Synthetic Aperture Position Errors

P. Vouras

July 8, 2020

Overview

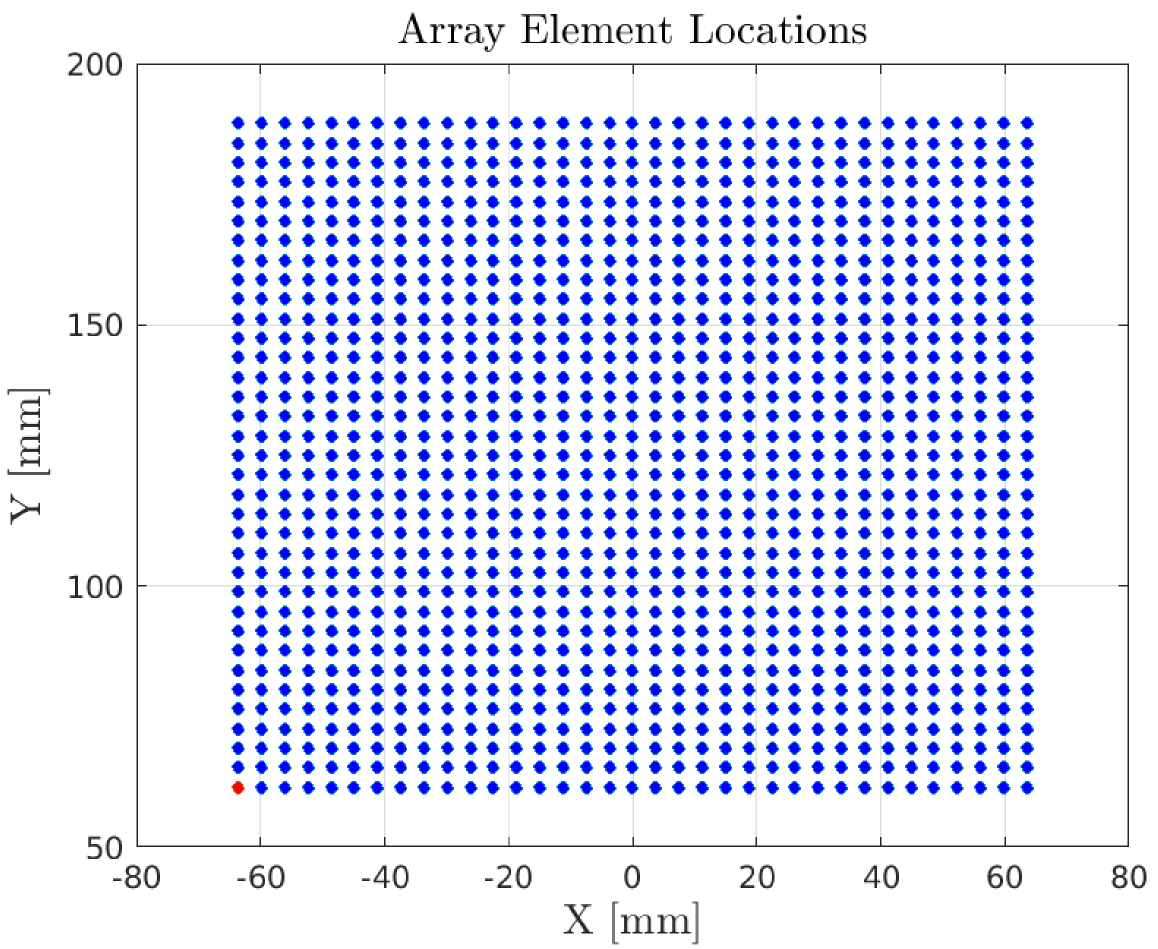
- Impact of position errors in synthetic apertures for channel sounding
- Impact of position errors in synthetic aperture radar
- Compensation techniques
  - With sensor feedback
  - Without

