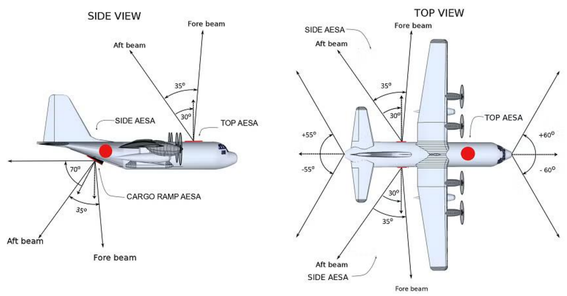
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Using Simulation to Find Pulsing Schemes that Meet Requirements for Airborne Polarimetric Doppler Phased Array Weather Radar

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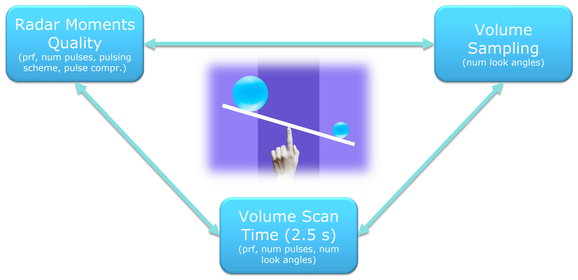
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Background:

Introduction: The Airborne Phased Array Radar (APAR) is an advanced atmospheric system which is currently being developed at NCAR. It will replace the expired X-band Electra Doppler radar (ELDORA). The ELDORA radar scanned the atmosphere using a rotating plate to direct the transmit pulses in fore- and aft-point cones geometry. APAR will operate on a completely different principle using electronic beam steering with as many as 4 C-band Active Electronically Scanned Arrays (AESAs).

Goal: Identify optimal pulsing scheme(s) (number of pulses, pulsing sequence, PRF, pulse compression/independent channels, multiplexing) that satisfy radar moment performance requirements as well as volume scan time and coverage goals for the side AESAs.



Requirements:

- **Scan modes: The typical strategy will be to have 3 scans for each cycle: 1) doppler 2) dual-polarization and 3) surveillance.**
- **The complete scan cycle needs to be completed in 2.5 seconds.**
- **For surveillance and Doppler modes, moment performance and volume sampling/coverage should be as good as ELDORA.**

Scan modes:

- **Surveillance: PPI from +15° to -50° at 1.5° spacing; 2000 PRF; Z**
- **Doppler: 2x RHI from +50° to -50° at 1° spacing; 2500 PRF (initially); Z, V**
- **Dual-polarimetric: RHI from +20° to -20° at 1° spacing; 2500 PRF; Z, V, W, Zdr, ρ_{hv}, φ_{dp}, Ldr**

Pulsing Schemes:

- **Each look angle is "visited" some number of times.**
- **At each "visit", a prescribed pulsing "sequence" (consisting of Hc, Vc, Hx, Vx pulses – H/V receive channel and c/x is co/cross) is transmitted.**
- **The multiplexing number specifies the total number of look angles in a cycle that are "visited". Affects the dwell time for a look angle but does NOT affect the total scan time.**
- **The total number of pulses = (# of visits) * (length of pulsing sequence)**
- **Pulse compression/independent channels are handled by using an "independence scale factor" (ISF) and simply dividing the standard deviations by the sqrt(ISF). E.g. ISF = 4 for ELDORA with 4 independent channels. For APAR, we expect ISF ≈ 2.5.**

Pulsing Schemes (cont'd):

Surveillance:

- **4-10 total pulses per look angle. Each "visit" consists of a single Hc pulse. 1-10 multiplexed beams**

Doppler:

- **6-20 total pulses per look angle. Each "visit" consists of <u>two</u> consecutive Hc pulses. 1-8 multiplexed beams**

Dual-pol:

- **Total number of pulses per look angle is fixed, currently, at 72.**
- **First class of pulsing sequences: (same each visit; in plots PS=1):**
  - **[Hc Vc Hc Vx] (n=1)**
  - **[Hc Vc Hc Vc Hc Vx] (n=2) etc.**
- **Pulsing sequences 2 (alternating odd/even visits; in plots PS=2):**
  - **[Hc Vc Hc Vx] / [Vc Hc Vc Hx] (n=1)**
  - **[Hc Vc Hc Vc Hc Vx] / [Vc Hc Vc Hc Vc Hx] (n=2)**
- **1-5 multiplexed beams.**

Methods:

- **Use I&Q simulator to generate 10,000 realizations of time-series data with known "true" moment values (simulation inputs) to easily quantify and fairly compare moment performances statistically for different pulsing schemes against moment performance standards.**
- **Weather simulation parameters were determined by considering typical values for weather phenomenon of interest (see table 1).**
- **Moment requirements (performance benchmarks) were determined by simulating ELDORA (9.5 GHz with 4 indep. channels; 2000 PRF; ~66°/s; 14 pulses), as well as NSF NCAR's S-POL (2.855 GHz; FA 1000 PRF; ~10°/s; 100 pulses) performance using the <u>same</u> weather simulation parameters (see table 2). Performance for different combinations of pulsing schemes and total number of pulses was computed and compared against the moment requirements.**

