Effects of Finite Pulse Length in SweepSAR Systems

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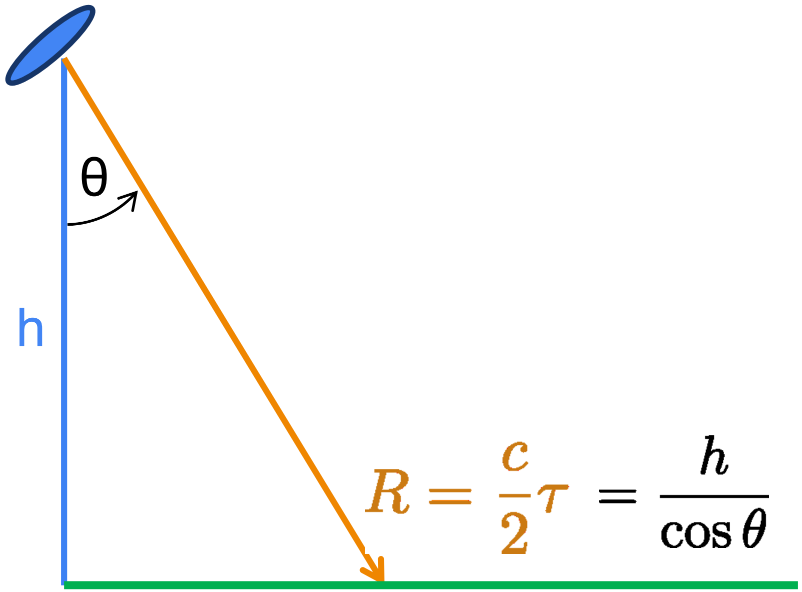
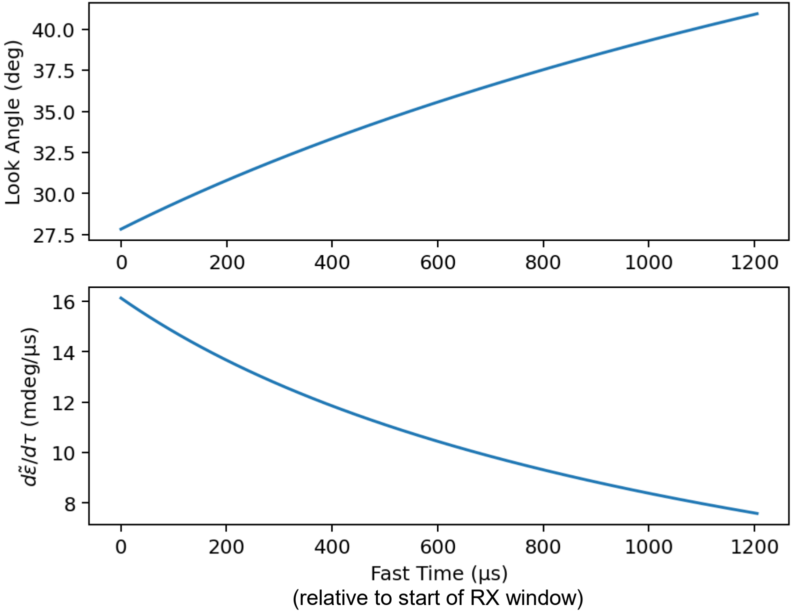
Introduction

- Upcoming NASA-ISRO SAR (NISAR) mission will use novel beamforming techniques to achieve high-resolution wide-swath imaging.
- New challenges with respect to calibration!
- This talk concerns issues related to finite pulse length.
    - What are the effects?
    - What can we do about it?
    - What should we do about it?