Error Definitions

- robot tip reported position = tip true position + sensor (camera) error
- robot tip true position = tip desired position + position error
- tip reported position = tip desired position + sensor error + position error
- total error = tip reported position – desired position = sensor error + position error
- array model error = reported position – true position = sensor error
- array perturbation error = true position – desired position = position error

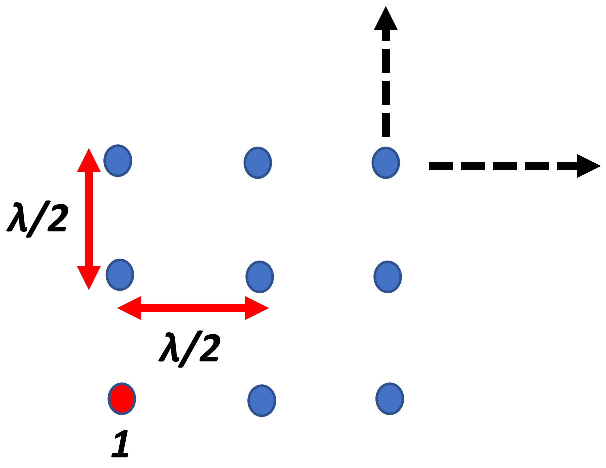
- ***For a beamforming or angle analysis only the position errors relative to a reference element are important***
- ***For a path length analysis the absolute position errors are important***
- ***The total error is embedded in the beamforming steering vectors***

