

# Active Electronically Scanned Array - (AESA) Radar

An Active Electronically Scanned Array (AESA), is a type of phased array radar whose transmitter and receiver functions are composed of numerous small solid-state transmit/receive (T/R) modules. AESAs aim their "beam" by broadcasting a number of different frequencies of coherent radio energy that interfere constructively at certain angles in front of the antenna. They improve on the older passive electronically scanned radars by spreading their broadcasts out across a band of frequencies, which makes it very difficult to detect over background noise. AESAs allow ships and aircraft to broadcast powerful radar signals while still remaining stealthy

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10/4/2010

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## Abstract

This paper describes active electronically scanned array (AESA) history performance and working of scanned array radar and how it fits significant in this present world.

An Active Electronically Steered Array (AESA) takes the concept of using an array antenna a step further. Instead of shifting the phase of signals from a single high power transmitter AESA employs a grid of hundreds of small "transmitter-receiver (TR)" modules that are linked together by high-speed processors.

A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference. The main beam always points in the direction of the increasing phase shift. If the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift, the beam direction will be electronically adjustable. While the aircraft that is being tracked will have no idea that a radar is tracking it since multiple frequency is used which is frequently changing.

## Introduction to AESA-Radars

Radar is an object detection system that uses electromagnetic waves to identify the range, altitude, direction, or speed of both moving and fixed objects such as aircraft, ships, motor vehicles, weather formations, and terrain. The term *RADAR* was coined in 1940 by the U.S. Navy as an acronym for *RADio Detection And Ranging*. The term has since entered the English language as a standard word, *radar*, losing the capitalization. Radar was originally called RDF (Range and Direction Finding) in the United Kingdom, using the same acronym as Radio Direction Finding to preserve the secrecy of its ranging capability.

A radar system has a transmitter that emits radio waves. When they come into contact with an object they are scattered in all directions. The signal is thus partly reflected back and it has a slight change of wavelength (and thus frequency) if the target is moving. The receiver is usually, but not always, in the same location as the transmitter. Although the signal returned is usually very weak, the signal can be amplified through use of electronic techniques in the receiver and in the antenna configuration. This enables radar to detect objects at ranges where other emissions, such as sound or visible light, would be too weak to detect. Radar uses include meteorological detection of precipitation, measuring ocean surface waves, air traffic control, police detection of speeding traffic, military applications, or to simply determine the speed of a cricket ball.

Radar systems generally work by connecting an antenna to a powerful radio transmitter to broadcast a short pulse of signal. The transmitter is then disconnected and the antenna is attached to a sensitive receiver which amplifies any echoes from target objects and then sends the resulting output to a display. The transmitter elements were typically klystron tubes, which are suitable for amplifying a small range of frequencies. In order to scan a portion of the sky, the radar antenna has to be physically moved to point in different directions.

Starting in the 1960s new solid-state delays were introduced that led to the first practical large-scale passive electronically scanned array (PESA), or simply phased array radar. PESAs took a signal from a single source, split it up into hundreds of paths, selectively delayed some of them, and sent them to individual antennas. The resulting broadcasts overlapped in space, and the interference patterns between the individual signals was selected in order to reinforce the signal at certain angles,

and mute it down in all others. The delays could be easily controlled electronically, allowing the beam to be steered without the antenna having to move. A PESA can scan a volume of space much more quickly than a traditional mechanical system. Additionally, as the electronics improved, PESAs added the ability to produce several active beams, allowing them to continue scanning the sky while at the same time focusing smaller beams on certain targets for tracking or guiding semi-active radar homing missiles. PESAs quickly became widespread on ships and large fixed emplacements in the 1960s, followed by airborne sensors as the electronics shrank.

AESAs are the result of further developments in solid-state electronics. In earlier systems the broadcast signal was originally created in a klystron tube or similar device, which is relatively large. Receiver electronics were also large due to the high frequencies that they worked with. The introduction of gallium arsenide microelectronics through the 1980s served to greatly reduce the size of the receiver elements, until effective ones could be built at sizes similar to those of handheld radios, only a few centimeters in volume. The introduction of JFETs and MESFETs did the same to the transmitter side of the systems as well. Now an entire radar, the transmitter, receiver and antenna, could be shrunk into a single "transmitter-receiver module" (TRM) about the size of a carton of milk.

The primary advantage of a AESA over a PESA is that the different modules can operate on different frequencies. Unlike the PESA, where the signal was generated at single frequencies by a small number of transmitters, in the AESA each module broadcasts its own independent signal. This allows the AESA to produce numerous "sub-beams" and actively "paint" a much larger number of targets. Additionally, the solid-state transmitters are able to broadcast effectively at a much wider range of frequencies, giving AESAs the ability to change their operating frequency with every pulse sent out. AESAs can also produce beams that consist of many different frequencies at once, using post-processing of the combined signal from a number of transmitter-receiver modules to re-create a display as if there was a single powerful beam being sent.

## Need for AESA Radar

### The Evolving Threat

Initially jet fighters were equipped with airborne radars purely for air to air combat. As long as the threat that a fighter aircraft was attempting to counter were enemy fighter aircrafts, first generation radars with dish antennas were effective. However, the introduction of long cruise missiles by the former Soviet Union in the 1970s changed the equation dramatically. The smaller size of the cruise missile, and the consequent reduced radar signature gave cruise missiles a good chance of penetrating the fighter air cover over US carrier groups and hitting home with devastating effects.

In order to effectively engage cruise missile the detection and guidance capability of airborne radar needed to be stepped up dramatically.

As the threat evolved so did airborne radars. In order to reduce the side lobes associated with dish antennas as well as reduce their reflectivity planar or slotted array antennas began to be developed in the 1970s.

## Evolution Of Radar

### Dish Antenna Radars

Early jet fighter, like the MiG-21, employed mechanically steered concave reflector antennas colloquially referred to as dish antennas. A concave reflector antenna is a simple and effective solution for generating a shaped radar beam as well as efficiently gathering any reflected energy from it.

Dish antennas, however, have their limitations. Their to and fro steering mechanisms are expensive to fabricate to the high accuracies required. Such steering mechanisms are also prone to frequent failures. In other words they have a relatively short Mean Times Between Failure (MTBF) of around 60 to 300 hours.

Another problem with dish antennas radars is that they have fairly large side-lobes which leads to signal losses and reduces their sensitivity.

