Overview of Antennas for UAVs

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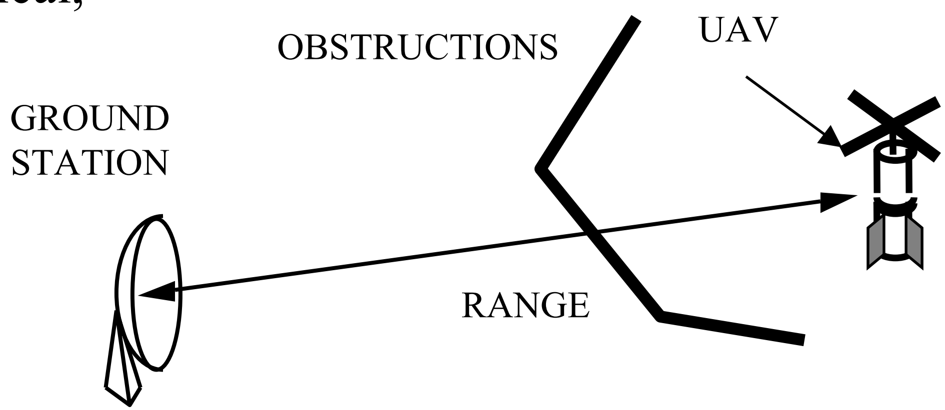
Antenna Systems for UAVs

- Antennas are required for a wide variety of UAV systems
- Antenna requirements depend on the specific platform and mission:
  - > Radar/Electronic Warfare
  - > Communications
  - > Data links
  - > GPS/geolocation
  - > Other sensors (biological, chemical, etc.)

- Ground station antennas not addressed here

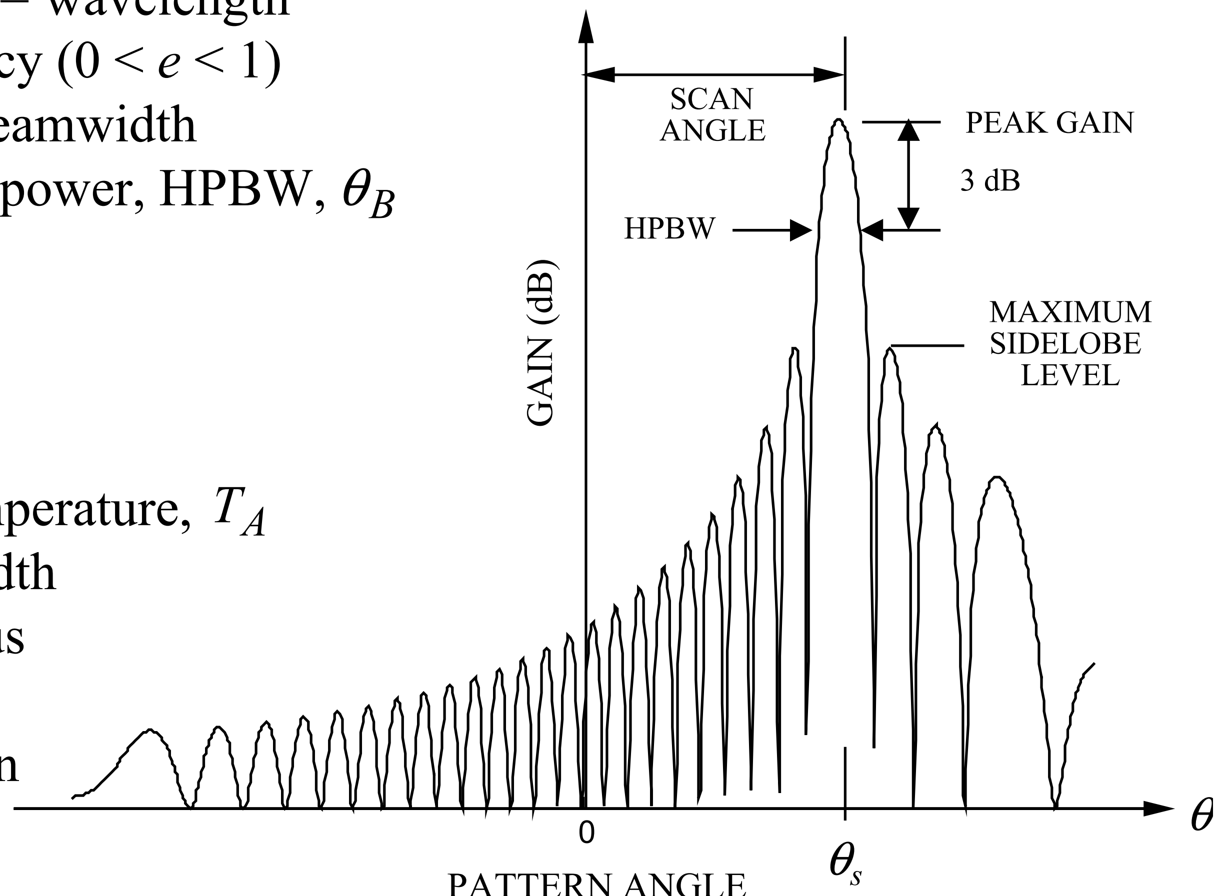


UAV Antenna Issues

- For airborne applications:
  - > Size, weight, power consumption
  - > Power handling
  - > Location on platform and required field of view (many systems compete for limited real estate)
  - > Many systems operating over a wide frequency spectrum
  - > Isolation and interference
  - > Reliability and maintainability
  - > Radomes (antenna enclosures or covers)
- Accommodate as many systems as possible to avoid operational restrictions
- Signatures must be controlled: radar cross section (RCS), infrared (IR), acoustic, and visible (camouflage)
- New architectures and technologies are being applied to UAVs

Antenna Performance Measures

- Gain, rule of thumb: $G = 4\pi Ae / \lambda^2$
  - > A = area, λ = wavelength
  - > e = efficiency ($0 < e < 1$)
- Field of view or beamwidth
  - > usually half power, HPBW, θ_B
- Polarization
- Sidelobe level
  - > maximum
  - > average
- Antenna noise temperature, T_A
- Operating bandwidth
  - > instantaneous
  - > tunable
- Radar cross section
  - > in band
  - > out of band



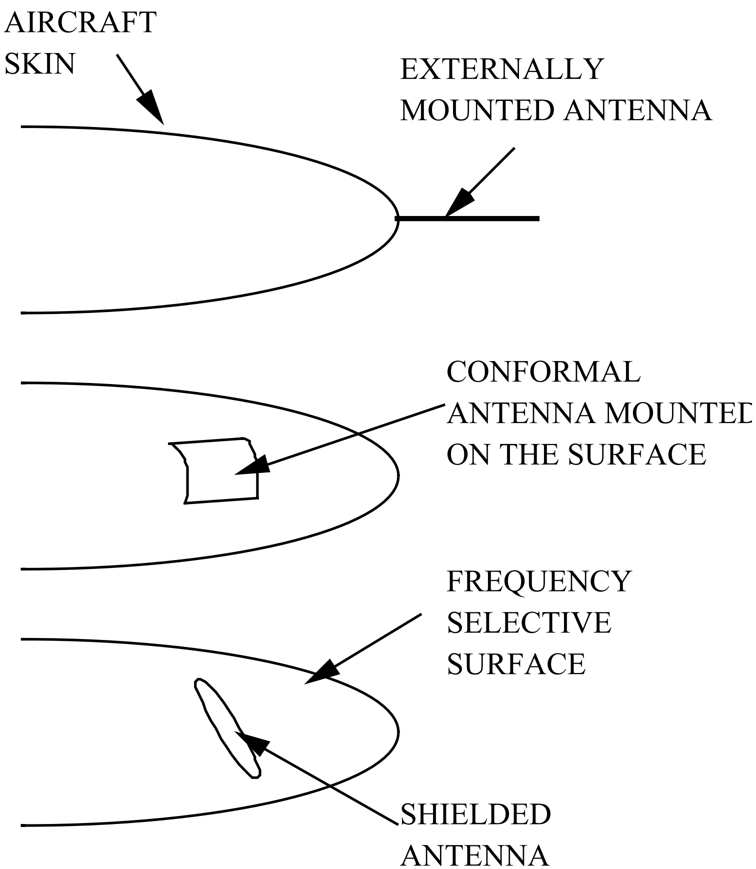
"New" Antenna Technologies for UAV Applications

- Some "new" concepts have been around since the 1960s, but have only recently become practical due to advances in computers and micro devices
- New technologies and architectures include:

> Solid state (active antennas)
> Conformal
> Smart antennas
("smart skins" or "living skins")
> Superconductivity
> Genetic algorithms
> Wide band (shared apertures)
> Frequency selective devices and surfaces
> New and exotic materials
> Adaptive
> Reconfigureable
> Multiple beams
> Photonics
> Digital beamforming
> Fractal antennas

Note: Most of these terms are not precisely defined and they are not mutually exclusive. An antenna can fall into multiple categories.