Array Sampling Trajectory

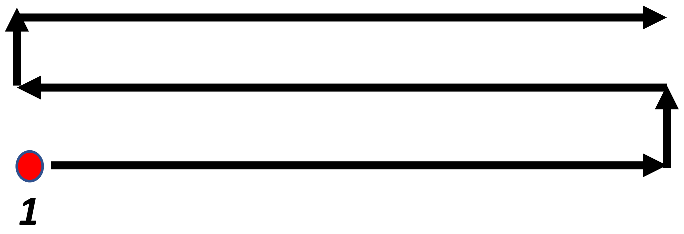


Red dot in left corner is first sample and reference element

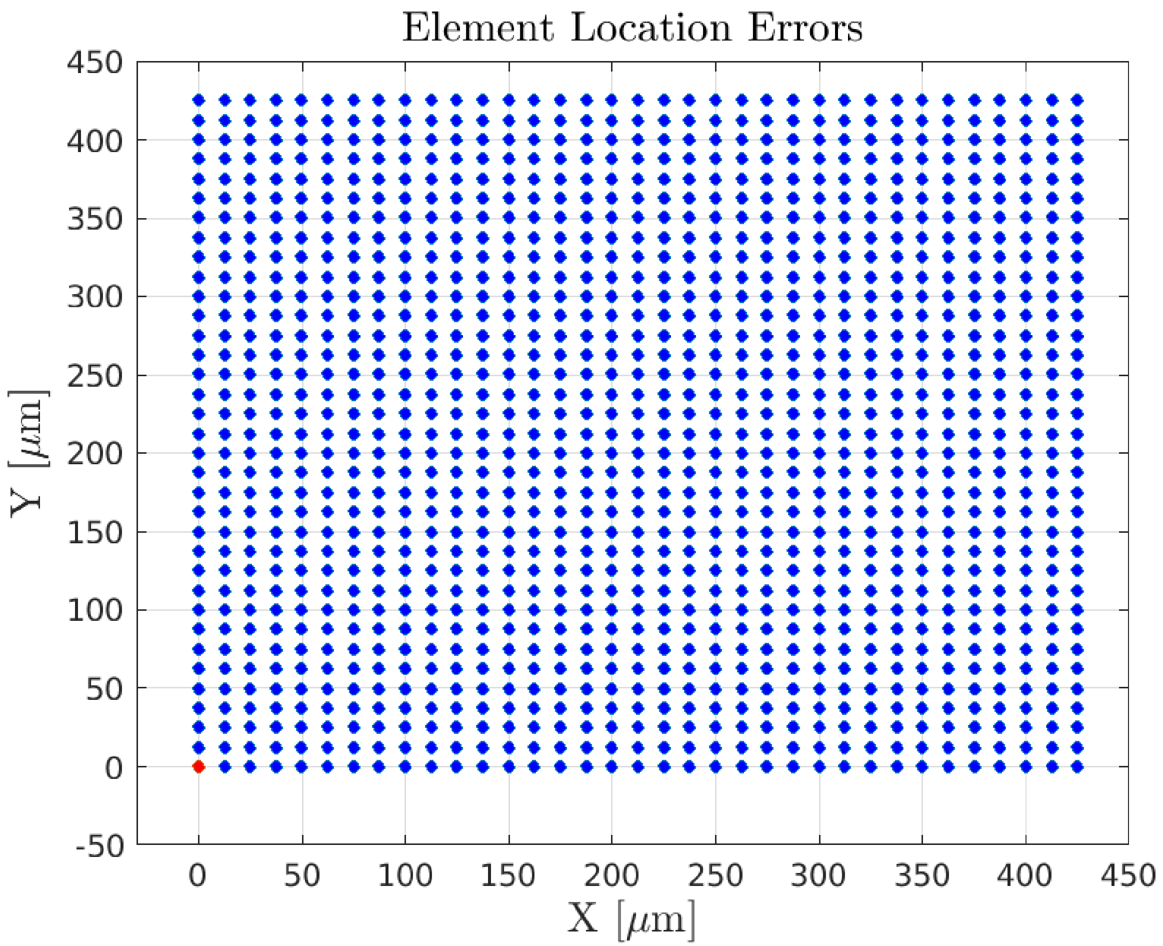
Ideal Rectangular Lattice



Zig-Zag Sampling Trajectory



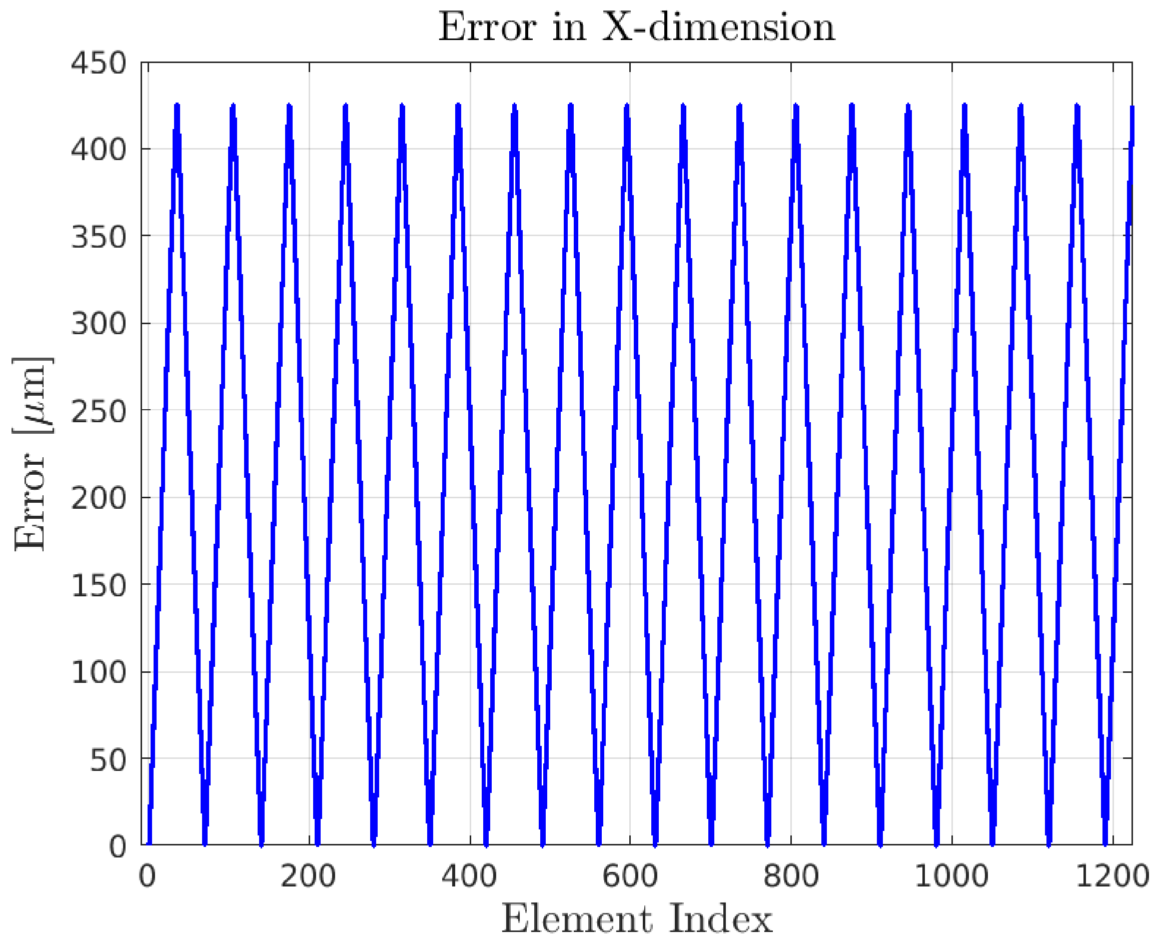
Measured Position Errors



- Max x error = 425 microns
- Max y error = 425 microns
- Mean x error = 212.5 microns
