter power (mean power)
- large antenna
- high sensitivity.

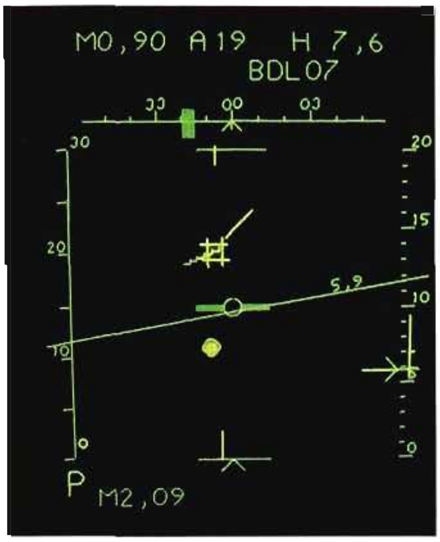


Fig. 5
The head-down display, track-while-scan mode. The target, which is shown in the square marker, forms a track consisting of indications from successive sweeps. The distance scale is to the left and the altitude scale to the right

The transmitter power can be limited by restrictions as regards volume, input power or cooling facilities or the availability of certain key components (transmitter tubes etc.). The travelling wave tube is a suitable component for airborne Doppler radar where a large bandwidth is required.

The size of antenna is determined mainly by the design of the nose of the aircraft.

High sensitivity is achieved through careful design of the receiver functions and signal processing.

All-weather performance is obtained by means of a suitable choice of microwave frequency. The X band gives a good compromise between volume requirements and demands for low atmospheric attenuation.

Satisfactory performance as regards targets in clutter is obtained by choosing a Doppler radar. This concept covers a large range of radar systems, from CW (Continuous Wave) to LPD (Low PRF Pulse Doppler). With CW radar the problem of transmitter and receiver separation exists and thus this is not a practical alternative for aircraft. Pulse Doppler radar is usually divided into HPD (High), MPD (Medium) and LPD (Low PRF Pulse Doppler), each of which has advantages as well as disadvantages.

HPD has unambiguous speed measurement with a PRF of 100–400 kHz, which gives it a very good performance for targets on an approaching course. The range for targets on a receding course is limited by side lobe clutter.

LPD measures distance unambiguously and has a PRF of 1–5 kHz depending on the application. However, a low PRF makes the Doppler filtering more difficult in the case of high fighter speeds or large antenna angles, since spectral widening of the ground return occurs. Even a very careful choice of PRF switching patterns leaves the radar system with certain blind speeds.

MPD has a PRF in the range 5–20 kHz, which means that this type of system usually has a certain ambiguity both as regards speed and distance. However, such ambiguities can be resolved with the aid of a special PRF pattern. A high PRF permits wide stop bands in the Doppler filter, which in its turn also gives good clutter suppression at high speeds and large antenna angles. In other words, the wave shape gives great freedom as regards tactical behaviour. In addition slow-moving ground targets are effectively suppressed. In spite of the wide filter stop bands it is possible to design the radar so that blind speeds are avoided, but an MPD radar will have certain blind distances. MPD usually requires lower antenna side lobe levels than LPD.

The ability to withstand interference is obtained through a robust basic design, with high output power and intelligently planned signal and data processing.

The man-machine communication is simplified by well designed presentation and control devices. The software contains logic functions which carry out automatic decisions and mode changes, thus relieving the pilot of some of the load.

The reliability is affected by such factors as materials, components and structure. The maintenance is simplified by a built-in test and fault location system.

System design

The following system design was chosen for PS-46/A.

- Wave shape MPD with a pulse repetition frequency in the range 7–17 kHz. Conventional pulse radar mode without Doppler filtering can be selected, together with a pulse repetition frequency that is suitable for unambiguous distance measurement.
- *Frequency band X* with a large bandwidth, 8.6–9.6 GHz
- *A Cassegrain antenna* mounted on a pedestal with two hydraulically driven gimbals with ±60° in azimuth and elevation.
- *Digital signal processing* with advanced functions for ensuring target detection and protection against interference.
- *Stored program controlled data processing* with spare capacity for future modifications.
- *Functional supervision and built-in testing*, adapted to suit the custom-

er's maintenance philosophy and resources.
- *Separate illuminator* for radar missile.

Function

Radar system PS-46/A provides the JA37 pilot with a tool that enables him to take action against serious threats. He communicates with the radar via control devices and display equipment mounted in the cabin of the JA37. The control devices are placed mainly in a special radar panel on the left-hand side. The display equipment comprises three units: head-down display, tactical display and head-up display. The head-down display, fig. 5, is dedicated to the radar function. It is designed with distance along the vertical axis and relative bearing along the horizontal axis (B-scope).

The control devices enable the pilot to choose different functional modes, for the radar system for combating air targets:

- *Search*, which means that the radar scans a section of the air space and displays targets on the head-down display. The pilot can choose the size and position of the searched space within the limits set by maximum antenna movement and the maximum range of the equipment.
- *Track-while-scan*, which means that the radar keeps scanning but automatically tracks and presents the data for a target selected by the pilot.
- *Continuous tracking*, which is used in combination with weapon delivery and means that the radar follows the target in question with the antenna and provides target data.
- *Target illumination*, which means that the continuous tracking is supplemented by an illumination signal for controlling a semi-active radar missile.

PS-46/A is equipped with fuctions for *measuring distances towards the ground* for attacks against ground targets. This means that the radar measures the slant range to a spot on the ground which the pilot has indicated with the aid of an aiming dot on the head-up display.

The radar is built up of a number of subsystems, fig. 6. It is administered from the radar data processor which also handles most of the communication with cooperating equipment. The information is transmitted in binary and serial form over data buses.