Radar Geometry and Timing



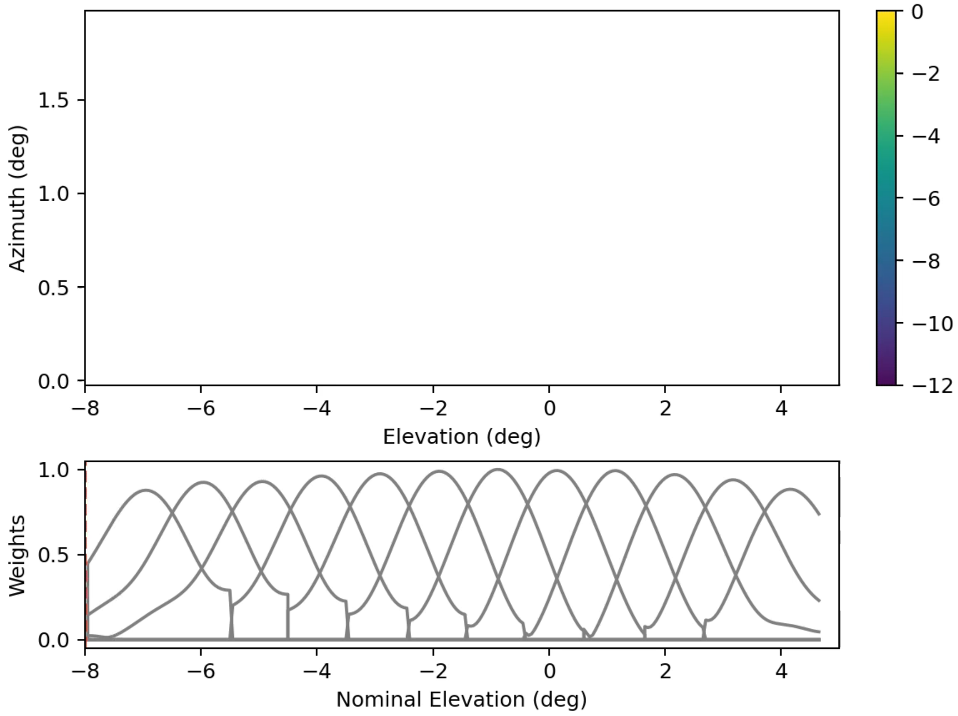
$$R = \frac{c}{2}\tau = \frac{h}{\cos\theta}$$



When the height above the ground is known, there’s a simple geometric relationship between the range (fast time) and direction of arrival θ.

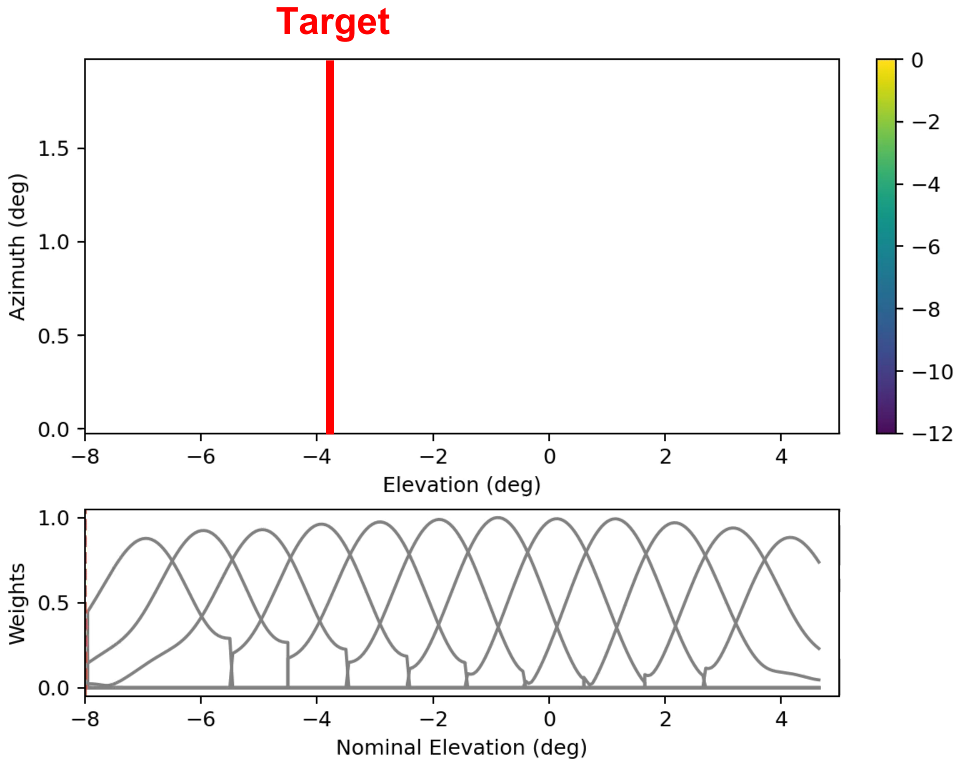
SweepSAR / Scan-on-Receive (ScoRe)