Antenna Installation Options



- The choice may limit operation of the system or degrade its performance
- Externally mounted
  - > structural/environmental stress
  - > if non-retractable, always in view
  - > if retracted, system unusable
- Conformal surface mounted
  - > aerodynamic (low profile)
  - > curvature complicates design and manufacture
- Radome enclosures
  - > controlled environment
  - > inefficient use of volume
  - > radome loss
  - > wider field of view (FOV)
  - > includes "pods"

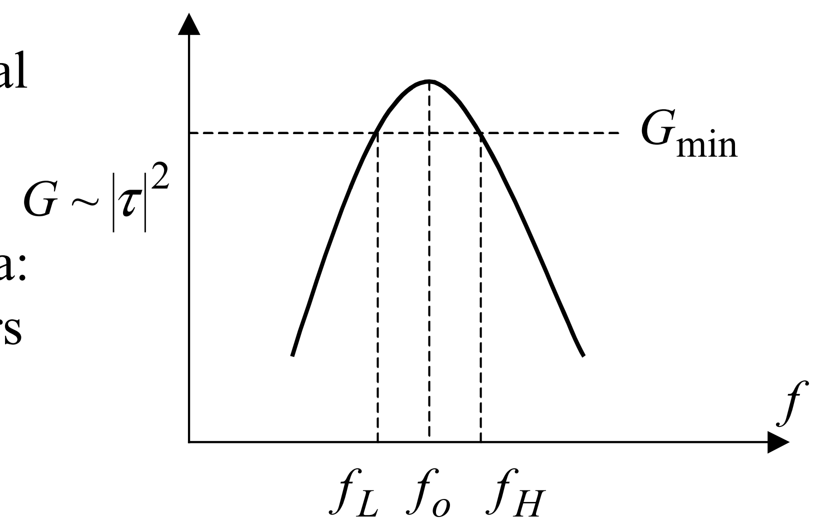
Motivation for Wide Bandwidth

- Bandwidth is the range of frequencies over which the antenna has "acceptable" performance
- Trend is toward wide band wave forms
  - > low probability of intercept
  - > frequency hopping
  - > multiple channels (i.e., orthogonal frequency division multiplexing)
  - > high resolution and data rates
- Shared aperture (multi-mission) antenna: a single antenna used for all EM sensors (radar, EW, comms, etc.)

Bandwidth, $B = f_H - f_L$

Center frequency, $f_o = (f_H + f_L)/2$

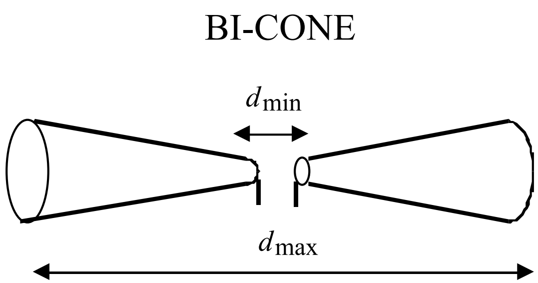
- Definitions (not standardized)
  - > narrow band: < 2%
  - > wide band: 2-10%
  - > ultra wide band: > 10%

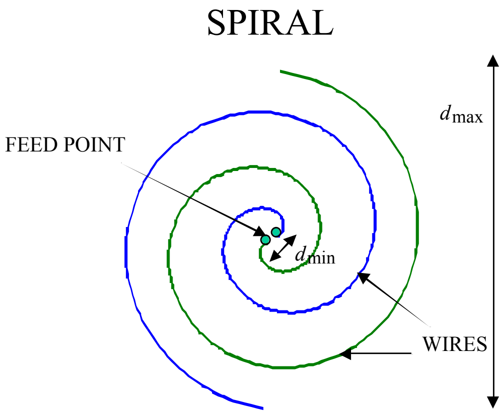


Wide Bandwidth Approaches

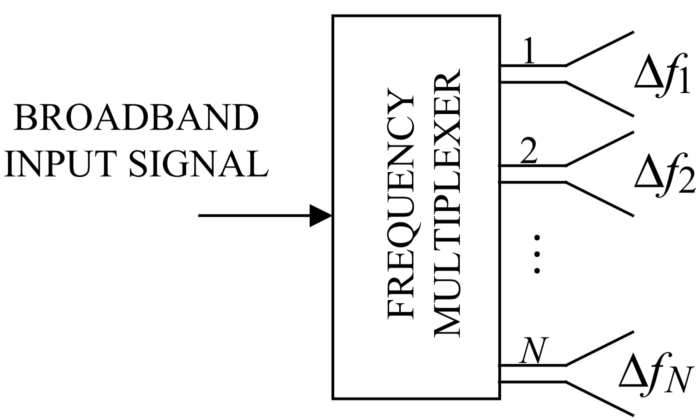
- Single radiating structure that operates over the entire frequency band

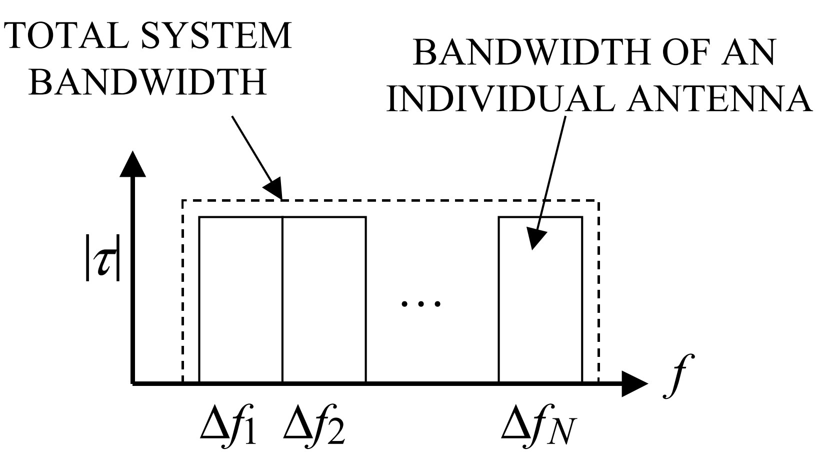
$$d_{\max} > \frac{\lambda}{2} > d_{\min}$$





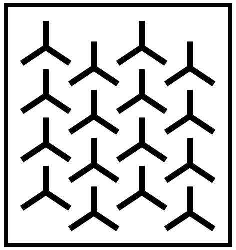
- Collection of nested or integrated narrow band antennas



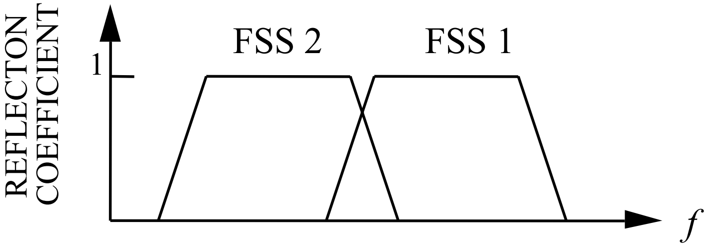


Frequency Selective Surfaces (FSS)

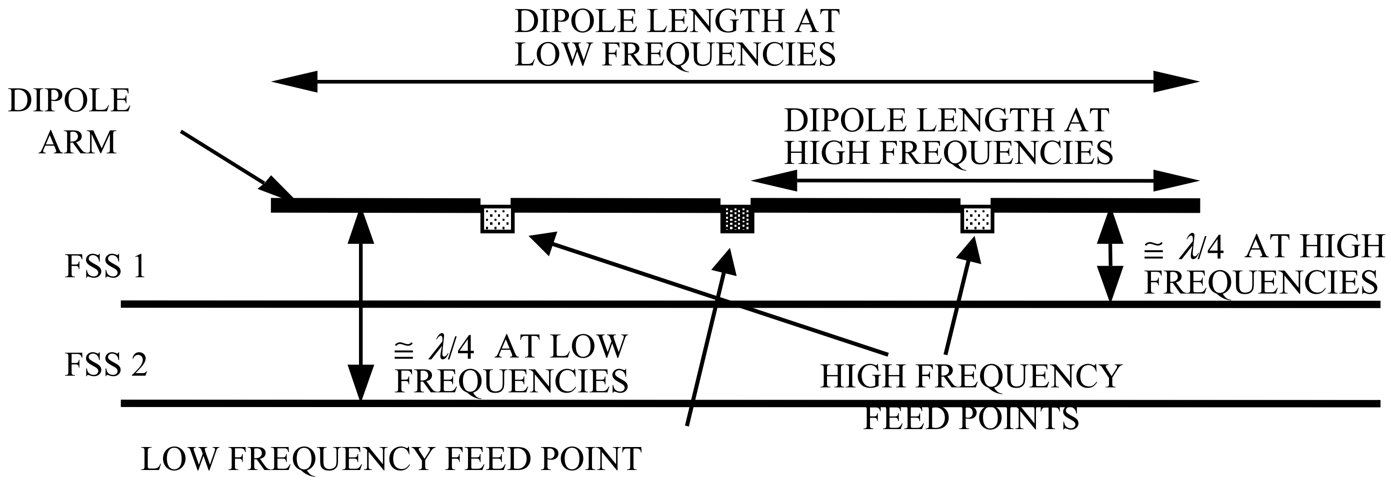
- Example of a FSS element (tripoles)