Finally, dish antennas do a good job not just of shaping their transmitter beams and gathering reflected energy from it but they are equally efficient at reflecting radar energy from enemy radars! In other words they are as good with detecting the enemy as they are with letting the enemy detect them.

## Planar Array Antenna Radars

Planar array antennas, like dish antennas, are also mechanically steered but they use a flat rather than concave receiver to gather the reflected radar energy. A flat panel reflector scatters the radar energy impinging on it from hostile radars, rather than sending it back as a well focused beam.

Planar arrays use an array of very simple slot antennas. They achieve their focusing effect by introducing and manipulating a time delay into transmissions from each antenna. A complex network of microwave waveguides on the rear surface of the array is used to achieve this. The controlled time delays result in a desired fixed beam shape with much smaller sidelobes compared to a concave reflecting antenna. The key to slotted array antennas is the time delay caused by waveguides. The signal that they transmit is in phase.

Since a planar array antenna is a flat plate, it tends to act like a flat panel reflector to impinging transmissions from hostile radars and thus produce a lower radar signature than a concave antenna. However, mechanical steering of planar array antennas continued to be a problem.

## Phased Array and Active Array Radars

AESAs are the result of further developments in solid-state electronics. In earlier systems the broadcast signal was originally created in a klystron tube or similar device, which is relatively large. Receiver electronics were also large due to the high frequencies that they worked with. The introduction of gallium arsenide microelectronics through the 1980s served to greatly reduce the size of the receiver elements, until effective ones could be built at sizes similar to those of handheld radios, only a few centimeters in volume. The introduction of JFETs and MESFETs did the same to the transmitter side of the systems as well. Now an entire radar, the transmitter, receiver and antenna, could be shrunk into a single "transmitter-receiver module" (TRM) about the size of a carton of milk.

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## Basic principle of operation

### Echo and Doppler Shift

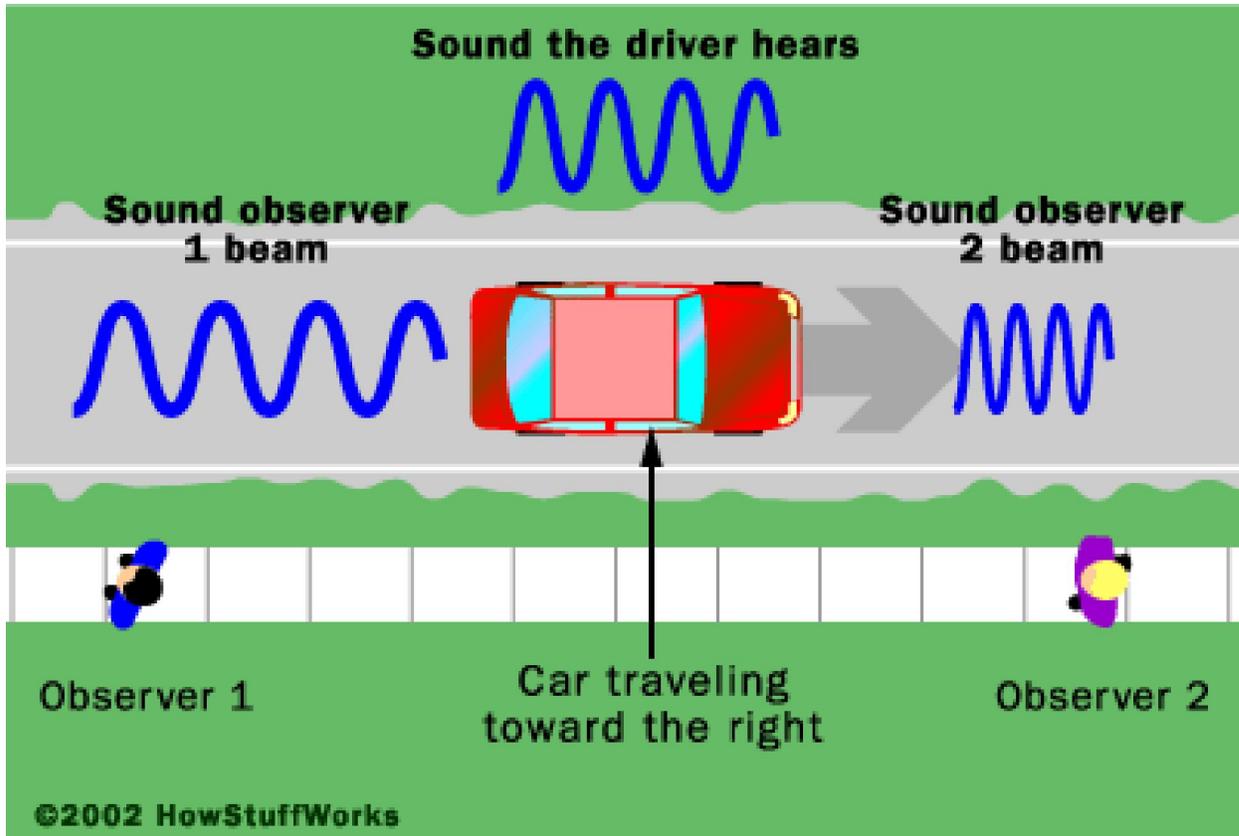
Echo is something you experience all the time. If you shout into a well or a canyon, the echo comes back a moment later. The echo occurs because some of the sound waves in your shout reflect off of a surface (either the water at the bottom of the well or the canyon wall on the far side) and travel back to your ears. The length of time between the moment you shout and the moment that you hear the echo is determined by the distance between you and the surface that creates the echo.

Doppler shift is also common. You probably experience it daily (often without realizing it). Doppler shift occurs when sound is generated by, or reflected off of, a moving object. Doppler shift in the extreme creates sonic booms (see below). Here's how to understand Doppler shift (you may also want to try this experiment in an empty parking lot). Let's say there is a car coming toward you at 60 miles per hour (mph) and its horn is blaring. You will hear the horn playing one "note" as the car approaches, but when the car passes you the sound of the horn will suddenly shift to a lower note. It's the same horn making the same sound the whole time. The change you hear is caused by Doppler shift.

Here's what happens. The speed of sound through the air in the parking lot is fixed. For simplicity of calculation, let's say it's 600 mph (the exact speed is determined by the air's pressure, temperature and humidity). Imagine that the car is standing still, it is exactly 1 mile away from you and it toots its horn for exactly one minute. The sound waves from the horn will propagate from the car toward you at a rate of 600 mph. What you will hear is a six-second delay (while the sound travels 1 mile at 600 mph) followed by exactly one minute's worth of sound.