The exciter (EXC) generates a very stable coherent HF signal in the X band. This signal is pulsed and amplified in the power amplifier (PA). The transmit pulse width and pulse repetition frequency are controlled by the radar signal processor (RSP). The transmit signal from PA goes via a T/R switch in the microwave unit (MWU) to the reflector (RFL), which shapes the electromagnetic radiation. The antenna beam is positioned mechanically by the pedestal (PED). The reflected signal is gathered by RFL and fed to MWU, where four RF signals are generated – a sum signal (Σ) and elevation and azimuth difference signals (ΔEL, ΔAZ) by a monopulse comparator, and a monitor signal from a widebeam antenna. The latter has a gain function that is adjusted to the side lobe

Fig. 6
The block diagram shows the line replaceable units in radar system PS-46/A and the most important signalling paths between them. The units are mounted in a rack, which in itself is a replaceable unit. *All the radar equipment (except the power divider and reference antennas) is mounted in the JA37 nose cone under the radome.* Units outlined in broken lines are other units in JA37 that cooperate with the radar equipment

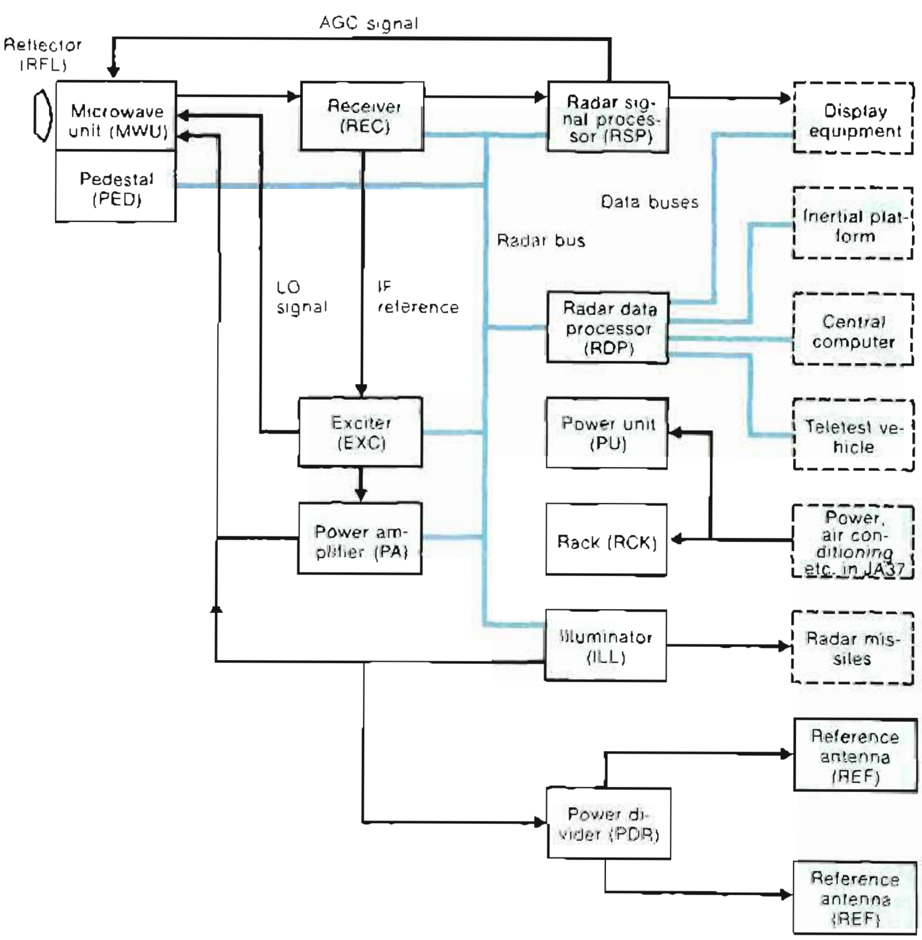
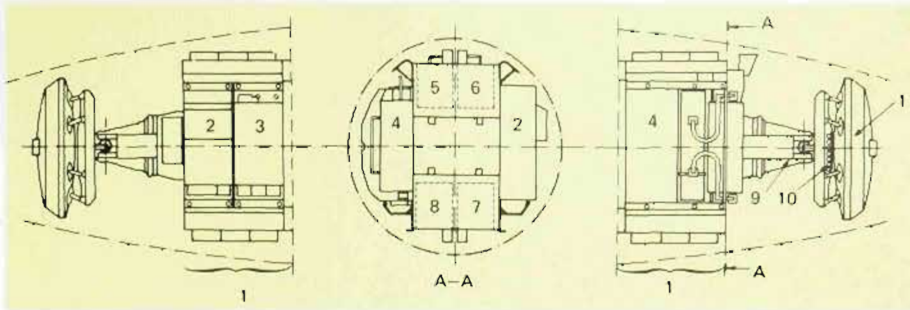


Fig. 7
PS-46/A. The units in the rack in the nose cone of the aircraft

1. **Rack**
2. **Illuminator**
3. **Exciter**
4. **Power amplifier**
5. **Radar signal processor**
6. **Receiver**
7. **Power unit**
8. **Radar data processor**
9. **Pedestal unit**
10. **Microwave unit**
11. **Reflector**



