Smart Antennas in Aerospace Applications
Workshop on Smart Antennas
April 22, NLR Amsterdam

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Overview

- **Smart Antennas in Aerospace Applications**

- **Example of Smart Antenna for military naval and aerospace applications**
  - null-steering antenna for satellite navigation

- **Example of Smart Antenna for civil aerospace application**
  - beam-steering antenna for satellite communication

- **Video of SATCOM antenna demonstration**
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Smart Antennas in Aerospace Applications

- **Smart Antennas adapt to environment**
  - Direction of arrival (of signal)
    - tracking/beam steering: moving platform(s)
    - beam forming: control beam shape to comply with requirements/regulations
  - Multipath
    - only multipath or multipath in addition to direct link
  - Interference
    - weaker than signal (SATCOM)
    - or stronger than signal (SATNAV)
  - Vibrations
    - large antenna arrays (e.g. on wing of UAV)
    - compensation techniques (mechanical/electrical)

- .. in order to maximize the signal-to-noise-plus-interference ratio
Smart Antennas in Aerospace Applications

- **Smart Antennas: link with hardware and algorithms:**
  - Smart Skins
    - integration in aircraft skin (fuselage)
  - Smart materials
    - meta materials for miniature multi-frequency antennas
      (periodic structures with “artificial permittivity or permeability”)
  - Multi-frequency/Broadband antennas or Multi-function antennas
    - reduction of space
  - “Onboard” processing: intelligent antenna
    - e.g. in radar: knowledge-based aiding to reduce clutter, adaptive send and receive antenna
    - e.g. in satnav: integration of antenna and receiver
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Adaptive antenna for satellite navigation

- Signal of GNSS signals is below noise floor
  - sensitive to interference
  - easy to jam

- Adaptive antennas for GPS
  - military: Controlled Radiation Pattern Antenna (CRPA)
    - null-steering antennas
    - null-steering and beam-steering
  - Space-Time Adaptive Processing (STAP)
Controlled Radiation Pattern Antenna (CRPA)

- Controlled Radiation Pattern Antennas (CRPAs) are array antennas, they optimise \( S / (N+I) \), two options:
  - beam-steering
  - null-steering
  - (or a combination)

- Null-steering versus beam-steering in general:
  - In the case of null-steering:
    the ratio between the gain in the direction of the jammer and the gain in the direction of the satellite is higher (for a small array)
  - In the case of null-steering:
    potential loss of wanted signal if a null is directed towards the satellite
  - In the case of beam-steering:
    large arrays needed for low-side lobes
Null-steering for GPS

- Null-steering antennas have special advantages in the case of GPS:
  - In the case of beam-steering:
    4 beams are needed to track 4 satellites which requires more antenna elements than needed to create nulls for one or more jammers
  - It is easier to create nulls towards the high level jammer signal than to create beams towards the low level GPS-signal (spread spectrum)

- State-of-the-art digital electronics enable combination of null-steering and beam-steering
Methods of null-steering

- **Some methods of null-steering:**
  - direct matrix inversion of the signal covariance matrix
  - method of steepest decent (LMS method): minimise output power (equals jammer power since satellite signals are below noise floor)
  - method of perturbation

- **Direct matrix inversion:**
  - + No iterations, exact solution, performance does not depend on number and power of jammers
  - - No closed control loop, practical implementation difficult (numerical instabilities, time consuming matrix inversion)
Methods of null-steering (2)

- **Method of steepest decent:**
  - + Closed control loop, simple implementation (even analog), not sensitive to non-linearities
  - - gain control loop difficult, convergence speed depends on difference in jammer power

- **Method of perturbation:**
  - + closed control loop, simple digital implementation, not sensitive to non-linearities
  - - often many iteration steps needed, convergence speed depends on difference in jammer power
Adaptive Nulling NAVSTAR Antenna (ANNA)

- **Prototype null-steering antenna**
  - Antenna to be used with L1/L2 PPS receivers
    - CRPA transparent for receivers (no interaction with RX needed)
  - Developed by NLR and MEOB (both NL)
  - Prototype for the Royal Netherlands Navy in the 80’s
  - NLR: implementation of algorithm, electronics development, integration and test
  - MEOB: design and procurement of mounting frame and protective casing
  - Significant influence of naval environment
  - Protected against high power shipboard transmitters
Controlled Radiation Pattern Antenna (CRPA)
Raytheon GAS-1 and ADAP

Naval applications: 7 antenna elements
Aircraft applications: 4 antenna elements

Array antenna +
antenna electronics

- **GAS-1**
  - nulling on one frequency

- **ADAP**
  - Space/Frequency and Space/Time Adaptive Processing (SFAP/STAP)
  - nulling on two frequencies
Current developments in CRPA antennas

- Combination of phased array antenna and digital receiver
- Raytheon Digital Anti-Jam Receiver (DAR)
  - space frequency adaptive processing (SFAP) technique
  - spatial nulls to suppress jammers,
  - multiple beams to amplify valid signals from GPS satellites.
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Smart Antenna for airborne SATCOM

- **Passengers onboard aircraft want**
  - High-speed internet (web, multi-media) and
  - Television (Digital Video Broadcast via Satellite).