Now let's say that the car is moving toward you at 60 mph. It starts from a mile away and toots its horn for exactly one minute. You will still hear the six-second delay. However, the sound will only play for 54 seconds. That's because the car will be right next to you after one minute, and the sound at the end of the minute gets to you instantaneously. The car (from the driver's perspective) is still blaring its horn for one minute. Because the car is moving, however, the minute's worth of sound gets packed into 54 seconds from your perspective. The same number of sound

waves are packed into a smaller amount of time. Therefore, their frequency is increased, and the horn's tone sounds higher to you. As the car passes you and moves away, the process is reversed and the sound expands to fill more time. Therefore, the tone is lower



Doppler shift: The person behind the car hears a lower tone than the driver because the car is moving away. The person in front of the car hears a higher tone than the driver because the car is approaching.

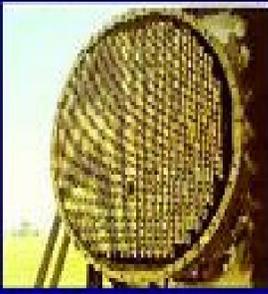
. You can combine echo and Doppler shift in the following way. Say you send out a loud sound toward a car moving toward you. Some of the sound waves will bounce off the car (an echo). Because the car is moving toward you, however, the sound waves will be compressed. Therefore, the sound of the echo will have a higher pitch than the original sound you sent. If you measure the pitch of the echo, you can determine how fast the car is going.

## **PHASED ARRAY RADAR SYSTEMS**

The systems that are addressed here are systems in which Northrop Grumman Electronic Systems (ES) have been involved. Northrop Grumman ES, headquartered in Baltimore, Maryland USA, is a world leader in the design, development and manufacture of defense electronics and systems, precision weapons, airspace management systems, space systems, marine systems, and automation and information systems. Since World War II Northrop Grumman has delivered over 50,000 airborne radars, and is currently providing airborne radars on 21 aircraft types in 26 Nations. Northrop Grumman ES has been designing and perfecting airborne radar systems for over 60 years, however the heritage of the phased array radar and particularly, Active Electronically Scanned Array (AESA) is relatively short. In fact, our first passive phased array radar was constructed in 1974 and the first active phased array was built just 17 years ago in 1985. This breakthrough in technology allowed for the demonstration of the concept of steering beams generated by distributed transmit and receive modules. Our 2nd generation AESA was the first to fly just three years later. This 2nd generation AESA was the first AESA to proceed to the Engineering and Manufacturing Development phase. Our 3rd generation AESA met the high performance requirements in clutter, which mechanical or passive electronically scanned arrays are unable to meet. With the high performance standard set, we focused on reducing cost and weight. This led to our 4th generation AESA that is half the cost and weight of the 3rd generation AESA. The 4th generation AESA design requirements were the result of merging requirements for airborne, sea based, and land based platforms. Due to the nature of the changing defense environment dictating commonality across the services and our own limited research and development funds, drives one to the practical decision of seeking common solutions. This 4th generation AESA and its associated T/R modules achieve the design commonality while satisfying unique airborne, sea borne and ground based platform requirements with high performance to meet the mission needs.

The first generation airborne surveillance radar array was the Airborne Warning And control System (AWACS) Brass board radar antenna system. This antenna employed passive phased shifters on each of 28 sticks of the antenna, which were used to electronically scan the antenna to obtain height measurement and stabilize the beam to compensate for aircraft roll and pitch.

**Electronically Scanned Array (ESA) Timeline:**

1st Generation	2nd Generation	3rd Generation	4th Generation
			
Ultra Reliable Radar 1985	Advanced Tactical Fighter 1989	F-22 1991	Multi-Function Array 1998



*5<sup>th</sup> Generation AESA 2002 for F-35*

Northrop Grumman ES is a world-leading producer of active aperture antennas. Figure above shows the evolution of our fire control radar active aperture development programs beginning with the 1<sup>st</sup> generation active aperture antenna in 1985 and covering up to our 5<sup>th</sup> generation multi-function array in 1998. The 4<sup>th</sup> generation active aperture (F-22) antenna is completing an EMD development phase and moving towards production. The 5<sup>th</sup> generation active aperture antenna has completed initial development and is being leveraged into emerging development programs such as JSF.

Current development efforts are focused on the 5<sup>th</sup> generation antenna development. Architectures are being investigated for the sixth generation active aperture as well, and key technologies are being identified and developed. Key programs included in the roadmap include the development of a Ka-band tile and the Reconfigurable Array (RECAP). The Ka-band development effort has strategic Significance to ES in the areas of radar as well as SATCOM.

### *Airborne Surveillance Radar Active Aperture Development Stages*

- 1970 – First ultra low side lobe phased array developed
- 1974 – First development stages of EAR
- 1977 – EAR Flight-tested
- 1985 – URR First active aperture (1<sup>st</sup> Generation)
- 1988 – First to fly (2<sup>nd</sup> Generation)
- 1989 – ATF Concept Definition Phase for F-22
- 1991 – Awarded F-22 Contract
- 1995 – First to E&MD (3<sup>rd</sup> Generation)
- 1997 – Range tested APG-77 (4<sup>th</sup> Generation)
- 1998 – Launched 4<sup>th</sup> Generation AESA
- 1972 – Phased array AWACS Brassboard radar system flight tested
- 1974 – Full Scale Development of AWACS
- 1982 – Development of JSTARS radar system (Norden Systems)
- 1989 – First ultra low sidelobe active phased array developed (AST/AR)
- 1994 – Flight test of Advanced Airborne Surveillance Testbed Radar (MCARM)
- 1998 – Prototypes of Multirole Electronically Scanned Array Radar/IFF
- 2000 – Award of 737 AEW&C MESA Radar Contract
- 2002 – First Full Scale MESA Radar/IFF Antenna

## Phased Array Radars

The key to improving radar capability lay in electronic steering of the radar beam a technique that first began to be employed in ground based anti missile radars in the 1970s. Such radars employ a group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions. Such radars are referred to as phased array radars, since they employ an array of antennas that work using a shift in the signal phase.