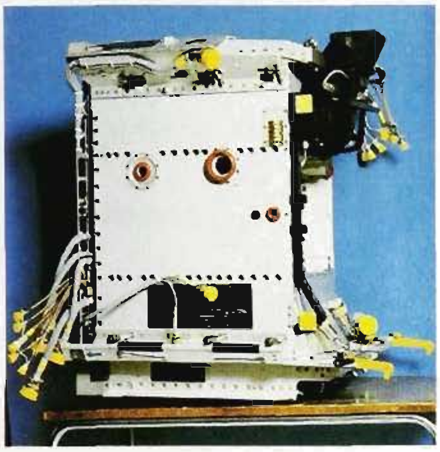
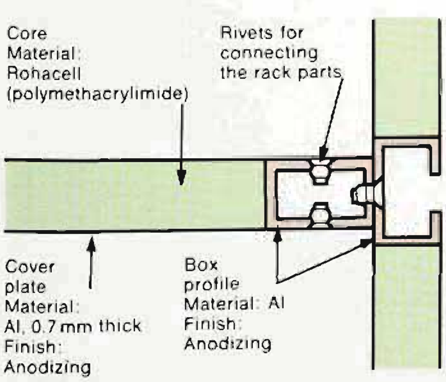


Fig. 8
The rack, with the starboard side seen obliquely from the front. A waveguide unit (black) is attached to the rack. The picture also shows springs for grounding, inputs for cooling air and cable harness

Fig. 9
A section of a shelf and wall in the rack. The parts are joined by means of a hot-setting glue film except for the joint between the wall and the shelf, which is secured with internal rivets



level of the main antenna. The monitor signal can therefore be used to determine whether a signal emanates from the side lobe ranges. The other RF signals are used for target detection and tracking.

ΔEL, ΔAZ and the monitor signal are time multiplexed in MWU to one receive channel. In MWU the signals are also converted down to an intermediate frequency (IF) with the aid of a local oscillator signal from EXC, the frequency of which is corrected with respect to the Doppler shift of the clutter. After amplification and automatic gain control (AGC) in MWU the two IF signals are fed to the receiver (REC) for final amplification and signal matching. The conversion to video is also carried out in REC, with the aid of the IF reference. The phase information is preserved since the video quadrature components (I/Q) are processed individually.

The video signals are sampled and converted to digital form in RSP. This results in a number of range bins, with the video amplitude represented by a binary number. The bin width is determined by the transmit pulse width. Doppler filtering, video integration and target echo detection are also carried out in RSP. The output signal to the indicator equipment consists of a synthetic video signal, 1 or 0. RSP also contains many other functions. For example, an AGC signal to MWU is generated which at any moment and for each bin adapts the incoming signal to the conditions prevailing at that instant. The unit also contains discriminator function for clutter and target tracking, as well as functions for protection against interference.

In the radar data processor (RDP) the functions are carried out by stored programs. RDP contains functions for mode control, target tracking and target data filtering, clutter tracking and test administration. The unit also handles most of the communications with cooperating equipment and is connected via data buses to the central computer of the aircraft, the inertia platform and the display equipment.

The illuminator (ILL) is a self-contained unit, separate from the radar transmitter (EXC + PA). It generates an illumination signal to be used with the semi-active radar missile. The generated CW signal has a slightly higher frequency than the radar signal. The output power goes via MWU and RFL.

A part of the power is fed via a power divider (PDR) to two reference antennas (REF), which are placed behind the missiles and are used to prepare these.

PS-46/A is supplied with electric power, hydraulic fluid, cooling air and compressed air from the aircraft. The power consists mainly of three-phase 200/115 V, 400 Hz. The conversion to the required voltages is mainly done locally. PA, ILL, RDP and RSP have their own power modules which are fed directly from the three-phase mains of the aircraft. A central power unit (PU) generates raw voltages for further regulation in certain units.

Mechanical construction

The requirements for equipment intended for military aircraft are severe as regards weight, volume and performance. Since the demands made on the performance of the radar system are rarely relaxed, the fact that it has to be constructed for the limited space available in the nose cone of an aircraft constitutes a real challenge. Fortunately the financial aspects of an aircraft project are usually such that sophisticated materials and components can be used to help solve the problems.

The mechanical structure offers support and space for the electrical components, distributes the cooling medium, dry compressed air and, via the cable harness, power to the system units.

The equipment is cooled by air at regulated temperature from the aircraft. Indirect cooling is mainly used, i.e. heat transfer to cold surfaces for more efficient heat exchange.

The mechanical environment in the nose cone of the aircraft is characterized by three main adverse components, namely vibration, acoustic pressure and shocks, all of which may at times be present simultaneously. This environment is caused by the progress of the aircraft through the air, by the launching of weapons, by landing and

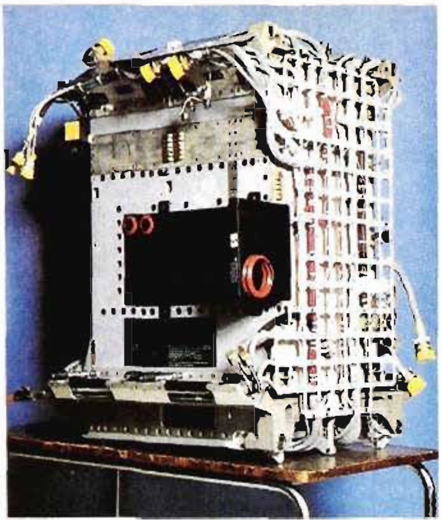


Fig. 10
The port side of the rack seen obliquely from the back. The cable harness, which is laced to a grid, constitutes a replaceable unit The cooling air input from the aircraft can be seen to the left

