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Employing Design of Experiments (DOE) in an Electronic Warfare Test Strategy/Design

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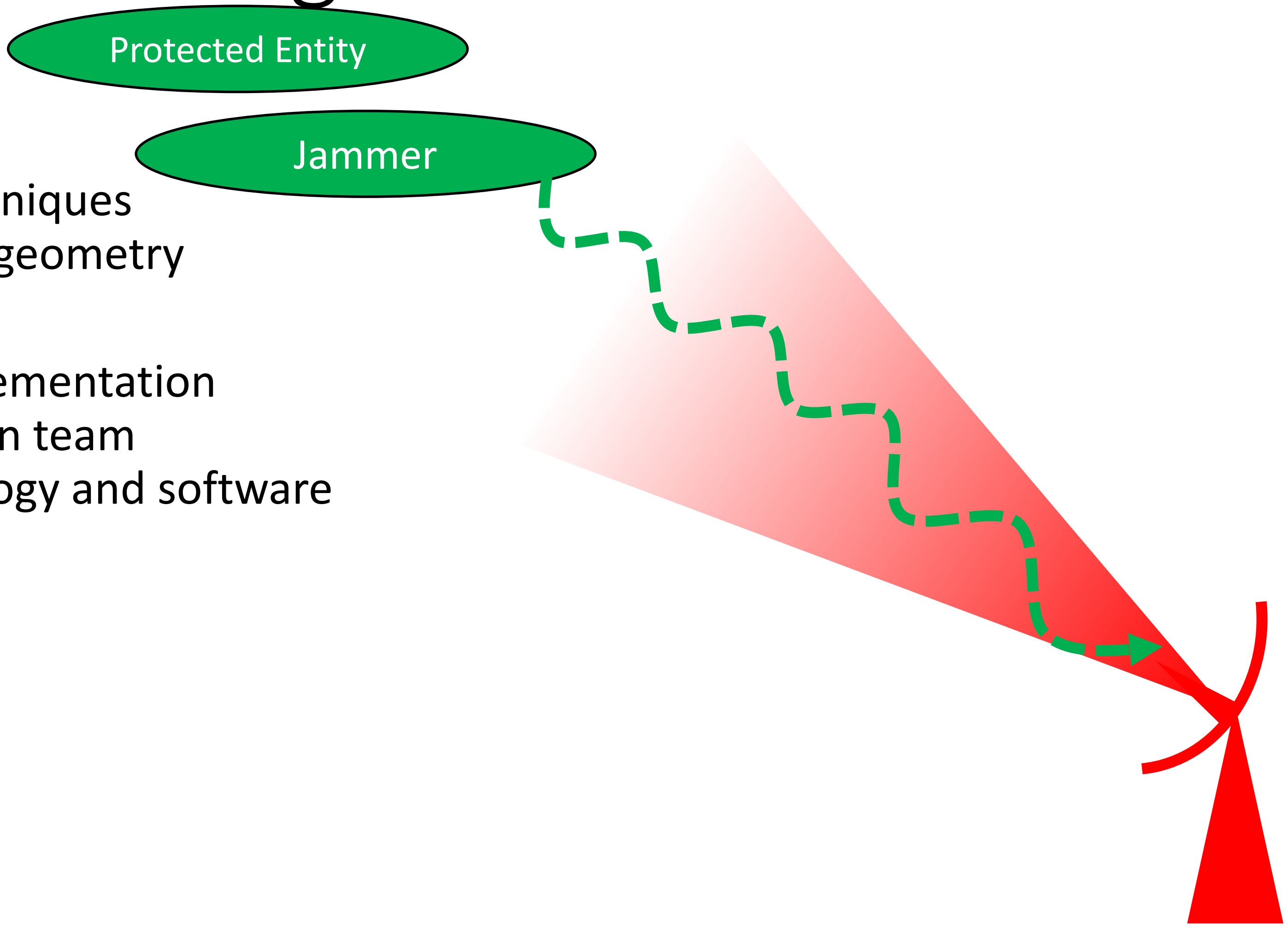
Outline

