ABSTRACT

Adaptive active phased array radars are seen as the vehicle to address the current requirements for true ‘multifunction’ radars systems. Their ability to adapt to the environment and schedule their tasks in real time allows them to operate with performance levels well above those that can be achieved from the conventional radars. Their ability to make effective use of all the available RF power and to minimize RF losses also makes them a good candidate for future very long range radars.
INTRODUCTION

Over the years radar systems have been changing on account of the requirements caused by
a) Increase in the number of wanted and unwanted targets
b) reduction in target size either due to physical size reduction due to the adoption of stealth measures
c) the need to detect unwanted targets in even more severe levels of clutter and at longer ranges
d) the need to adapt to a greater number of and more sophisticated types of electronic counter measures

Radar designers addressed these needs by either designing radars to fulfill a specific role, or by providing user selectable roles within a single radar. This process culminated in the fully adaptive radar, which can automatically react to the operational environment to optimize performance.

Conventional radars fall into two categories independent of what functions they perform. The first category has fixed antenna with centralized transmitters which produces patterns by reflector or passive array antennas. The beaming being fixed, scanning can only be achieved by physically moving the antenna. Typically a surveillance radar will
produce a fan shaped beam with a fixed elevation illumination profile, the azimuth scanning being achieved by rotating the antenna. A tracking radar will have a pencil beam that is used to track targets by the use of a mechanical tracking mount. Because of the limitations imposed on such radars by their design such radars are "single-function radars".

The second category of radars is the passive phased array. These incorporate electronic beam scanning or beam shaping by the use of phase shifters, switching elements or frequency scanning methods. These features enable the radar designer to implement more complex systems having the
capability to carry out more than one radar functions. i.e. 'multi function radars'. Generally however, the functions of the radars are pre-programmed and not adaptable as the radar environment or the threat changes.

In order to improve the multifunction capability over that of a conventional phased array, in many cases the adaptive active phased array radar (AAPAR) is the only practical solution. In the AAPAR, transmitter/receiver modules are mounted at the antenna face and adaptive beam forming and radar management and control techniques are used.
BACKGROUND

TARGET SIZE

Radar echoing areas have become smaller through practical size reduction, modern materials and the introduction of stealth techniques. In parallel with this reduction in target size the effectiveness of weapons delivery systems has improved substantially. The range at which munitions can be released has increased. This compounded by the increased speed and lethality of the modern weapons has led to a commensurate increase in the range at which the targets need to be detected.

ENVIRONMENTAL CONSIDERATION

Along with changes in target characteristics there has also been a major change in the radar electromagnetic (EM) environment. This consist of natural elements- land, sea and whether clutters etc. and man made elements such as background interference, mutual interference from other systems and ECM. The effect of natural clutter on radar performance is well known and standard techniques of varying effectiveness have been developed for conventional radars to deal with these effects.
Over the years the design of ECM systems has become much more effective and radars have had to become more sophisticated in order to counter them. As in the case of natural clutter the methods used to defeat ECM have usually been provided as a series of predetermined functions. It has not proved possible to adapt the radar parameters quickly to cope with the changing ECM environment.

In the short term, conventional radar parameters cannot easily be adapted as the ECM threat changes throughout a mission. In the longer term the radar design needs to be constantly updated to cope with the change of types and number of ECM equipments.

**ADAPTIVE ACTIVE PHASED-ARRAY RADAR**

**ACTIVE ARRAYS**

A major reason for the large size and power requirements of a conventional phased array radar is the need to overcome the loss in their RF signal between the bulk transmitter and the antenna, and between the antenna and the receiver. Losses typically can be 7dB and in some compiled designs can reach as much as 10dB. Typically 95% of the prime power and 80% of the effective transmitter power is lost, with only 20% being used for detection.
Combining in space the power of many low power radiating modules, mounted on the antenna face as in the AAPAR, ensures that the power is radiated directly into space with minimum loss. If the same module are used for reception with a low noise amplifier (LNA) stage closed to the array face, then similar reduction in receiver losses are obtained. This gives active arrays a major benefits in pure detection performance. Prime power requirements are also greatly reduced, allowing the use of smaller generators in mobile systems and reducing power consumption costs in static systems.
ADAPTIVE RADAR FEATURES