- Mean y error = 212.5 microns
- λ/50 @ 40 GHz = 150 microns

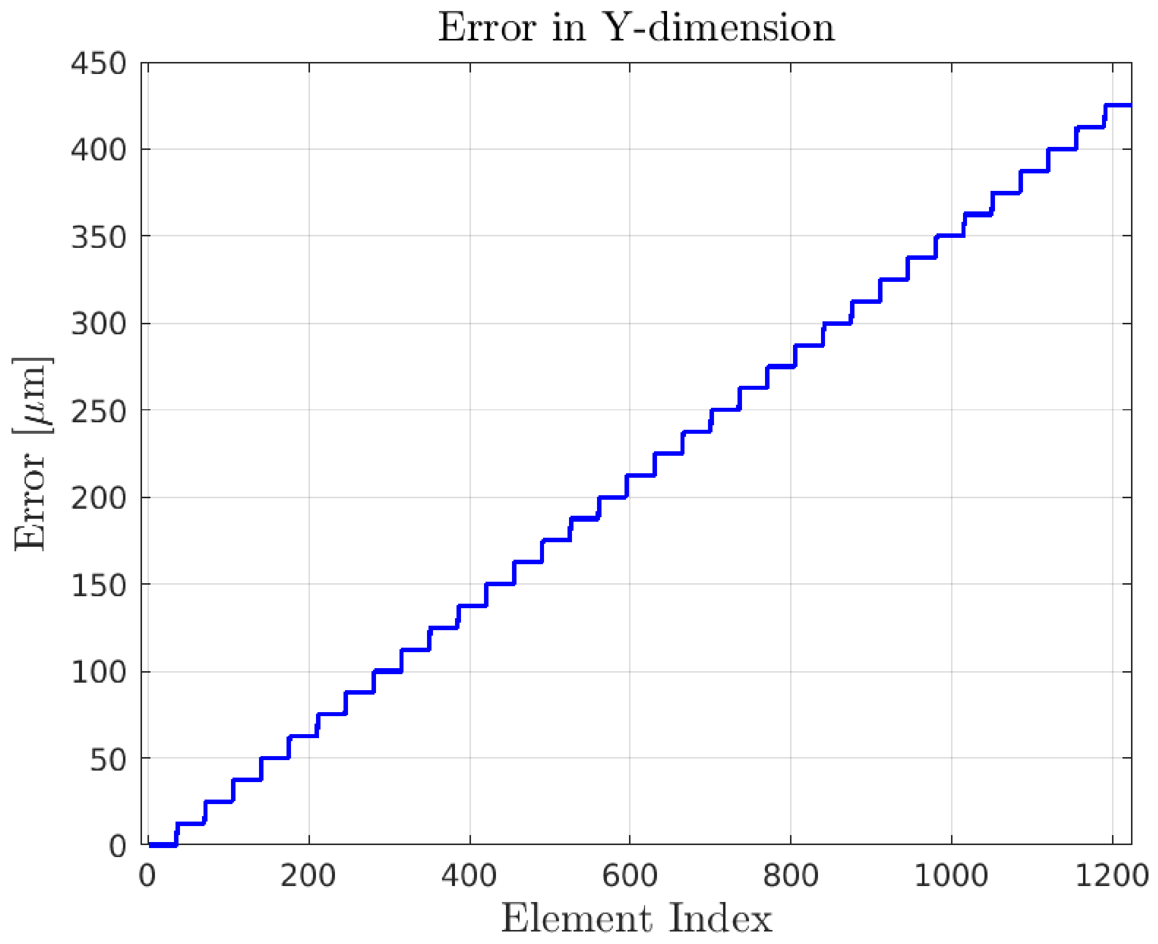
- ***The errors shown correspond to total error = reported position – desired position***
- ***The errors are clearly correlated since all the elements in the same column have the same x error and***
- ***All elements in the same row have the same y error***