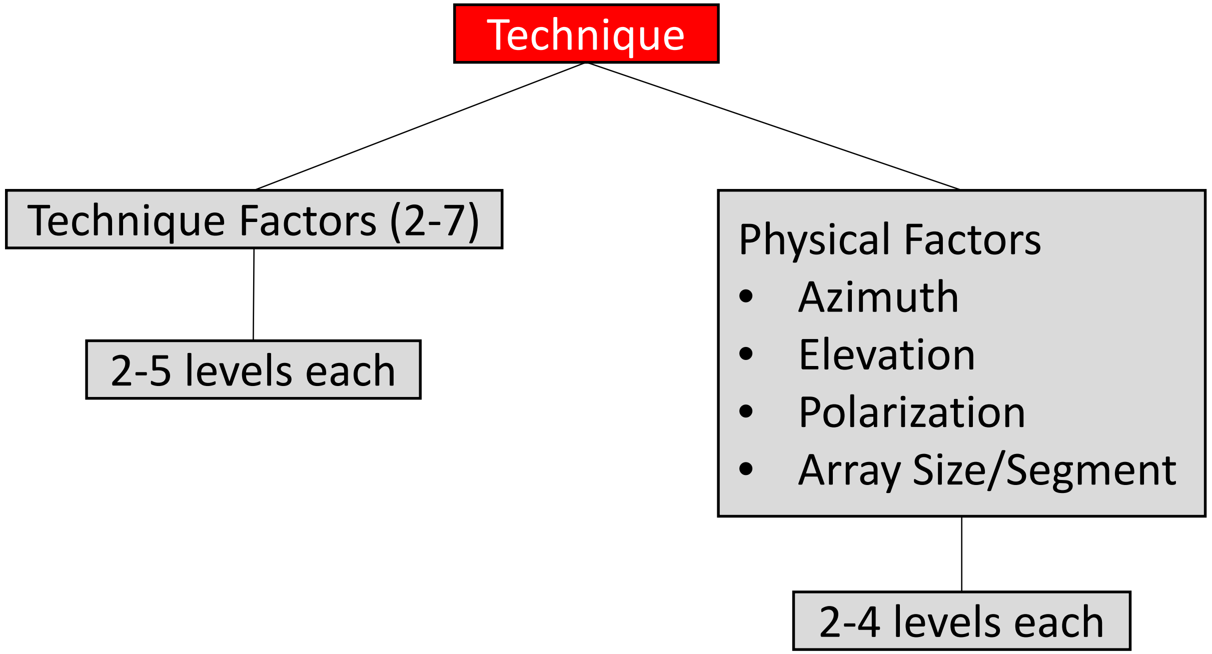
- Challenges
- Factor Space Complexity
- Application of the STAT Process
- Strategy Development
- Responses and Factor Issues
- Modified Strategy
- Conclusions and Recommendations