By the early 1980s the technology had been mastered to an extent where it could be employed in airborne radars. Electronic steering and shaping of a beam provides unprecedented beam agility - beam shape and direction can be digitally controlled by a computer within a matter of tens of milliseconds. Such beam agility makes it possible for one phased array radar to act as multiple radars each with its own beam shape and scan pattern! This is referred to as interleaving radar modes. The same radar can be tracking for airborne threats using one beam shape and scan pattern while searching for ground targets using another beam shape and scan pattern.

The Russian NIIP N-011M Bars radar fitted on the Su-30MKI and the NIIP Bars-29 radar proposed to be fitted on the MiG-29M2 being offered to the IAF are examples of phased array radars. The B-1B Bone has flown since the 1980s with an AN/APQ-164 radar, fitted with an electronically steered array. The B-1A Batwing also exploits this technology in its AN/APQ-181 multimode attack radar

Phased array radars also referred to as passive array radars, represent a big leap forwards. Using beam steering they provide stealth, interleaving modes and reliability. However, the shift in phase of the radar signal comes at a cost. High-power phase control leads to losses in the signal and a consequent reduction in radar sensitivity. Typical total losses in early systems resulted in a factor of 10 reductions in radiated power; in modern systems these losses are still in the factor of 5 ranges.

## **AESA**

An Active Electronically Steered Array (AESA) takes the concept of using an array antenna a step further. Instead of shifting the phase of signals from a single high power transmitter AESA employs a grid of hundreds of small "transmitter-receiver (TR)" modules that are linked together by high-speed processors.

Each TR module has its own transmitter, receiver, processing power, and a small spikelike radiator antenna on top. The TR module can be programmed to act as a transmitter, receiver, or radar. The TR modules in the AESA system can all work together to create a powerful radar, but they can do different tasks in parallel, with some operating together as a radar warning receiver, others operating together as a jammer, and the rest operating as a radar. TR modules can be reassigned to any role, with output power or receiver sensitivity of any one of the "subsystems" defined by such temporary associations proportional to the number of modules.

AESA provides 10-30 times more net radar capability plus significant advantages in the areas of range resolution, countermeasure resistance and flexibility. In addition, it supports high reliability / low maintenance goals, which translate into lower lifecycle costs. Since the power supplies, final power amplification and input receive amplification, are distributed, MTBF is significantly higher, 10-100 times, than that of a passive ESA or mechanical array. This results in higher system readiness and significant savings in terms of life cycle cost of a weapon system, especially a fighter.

The use of multiple TR modules also means failure of up to 10% of the TR modules in an AESA will not cause the loss of the antenna function, but merely degrade its performance. From a reliability and support perspective, this graceful degradation effect is invaluable. A radar which has lost several TR modules can continue to be operated until scheduled downtime is organized to swap the antenna.

## Technological Leap

AESA technology has not been easy to acquire. It has come from years of research and heavy investments. Improvement of gallium arsenide material and the development of monolithic microwave integrated circuit (MMIC) have been key enablers to the development of AESA technology.



*Northrop Grumman AN/APG-81 and AN/APG-79 AESA radar*

Two prominent early programs in X-band AESA technology development have been the Army family-of-radars program (which provided the basis for the X-band AESAs in the THAAD and GBR radars for theater and national missile defense systems, respectively), and the Air Force programs to produce X-band AESAs for the F-15 and the F-22. The investments in JSF radar technology have also fostered pivotal advances in reducing cost, weight, and mechanical complexity. JSF transmit/receive (T/R) modules are referred to as "fourth generation" T/R module technology.

As can be expected, the technology comes at a cost. Each TR module is independent radar. Initial cost of a TR module was reportedly around \$2000. Fighter radars are usually in the 1000 to 2000 modules size range. In other words just the radar antenna could cost as much as \$4 million