Table 1: APAR Simulation Parameters

	Parameter	Value(s)
Radar		
	Frequency	5.4 GHz
	PRF	Surv: 2000, Dopp & Dual-pol: 2,500
	Number of pulses per look angle	Surv: 4-10, Dopp: 6-20, Dual-pol: 72 (48,96)
	Number of realizations	10,000
Weather		
	SNR	30 dB
	V	5 m/s
	SW	2, 3, 4, 5
	Zdr	0.5 dB
	ρ_{hv}	0.99
	φ_{dp}	45º
	ldr	-20 dB

Table 2: Draft Performance Requirements

	|Bias| (currently stdev/4)	Stdev
SNR	0.3 dB	1.2 dB
V	0.25 m/s	1 m/s
SW	0.15 m/s	0.6 m/s
Zdr	0.065 dB	0.26 dB
ρ_{hv}	0.0055	0.022 (var = 0.000484)
φ_{dp}	0.425º	1.7º (Var = 2.89º)
ldr	0.525 dB	2.1 dB

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Results:

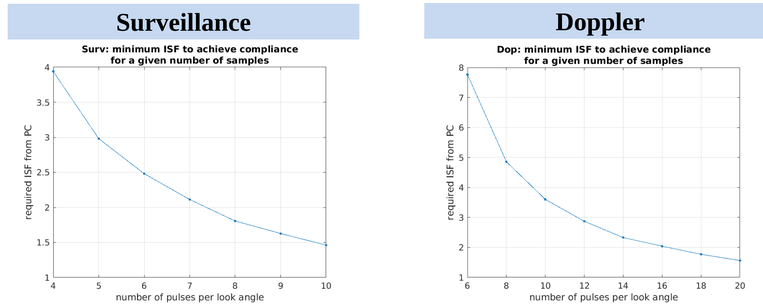


Figure 1: The x-axis is the total number of pulses per look angle, and the y-axis is the minimum ISF required so that there is at least ONE pulsing scheme that satisfies all required moments for that scan mode.

From these plots, we can see that if ISF=2.5. then 6 and 14 total pulses are required for surveillance and Doppler scans (resp.). Digging deeper, the compliant pulsing schemes have multiplexing of 10 and at least 4 (resp.).

Thus, total scan times for the surveillance and Doppler scans are 0.1320 and 1.1312 sec, resp., leaving 1.2368 sec for dual-pol (~75 total pulses per look angle; 72 are studied here since there are more pulsing schemes).

Dual-pol:

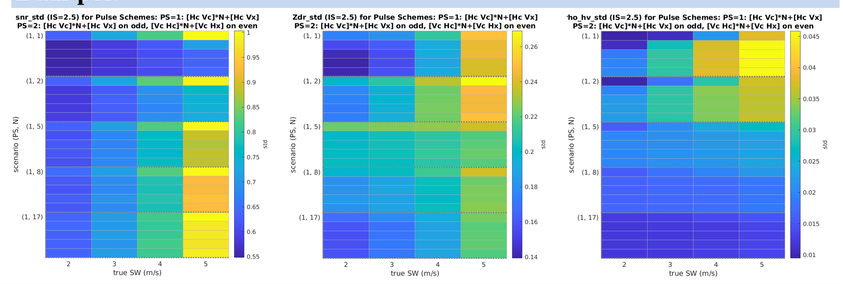


Figure 2: The x-axis is the input simulation W, and the y-axis is the different pulsing schemes. The 5 different rows per label correspond to multiplexing 1-5 beams. The color corresponds to the standard deviation of SNR (left), Zdr (center), ρ_{hv} (right). Note: the ISF=1 for these.

Note how different pulsing schemes are better suited for the different moments. This validates the approach taken in this study.

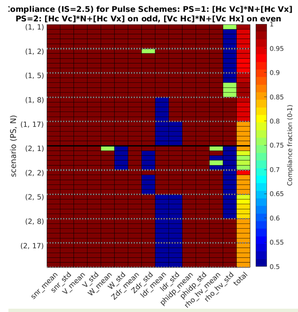


Figure 3: The x-axis is the different moment statistics and the y-axis is the different pulsing schemes. The color corresponds to the compliance ratio (1 means the statistic is fully compliant).

No tested pulsing scheme is fully compliant, though some are very close, only "failing" on one moment. Ldr and ρ_{hv} are the main drivers.

Examples of dual-pol pulsing schemes that are close: pulsing sequence is [Hc, Vc, Hc, Vx] with no multiplexing (i.e. 1) *or* pulsing sequence is [Hc, Vc] repeated 8x followed by [Hc, Vx] (i.e. 18 pulses per visit) with any value of multiplexing (i.e. 1-5)

Options for dual-pol scan to becoming fully compliant:

1) **increase the total number of pulses per look angle (e.g. fewer look angles or more time for dual-pol)**
2) **increase ISF to 2.75 - pulsing sequence: [Hc, Vc] repeated <u>5</u>x followed by [Hc, Vx] with multiplexing of 3 or 4**
3) **alter the moment requirement (e.g. relax Ldr and/or ρ_{hv})**

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