Obvious and Initial Challenges



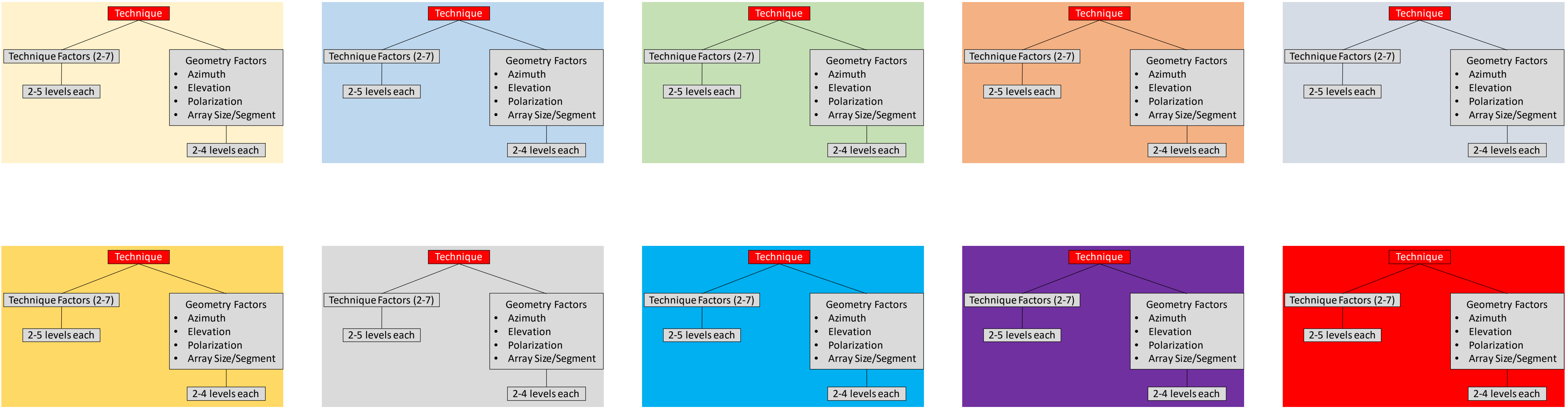
- EW systems are complex
  - Generate many diverse types of techniques
  - Many simultaneous threats/moving geometry
- New system development
  - All new equipment and control implementation
  - Limited developmental experience on team
  - New capabilities enabled by technology and software
- Multiple test venues
  - ***Pod alone (focus of this brief)***
  - Pod installed (chamber)
  - Open air ranges
- Primary Objectives
  - ***Signal quality (focus of this brief)***
  - Jammer effectiveness

Factor Space Complexity (Single Beam)



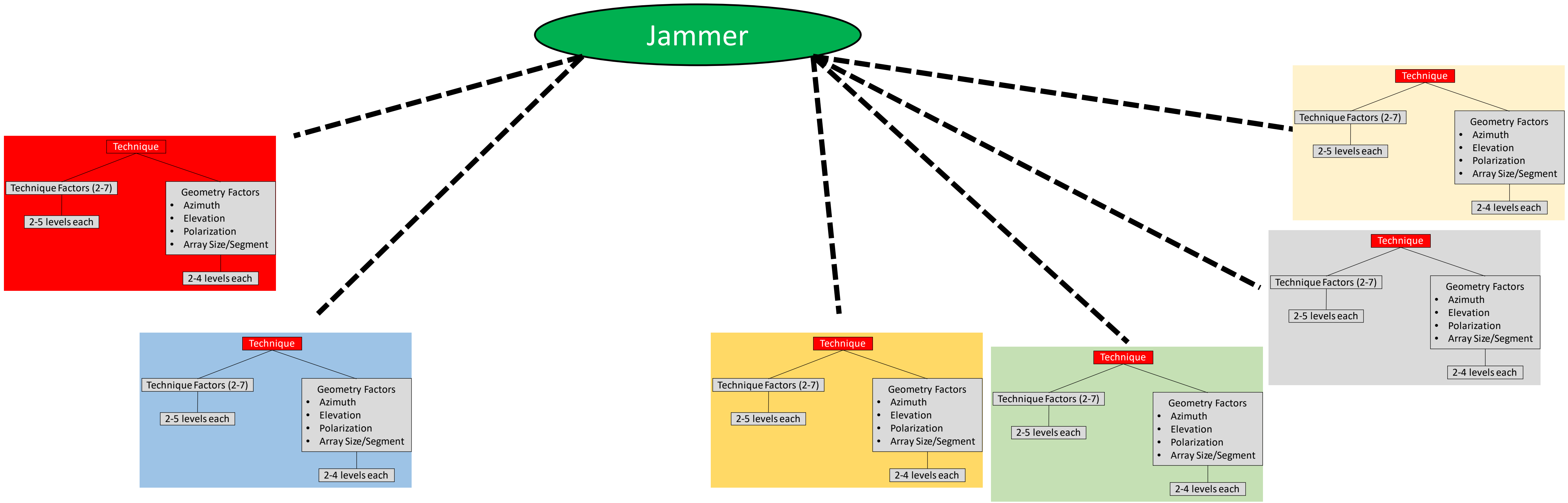
6-11 factors required to adequately describe a single beam in space