- **This can be realised by using a broadband SatCom antenna:**
  - Mechanically steered reflector/array antennas
    - Aerodynamic drag/Moving parts
  - Hybrid mechanically/electronically steered
  - Electronically steered phased array antennas
    - Conformal to the aircraft fuselage
    - No moving parts
FlySmart project: airborne antenna development

- Development of an **antenna system for airborne use**, to enable **broadband communication via Ku-band satellite**:
  - electronically scanned antenna (phased array antenna)
    - high gain, small beamwidth (2 to 3 degrees)
    - downlink frequencies: 10.7 - 12.75 GHz
  - fixed satellite service
  - broadcast satellite service
    - **broadband** antenna system (downlink up to 2 GHz)
  - antenna **conformal** to the aircraft fuselage
    - to improve aerodynamic characteristics
    - to increase antenna view
  - large scan angles (low elevation angles) to accommodate operation at high latitudes
Design of Ku-band receive antenna array for SATCOM

Inmarsat (L-band)

DVB-S/Internet (Ku-band)

Asynchronous data link (internet)

Ground Earth Station
FlySmart project: 2 antennas

- **Research on airborne phased array antenna**
  - larger bandwidth than current designs
  - larger scan angle than current designs
  - transmit and receive
  - fully environmentally qualified
  - study only

- **Demonstrator phased array antenna**
  - large bandwidth and scan angle
  - limited gain and beamwidth
  - receive only
  - limited environmental qualification
  - manufacturing and test
System aspects

- Ku-band receive-only antenna system with broadband optical beam-forming network and broadband phased array antenna

  AES receive band 1: 10.70 – 11.70 GHz
  Satellite TV: 11.70 – 12.50 GHz
  AES receive band 2: 12.50 – 12.75 GHz

  } 2 GHz bandwidth
Key technologies

- Development of broadband Ku-band antenna element/array
- Development of broadband beam forming network optical chip (CMOS compatible)
Design of dual-frequency L/Ku-band antenna

- Size L-band antenna = 8 * size Ku-band antenna
- Broadband Ku-band element: Stacked patches
- Design of L-band element is constrained by Ku-band element
- L-band element: Two crossed L-band slots in ground plane with feeding slots of Ku-band array
Design for dual-frequency breadboard antenna

- Feed Substrate
- GND plane with L-band slots
- Feed trace
- Patches
- "Foam"
- Aperture
- Trace layers
Development of broadband Ku-band antenna

- Stacked patch antenna element
Development of broadband Ku-band antenna

- Stacked patch antenna element with
  - Broadband radiation pattern
  - Broadband input impedance
Position of antenna on aircraft

- Required scan angles:

- Multiple satellites, one antenna on top
- Multiple satellites, two antenna (E-W)
- Multiple satellites, two antenna (S-N)

Beam will be steered based on aircraft position and attitude.
With two antennas max. view angle +/- 45 degr.
Beam Squint in case of phase shifting
\( f_{\text{min}} = 10.7 \text{ GHz}, \ f_{\text{mid}} = 11.7 \text{ GHz}, \ f_{\text{max}} = 12.75 \text{ GHz} \)

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Single-Chip 1x8 OBFN
CMOS-Compatible Waveguide Technology

Waveguide Loss < 0.3 dB/cm
Thermal Tuning Mechanism
Average Power Consumption per Heater 0.25 W
Optical beamformer

Optical sideband filter chip in the same technology as the OBFN

MZI + Ring

5 mm
Ku-band demonstrator array

- 8x8 array preliminary measurements
- radiation pattern and relative gain
Technology Readiness Level FlySmart

- **TRL 1**: Basic principles observed and reported
- **TRL 2**: Technology concept and/or application formulated
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof-of-concept
- **TRL 4**: Component and/or breadboard validation in laboratory environment
- **TRL 5**: Component and/or breadboard validation in relevant environment
- **TRL 6**: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
- **TRL 7**: System prototype demonstration in a space environment
- **TRL 8**: Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)
- **TRL 9**: Actual system “flight proven” through successful mission operations

*FP7 SANDRA*
*IS FlySmart*
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  - FlySmart/Anastasia
Demonstrator set-up (laboratory measurement)
Measurement plan

- **Objectives**
  1. Verify broadband properties of antenna and OBFN
  2. Verify optical beam steering capabilities

- **Measure C/N ratio for range of frequencies (objective 1):**
  - 10.7 to 11.7 GHz (steps of 100 MHz)

- **Measure C/N ratio for the following antenna positions (objective 2):**
  - Antenna at broadside (no beam steering)
  - Antenna rotated 27 degrees to left side
  - Antenna rotated 27 degrees to right side