- L-band instrument has 12 transmit/receive modules (TRMs) feeding a 12 m circular reflector.
- All TRMs emit simultaneously on transmit, illuminating a small spot on the reflector and thus a large swath on the ground.
- On receive, steer a narrow beam to follow the desired echo (and suppress range ambiguities).



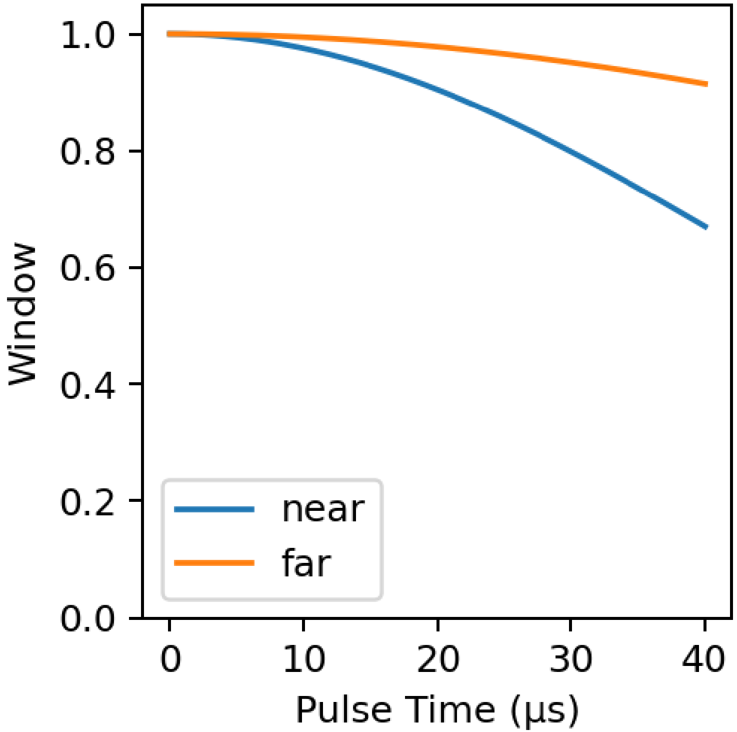
Finite Pulse Length

- DBF implemented on raw data (not range-compressed) so must consider duration of transmit pulse
- Takes a finite amount of time to record echo from a given target.
- Beam is sweeping continuously!
- Envelope is modulated because beam pattern is changing while the echo is coming in.



Reviewed and determined not to contain CUI.