Factor Space Complexity (10 Techniques)



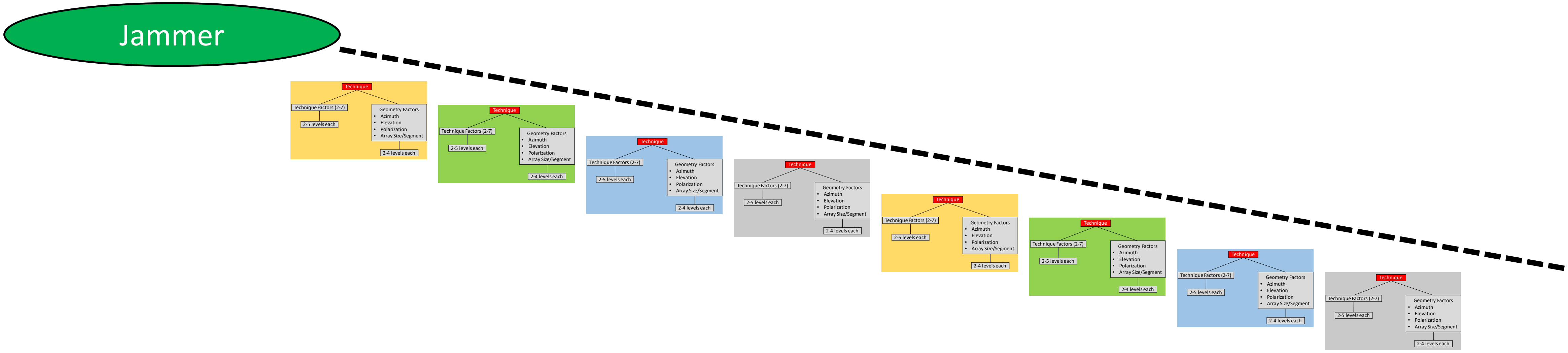
We are interested in characterizing each technique, not statistical significance between techniques

Factor Space Complexity (Multiple Beams)



