Phased Array Radar

Advanced Mobile Robotics

Conventional Detection Platforms

- RADAR
- SONAR
- LIDAR

Conventional Detection Limitations

- High Cost
- Limited Resolution
- Limited Scanning Frequency
- Unwanted Interference
- Mechanical Failure

What is a Phased Array Antenna?

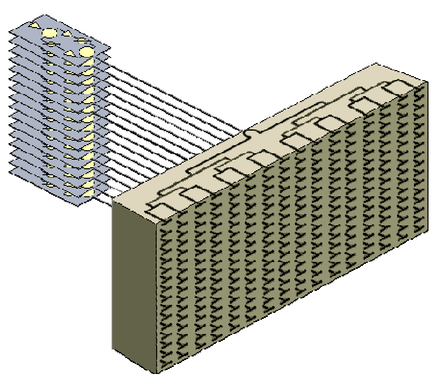
- In wave theory, a phased array is a group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is <u>reinforced</u> in a desired direction and <u>suppressed</u> in undesired directions.

Passive vs. Active

- PESA: In a passive electronically scanned array (PESA), the microwave feed network in the back of the antenna is powered by a single RF source (magnetron, klystron, TWT, etc.), sending its waves into phase shift modules (usually digitally-controlled), which, in turn, feed the numerous emitting elements
- AESA: An AESA, instead, has an individual RF source for each of its many transmit/receive elements, making them "active."
- This provides for a graceful degradation, so that many T/R modules may fail and the radar would not stop functioning.

Antenna Concept

- An **antenna array** is a plurality of active antennas coupled to a common source or load to produce a directive radiation pattern
- Usually the spatial relationship also contributes to the directivity of the antenna
- Use of the term "active antennas" is intended to describe elements whose energy output is modified due to the presence of a source of energy in the individual element



AESA Advantages

- Short to instantaneous (millisecond) scanning rates
- Much higher range
- Multiple agile beams: tremendous number of targets being tracked
- Desirable low probability of intercept.
- Solid state devices with vastly simpler mechanical designs
- No complex hydraulics for antenna movement nor hinge appendages that are prone to failure
- Occupies less space than typical radar
- Distributed transmit function eliminates most common single-point failure seen in a conventional radar
- Low maintenance, much more reliable.
- Ability to function as a radio/jammer
- High electronic counter-measure (ECM) resistance
- Less susceptible to voltage failures: very low voltage in individual elements

Did you Know?

- Phased arrays are required to be used by many AM broadcast stations to enhance signal coverage in the city of license, while minimizing interference to other areas.
- Due to the differences between daytime and nighttime ionospheric propagation, it is common for AM broadcast stations to change between day and night radiation patterns by switching the phase and power levels supplied to the individual antenna elements daily at sunrise and sunset.

Naval Uses

- Phased array radars allow a warship to use one radar system for surface detection and tracking (finding ships), air detection and tracking (finding aircraft and missiles) and missile uplink capabilities.
- Prior to using these systems, each surface-to-air missile in flight required a dedicated fire-control radar, which meant that ships could only engage a small number of simultaneous targets.

Performance

- A phased array may be used to point a fixed radiation pattern, or to scan rapidly in azimuth or elevation.
- Because the radar beam is electronically steered, phased array systems can direct radar beams fast enough to maintain a fire control quality track on many targets simultaneously while also controlling several in-flight missiles.
- The AN/SPY-1 phased array radar, part of the Aegis combat system, is able to perform search, track and missile guidance functions simultaneously with a capability of over 100 targets.

Theory

- A phased array is an example of N-slit diffraction
- It may also be viewed as the coherent addition of N line sources.
- Since each individual antenna acts as a slit, emitting radio waves, their diffraction pattern can be calculated by adding the phase shift φ to the fringing term.