The use of active modules provides the ability to control the radiation and receiver parameters of an active array radar in real time and to adapt these as the threat changes. Adaptive radar features are added to an active array to produce an AAPAR features that can be adapted include:

- digital beam forming
- waveform generation and selection
- beam management
- frequency selection
- task scheduling
- tracking

The increase in performance of an active array radar within the environment and its improved detection performance over conventional radars make the active array radar highly versatile and flexible in operation. It is now possible to design a radar to react to changes in the threat scenarios and to adapt its own parameters to optimize performance.
OPERATIONAL REQUIREMENTS

RADAR ROLES

The roles of the radar sensors in a typical air defense systems need to be specified in order to define what the AAPAR is required to do. A radar sensor as part of an air defense system may be required to perform a number of functions in order to generate and maintain target data and to assist in engagement of targets. The principal functions are:

- volume surveillance
- target detection and confirmation
- target tracking
- target identification by both co-operative and non co-operative methods
- target trajectory or impact point calculation
- tracking of ECM emissions
- kill assessment
- missile and other communications
VOLUME SURVEILLANCE

The AAPAR can provide a number of operating mode to tailor surveillance volumes to the system or mission requirements. Energy usage is optimized and the probability of target determination is maximized by the management of radar waveforms and beams. Volume surveillance can be managed in order to cope with varying threats - lower priority surveillance tasks can be traded for higher priority tasks such as short range surveillance or target tracking as the threat scenario changes.
DETECTION AND CONFIRMATION

A look back beam using the position data derived from the detection beam can immediately confirm each detection that is not associated with a target already in current track files this significantly reducing the track confirmation delay.

TARGET TRACKING

Separate tracking beams can be used to maintain target positions and velocity date. Targets with low maneuvering capability and those that are classified as friendly or neutral may be tracked using track-while-scanning techniques during normal surveillance.
TARGET IDENTIFICATION

Cooperative technique use an IFF (Identification: Friend or Foe) integrated system controlled by a radar. Depending on the role of the radar, integration of target is performed only when the demanded, or on a continuous 'Turn and Burn' basis. Selective integration is used to minimize transmission from the radar to reduce the probability of ESM (Electronic Surveillance Measures) intercepts and is merely always used when mode 4; the secure IFF mode, is being used.

Non-cooperative technique extract additional data from radar returns by extracting features and comparing them with information held on threat date bases. A correlation process is used that finds the best fit to the data. This method can provide good accuracy in recognizing a target from a class of targets, or a specific type of targets.

TARGET TRAJECTORY CALCULATION

Calculation of an impact point is one input to the threat assessment process and the radar can assist by adapting to a mode that fits the trajectory to a complex curve fitting law. This process is more effectively performed by the AAPAR since it can adapt its tracking priorities and parameters and form the date quickly to the required accuracy.
TRACKING OF ECM EMISSIONS

Receive-only beams can be formed with an active array, giving all the normal receive processes without the need for transmitted RF. Utilizing these beams, sources of in band radiation can be accurately tracked in two dimensions. The track data can be correlated with strobes from other sensors to enable the positions of the jamming sources to be determined and tracked in conditions in which the presence of jamming may prohibit the formation of tracks.

KILL ASSESSMENT

It is possible to use a radar sensor to give some information to the kill assessment process. The radar can only be used in two ways. Firstly, it can determine whether the trajectory or track vector has changed sufficiently to indicate that the threat has aborted its mission or been damaged sufficiently to loose control. Secondly, the radar can form a high resolution image of the target to determine if it has been fragmented.
MISSILE COMMUNICATION

In a system, where an interception is being performed by a surface-to-air missile, the multifunction radar is likely to be located in a position where it has good visibility of both the targets and the outgoing missile. In this system the ground-to-missile communication's link. Used to control the missile in its various stages of flight could be performed by the radar.
AAPAR DESIGN

SYSTEM DESIGN

To perform its multifunctional role the AAPAR is required to

- signal generation
- transmit
- receive
- beam forming
- signal processing
- tracking
- data extraction
- radar management
- power and cooling
These processes may appear similar to those in conventional radar; however the detailed implementation in a AAPAR is fundamentally different and provides the flexibility required for the radar to perform the multifunction role.