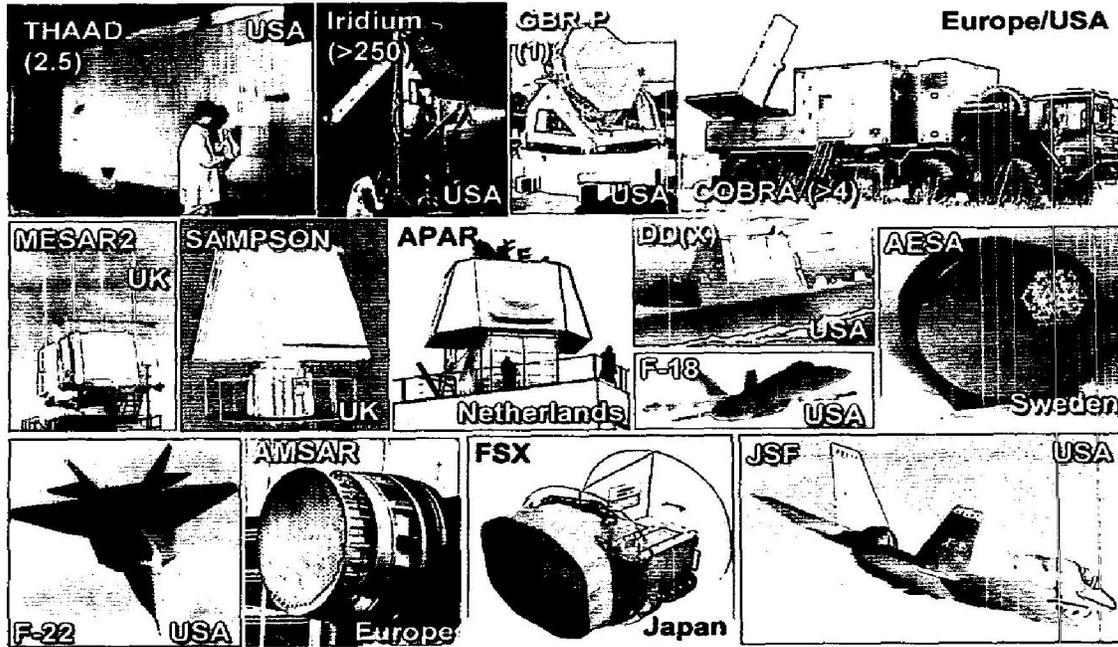


Figure 4 – Example MMIC Active Arrays Deployed and Under Development

TABLE 1 – EXAMPLE RADAR PHASED ARRAYS HAVING LARGE PRODUCTIONS

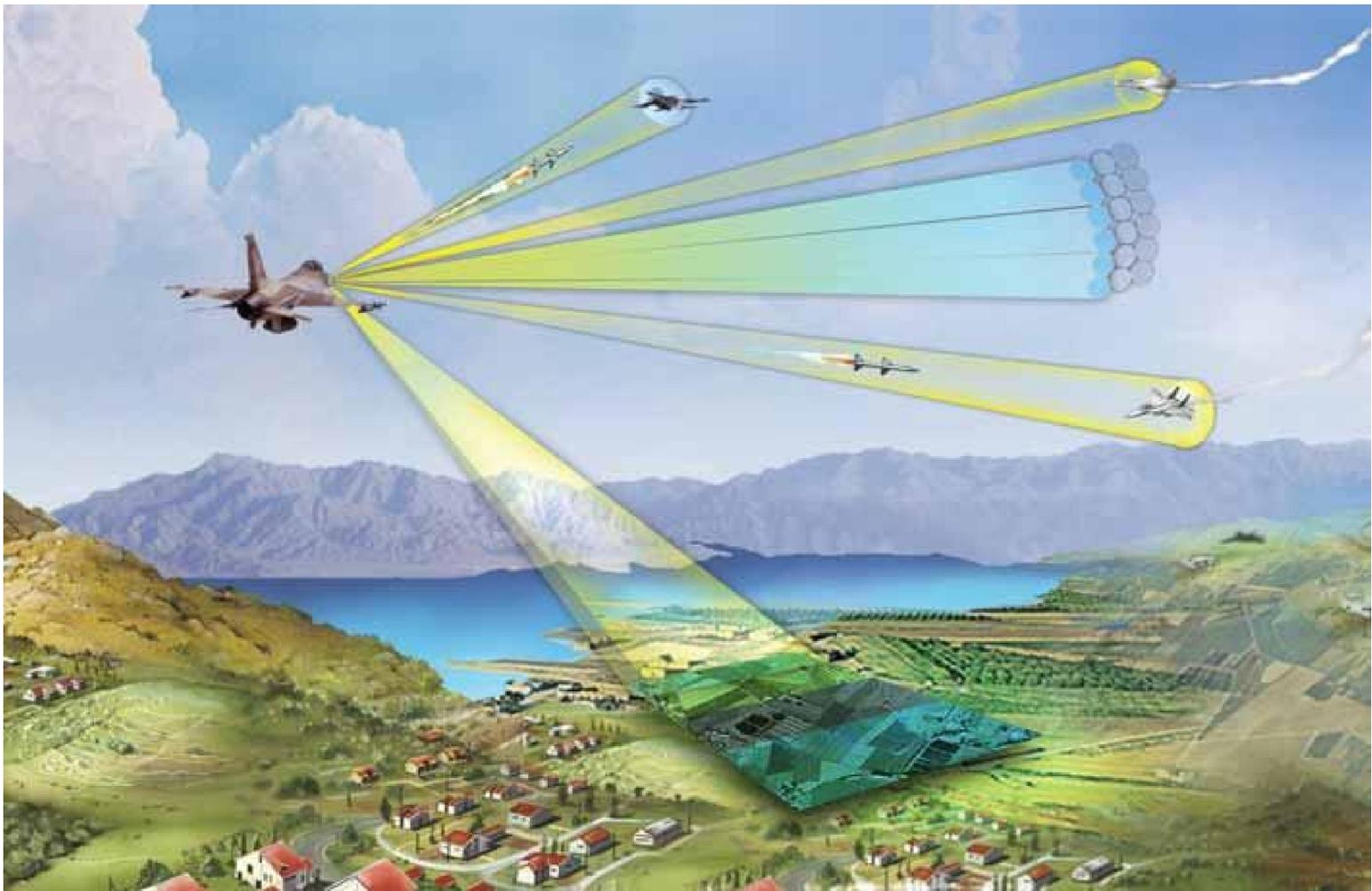
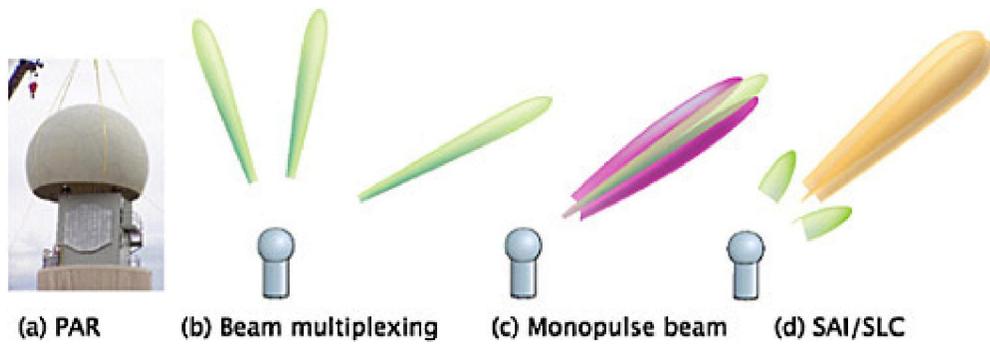
System	Frequency Band	Number Mfg'd	Number of Phase Shifters Per Array	Total No. of Elements Manufactured	Manufacturer
AN/TPN-25	X	18	824	14,850	Raytheon
AN/GPN-22	X	60	443	26,580	Raytheon
COBRA DANE	L	1	15,360 (34,769 Els.)	15,360 (34,769 Els.)	Raytheon
PAVE PAWS	UHF	4	1,792/face (2,677 Els.)	14,336 (21,416 Els.)	Raytheon
BMEWS UPGRADE	UHF	2	2,560/face (3,584 Els./Face)	12,800 (17,920 Els.)	Raytheon
COBRA JUDY	-	1	12,288	12,288	Raytheon
PATRIOT	C	173	5,000	1,730,000	Raytheon
AEGIS (SPY-1)	S	234	4,000	936,000	Lockheed-Martin
B-1	X	100	1,526	152,600	Northrop Grumman
AN/TPQ-37	S	102	359	36,618	Raytheon
AN/TPQ-36	X	243			Raytheon
FLAP LID	X	>100(?)	10,000	>2 million (?)	Russia

## Working of AESA

A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference. The main beam always points in the direction of the increasing phase shift. If the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is  $120^\circ$  ( $60^\circ$  left and  $60^\circ$  right).