Mathematics

$$\psi = \psi_0 \left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right] \left[\frac{\sin\left(\frac{N}{2}kd\sin\theta\right)}{\sin\left(\frac{kd}{2}\sin\theta\right)}\right]$$

$$\psi = \psi_0 \left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right] \left[\frac{\sin\left(\frac{N}{2}(\frac{2\pi d}{\lambda}\sin\theta+\phi)\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta+\phi\right)}\right]$$

$$I = I_0\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin[\theta]}\right]^2 \left[\frac{\sin\left(\frac{N}{2}(\frac{2\pi d}{\lambda}\sin\theta+\phi)\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta+\phi\right)}\right]^2$$

$$I = I_0\left[\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta}\right]^2 \left[\frac{\sin\left(\frac{\pi}{\lambda}Nd\sin\theta+\frac{N}{2}\phi\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta+\phi\right)}\right]^2$$

$$I = I_0\left[\frac{\sin\left(\frac{\pi}{\lambda}a\theta\right)}{\frac{\pi}{\lambda}a\theta}\right]^2 \left[\frac{\sin\left(\frac{\pi}{4}N\sin\theta+\frac{N}{2}\phi\right)}{\sin\left(\frac{\pi}{4}\sin\theta+\phi\right)}\right]^2$$

$$\frac{\pi}{4}N\sin\theta + \frac{N}{2}\phi = \frac{\pi}{2}$$

$$\sin\theta = \left(\frac{\pi}{2} - \frac{N}{2}\phi\right)\frac{4}{N\pi}$$

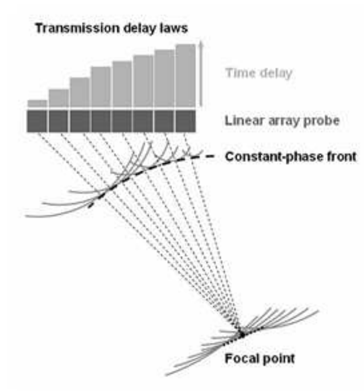
$$\sin\theta = \frac{2}{N} - \frac{2\phi}{\pi}$$

$$\theta = \sin^{-1}(1) = \tfrac{\pi}{2} = 90^\circ$$

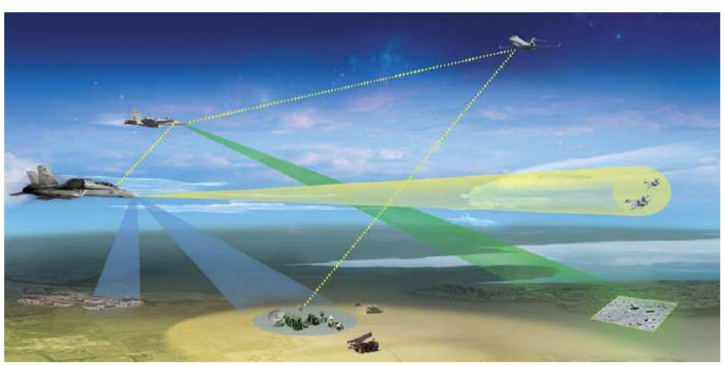
Additionally, we can see that if we wish to adjust the angle at which the maximum energy is emitted, we need only to adjust the phase shift φ between successive antennae. Indeed the phase shift corresponds to the negative angle of maximum signal.

AN/SPY-1 Features

- Agile beam forming (permits
- thousands of beam positions
- per second)
- Interleaved radar modes, including
- air-to-air and air-to-ground
- Multiple radar modes, including:
- – Real beam mapping
- – **Synthetic aperture radar**
- – Air-to-air search
- – Air-to-air track
- – Sea surface search
- – Ground moving target
- indication/track



AN/SPY-1 in Action



Synthetic Aperture Radar

- Synthetic aperture radar (SAR) is a form of radar in which sophisticated post-processing of radar data is used to produce a very narrow effective beam. It has seen wide applications in remote sensing and mapping.
- Radar waves have a polarization. Different materials reflect radar waves with different intensities, but anisotropic materials such as grass often reflect different polarizations with different intensities.
- If two observations of the same terrain from very similar positions are available, aperture synthesis can be performed to provide the resolution performance which would be given by a RADAR system with dimensions equal to the separation of the two measurements. This technique is called **Interferometric SAR** or **InSAR**.
- One can extract terrain altitude as well as radar reflectivity, producing a digital elevation model (DEM) with a single pass

Other Ground and Sea-based Systems

- APAR multi-function radar, primary sensor of Dutch De Zeven Provinciën and German Sachsen class frigates
- Elta EL/M-2080 *Green Pine* ground-based early warning AESA radar
- AN/SPY-3 multi-function radar for U.S. DD(X), CG(X) and CVN-21 next-generation surface vessels
- Raytheon U.S. National Missile Defense X-Band Radar (XBR)
- SAMPSON multi-function radar for UK. Type 45 destroyers
- MEADS's fire control radar
- THAAD system fire control radar

Thank You