In principal the AAPAR is the same as the block diagram of conventional radar. However the radical difference in beam management means that the signal processing of an AAPAR is closed to that of tracking radar than that of surveillance radar. The other obvious difference is in the construction of the transmitter/antenna/receiver chain.

PERFORMANCE DRIVERS

The driver of an AAPAR is driven the same way as conventional radar by the type of targets it is required to detect and their ranges and properties. Because of the adaptive nature of the radar a much wider mix of target types can be accounted and the mix can be physical still apply and the radar needs enough time and power to accomplish a detection. The design of the AAPAR can be optimized to make the best use of the time and power available such that maximum performance can be achieved in any given target mix. The system can also be pre-programmed to priorities role and to 'turn off' functions as the target load increase in order to provide more time and power to the more critical functions.
The typical design drivers that have to be accommodated are:

- stealth i.e very low radar cross-section targets
- rapid reaction/uploads
- highly maneuverable
- multiple targets
- very low sea-skimming targets
- intense jamming
- sever clutter
- weight and prime power limitation
- mobility and transportability
CHOICE OF FREQUENCY

The choice of radar frequency is usually in the range 1-20GHz for medium range weapon systems. Clutter is a key performance limiter and trends to increase rapidly with radar frequency and consequently radar designers try to use as low as frequency as possible. The antenna aperture is chosen to provide the required beam width and is made as large as possible so as to give the maximum transmit EIRP(Effective Isotropically Radiated Power) and receive gain consistent with the largest practical physical size.

In an active array it is the EIRP that needs to be considered because the directivity and the total transmitted power are directly linked. The gain and the power radiated are a function of the number of antenna modules, which is directly related to antenna area and gain. The practical difficulties of cooling RF power modules and their inherent cost also increase nonlinearly with frequency.

Target size is tending to fall, in particular due to the use of stealth techniques. This requires even more transmitter power to achieve a signal return greater than the noise to ensure that the target can be detected. Given that, in practice, transmitter efficiency, and hence the power, tends to fall with increasing frequency and that stealth techniques are less effective at lower frequencies, the operating frequency is therefore chosen as low as possible consistent with physical size constraints.
A simplified method for choosing the frequency is as follows:

a) decide on the beamforming/ aperture required based on a compromise between tracking, surveillance and clutter
b) select the minimum number of elements to fill the aperture based on the beam scanning requirements.
c) select the lowest frequency based on the constraints on the aperture size required for the number of element.
d) select the lowest power module based on the required detection performance.

**OPERATING BANDWIDTH**

The operating bandwidth and the number of operational frequencies is a function of the roles specified for the radar. Potentially an AAPAR can have an overall bandwidth of upto 25% of the carrier frequencies and can operate with pulses to long expanded pulses with large amount of chirp or coding. The number of individual frequencies and their instantaneous band-widths can be chosen from within this overall band-width. Digital wave form in generation within the AAPAR allows it to use adaptive waveform and frequency selection.
ARRAY DESIGN

CHOICE OF ELEMENTS AND SPACING

The design of the array is a trade off between the EIRP require, the sidelobes and the scan volume required.

The scanning performance of the array is a function of the radiating element design and the element spacing. The elements need to be spaced such that when the beam is scanned to the maximum extend grating lobes are not generated.

A phenomenon, which needs to be assessed is that of blind angles. Blind angles are a function of the array spacing, lattice geometry and specific element design. At a blind angle the mutual coupling between elements results in the active reaction co-efficient of the array approaching unity, the gain falling to zero with no radiation taking place. At a blind angle all the transmitted power is reflected back into the active modules.

The design must be such that sufficient EIRP is available at the required scan angles. The gain at a given scan angle is a function of the broadside aperture gain and the radiation pattern of the arrays elements. This generally results in loss of gain that approximates to a $\cos^{1.5}$ or a $\cos^{2}$
The broadside gain of the array is the function of the array area and the amplitude tapers applied in order to reduce the side lobes. In a traditional array design the RF beam forming network applies the taper. In active arrays the transmit / receive active modules can be used as well if required, to add a taper. The modules can be operated in class A or transmit and /or fitted with controllable attenuators to apply a required taper. Power and efficiency considerations however, generally means that the power stages operate in class C and no amplitude taper is applied on transmit. For large arrays with high numbers of elements the possibilities exist to provide space weighing to shape the beam.