In contrast to the usual scanning “dish” antenna illuminated from a single feed point, a phased array antenna uses electronic control of the signal phase at individual array elements to produce constructive interference in the desired beam-pointing direction. Consequently, no mechanical motion, with the associated inertial effects, is necessary; this allows arbitrary steering of the radar beam on a pulse-to-pulse basis, which is typically at intervals of order 0.001 s. The beam can be steered at this rate to any direction in a typical angular range of  $\pm 45$  degrees. This flexible beam steering is in stark contrast to mechanically scanned radars, which must scan in a systematic and angularly continuous pattern to minimize stress on pedestals, motors, gears, and other associated mechanical components.

Phased array radars have been used by the military for aircraft surveillance and tracking for some three decades. Fig shows a prototype phased array radar for weather observations - the National Weather Radar Test bed (NWRT) located in Norman, Oklahoma (Zrnic et al., 2007; Forsyth et al., 2008). This S-band radar uses a passive phased array antenna (one in which the signals sent to individual elements originate from a single transmitter) from the AN/SPY1-A radar of the Navy’s Aegis system. Other parts of Fig illustrate several important capabilities of phased array radars which are briefly discussed below.



*Tracking capability of AESA Radar*

Peak power and range performance claimed to be competitive against the publicly disclosed figures of F-22A's APG-77. NIIP claim a detection range for a closing 3 square meter co-altitude target of 190 - 215 NMI (350-400 km), and the ability to detect a closing 0.01 square metre target at ~50 NMI (90 km). In Track While Scan (TWS) mode the radar can handle 30 targets simultaneously, and provide guidance for two simultaneous shots using a semi-active missile like the R-27 series, or eight simultaneous shots using an active missile like the RVV-AE/R-77 or ramjet RVV-AE-PD/R-77M. The Irbis-E was clearly designed to support the ramjet RVV-AE-PD/R-77M missile in BVR combat against reduced signature Western fighters like the Block II Super Hornet or Euro-fighter Typhoon. Curiously, NIIP do not claim superiority over the F-22A's APG-77 AESA, yet their cited performance figures exceed the public (and no doubt heavily sanitized) range figures for the APG-77. Agile Beam Radar Enhances Situational Awareness

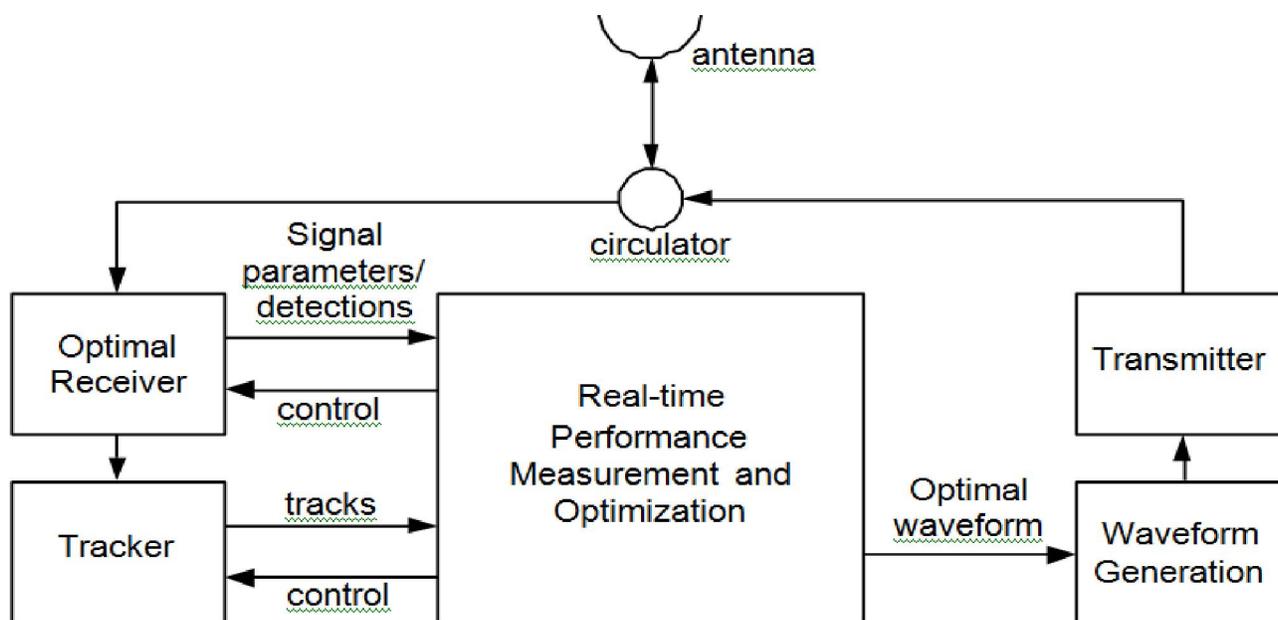


Figure 1 Block diagram of the basic concept of adaptive-transmit radar. (See the text for discussion of the block functions).

The heart of the system is the real-time performance measurement and optimization block. Having chosen some initial transmit waveform, the detection and tracking performance are evaluated using a *performance metric*. An optimization procedure is run to select or create the next transmit waveform, which is produced by the waveform generator. At the same time, the Processing in the receiver and tracker is adapted to optimally process the new transmit signal.

The process continues in an iterative manner. The waveform may be changed on a pulse-by-pulse basis, or between blocks of pulses. One of the key design issues is the choice of the performance metric to be used in the optimization process.