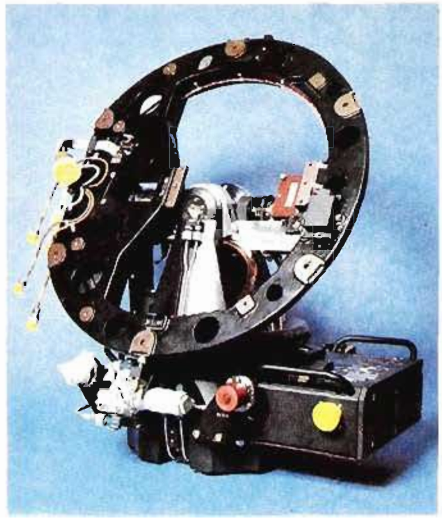


Fig. 11
The pedestal unit with the electronic equipment in a box on the right, and connectors and filters for the hydraulic fluid at the bottom. The reflector is attached to the ring with six screws

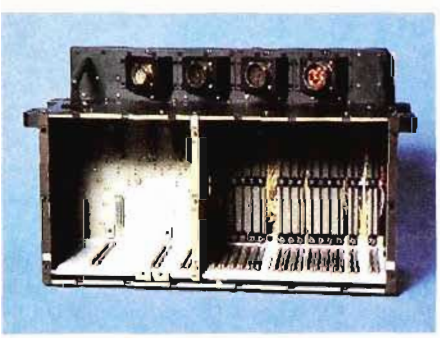


Fig 12 1
An empty magazine for digital technology circuits. The picture shows, among other things, board guides with cooling air inputs and keyed connectors at the rear. The cable harness is connected to connectors in the "ridge"

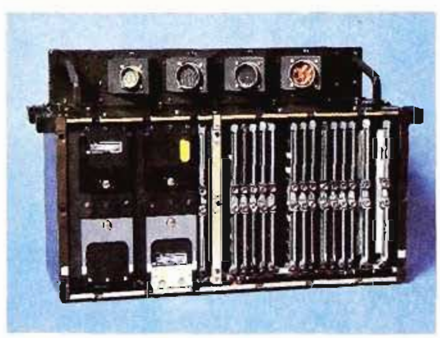
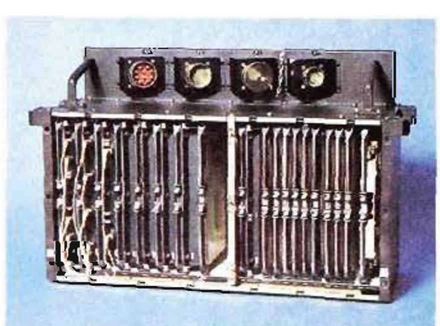


Fig. 12 2
A magazine for digital technology circuits, fully equipped with power modules on the left. All modules are held in place by levers and snap locks

Fig 12.3
An empty magazine for high frequency technology circuits. The picture shows the front and rear coaxial connectors

Fig. 12:4
A magazine for high frequency technology circuits, fully equipped



by rolling on runways. Transports and handling of spare units constitute a jolting and shaking environment.

The mechanical stucture has to accommodate units using electrical signals of widely divergent types, such as
- high-frequency, low-power signals (receiver)
- high-frequency, high-power signals (transmitter)
- high voltage, 30 kV (transmitter)
- low-frequency signalling voltages

The structure must provide these units with good framework connections and good screening and also prevent disturbing radiation as far as possible; electromagnetic compatibility requirements have to be met.

The structure must also facilitate maintenance i.e replaceable units and subunits must be easy to install and remove

Radar PS-46/A consists of ten line replaceable units with a total weight of 245 kg. They are placed in a rack which in its turn constitutes a replaceable unit, fig. 7.

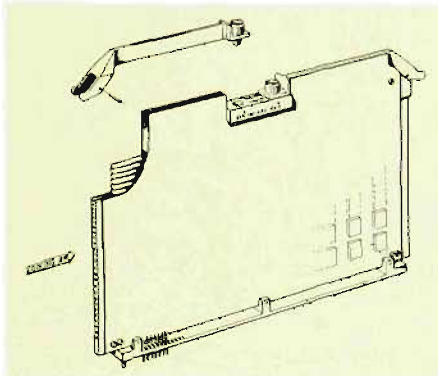
The rack that holds the ten units is designed as a box girder with two vertical ribs, which in their turn form the walls of an upper an a lower rectangular shaft This provides an upper and a lower space for mounting rectangular magazines as well as two side walls where large units can be mounted, fig 8

The central cavity of the box girder is used to distribute cooling air to the various units. The front end of the girder forms the mount for the antenna unit

Forces and moments are absorbed by the box girder and transmitted to the fuselage via four bolts.

The rack is built up of sandwich panels consisting of aluminium plates with a core of acrylicimid foam plastic. Such a panel is light and rigid, and it also acts as a damper, fig. 9 The rack cable harness is run on the outside in order to simplify production and maintenance. The cables are laced to a coarse grid, which is placed at the rear of the rack, fig 10.

The antenna unit consists of three plug-



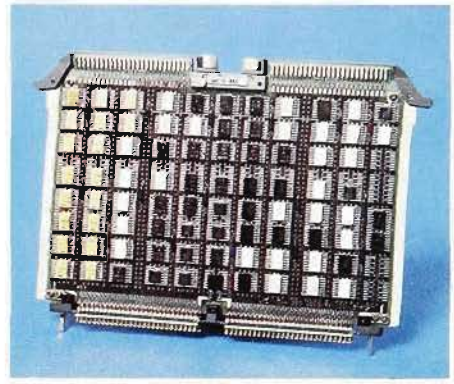
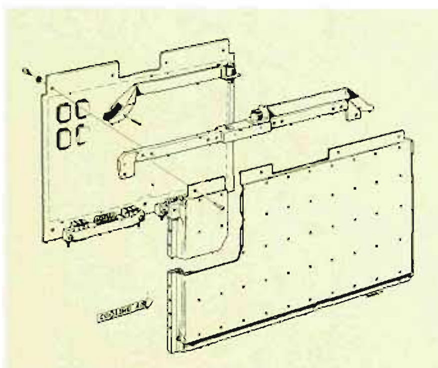