Error Trajectory – X Direction



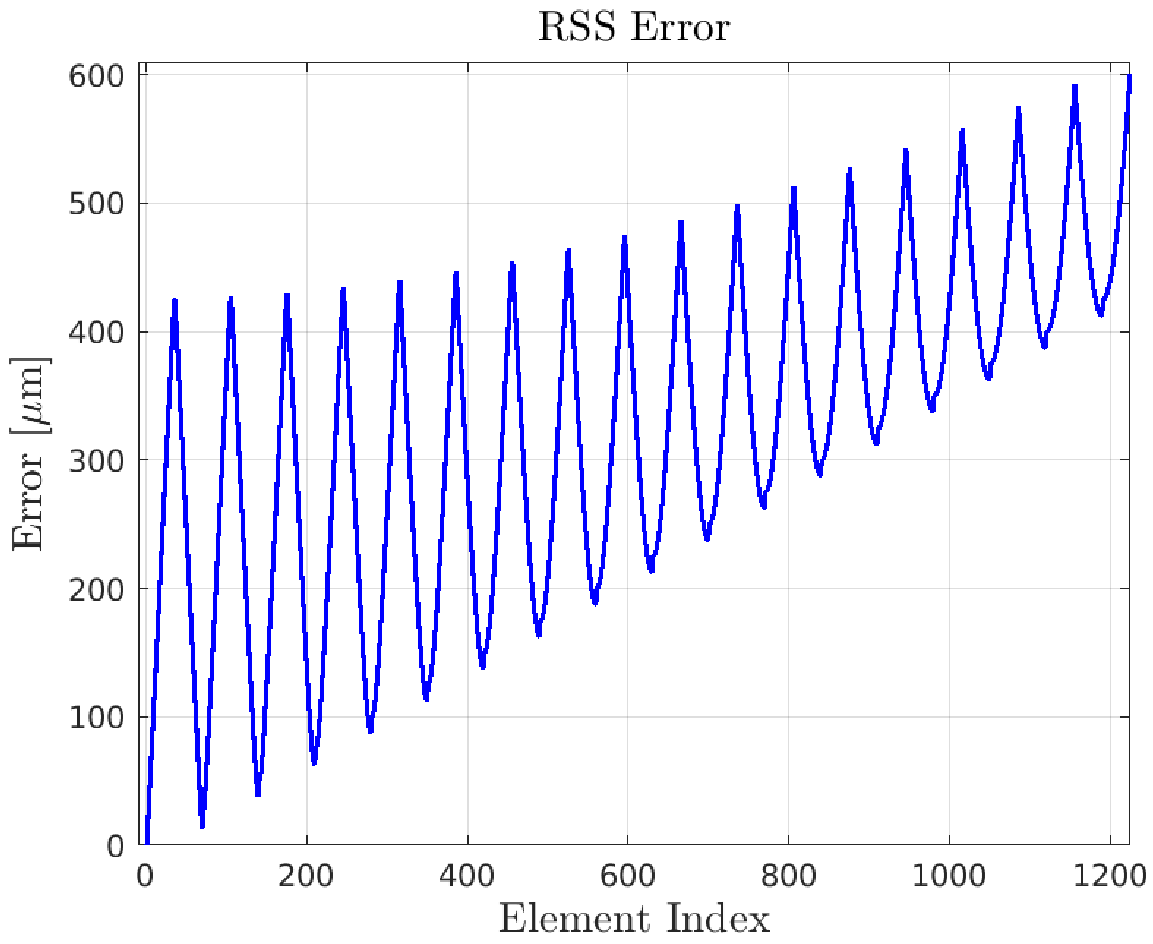
- ***In the x-direction the total error increases linearly as the tip moves farther away from the initial position***
- ***And then the error decreases linearly at the same rate as the tip moves back towards the initial position***