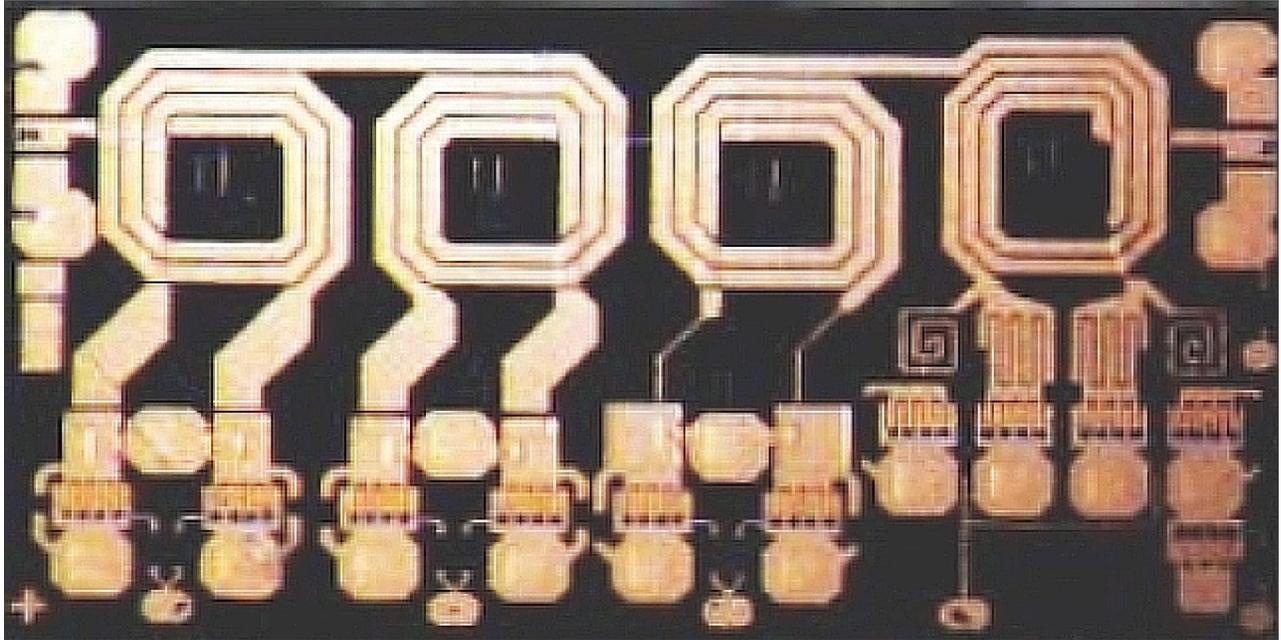
## **Agile Beam Radar Enhances Situational Awareness**

As the world's most advanced tactical radar, the AN/APG-79 makes fighter aircraft more lethal and less vulnerable than ever before. Featuring active electronic beam steering — which allows the radar beam to be repositioned nearly instantaneously — the APG-79 enables image resolution, and targeting and tracking ranges, significantly greater than the radar it replaces. With these enhanced capabilities, aircrews can now detect and identify targets beyond the reach of most missiles. The APG-79's long standoff range also allows more time for persistent target observation, information sharing, and assessment by commanders before critical decisions are made. The result: greatly increased aircraft and aircrew effectiveness and survivability.

## Powerful New Functions Increase Flexibility

An advanced four-channel receiver/exciter gives the APG-79 wide bandwidth capability and the ability to generate a broad spectrum of waveforms for air-to-air, air-to-ground and electronic warfare missions. The APG-79 radar can track significantly more targets than current radar systems and can operate in multiple air-to-air and air to-ground modes simultaneously. In response to mission requirements, its built-in resource manager automatically schedules tasks to optimize radar functions and minimize aircrew workload. Open Systems Architecture Improves Affordability and Performance With its open systems architecture, incorporating ruggedized commercial off-the-shelf (COTS) components and weapon replaceable assemblies (WRAs), the APG-79 demonstrates a significant increase in reliability over its predecessors. It also offers greater affordability over the life of the radar. The ultrathin, light antenna (the array weighs only 95 pounds) has an extremely low failure rate, with no maintenance predicted for 10 to 20 years. In addition, the modular design of the WRAs makes hardware/software module repairs faster, easier, and less expensive. The design permits built-in testing, software isolation, and easy upgrades, resulting in significantly reduced total ownership costs. Network-Centric Capabilities and Future Enhancements the APG-79's flexibility and versatility make it an important addition to the modern military's networked battle space. Built with secure, interoperable technology, this leading edge radar enhances the sharing of information with manned, unmanned, and ground-based systems for close cooperation on the battlefield. It offers the F/A-18E/F the capability to perform as an essential node in the air and ground global information network. Currently deployed on the F/A-18E/F, the APG-79 offers revolutionary technology and scalability that can be adapted to other platforms. Raytheon and the U.S. Navy continue to develop enhanced sensor features through sensor fusion and sensor integration that leverage the inherent capabilities of the APG-79

## ESA KEY ENABLING TECHNOLOGY AND OPERATIONAL BENEFITS



*GaAs 4-bit phase shifter MMIC die*

The key enabling technology for AESA is the Transmit/Receive Module the T/R modules provide the main functionality Power amplification Phase shifting Amplitude setting Low noise amplification. The key challenges were the improvement of the GaAs material and the development of GaAs monolithic microwave integrated circuit (MMIC) technology. MMIC technology uses lithographic-type processes to produce

Microwave circuits on chips at very high levels of integration. A modern X-Band T/R module contains 4-7 MMICs produced in a foundry and later integrated into a substrate with a few of discrete components. Packaging technology was also a subject of concern. A modern T/R module is shown in Fig. 2. Typical T/R modules provide a peak power of appr. 10 Watt and appr. 1-3 Watts average power. A bandwidth of 30% + is achievable. Due to the fact that most of the AESA radar applications require several thousands of T/R modules per array leads to the strong requirement of low cost T/R modules.

Current X-Band T/R modules of the 10 Watt class are still in the cost range of 1000-3000 \$. A significant cost reduction is still required to establish this new antenna generation more rapidly in advanced systems. In addition to the features which are common to both passive and active – AESA radar systems provide outstanding capabilities within the operational context:

## Ship borne Active Electronically Scanned Array Radar



*APAR (Active Phased Array Radar) manufactured by Thales Nederland*

**APAR (Active Phased Array Radar)** is a ship borne multi-function radar (MFR) developed and manufactured by Thales Nederland. It is the first naval Active Electronically Scanned Array MFR to be used on an operational warship.

APAR is typically paired with Thales Nederland's SMART-L radar (which operates at L band frequencies). SMART-L is a long-range Volume Search Radar (VSR) that is able to provide volume search and tracking out to 400 km. The whole system is called Anti-Air Warfare Systems (AAWS), and is based on the NATO Anti-Air Warfare (NAAWS) concept of the late 1980s. The principle behind this concept is that an X band MFR coupled with an L band VSR provides the optimal combination of complimentary capabilities: the VSR is optimized for long range detection and tracking of targets, while the MFR is optimized for medium range high accuracy tracking of targets, as well as horizon search and missile guidance functions.

As discussed below, some have questioned the optimality of separate MFR/VSR installations on-board ship. However, the wisdom of NATO's concept is evident to this author:

BAE Systems have also claimed that Sampson eliminates the need for several separate systems. They suggest that on the Type 45 destroyer, the Alenia Marconi Systems/Signal [now Thales Nederland] S 1850M long-range 3D radar that is designed to work in partnership with Sampson "really is superfluous and is not needed to perform the mission of the ship". BAE Systems believes that the reason the large volume search radar has been incorporated in to PAAMS is "more of a historic nature, associated with [the] work sharing issues" that were a huge problem during the trilateral Project Horizon.