Fig. 13:1
A six-layer printed circuit board module. The figure shows the cooling principle and surface-mounted components. The construction permits 160 flatpacks and 35 W dissipation. The built-in test device can be seen between the levers



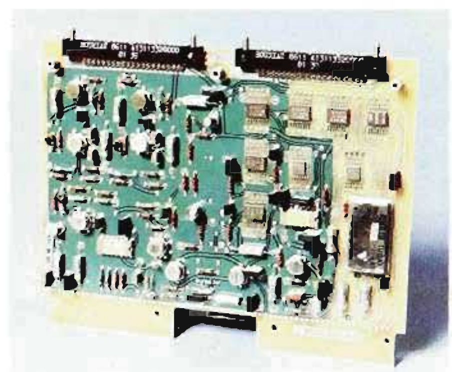
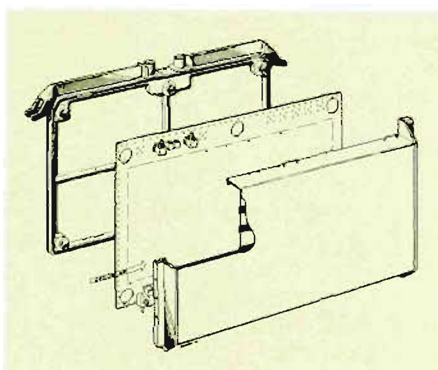


Fig. 13:2
A two-layer printed circuit board module for mixed technology circuits. The components are cooled by means of an air flow through the cover



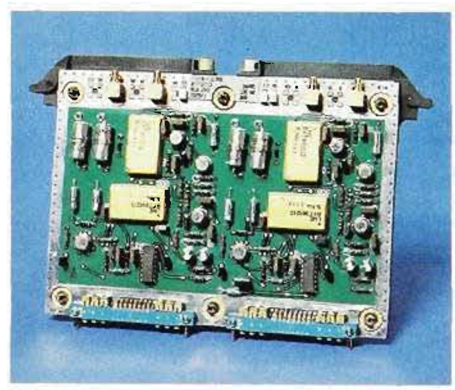
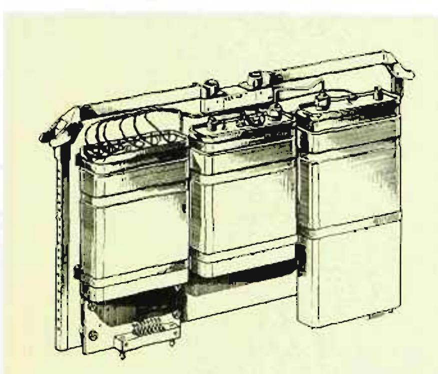


Fig. 13:3
A printed circuit board module for high frequency technology circuits. Screening is obtained with the aid of a metal frame and the cooling cover, which is also made of metal



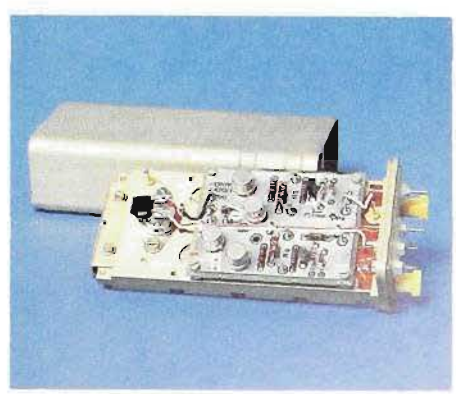


Fig. 13:4
A module for microwave technology circuits. The microwave circuits are mounted in hermetically sealed cans mounted on a heat exchanger

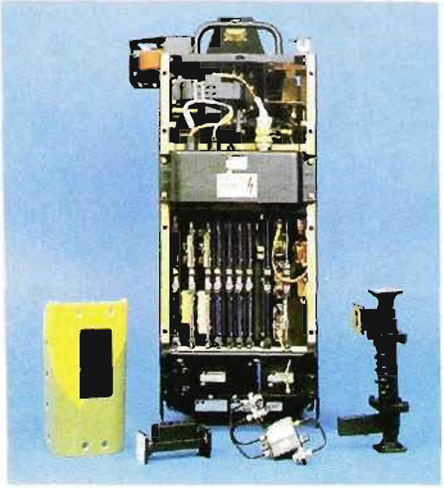


Fig. 15
The illuminator with the cover removed. The klystron with high voltage parts is placed at the top, and the printed circuit board assemblies below. The picture also shows (from the left) a *reference antenna*, a microwave stop filter for the illumination signal, a power divider and a diplexer. The latter is used to interleave the radar transmit pulse and the signal from the illuminator

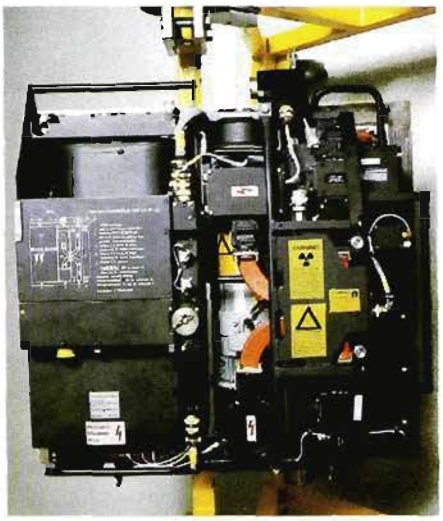
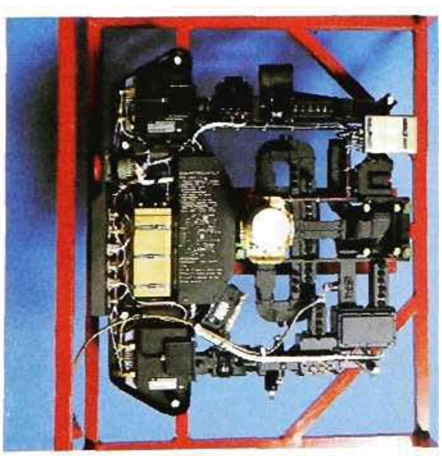


