An Indoor, Live Dynamic Constellation Simulator Using Static Phased Array Antennas

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Outline

• Motivation
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• Proposed solution
• System overview
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Motivation

• What is a constellation simulator?
  – Reproduces the environment of a GPS receiver on a dynamic platform
  – Models
    • Vehicle and satellite motion
    • Signal characteristics
    • Atmospheric effects
Motivation

- Satellite navigation receivers require stringent testing under a variety of conditions (including electronic attack)
- Live sky testing presents a variety of obstacles (density, planning and scheduling, etc)
- Laboratory environment testing often limited to a static Angle of Arrival (AOA)
Wavefront Simulations

- Wavefront simulation
  - Precise Scenario Control
  - Complex system with dozens of processors for signal generation
  - Bypasses the antenna elements directly into AJ electronic unit
Anechoic Chamber Simulations

- Anechoic chamber testing
  - Added realism
  - Transmissions can switch from antenna to antenna
  - Static placement of multiple antennas to achieve AOAs for navigation and threat signals
  - Switching can cause phase discontinuities
Open-Air Testing

- Open-Air testing
  - Achieves the most realism
  - Low density number of test ranges
  - Cost/Schedule/Risk

What bridges this technology gap?
Proposed solution

- System of phased antenna arrays placed strategically in an anechoic chamber environment
- Antenna arrays would change the measured AOA at the UUT
- Handoff between the arrays would help simulate a horizon to horizon track of a single satellite

- Ideally, the solution should be
  - Adaptable
  - Customizable
  - Easily Calibrated
Technical Objectives

• Design a system capable of simulating dynamic AOAAs representative of satellite navigation system constellations
• System design should be suitable for anechoic chamber environments
• Prove that dynamic AOA determinations are possible with static components
• Identify an RF distribution system that would interface the system to existing constellation signal generators
Transmitting Array Design

Uniform Linear Phased Array
- Share a power distribution network
- Antenna elements identical
- Beam steered via linear phase shift to create a planar wave in the desired direction

\[ \varphi = \beta d \cos(\phi) + \alpha \]

\[ A_F = \frac{\sin \left( \frac{N}{2} \varphi \right)}{\sin \left( \frac{\varphi}{2} \right)} \]
Transmitting Array Design

- For Phase 1, design goal was to achieve 1D steering capability
- Original design accounted for five-element array
  - After simulation and array pattern analysis, design was altered to a three-element array
Transmitting Array Design

- Array components
  - Potentiometers altering voltage to phase shifters
  - Slotted aluminum chassis
  - DC power supply
  - Antcom passive L1/L2 antennas
Testing

- Internal testing was performed on phase shifters and individual antenna elements to ensure performance integrity.
- Initial system testing of the array took place in an anechoic chamber on AU campus.
- Further testing in an isolated outdoor environment provided better dynamic range of the system.
Testing

- Receive antenna at the UUT (pyramidal horn, quarter-wave monopole)
- Phase shifters were calibrated and set using the potentiometers to achieve a beam steered 30-degrees off broadside
- Array was then manually rotated at 5-degree intervals and forward gain (S21) was measured at each position
Steering Results

- The testing proved the capability of the array to steer the beam at a desired angle.
- Good dynamic range (15 to 20-dB)

![Graphs showing phased array scanned at +30 and -30 degrees.](image)
Unit Under Test-CRPA

• Controlled reception pattern antenna (CRPA)
  – Popular during the Cold War era as an anti-jam unit
  – Array elements act as a spatial filter
  – Uses a series of weights to perform beam/null steering
  – Useful in AOA estimation
AOA Results

On a broadside steer of the phased array, the CRPA correctly interprets the AOA of the broadcast signal.
At 30 degree steer, the CRPA detects a change in AOA but not an accurate one.
Deductive Analysis

• Why the inaccuracy in the case of steering the beam?
  – Wavefront has already assumed planar characteristics at CRPA
    • Restricts the incident angle from assuming the full steer angle from the transmitting antenna
A New Approach

- It is evident that the steered angle from the transmitting antenna does not have a direct reciprocal response at the DUT
  - New algorithm had to be created
A New Approach

- A series of weights was calculated for the transmitting antenna elements
  - These weights were set using attenuators added to the original transmitting antenna prototype
- Goal was to physically alter the incident angle from the transmitting antenna without moving the transmit antenna
Testing

- Anechoic chamber testing with transmitting array and CRPA UUT
- Transmitting array attached to positioner arm within the chamber
- CRPA connected to SDR record rack outside chamber
Testing

- SD CRPA composed of signal conditioning, multiple SDRs, and clock distribution system for synchronizing SDRs
- Additional recording calibration used to remove constant delay offsets between channels
- IQ data from SD CRPA used to perform MUSIC AOA estimation in post process
Anechoic Chamber Steering Results

- Knowing that the array did indeed steer a beam, further testing was conducted at an anechoic chamber to confirm steering results.
Physical Representation

- Angle of incidence has changed at the DUT
  - Tradeoff with magnitude does exist
Physical Representation

- It can be seen that a linear phase taper exists in the region of a pattern local minima
Anechoic Chamber AOA

Results

• Latest results show the new algorithm possesses more effectiveness in changing the AOA at the DUT
Future Work

• Work to complete an analytical expression describing the phenomena occurring in the electromagnetic space
• Create a MATLAB simulation to confirm the analytical expression
• Move prototype from "breadboard" to the "brass-board" level
• Expand the expression to the 2-D domain
• Explore different array geometries
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Questions?