Some tasks are difficult to combine, for example (long range) volume search takes a lot of radar resources, leaving little room for other tasks such as targeting. Combining volume search with other tasks also results either in slow search rates or in low overall quality per task. Driving parameters in radar performance is time-on-target or observation time per beam. This is perhaps a the [sic] key reason why the Royal Navy selected the S1850M Long Range Radar to complement Sampson on the Type 45 destroyers. It is also a reason why NATO in its NATO Anti-Air Warfare System study (NAAWS) defined the preferred AAW system as consisting of a complementary Volume Search Radar and MFR. This - as NATO points out - gives the added advantage that the two systems can use two different radar frequencies; one being a good choice for long range search, the other a good choice for an MFR (which is especially nice as physics makes both tasks difficult to combine).

## Advantages

In addition to the advantages offered by PESAs, notably the lack of mechanical steering and the ability to form multiple beams, AESAs add many capabilities of their own. Among these are the ability to use some of the TRMs for "other purposes", like radar detection, and more importantly, the difficulties that AESAs cause for radar detectors.

### *Low Probability of Intercept*

Radar systems work by sending out a signal and then listening for its echo off distant objects. Each of these paths, to and from the target, is subject to the inverse square law of propagation. That means that a radar's received energy drops with the fourth power of distance, which is why radar systems require high powers, often in the megawatt range, in order to be effective at long range.

The radar signal being sent out is a simple radio signal, and can be received with a simple radio receiver. It is common to use such a receiver in the targets, normally aircraft, to detect radar broadcasts. Unlike the radar unit, which has to send the pulse out and then receive its reflection, the target's receiver does not need the reflection and thus the signal drops off only as the square of distance. This means that the receiver is always at an advantage over the radar in terms of range - it will always be able to detect the signal long before the radar can see the target's echo. Since the position of the radar is extremely useful information in an attack on that platform, this means that radars generally have to be turned off for lengthy periods if they are subject to attack; this is common on ships, for instance.

Turning that received signal into a useful display is the purpose of the "radar warning receiver" (RWR). Unlike the radar, which knows which direction it is sending its signal, the receiver simply gets a pulse of energy and has to interpret it. Since the radio spectrum is filled with noise, the receiver's signal is integrated over a short period of time, making periodic sources like a radar add up and stand out over the random background. Typically RWRs store the detected pulses for a short period of time, and compare their broadcast frequency and pulse repetition frequency against a database of known radars. The rough direction can be calculated using a rotating antenna, or similar

passive array, and combined with symbology indicating the likely purpose of the radar - airborne early warning, surface to air missile, etc.

This technique is much less useful against AESA radars. Since the AESA can change its frequency with every pulse, and generally does so using a pseudo-random sequence, integrating over time does not help pull the signal out of the background noise. Nor does the AESA have any sort of fixed pulse repetition frequency, which can also be varied and thus hide any periodic brightening across the entire spectrum. Traditional RWRs are essentially useless against AESA radars.

### ***High jamming resistance***

Jamming is likewise much more difficult against an AESA. Traditionally, jammers have operated by determining the operating frequency of the radar and then broadcasting a signal on it to confuse the receiver as to which is the "real" pulse and which is the jammer's. This technique works as long as the radar system cannot easily change its operating frequency. When the transmitters were based on klystron tubes this was generally true, and radars, especially airborne ones, had only a few frequencies to choose among. A jammer could listen to those possible frequencies and select the one being used to jam.

Since an AESA changes its operating frequency with every pulse, and spreads the frequencies across a wide band even in a single pulse, jammers are much less effective. Although it is possible to send out broadband white noise against all the possible frequencies, this means the amount of energy being sent at any one frequency is much lower, reducing its effectiveness. Moreover, AESAs can be switched to a receive-only mode, and use the jamming signals as a powerful source to track its source, something that required a separate receiver in older platforms.

AESAs are so much more difficult to detect, and so much more useful in receiving signals from the targets, that they can broadcast continually and still have a very low chance of being detected. This allows the radar system to generate far more data than if it is being used only periodically, greatly improving overall system effectiveness.

### *Other advantages*

Since each element in a AESA is a powerful radio receiver, active arrays have many roles besides traditional radar. One use is to dedicate several of the elements to reception of common radar signals, eliminating the need for a separate radar warning receiver. The same basic concept can be used to provide traditional radio support, and with some elements also broadcasting, form a very high bandwidth data link. The F-35 uses this mechanism to send sensor data between aircraft in order to provide a synthetic picture of higher resolution and range than any one radar could generate.

AESAs are also much more reliable than either a PESA or older designs. Since each module operates independently of the others, single failures have little effect on the operation of the system as a whole. Additionally, the modules individually operate at low powers, perhaps 40 to 60 watts, so the need for a large high-voltage power supply is eliminated.

Replacing a mechanically scanned array with a fixed AESA mount (such as on the F/A-18E/F Super Hornet) can help reduce an aircraft's overall radar cross-section (RCS), but some designs (such as the Euro fighter Typhoon) forgo this advantage in order to add the limits of mechanically scanning to the limits of electronic scanning and provide a larger angle of coverage.

## Disadvantages

Cost is very high at the range of \$ 6 to 7 million apiece.

Due to large number of Transmit/Receive Module (T/R modules) the radar gets heated up very fast and a cooling mechanism is required.

Beams of different frequency range cannot be maintained for a long duration of time and hence the support of Airborne Early Warning, Command and Control (AEWC&C) system will be required for extended operation.

## Conclusion

With the evolution of radar from the ground based antenna of the World War II era which the British developed to the AESA the most advanced radar available. Major progress in radar technology development is making unprecedented contributions to aerospace platforms and national defense capability. Over the last decade, in the creation of active electronically scanned array (AESA) radars has enabled remarkable advances in fire control systems for fighter aircraft of the airforces across the world with the advent of the AESA Radars the fighter aircrafts can track and target the enemy aircraft from long distances well out of the missile ranges for example F22 can track a enemy fighter from a range of 400 km away and gives a edge to the radar jamming devices since it produces a radio beam of different frequency .

These radars can track a aircraft without the aircraft sensors knowing that they are being tracked. With the development of the Electronically scanned array radar the problem of the range and radar stealth is solved to certain extent and we shall expect more development on the range and the anti jamming field of the radar.

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