Error Trajectory – Y Direction



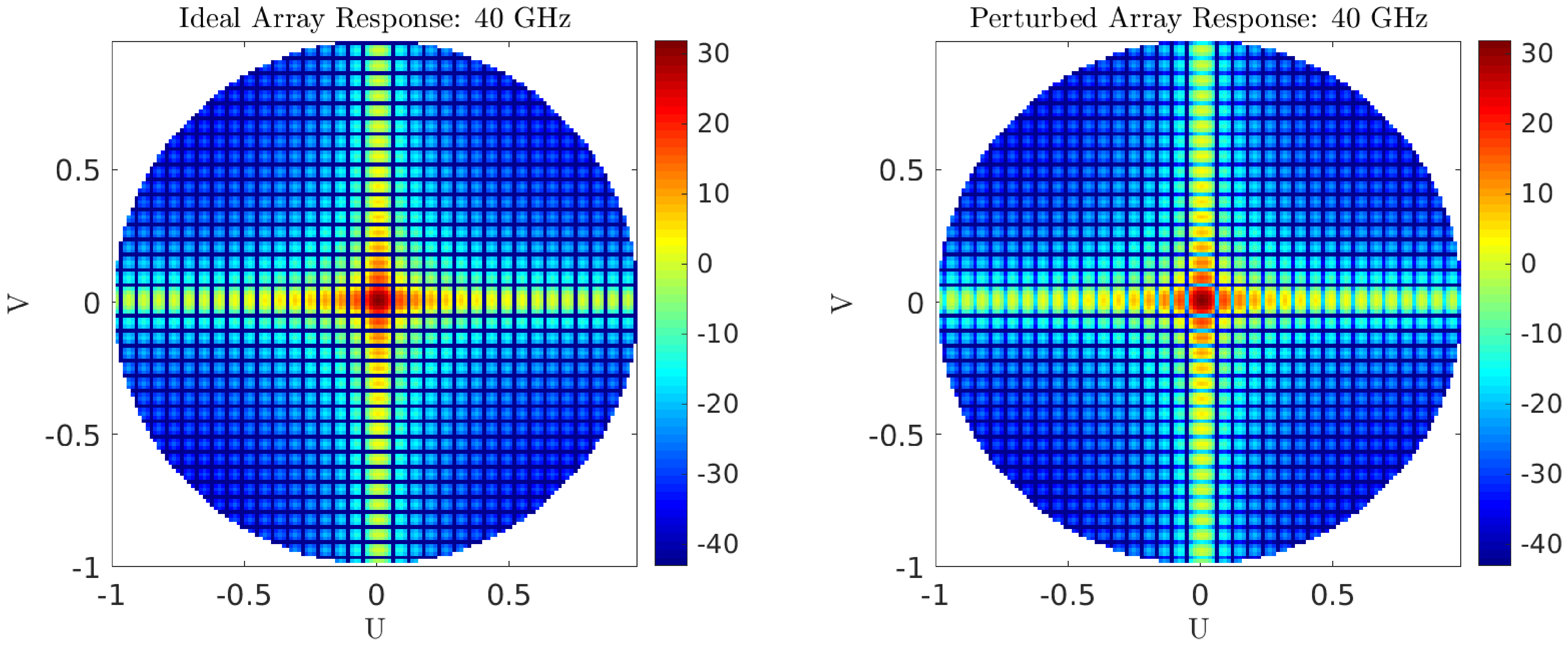
- ***In y-direction the total error increases in step-like fashion because it is constant along each row of the zig-zag***
- ***Again the total error is proportional to the distance traveled from the reference element***