- Band-stop frequency characteristic

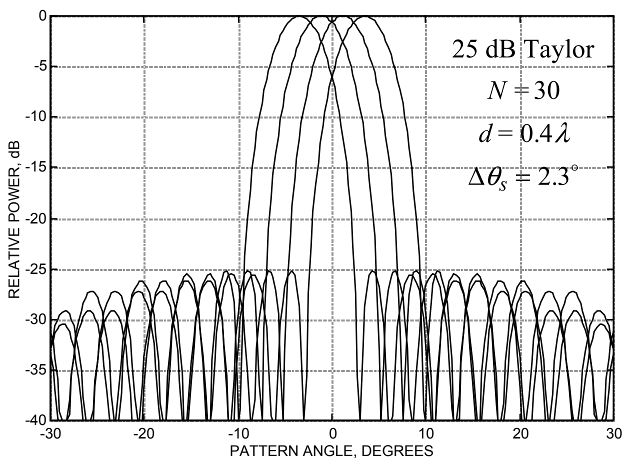


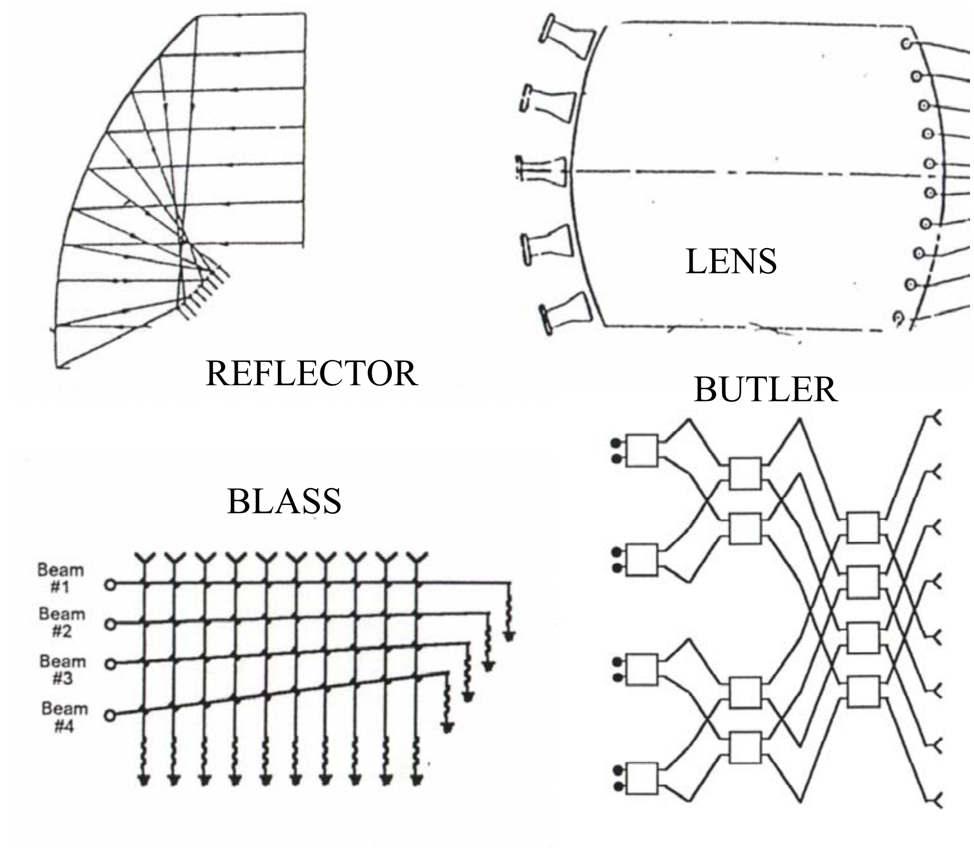
- Applications:
  > stealth -- shield antennas at high out of band frequencies
  > antennas -- reflector antennas; array ground planes (below)



Multiple Beams

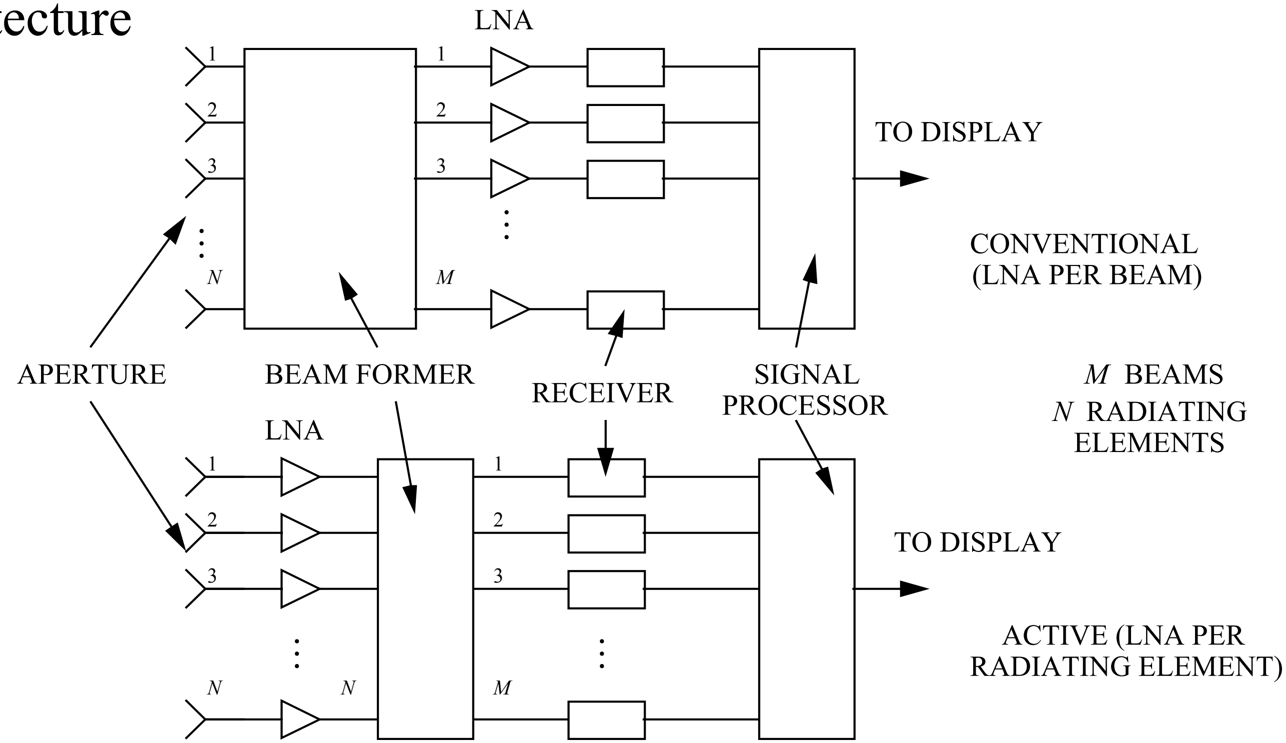
- Multiple beams share the same aperture (they exist simultaneously)
- Cover large spatial volumes quickly
- Receiver on each beam (increases the system bandwidth)
- Beam coupling losses
- Increased complexity





Active vs. Passive Antenna

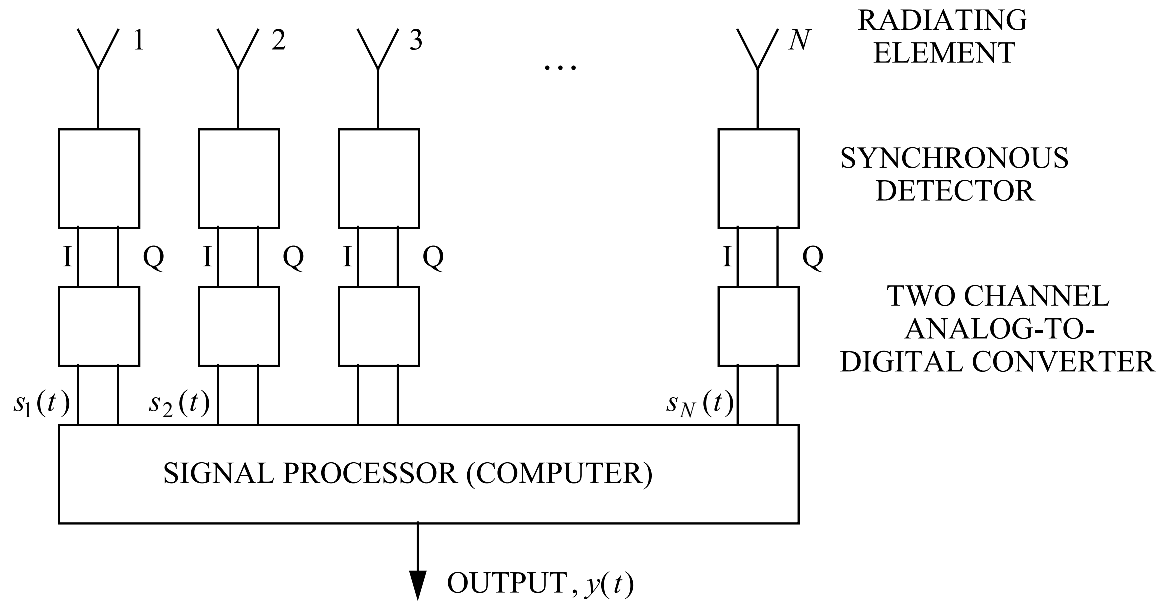
- Receive architecture



- Can be applied to transmit antennas using power amplifiers
- Transmit and receive channels are packaged together to form T/R modules

Digital Beamforming (DBF)