Fig. 14
The power amplifier. The travelling-wave tube is placed in the centre of the unit, with the high-voltage parts to the left and the printed circuit board assemblies to the right. The microwave signals are fed in via flexible waveguides

Fig. 16
The microwave unit. The feed (with a cover for protection during transport) and the monopulse comparator are mounted at the centre of the unit. The sum channel (top) contains a circulator, T/R tube, mixer and preamplifier. The time multiplexed channel (bottom) contains switches, a T/R tube, mixer and preamplifier



in units, the pedestal unit, the microwave unit and the reflector. The pedestal unit, fig. 11, is a two-axis pedestal with movement in two orthogonal directions, azimuth and elevation. The reflector and the microwave unit are mounted on the front end of the pedestal. The pedestal is made of magnesium and its hydraulic motors of stainless, stress-free steel. The hydraulic motors are designed as wing motors with a working pressure of 20 MPa. The front, moving part of the pedestal unit is designed as a ring on which the microwave unit and reflector are mounted. The movement of the ring is limited by rubber stops at the base of the pedestal.

The microwave unit, fig 16, is a structure of waveguides, which together with the associated electrical devices forms a rigid mechanical unit.

The reflector is of the Cassegrain type and is made of epoxy impregnated glass fibre cloth having a core of PVC foam plastic which contains a metal net. The box shape gives the necessary rigidity, fig 17.

The magazines that are placed in the two shafts are built up in a similar way, since they all contain printed circuit board assemblies. These magazines all have a top ridge for connectors and cabling. The magazine includes a back panel and guides for different types of printed circuit board assemblies. Both the bottom and the top of the magazine have a plenum construction, the plenum being used to distribute cooling air to the units. The cooling air enters the base of the magazine via an outlet in the rack, fig 12:1

There are three different types of printed circuit board assemblies, fig 13.
- printed circuit board assemblies for digital technology with two six-layer boards mounted back to back on a heat exchanger
- printed circuit board assemblies for mixed technology with two-layer boards equipped with a cooled cover over the component side
- printed circuit board assemblies for high frequency technology with a cooled cover, which together with a metal frame provides good screening of the unit.

A board unit has been developed for microwave circuits, consisting of a heat exchanger on which a number of aluminium cans containing microwave components are mounted, fig. 13:4.

A lever arrangement simplifies the extraction and insertion of boards.

The power amplifier is mounted on the starboard side of the rack, fig. 14. It contains a travelling wave tube and its power supply. All high-voltage components are placed in a container filled with the inert liquid FC77. The liquid insulates and transports heat out to cooled surfaces.

The port side of the rack holds the exciter and illuminator, two units with similar structures. The exciter contains only microwave units of the board type. The illuminator, fig. 15, also contains units for the high voltage supply to a klystron amplifier.

Individual units can easily be removed with the aid of a few tools, fig. 19. All units, with the exception of the power amplifier and the pedestal unit, can be handled by one person. The power amplifier and pedestal unit require lifting gear or two persons.

Subsystems

Exciter

The exciter provides the power stage with a driving signal generated from crystal oscillators at approximately 125 MHz. This frequency is converted to the required X band signal with the aid of multiplier diodes, amplifiers and pulse circuits. The frequency can quickly be switched to different values in the band 8.6–9.6 GHz.

The local oscillator signal to the mixer in the microwave unit is generated from the drive signal to the power amplifier and an IF signal from the receiver. This latter signal is corrected for momentary clutter frequency.

The noise requirements for the output signals from the exciter are very exacting. Special care has therefore been given to the construction in order to reduce the effect of external disturbances such as vibrations, noise and elec-

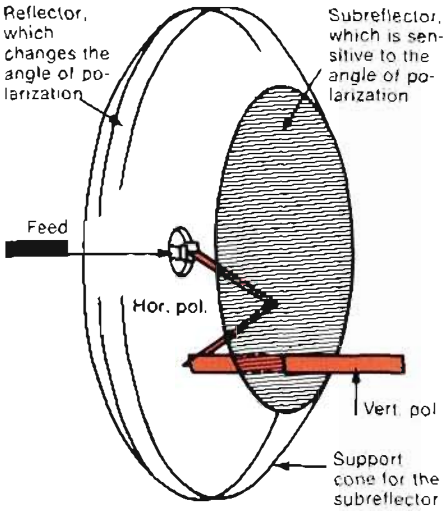


Fig. 17
The basic principle of the Cassegrain antenna The horizontally polarized beam from the feed is reflected in the subreflector. The polarization is turned through 90°, to vertical polarization, when the beam is reflected in the main reflector Since the subreflector lets through vertically polarized beams, the signal can pass unobstructed. In PS-46/A the subreflector support cone contains absorbent material in order to reduce side lobes to the greatest possible extent

tromagnetic signals. For example, the crystal oscillators are suspended on rubber springs in order to obtain mechanical isolation.

Power amplifier

The power amplifier, fig. 14, is built up around an air-cooled travelling-wave tube with a peak pulse power of 50 kW and a mean power of 500 W. The bandwidth is 8.6–9.6 GHz.

