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: \( G = \frac{4\pi Ae}{\lambda^2} \)
  - \( A = \) area, \( \lambda = \) wavelength
  - \( e = \) efficiency \((0 < e < 1)\)
- Field of view or beamwidth
  - usually half power, HPBW, \( \theta_B \)
- 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)  > Adaptive
  > Conformal  > Reconfigurable
  > Smart antennas  > Multiple beams
  (“smart skins” or “living skins”)  > Photonics
  > Superconductivity  > Digital beamforming
  > Genetic algorithms  > Fractal antennas
  > Wide band (shared apertures)
  > Frequency selective devices and surfaces
  > New and exotic materials

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
  \[ d_{\text{max}} > \frac{\lambda}{2} > d_{\text{min}} \]

- Collection of nested or integrated narrow band antennas

\[ \Delta f_1 \quad \Delta f_2 \quad \vdots \quad \Delta f_N \]
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)

- Diode Length at Low Frequencies
- Diode Length at High Frequencies
- ≈ \(\lambda/4\) at High Frequencies
- ≈ \(\lambda/4\) at Low Frequencies

- High Frequency Feed Points
- Low Frequency Feed Points
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

![Diagram of antenna elements and beam patterns]
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 \((I\text{ and } Q, \text{ or equivalently, amplitude and phase})\) 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)
Conformal Shapes

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

\[ k = \frac{2\pi}{\lambda} = \frac{2\pi f}{c} \]

BEAM SCANNING USING CABLES TO PROVIDE "TRUE TIME DELAY"

BEAM SCANNING WITH PHASE SHIFTERS GIVES A PHASE THAT IS CONSTANT WITH FREQUENCY
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

- Monolithic 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 $P^2R$ 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

- **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

MiniSAR installed

http://www.imicrosensors.com/
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)