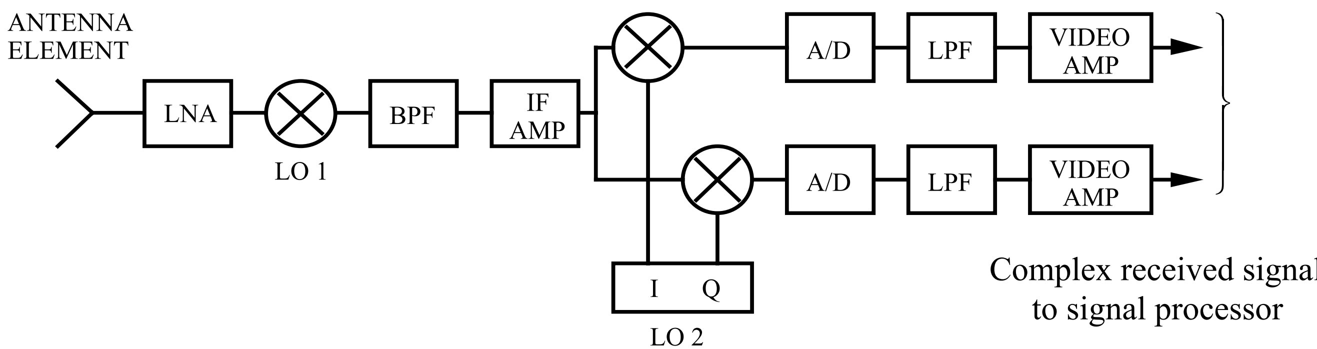
$$y(t) = \sum_{n=1}^{N} w_n s_n(t)$$



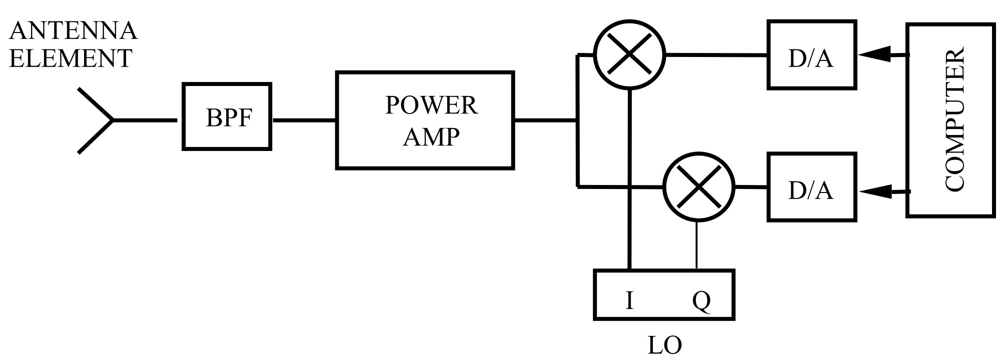
- The complex signal (*I* and *Q*, or equivalently, amplitude and phase) are measured and fed to the computer
- Element responses become array storage locations in the computer
- The weights are added and the sums computed to find the array response
- In principle any desired beam characteristic can be achieved, including multiple beams

Digital Beamforming (DBF)

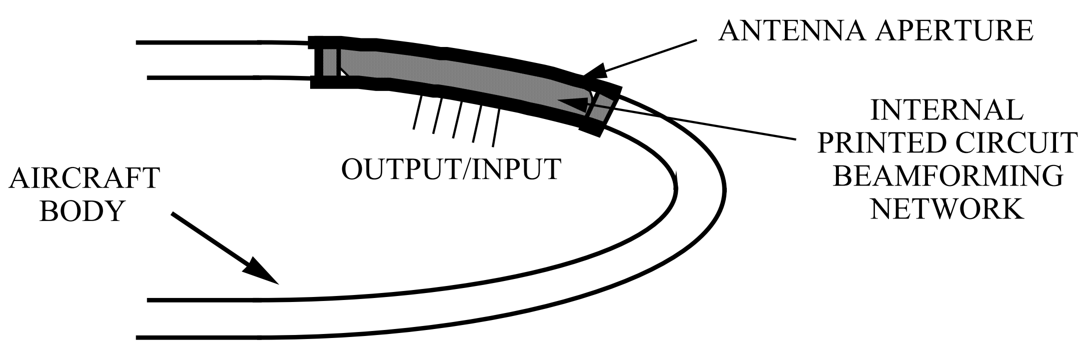
- Direct conversion to baseband is preferred, but high speed A/Ds are a problem
- Receive channel: (down conversion using two mixing stages)



- Transmit channel (up conversion using one mixing stage)



Conformal Antennas

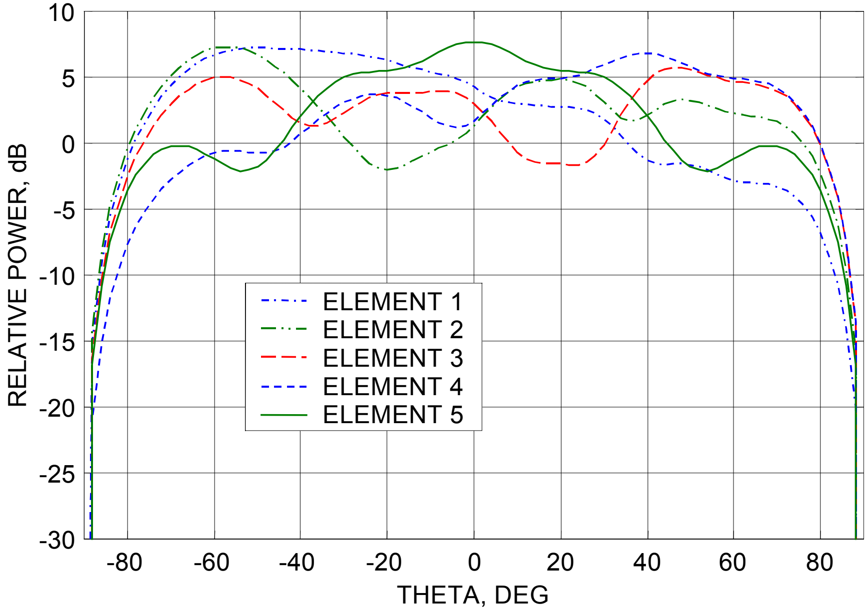


- Conformal antenna apertures conform to the shape of the platform
- Typically applied to composite surfaces; the antenna beamforming network and circuitry are interlaced with the platform structure and skin
- Can be active antennas with processing embedded (i.e., adaptive or "smart")
- Self-calibrating and fault isolation (errors and failures detected and compensated for or corrected)
- Can be re-configurable (portion of the aperture that is active can be changed)
- Infrared (IR) and other sensors can be integrated into the antenna

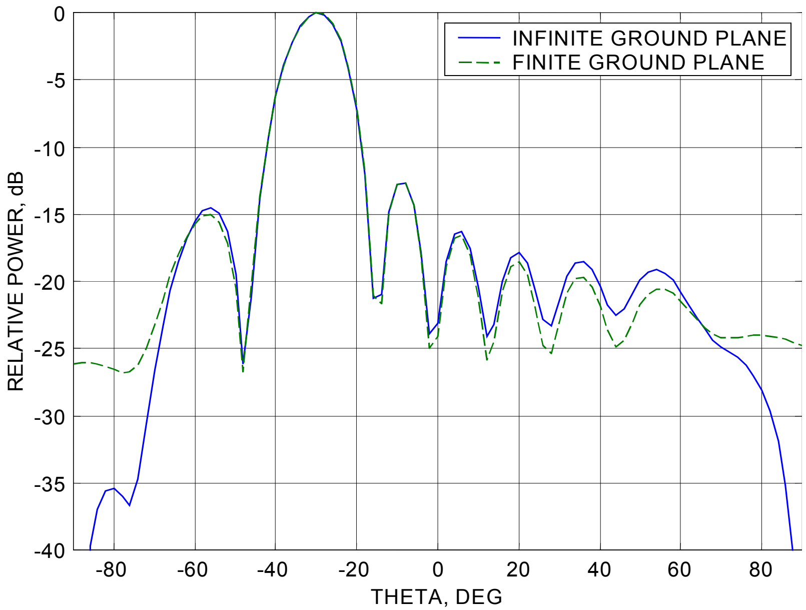
Mutual Coupling

- Elements in an array interact with each other (patterns of edge elements deviate from those in the center)
- Example: 10 element array (element 1 is at edge; element 5 at center)

Individual dipole element H-plane patterns (infinite ground plane)

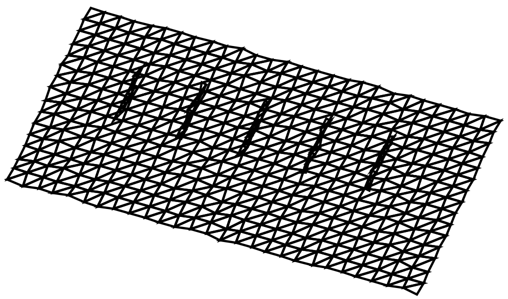


Infinite vs. finite ground plane



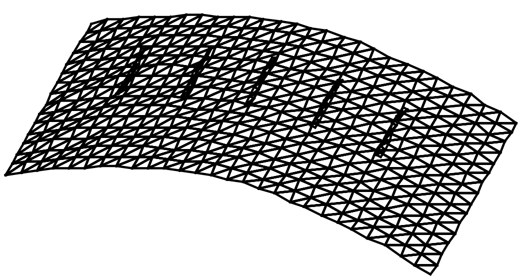
Conformal Shapes

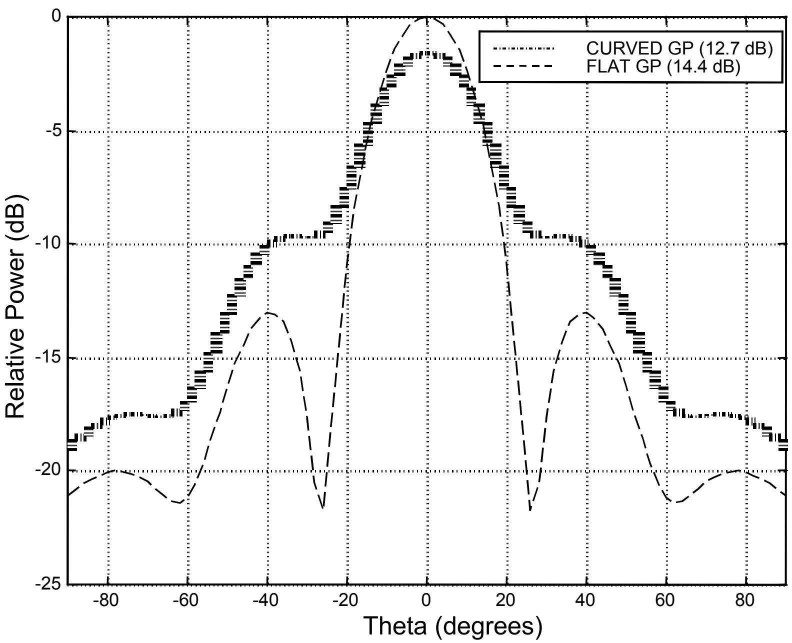
- Curvature must be considered in the design process, or pattern distortion occurs
- Example below: finite ground plane, mutual coupling included