Finite Pulse Length



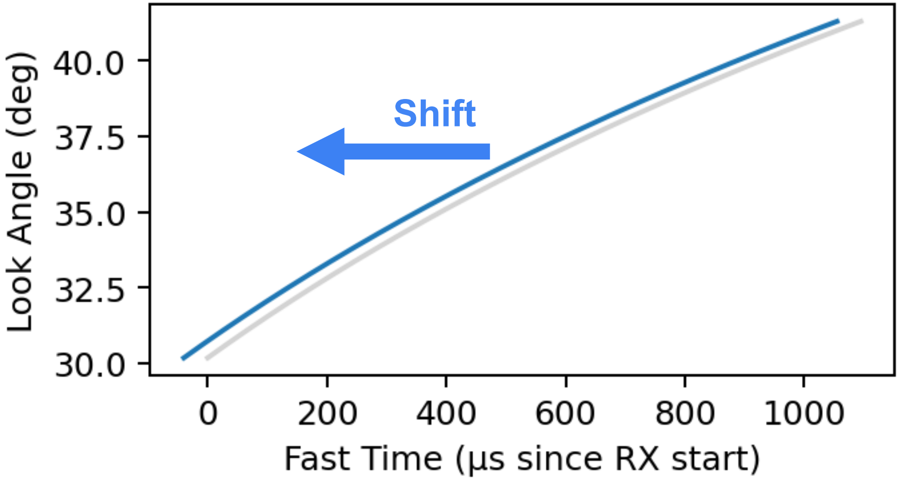
- Droop caused by radar beam sweeping over target while recording its echo.
- Beam sweeps faster in near range than far range.
  - Effects are **range-dependent**.
- For given antenna size, beam width is proportional to wavelength.
  - Effects are **frequency-dependent** (more severe at S-band than L-band for NISAR)

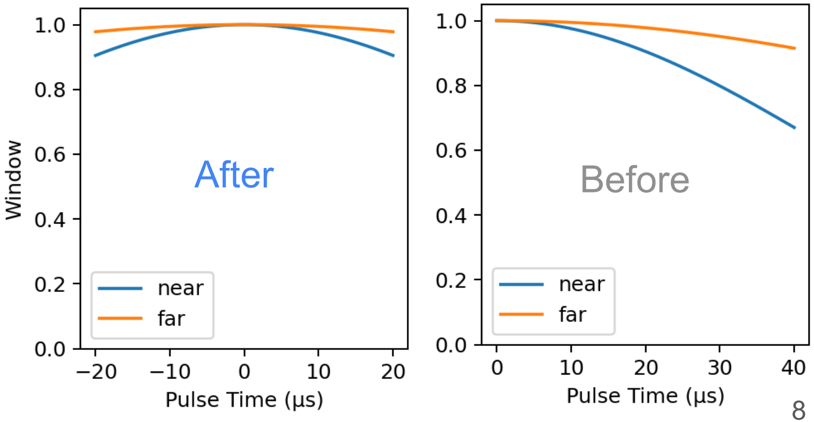
What to do about it?

- Use shorter pulses!
  - Max chirp length planned for NISAR (L-band) is 40 μs
- Adjust SweepSAR steering law
- Compensate loss (“pulse extension loss”)
- Compensate shape

Steering Law Adjustment

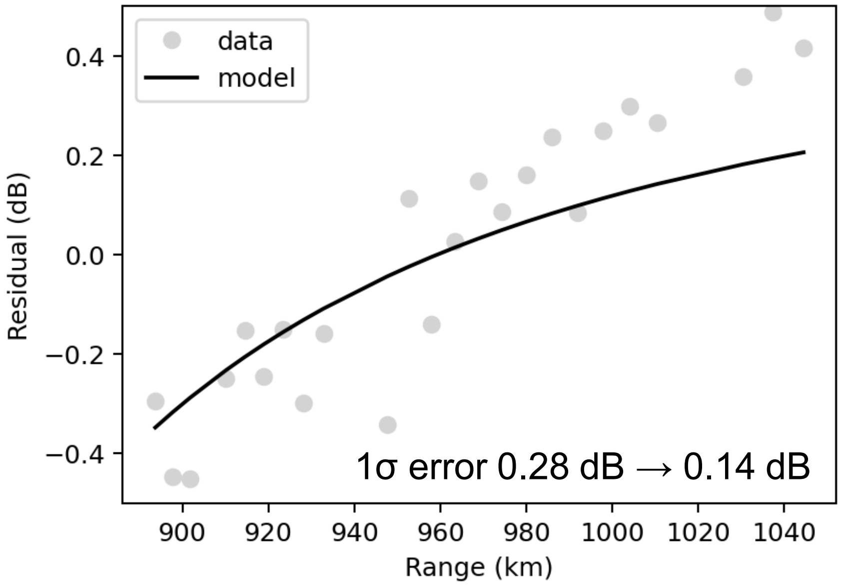
- Calculate steering so that beam arrives at a given angle **earlier** so that max gain occurs in **middle** of echo.
- Ideal adjustment would be range-dependent (following sweep rate), hence new curve for every pulse width.
- Simpler adjustment is to shift whole curve by half chirp duration.
- NISAR (L) currently does neither.