The high voltage of the travelling-wave tube has to be carefully filtered in order to obtain the necessary spectral purity of the transmitted signal. The method used is active filtering, which reduces the remaining ripple on the cathode voltage (approximately −30 kV relative to the anode) to a few volts. The pulsing of the tube is arranged by feeding a positive pulse to the grid, which normally has a negative bias (relative to the cathode).

The power amplifier is equipped with an extensive supervision and safety system in order to prevent damage to the travelling-wave tube. An ion pump removes residual gas.

Illuminator

The illuminator, fig. 15, is built up around an air-cooled klystron, which gives a CW signal of 200 W. The klystron is driven by frequency units of the same type as in the high-frequency generator. The noise requirements are stringent in this case too, and active filtering of the cathode voltage (−4.3 kV) is carried out.

Pedestal unit

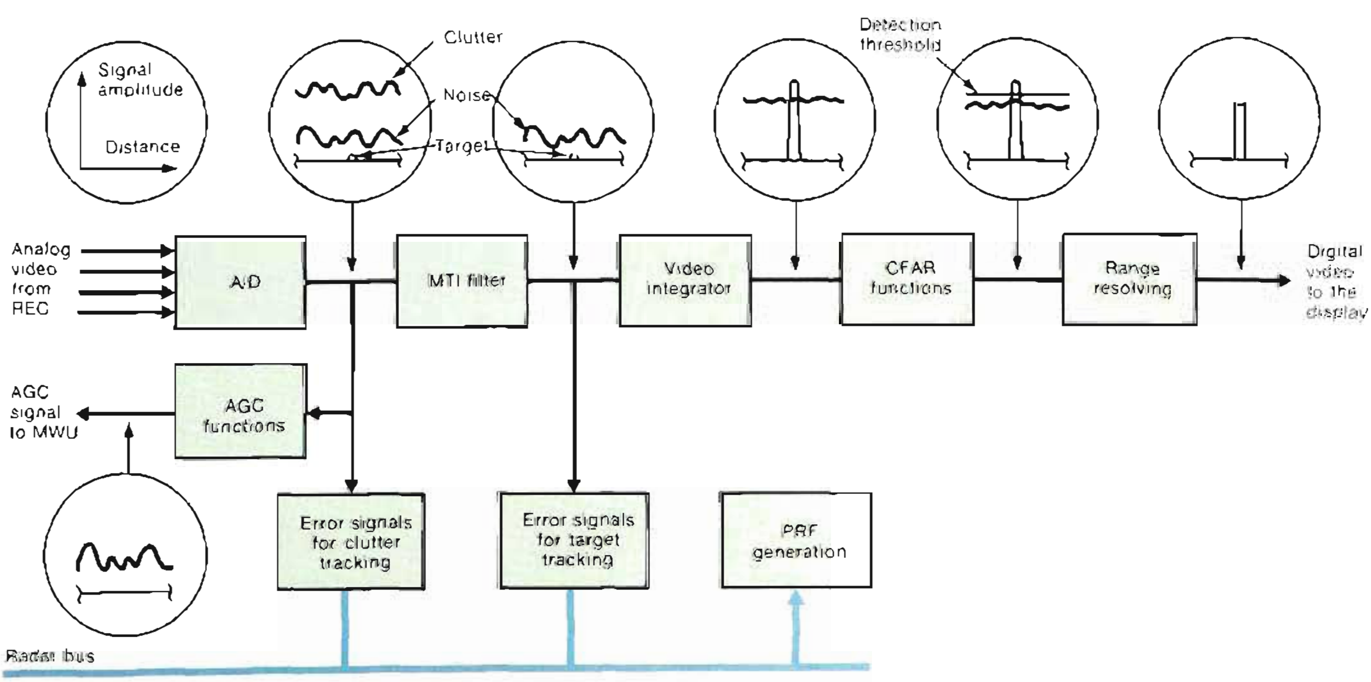
The pedestal unit, fig. 11, consists of a two-axis pedestal which can rotate the antenna in a cone with a top angle of 120°. It is driven by electrohydraulic servo systems, which are controlled from the radar data processor via the radar bus.

Microwave unit

The microwave unit, fig 16, contains transmitter and receiver functions. The receiver uses passive T/R tubes and thus provides satisfactory protection even against signals from other radar stations. The illumination power is rejected in band stop filters, so that full radar performance can be maintained even when the illuminator is operating.

The microwave unit is placed close to the reflector in order to keep the signal loss at a minimum. The sum signal has a separate receive channel with mixer and amplifier. The difference signals are time multiplexed with each other and with the monitor signal from the wide-beam antenna in a second receive channel.

Fig. 18
Block diagram for the radar signal processor. The circles show the basic signal shapes (amplitude as a function of distance) at different points



Reflector

The reflector, fig. 17, consists of a double reflector arangement of the Cassegrain type. The reflector contains two supplementary antennas, a wide-beam antenna and an antenna for identification equipment (IFF).

Receiver

The receiver, fig. 12:4, contains two parallel receive channels with IF amplifiers, AGC functions, phase detectors (I/Q) and video filters. The unit also includes a reference oscillator for the intermediate frequency, and clutter tracking functions. The latter provide the exciter with an IF signal having a frequency shift that corresponds to the instantaneous clutter frequency. The clutter frequency is obtained from the radar data processor via the radar bus.

Radar signal processor

Roughly speaking the functions of the signal processor, fig. 12:2, can be divided into preprocessing and postprocessing of the video signals. The preprocessing requires very high speed, since each individual radar pulse must be processed in real time, bin by bin. After the video integration, where many radar pulses are integrated, the data speed is reduced and the postprocessing starts.