FLAT GROUND PLANE

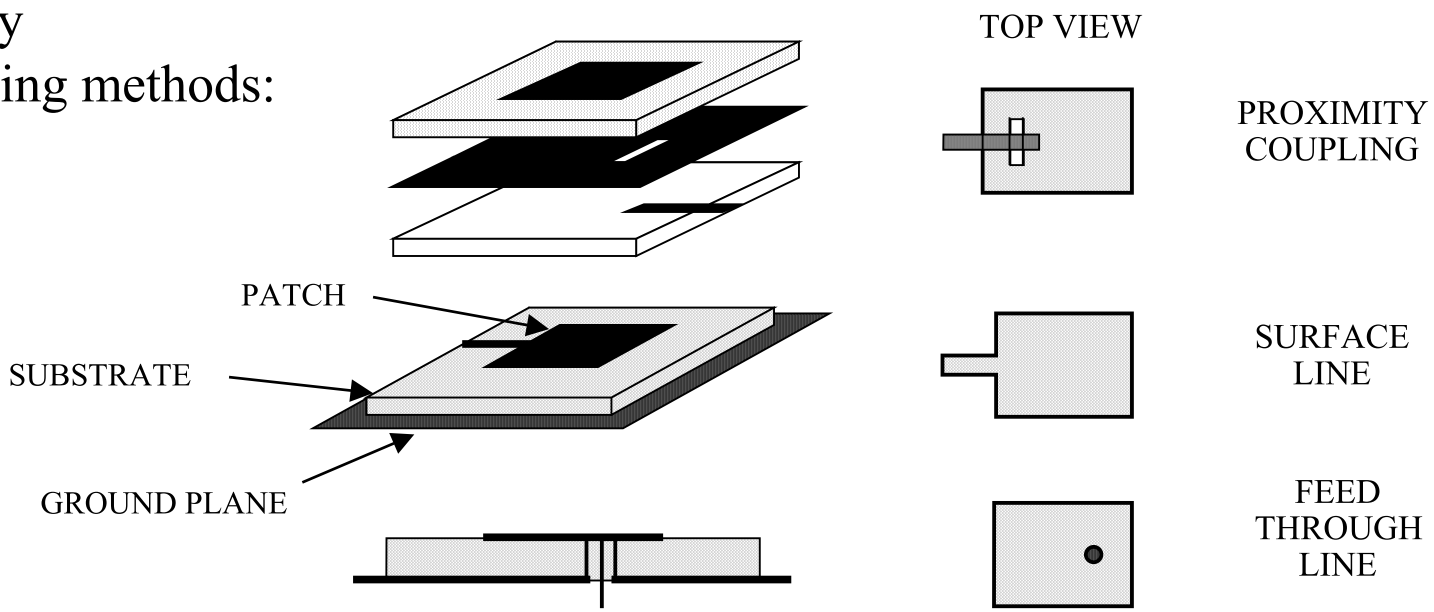
CURVED GROUND PLANE





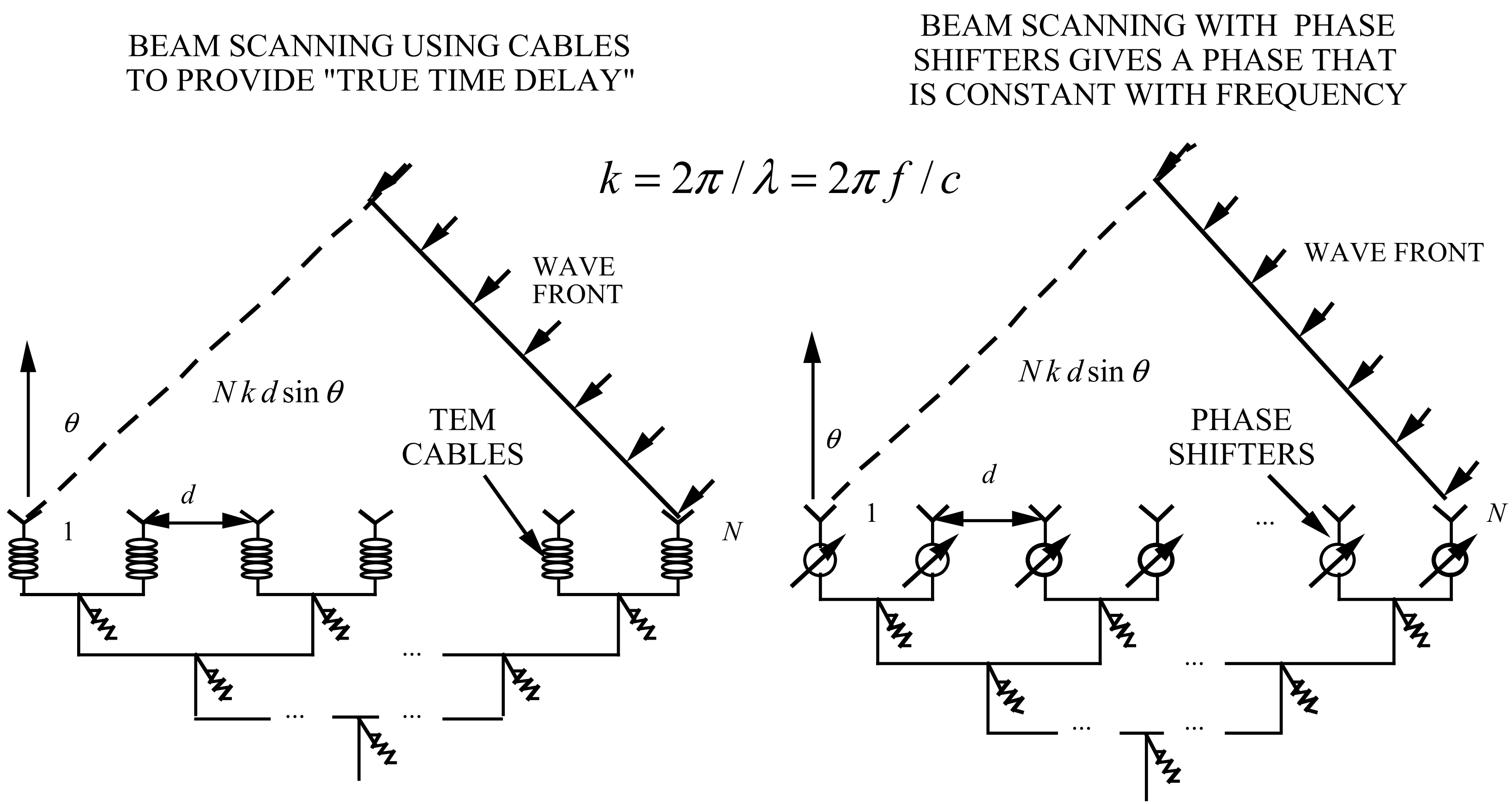
Patch Antennas

- Lend themselves to printed circuit fabrication techniques
- Low profile - ideal for conformal antennas
- Circular or linear polarization determined by feed configuration
- Difficult to increase bandwidth beyond several percent
- Substrates support surface waves
- Lossy
- Feeding methods:



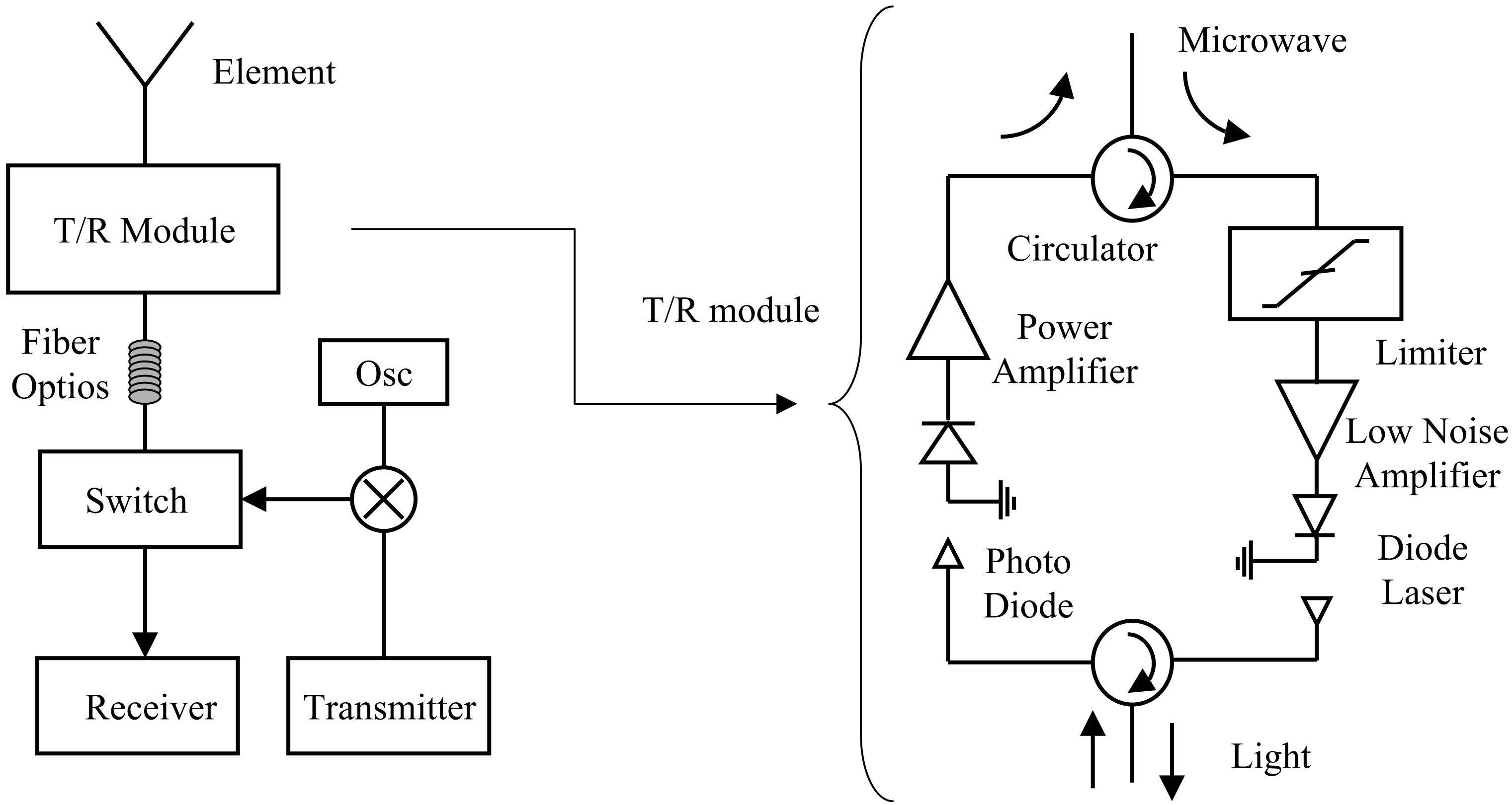
True Time Delay for Wide Band Scanning

- For wideband scanning the phase shifter must provide true time delay

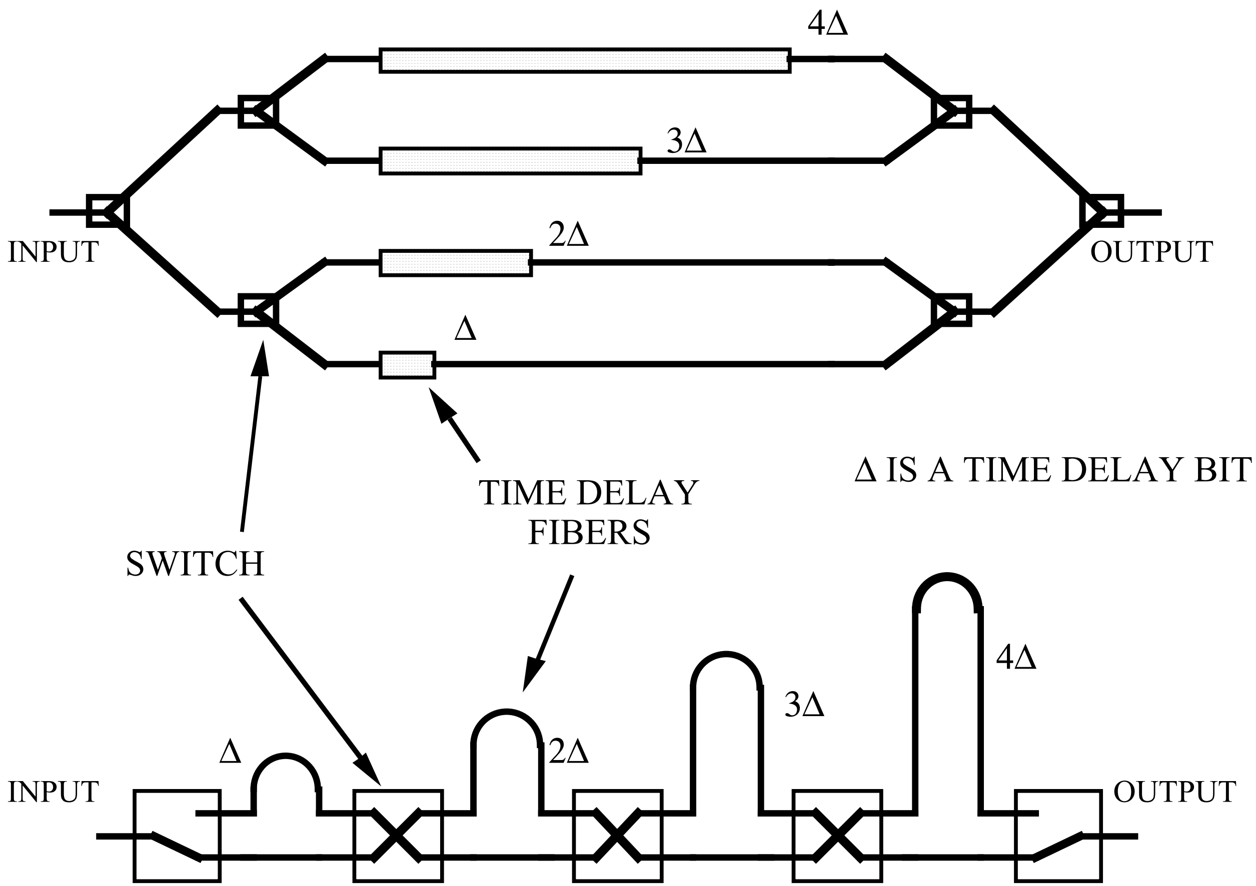


Fiber Optic Beamforming

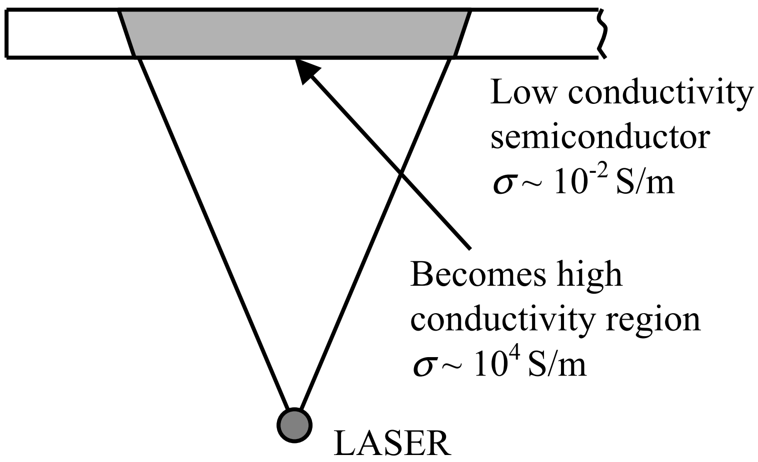
- Fiber optic beamforming architecture and T/R module
- Conversion loss from microwaves to light > 20 dB (as of 1998)



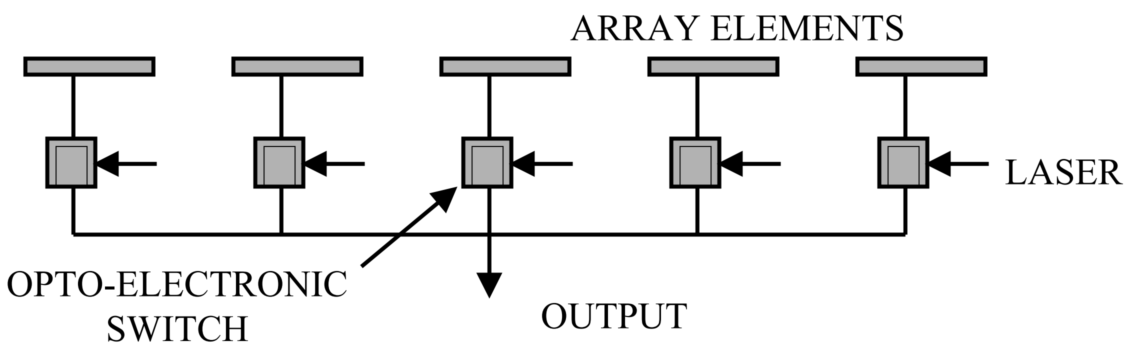
Photonic Time Delay Phase Shifters



Photonics for Reconfigurable Arrays



- High energy beams are used to produce conducting antenna-shaped regions (left)
- Laser excitation of the switch activates a particular portion of the aperture (below)



MMIC

- Monolilthic microwave integrated circuit (MIMIC): All active and passive circuit elements, components, and interconnections are formed into the bulk or onto the surface, of a semi-insulating substrate by some deposition method (epitaxy, ion implantation, sputtering, evaporation, or diffusion)
- Technology developed in late 70s and 80s is now common manufacturing technique
- Advantages:
  - > Potential low cost
  - > Improved reliability and reproducibility
  - > Compact and lightweight
  - > Potentially broadband
  - > Design flexibility and multiple functions on a chip
- Disadvantages:
  - > Unfavorable device/chip area ratios
  - > Circuit tuning not possible
  - > Troubleshooting is a problem
  - > Coupling/EMC problems
  - > Difficulty in integrating high power sources