Root-Sum-Square Error



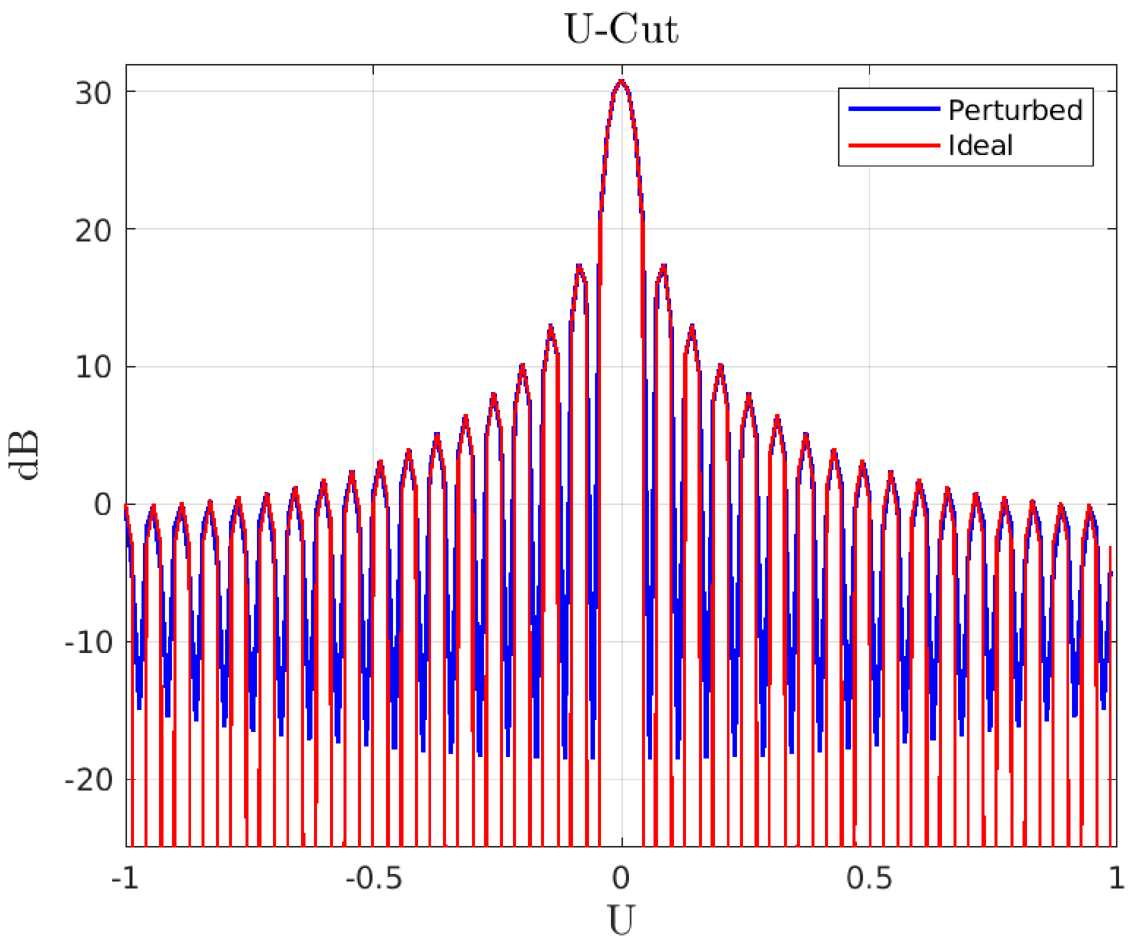
- ***RSS error = sqrt(x_error^2 + y_error^2)***
- **The RSS error is periodic with an increasing trend as the tip moves farther away from the initial element**