**TRANSMITTER RECEIVER MODULE**

This module contains the transmit power stages, low noise receive amplifiers and limiter, associated phase shifters, attenuators and circulators. Filtering must be provided to band limit emissions and to provide protection against out-of-band interference. Together with the microwave elements the module must also contain any control, communication and power conditioning electronics that are required. Generally modules are grouped into LRUs(Line Replaceable Units) containing a number of channels to optimize the use of silicon in the control electronics and the power conditioning components. The modules must be housed, powered and cooled. The array structure carries out these functions. The cooling of the modules are particularly critical. In order to
maintain the performance of the RF module they must be held within a required temp range. The design of the cooling system is seen as key to the performance of the array.

**SUB ARRAYS**

In order to carry out digital adaptive beam forming more than one receiver channel is required; in the limit, receiver channel could be provided for each receiver module. Practical considerations, however, normally limit the number of receiver channels to the low tens. In order to do this the transmit /receive modules must be grouped in to sub arrays by the use of traditional RF beam forming techniques.

**DIGITAL ADAPTIVE BEAM FORMING**

Each radiating element of the active array has its own low-noise amplifier(LNA). Small groups of co-located modules are combined in microwave networks to form subarrays. Each subarray is provided with a down-converter and a digitizer, which produces an accurate version of the amplitude and phase of the received signal.

The subarray elements can simply be summed to provide the normal 'un adapted' or quiescent antenna pattern, which would receive main beam target signals, with clutter and any noise jamming entering via side lobes. In the adaptive beamformer each subarray received signal is adjusted in amplitude and phase before summing to shape the radiation pattern.
The antenna pattern is modified so that nulls in the antenna side lobe pattern are 'driver' in to the direction of noise jammers. At the same time the main beam remains pointing at the target. Unlike some side lobe canceller systems, the beamformer does not use any feedback and the signals appear at the same time, as if the some arrays where summed together i.e the nulls are formed at the same time as the main beam.

The beamformer can provide more than one output by processing the input signal in different ways. In addition to the standard sum output, a monopulse and a side lobe blanking beam can be provided. The monopulse output may be needed to provide a 2-dimensional measurement of the angle effect of a target or own missile track from the bore sight. This permits the absolute angular position to be output from the radar based on the known mechanical antenna position and the measured electrical bore sight.
SEMINAR REPORT  ADAPTIVE ACTIVE PHASED ARRAY RADAR

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The adaptation of AAPAR is not limited to the antenna beam patterns. The time management and waveforms of the radar must also be adapted to suit the radar's various role. This requires that the signal generated be capable of generating pulses of varying lengths, pulse repititions intervals (PRIs), compression ratios and coding.

AAPARs which derive low peak power, relatively high duty pulses from solid-state modules, use long pulses. This requires digital pulse compression and expansion techniques coupled with digital frequency synthesis under the control of the radar's management system. Digital synthesis must be employed to achieve the very high stability need to achieve the required clutter filtering and target Doppler filtering. The requirements to carry out target identification puts further demands on the stability and coherence of the signal source.

Signal processing is a generic term used to describe the filtering and extraction of data from radar signals. In common with the trends in conventional radars, AAPAR signal processing is increasing carried out in software. The sequences in which these process are performed are, however much more complex because the radar performs multiple functions and can
perform these in a random manner. The signal processing function must be configure to accept signals in 'batches' that require specified processing depending on the role or task that the signals represent. The radar management software has the task of controlling the processing to suit the current batch.

The processing carried out on each batch is familiar:

- moving target filtering
- Doppler filtering
- integration
- background averaging
- plot extraction
- track extraction
ADAPTIVE PHASED ARRAY RADAR SIGNAL PROCESSING USING PHOTOREFRACTIVE CRYSTALS

This report covers the development, test and evaluation of an adaptive phased array optical processor. This system is designed to optimally process the wide band signals from large phased array antennas in real time, achieving a computational throughput approaching $10^{15}$ multiplies per second, demonstrating the potential of optical-based architectures to surpass performance achievable with conventional technology. The processor uses a three-dimensional volume hologram to create and store adaptive weights to simultaneously perform beam steering and jammer-nulling functions.