Smart Antennas

- Antennas with built-in multi-function capabilities and processing are often called smart antennas
- If they are conformal as well, they are known as smart skins
- Functions include:

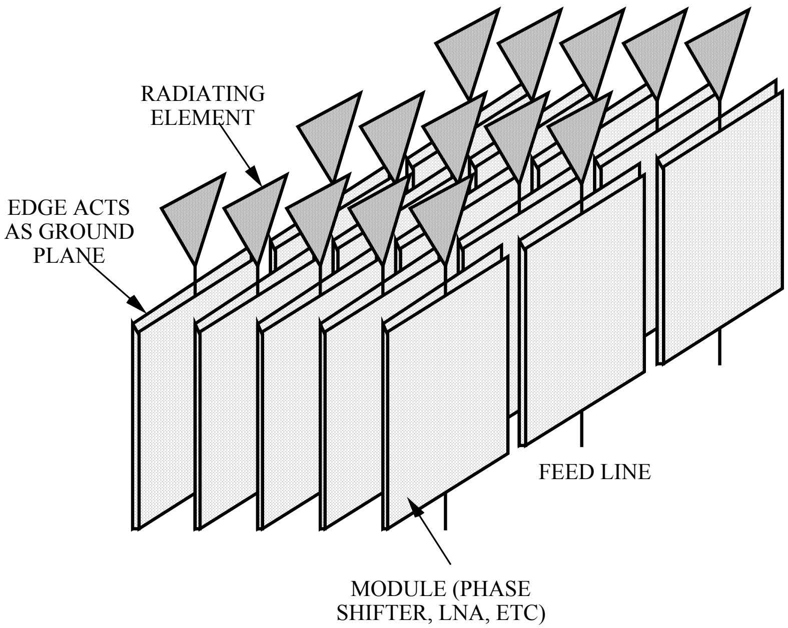
    > Self calibrating: adjust for changes in the physical environment (i.e., temperature)
    > Self-diagnostic (built-in test, BIT): sense when and where faults or failures have occurred

- Tests can be run continuously (time scheduled with other system functions) or run periodically
- If problems are diagnosed, actions include:

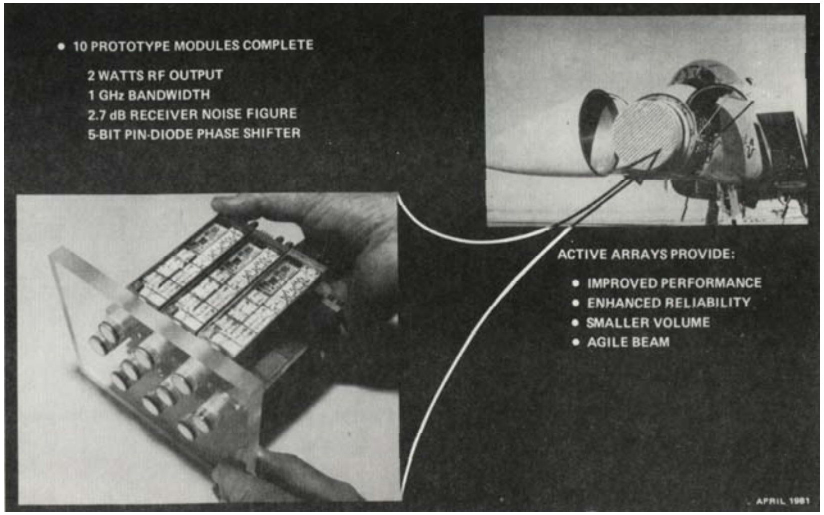
    > Limit operation or shutdown the system
    > Adapt to new conditions when processing, or reconfigure the antenna

T/R Module Concept

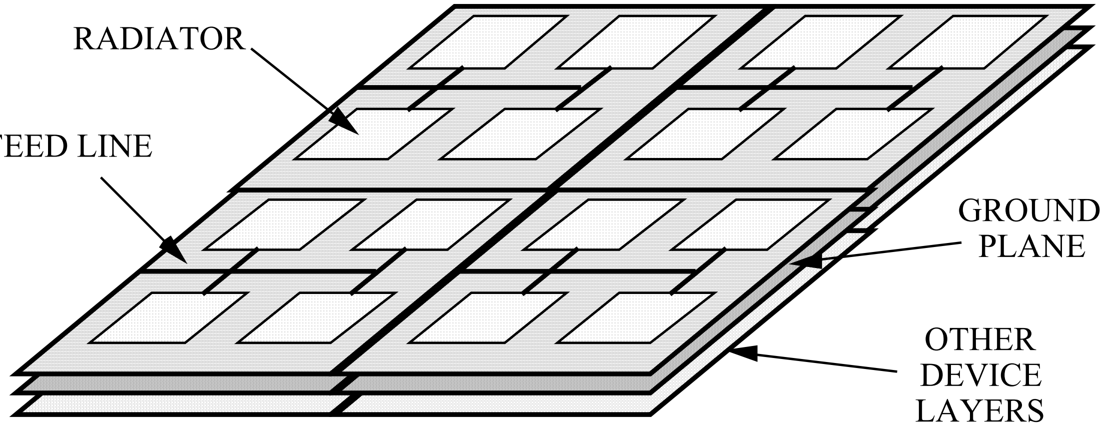
- Transmit and receive channels for each element are side by side
- Depth is a disadvantage, but module replacement easy



- F-15 radar

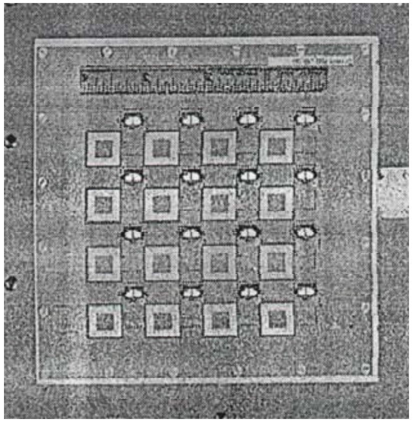


T/R Tile Concept

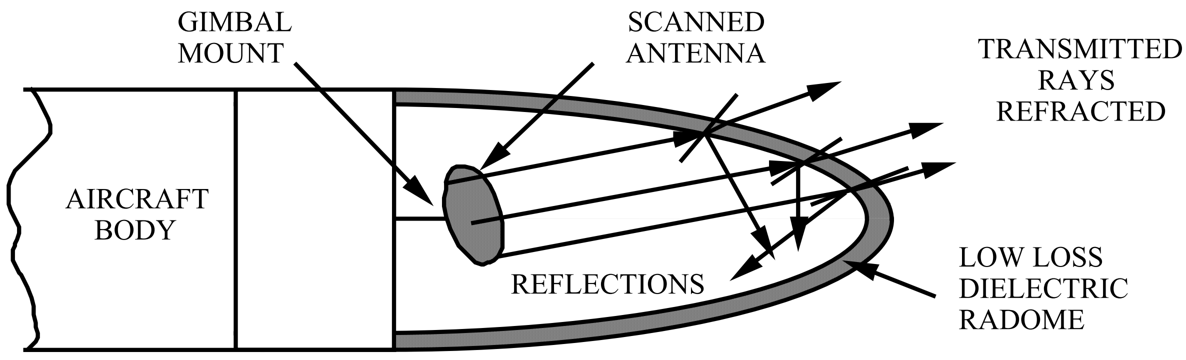


- Low profile
- A point failure requires that the entire tile be replaced

From paper by Gouker, Delisle and Duffy, *IEEE Trans on MTT*, vol 44, no. 11, Nov. 1996



Radomes

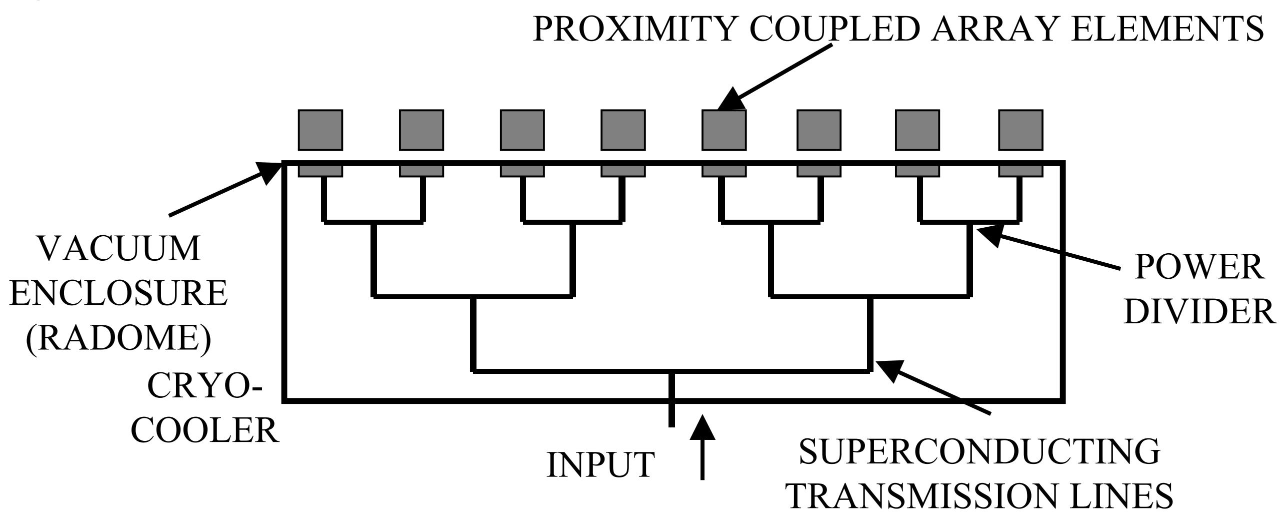


- Radome must be transparent in the operating band
- Protects the antenna from the environment
- The antenna pattern with a radome will always be different than that without a radome
- Radome effects on the antenna pattern:

    1. beam pointing error from refraction by the radome wall
    2. gain loss due to loss in the radome material and multiple reflections
    3. increased sidelobe level from multiple reflections

Superconductivity

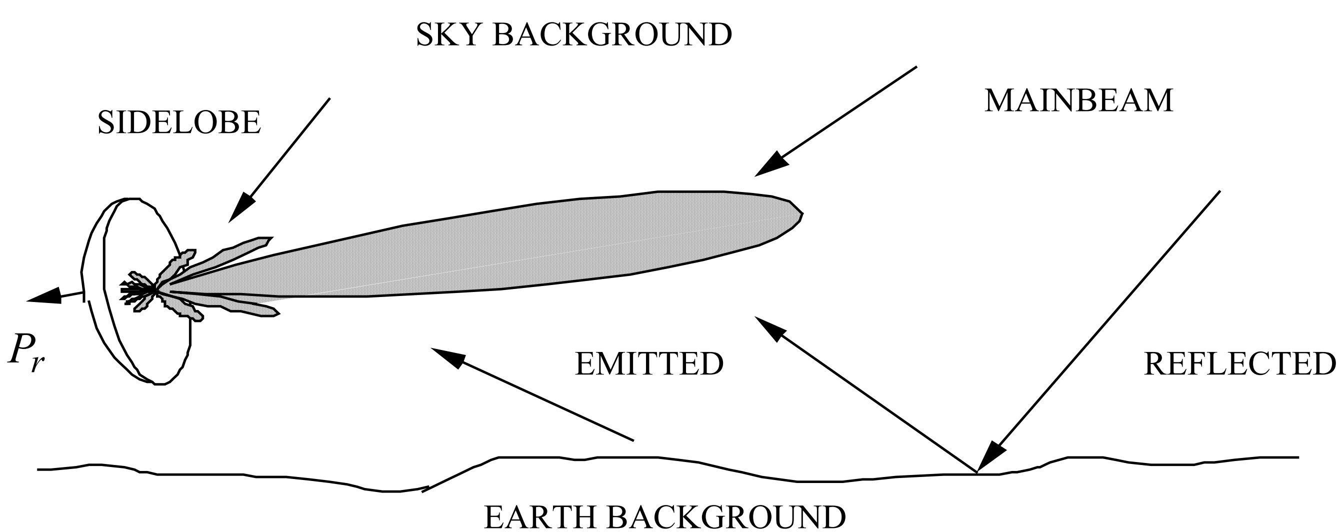
- Reduces loss in feed lines (as much as 25 dB for a 16 element array operating at 60 GHz)



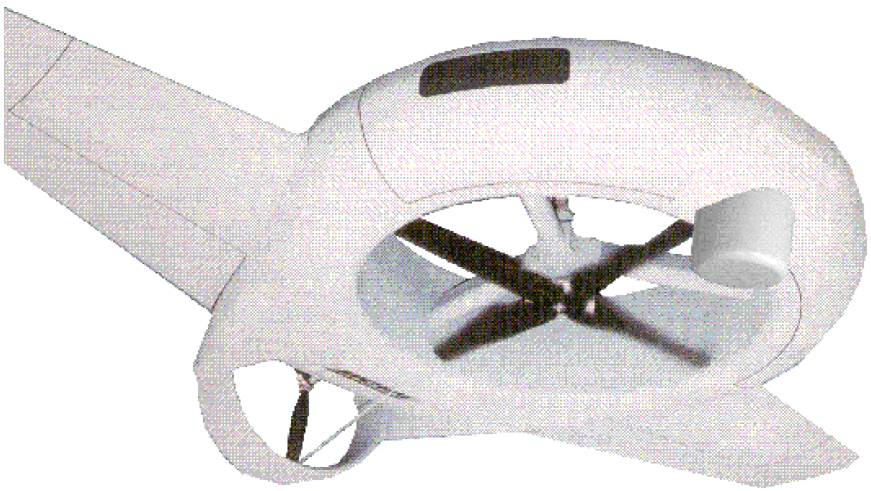
- Makes possible "super-directive" arrays
  > gain much higher than expected for the given array area
  > requires some feed lines to have very high current, and therefore I^2R losses are prohibitive in conventional conductors

Antenna Temperature

- Antenna noise temperature is specified in degrees Kelvin
- Indication of the noise power out of the antenna when no signal is present
- Depends on background radiation
- Especially important when very low signal power is expected



Example: Mini- and Micro-SAR



MiniSAR installed

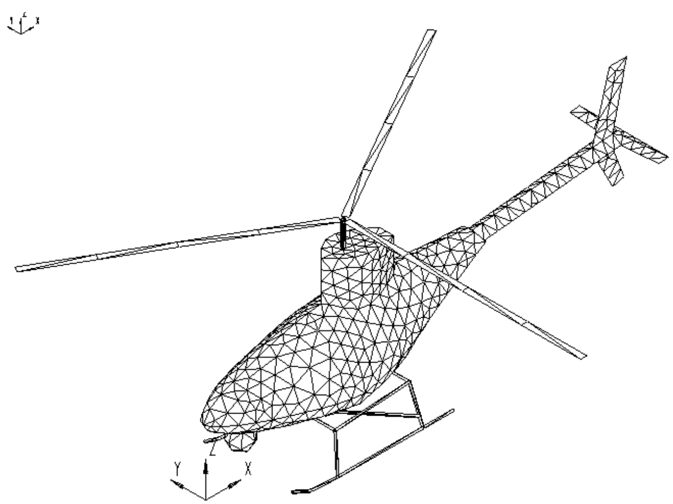
http://www.imicrosensors.com/

- MicroSAR
  - 0.3 m Resolution
  - 2 km Sensor Range
  - 1 lb Payload
  - Ka-band Radar Design
  - Innovative Motion Compensation
  - Suitable for mini UAVs
  - May be Further Miniaturized for MAVs
- MiniSAR
  - 0.1 m Resolution SAR
  - 10 km Sensor Range
  - MTI Mode
  - 15 lb Payload
  - Ku-Band

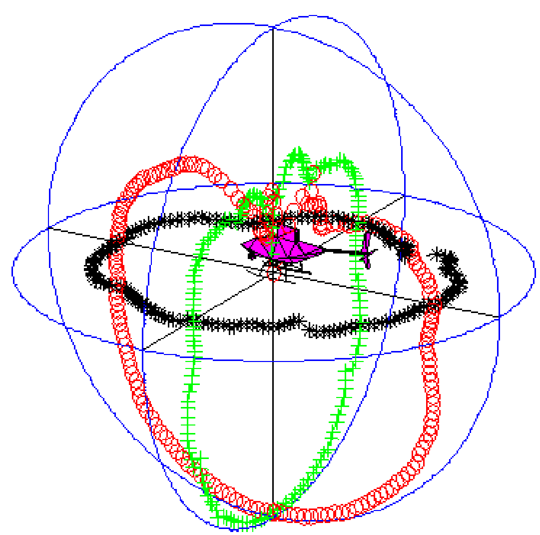
Vertical Takeoff UAV

- USN VTUAV has multiple missions
- Use EM simulation codes to study
  - > antenna placement
  - > effect of nearby structure on patterns
  - > interference with other systems

VTUAV mesh model

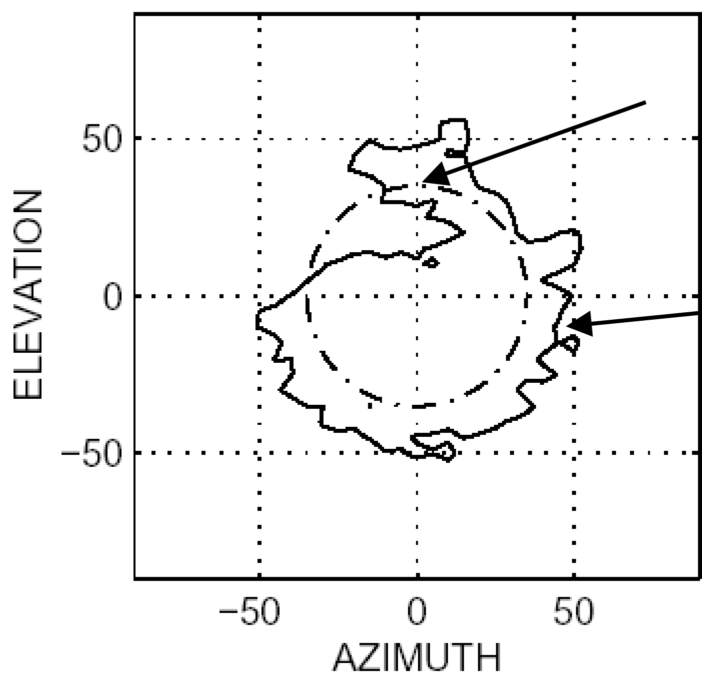


Pitch, roll, and yaw patterns



JSOW Captive Carry

- Problems similar to a UAV
  - > blockage
  - > radome losses



Gain specification (dashed)

HPBW contour of captive antenna (solid)