The analog/digital converter, A/D in fig. 18, converts the bipolar analog video signal from the receiver to digital form. The I and Q components for the two channels are converted to numbers for each bin (approximately 1 μs). Doppler filtering is then carried out in the moving target indicator (MTI) filter. This is designed as a third-order digital filter. In the video integrator several radar pulses are added linearly during a fixed time. The CFAR (Constant False Alarm Rate) circuits compare the signals in a certain bin with their environment, and only significant differences result in detection.

In connection with detection the time between transmitted radar pulses and received target echo pules is determined. The measured time difference corresponds to a number of possible distances to the target. A modified pulse repetition frequency and a new measurement give a new set of possible distances. The possible distance that is obtained with both pulse repetition frequencies gives the real target positon, calculated in the so-called range resolver.

If several target echoes are obtained simultaneously it is not always possible to resolve the distance ambiguity directly. This is because the echo from a certain target obtained with one pulse repetition frequency is correlated to an echo from another target when using the second pulse repetition frequency. This gives rise to so-called ghost echoes. These can be eliminated by using one or a few more pulse repetition frequencies in the range resolution calculations.

The radar signal processor calculates error signals for the tracking functions of the radar. The unit also controls the AGC (Automatic Gain Control) function, which momentarily adapts the dynamic range of the radar to the prevailing input signal conditions.

Radar data processor

The radar data processor is designed as a minicomputer with programs stored in a program store. The word length is normally 16 bits. Double word length can be used. Trigonometric tables are included in order to simplify the work of carrying out a great number of coordinate conversions extremely quickly. The shortest calculation cycle is 3 ms. The control unit communicates with the environment via five input/output channels, fig. 6. The unit contains

- data store
- program store
- processor unit
- control unit
- input/output unit.

The program store comprises 32 k words and the memory components are of type FAMOS. The memory components are programmed at the factory. The writing is done by means of electrical pulses and erasing by means of ultraviolet light.

The software uses approximately 20 k words of the program store and contains functions for, for example,

- selecting radar mode and logic control of the other subsystems
- antenna and marker control
- target data filtering during tracking
- clutter tracking
- interference processing

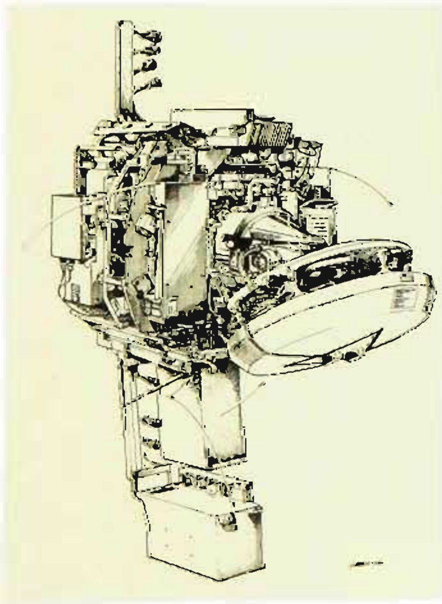


Fig. 19
Depending on their positions in the rack, the rack mounted units can be lifted upwards, or swung downwards or outwards from the sides of the rack, in order to facilitate replacement

Fig. 20
Radar PS-46/A in aircraft JA37

- functional supervision
- test administration

Operational reliability

High availability, high functional reliability and good maintenance characteristics are among the prerequisites for military equipment.

By high availability is meant that the equipment must be reliable and easy to maintain.

High functional reliability is achieved if the failure rate is low, and the equipment is able to carry out functional tests and inform the operator about any faults. The predicted mean time between failures (MTBF) for PS-46/A is 160 hours in full flight operation. The radar is continuously monitored by a supervisory system which does not affect the operation of the radar. The pilot is informed of any faults via the head-down display or indicator lamps.

By good maintenance characteristics is meant that any faults are easy to locate and repair. It must be possible to adapt the equipment to suit the customer's maintenance philosophy and resources. In the case of PS-46/A conscripts must be able to locate and repair any faults while the system is still mounted in the aircraft. The construction with units that are easy to handle and replace is one step along this path. A good test system is another. PS-46/A has three different test levels
- functional testing (FT)
- built-in performance testing and fault location (IPT/IFL)
- external performance testing and fault location (EPT/EFL).

The last level requires the assistance of a JA37 teletest vehicle and comprises tests that require external aids. The fault detection ability of the test system is approximately 95% of the total number of faults.

FT can be carried out before each flight and takes about one minute. The time required for IPT/IFL is in the order of five minutes. EPT/EFL takes about half an hour.

The functional supervision and testing uses generators, transmitters and logic signals that have been designed for this purpose. For example, target and clutter signals can be generated at the RF, IF and video level. The antenna direction is checked by means of an optical system, where the transmitter is placed on the moving part and the receiver on the fixed part. The noise factor of the radar can be measured with the aid of a built-in noise source. The transmit power from the power amplifier and the illuminator is monitored continuously. The radar data processor administers all supervision and test fuctions, evaluates the results and transfers them to the central computer in the aircraft.

Summary

The radar equipment which the Swedish Air Force now obtain in the fighter version of aircraft JA37 makes it possible to detect and determine the position of targets at any height. A particularly interesting feature is its ability to detect small aircraft echoes against a background of large ground return – a prerequisite for a modern fighter radar.

The chosen system design is a compromise between different technical solutions in order to obtain a good balance between economical and tactical requirements. Much of the long development work has been devoted to optimizing the ability of the radar to penetrate electronic counter measures (ECM). Data processing by means of software also provides a certain amount of adaptability to variations in ECM tactics.

The extensive signal and data processing, in combination with the limited amount of space available in the aircraft, has necessitated a compact construction using, for example, multi-layer printed circuit board assemblies.

Special consideration has been paid to operational reliability throughout, in selecting components and structure, predicting functional reliability and designing the built-in systems for functional supervision and testing.