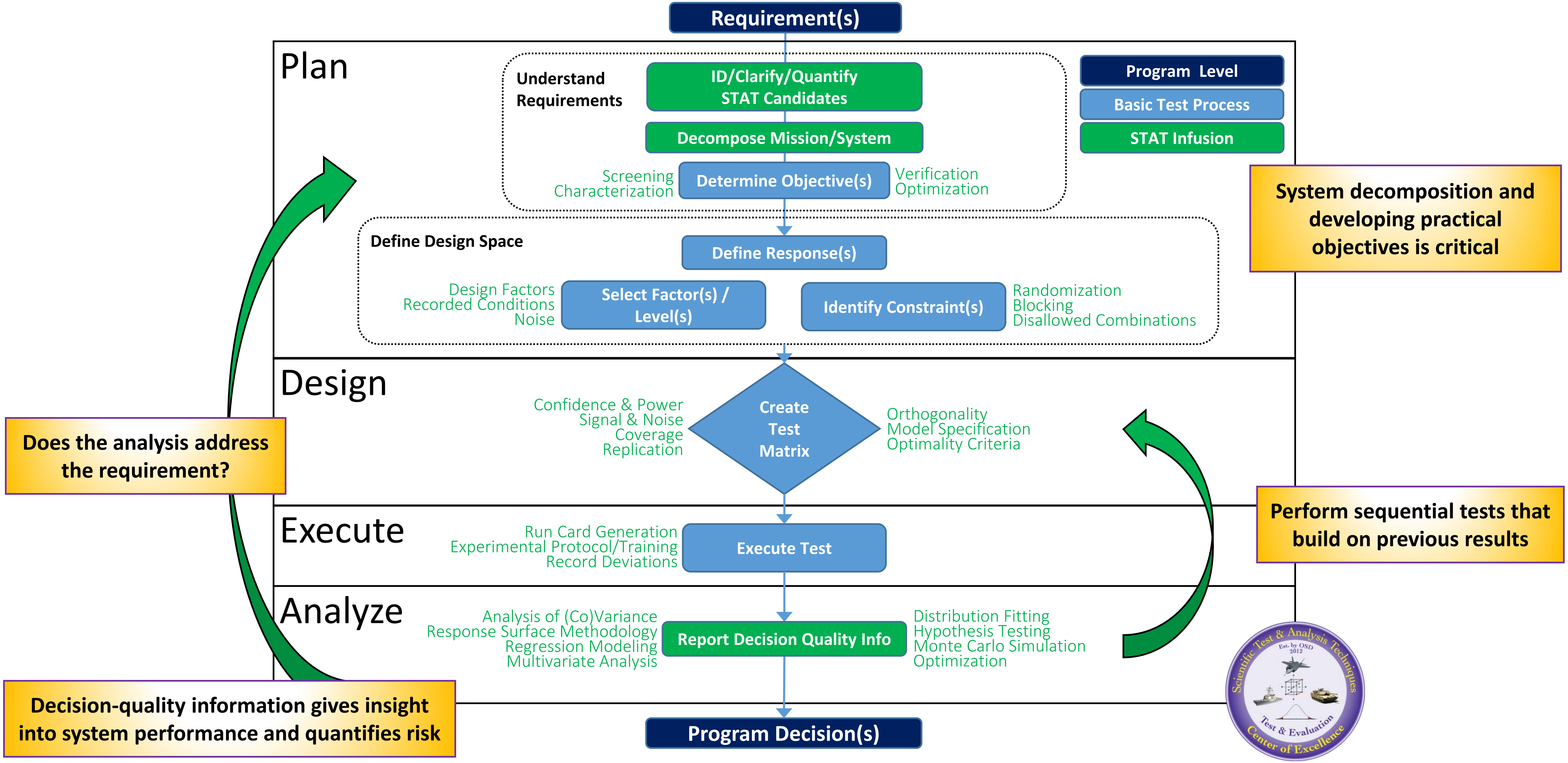
These combinations can happen simultaneously and vary over time

Factor Space Complexity (Time Commutated)



“Decomposition is sufficient when the responses and factors are obvious and easily defined”

STAT in Test & Evaluation



Employ a STAT Working Group for Best Results

Strategy Development

First, we had to ***admit we had a problem*** the STAT process could address.
I ***briefed and cajoled*** the team at every WIPT over an 18 month period and offered half-day short courses.

- Objectives
  - Evaluate quality of signal, uninstalled, across the variety of technique and physical factors, alone and in the presence of other beams
- Strategic breakdown
  - Single beams (minimum capability)
  - Multiple beams (enhanced capability)
    - Leverage expectations gained testing single beams
  - Advanced Techniques (new capability)
    - Explore/characterize (combinatorics) new functions and build user expectations
- A note about sequential T&E
  - Rapid data acq (~10s/point) vs days for data reduction and analysis
  - Opted to generate full model designs and see if budget/schedule could handle it

Single Beam Responses

Design sizes 120-240 points/technique
95% Confidence, 80% Power @ SNR=2.0
Model Main Effects, 2FI, Quadratics

- What do we measure for the different techniques?
  - How can we characterize performance if they all behave differently?
  - Do we know what to expect?
- We settled on measuring "waveform error" and beam characteristics
  - Ex: Sin Wave "error" = period, amplitude, rise time differences from desired
    - These are standard measurement capabilities in the lab
    - Expectation is "zero error" across factors (nothing significant)
  - Beam characteristics: distortion, spreading, coherency, etc.
  - Significant factors indicate what is driving error
  - Creates expectations for performance in presence of other beams

At a minimum, we would know if the new system could replicate the existing system

Multi-Beam Challenges

Design sizes ~ 360 points each (2, 3, 4)
95% Confidence, 80% Power @ SNR=2.0
Model Main Effects, ***critical*** 2FI, Quadratics