The adaptive processor consists of two sub-sections, the main beam steering processor and the jammer-nulling processor. The nature of the architecture is that the number of processor components used is independent of the number of elements in the phased array. The report contains extensive treatment of models and analytical expressions developed to relate system parameters and to predict expected system behavior and performance of the experimental signal processors. A variety of jammer scenarios are described and analyzed. Experimental results obtained in a working hardware configuration of the processor are shown to verify the theoretical models.
The models guided the development and evolution of the experimental optical hardware system with increasingly improved performance. By improving component stability, electronic gain, and feedback loop isolation, 45 dB jammer cancellation was demonstrated in the experimental system. Also described are results of main beam formation experiments that did not require a priori knowledge of the angle-of-arrival of the desired signal. In addition, results from simultaneous operation of both the nulling processor and the main beam processor are presented. The report contains extensive references and bibliography of the twenty technical papers published in con

RADAR MANAGEMENT

The degree to which the beams are required to be overlapped depends on the detection requirements. The number of transmit pulses required at each pulse position is the function of the detection requirement and the required false alarm rate. These in turn are functions of the instrumented range, the size of the target to be detected and/or tracked, requirements for clutter filtering, etc.

The radar management system is designed to control and optimize the radar process to perform these tasks at the correct time. When peak loading causes short-term problems with radar recourses, the manager is designed to act on task priorities, rescheduling task to maximize the value
of the radar data to the defense system and making optimum use of the defense system product.

The radar management function has to co-ordinate the process of signal generation, beam pointing, dwell, transmission, reception, signal processing and data extraction to ensure that the correct parameters are applied through each process to carry out the task demanded.
SUMMARY

The AAPAR can provide many benefit in meeting the performance that will be required by tomorrow’s radar systems. In some cases it will be the only possible solution. It provides the radar system designer with an almost infinite range of possibilities. This flexibility, however, needs to be treated with caution: the complexity of the system must not be allowed to grow such that it becomes uncontrolled and unstable. The AAPAR breaks down the conventional walls between the traditional systems elements- antenna, transmitter, receiver etc-such that the AAPAR design must be treated holistically.

Strict requirements on the integrity of the system must be enforced. Rigorous techniques must be used to ensure that the overall flow down of requirements from top level is achieved and that testability of the requirements can be demonstrated under both quiescent and adaptive condition.
CHALLENGES

Though it is quite evident the benefit that would be achieved from a national MPAR network, there remains a number of technical, operational, and cost issues that would need to be addressed before MPAR can become a reality. The foremost challenge lies in demonstrating that the individual functionality required by both the weather and surveillance communities can be obtained from a single multifunctional environment. There are also challenges related to dual polarization and the ability to satisfy cross-polarization isolation requirements. Determining a means of accurate and repeatable calibration of the radar also remains a challenge to be addressed. Yet another challenge is with digital beamforming, specifically the tradeoffs associated with the overall MPAR architectural complexity versus capability. Additional obstacles to overcome include the challenge of cost. Given the limited funding accessible to civilian government agencies, MPAR cost targets must fall within a practical range while still satisfying its operational requirements.

A final challenge is that of the program management of a multi-agency procurement. However, the success of the NEXRAD program that used a senior program council format, shows this to be a valid approach to a multi-agency program. While there are a great many risks and challenges
ahead, the payoff would be significant. The National Research Council (NRC) has acknowledged this statement by recommending that “the MPAR Research and Development (R&D) program be continued with the objective of evaluating the degree to which a deployable MPAR system can satisfy the national weather and air surveillance needs cost effectively.”
CONCLUSION

Adaptive active phased array radars are seen as the vehicle to address the current requirements for true ‘multifunction’ radars systems. Their ability to adapt to the environment and schedule their tasks in real time allows them to operate with performance levels well above those that can be achieved from the conventional radars. Their ability to make effective use of all the available RF power and to minimize RF losses also makes them a good candidate for future very long range radars.
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