Compensate Loss

- Calculate overall gain loss as a function of range and remove from imagery, like elevation antenna pattern compensation.
- Closed-form expressions in literature for rectangular apertures.
- Derived here for Gaussian beam approximation, which allows closed-form expressions using Gauss error function.
- Depends on beam shape parameter and angle subtended during chirp

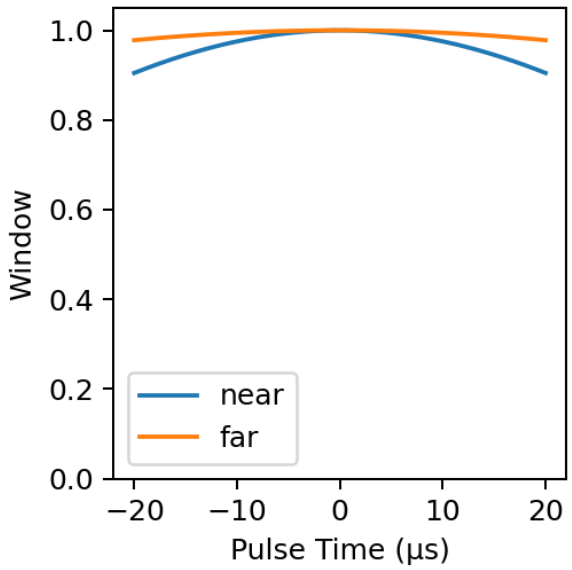


Naive steering [redacted]

Centered steering [redacted]