- How do we address the multiplicity of factors?
  - 6-11 factors per beam x 2/3/4 beams: ***HUGE DESIGNS THAT BROKE JMP***
  - Resolutions to mitigate design size
    - Employ single representative (fixed) technique
    - Focus on discovering differences from single beam performance
    - Limit model to specific two factor interactions of interest and quadratic terms
- How do we define physical factors (Az, El, frequency)?
  - Az: Beam 1 defines actual value, other beams described by delta from beam 1
    - Requires some planning for edges of factor space
    - Is the delta factor spacing even/linear (e.g. 0, 5, 10 or 0, 5, 20)?
  - Frequency: Similar approach but… are deltas added or multiplied?
    - Is 100Hz delta the same "closeness" for low and high frequency beams
    - Is the spacing linear? (harmonics are multiples, not additive)

Fun Fact: The complete multi-beam factor space is 540,000 Trillion combinations! We cover it in about 8000 points.

Then, Things Changed…

- Development schedule got loooonger… and squeezed test…
- Schedule/testing venue order changed (pod-alone was no longer first)
- What if single beam went really well? (risk lowered for multi-beam)
- What if we didn't want to test multi-beam so extensively?
  - If 2 beam performs well and we need less info for 3 and 4
  - If other venues generated useful data and reduced risk
- What if leadership needed to prioritize certain information?

We needed a more flexible test strategy with the ability to off-ramp and prioritize

Modified Approach Overview

#	Test Name	Objective	Design Type (DOE, Demo)	CW only	Technique	Azimuth (near and close)	Azimuth (opposite/crossed)	Elevation	Polarization	Center Freq (near and close)	Center Freq (harmonics)	IBW	Beam Spoil State	Array Segments
1	2 Beam CW	Understand AZ impacts	Screening DOE	X		V		V	V	V		V	V	V
2	2 Beam CW	Understand AZ impacts	Screening DOE	X			V	V	V	V		V	V	V
3	2 Beam CW	Model AZ impacts	Augment 2 beam CW DOE (if needed)	X		IS		IS	IS	IS		IS	IS	IS
4	2 Beam Tx	Investigate any gross violations of expected performance	Demo		X	D		D	D	D		D	D	D
5	2 Beam CW	Assess harmonic impacts	Demo	X		D		D	D		D	D	D	D
6	3 Beam CW	Check for 3 beam AZ/Freq deltas from 2 beam	Screening DOE	X		V		V	V	V		V	V	V
7	3 Beam CW	Model AZ/Freq impacts	Augment 3 beam CW DOE (if needed)	X		IS		IS	IS	IS		IS	IS	IS
8	3 Beam Tx	Investigate any gross violations of expected performance	Demo		X	D		D	D	D		D	D	D
9	4 Beam CW	Investigate any gross violations of expected performance	Demo	X		D		D	D	D		D	D	D
10	4 Beam Tx	Investigate any gross violations of expected performance	Demo		X	D		D	D	D		D	D	D

F Fixed
D Demo selected values
IS If Significant (in DOE)
V Varied in DOE
X Selected Choice

Strategic Direction Update

- Focus designs at a lower level
- Divide and conquer Az and Freq definition issues
- Create designs for Main Effects then Augmented scope
- Identify demonstrations for resource planning

So that brings us up to today…

Conclusions & Recommendations

- Make opportunities
  - Leverage WIPT briefs and interactions to ***offer advice and ideas***. Don't give up.
- Team effort
  - You ***need everyone*** at the table: engineers, software, operators, STAT
- Strategy is critical to deal with complexity
  - ***Decomposition*** makes or breaks the process
- You are probably breaking new ground
  - Application of DOE/sequential testing is not necessarily clear
  - ***Track and document*** the fundamentals, record any you might break, keep team (non-STAT folks) aware of limitations and expectations
- Be flexible
  - Risk and priorities are valid considerations, even if they make the process imperfect
  - Be ready for change: if it's overwhelming ***take a step back*** up the process chain

Questions?