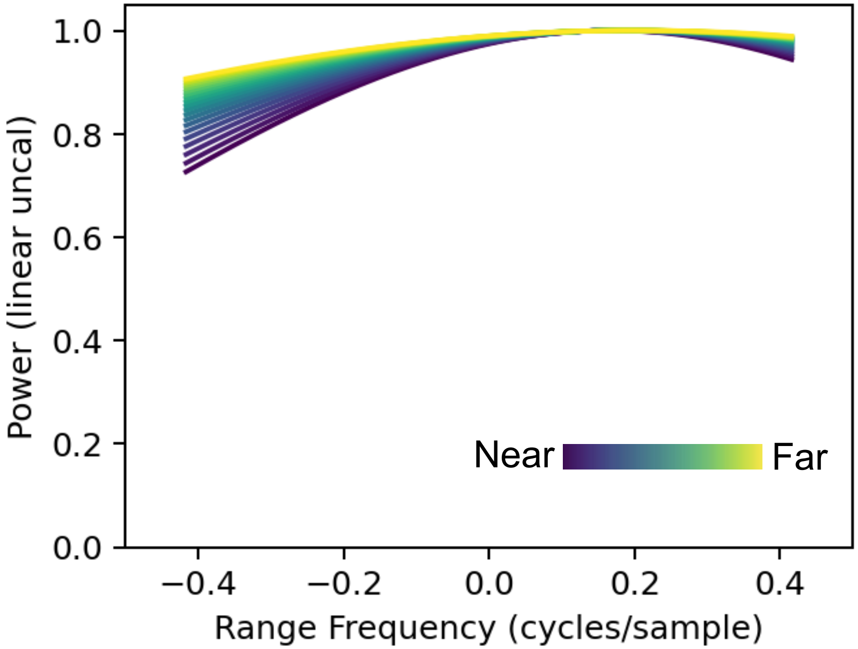
Compensate Shape: Centered Steering

- Range-dependence means we can't easily use fast convolution with FFTs.
- Helpful observation: We want to apply an apodization window anyway!
  - Don't need to get back to a flat spectrum, just want the same spectral shape at all ranges.
- Raised cosine windows are a 3-tap filter in time-domain.
- Easy to design: Pick pedestal height based on ratio of actual and desired amount of "droop"
- Reasonable computation cost: 3MN multiplies for an image with M pulses and N range samples.
- Hard to achieve perfectly centered steering due to continuously varying altitude and terrain.



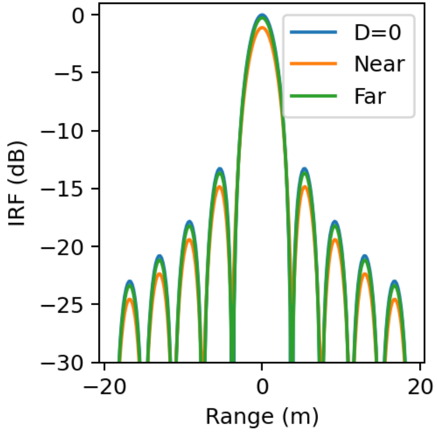
Compensate Shape: General Steering

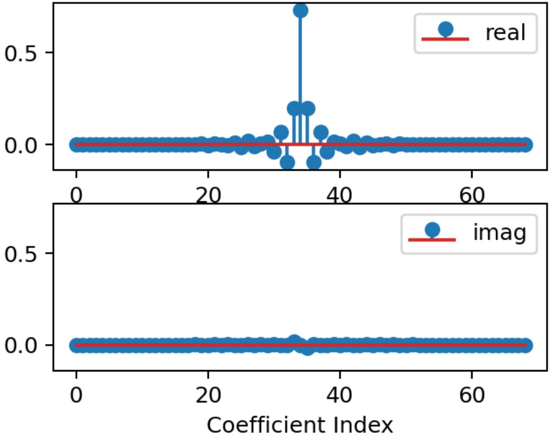
- Asymmetry complicates filter design. Consider one approach:
  - Define desired passband response as ratio of desired window to modeled “sweep over” modulation.
  - Use Parks-McClellan algorithm to design a band-pass filter with desired shape at 2x sample rate.
  - Shift the passband to baseband
  - Lowpass filter and decimate 2x

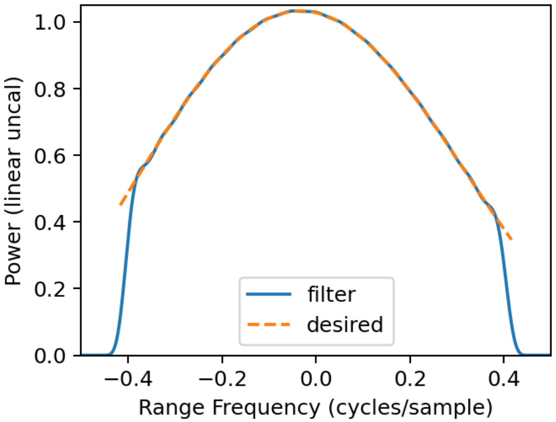


Compensate Shape: General Steering

- Solve N numerical filter design problems.
- Filters are long: K≈70 for NISAR scenario.







- Applying filters takes KMN ops
  - Several times more expensive than range compression, for example.
- A lot of work for marginal payoff!

Reviewed and determined not to contain CUI.

Conclusions

- Finite pulse lengths pose challenges for SweepSAR / SCORE systems.
- Simplest mitigation is to use short pulses.
- Steering law can be modified improve signal-to-noise ratio (SNR) and impulse response function (IRF) relative to “naive” steering.
- Radiometric corrections are straightforward.
- Compensating IRF is possible but challenging.