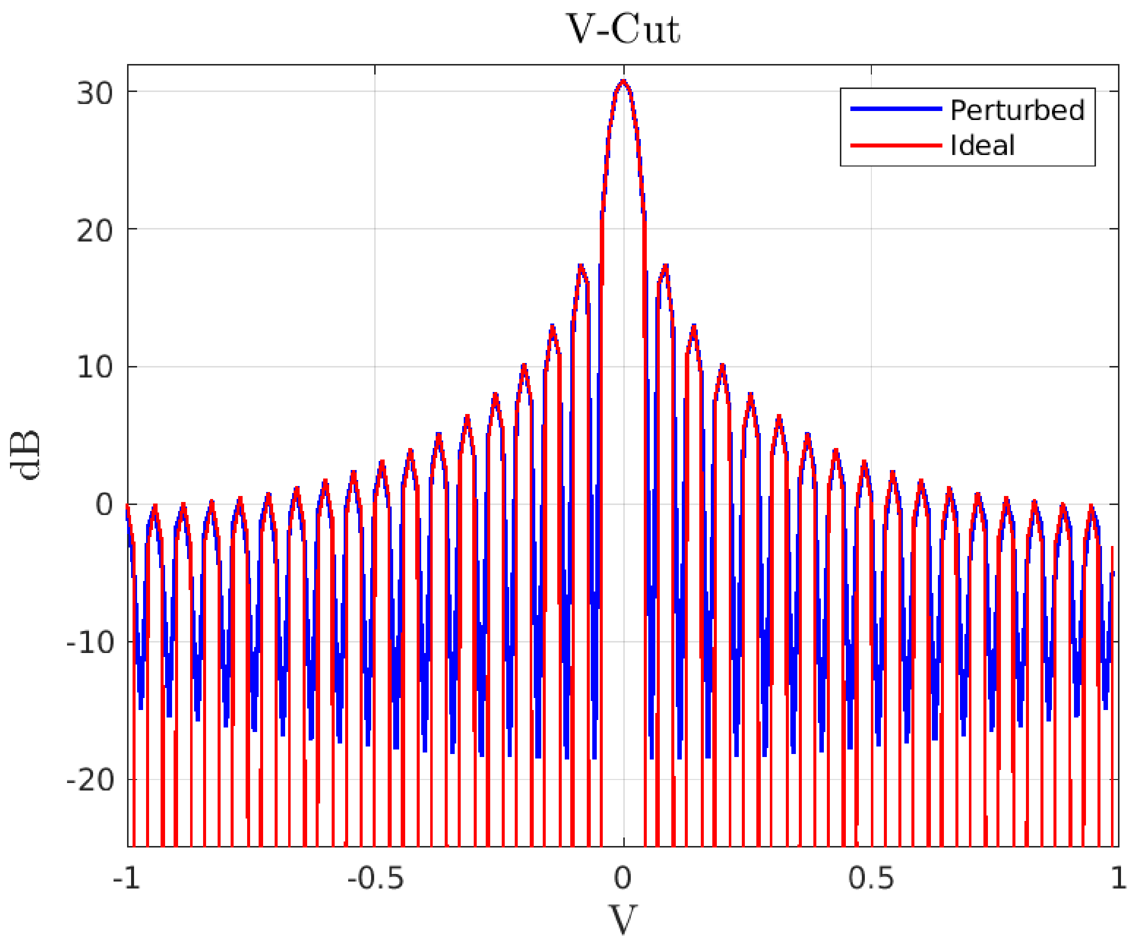
Effect on Array Response



- *On close inspection one can see that the errors manifest themselves most visibly in the principal sidelobe region*
- *The sidelobe nulls are filled in and not as deep as the ideal pattern*

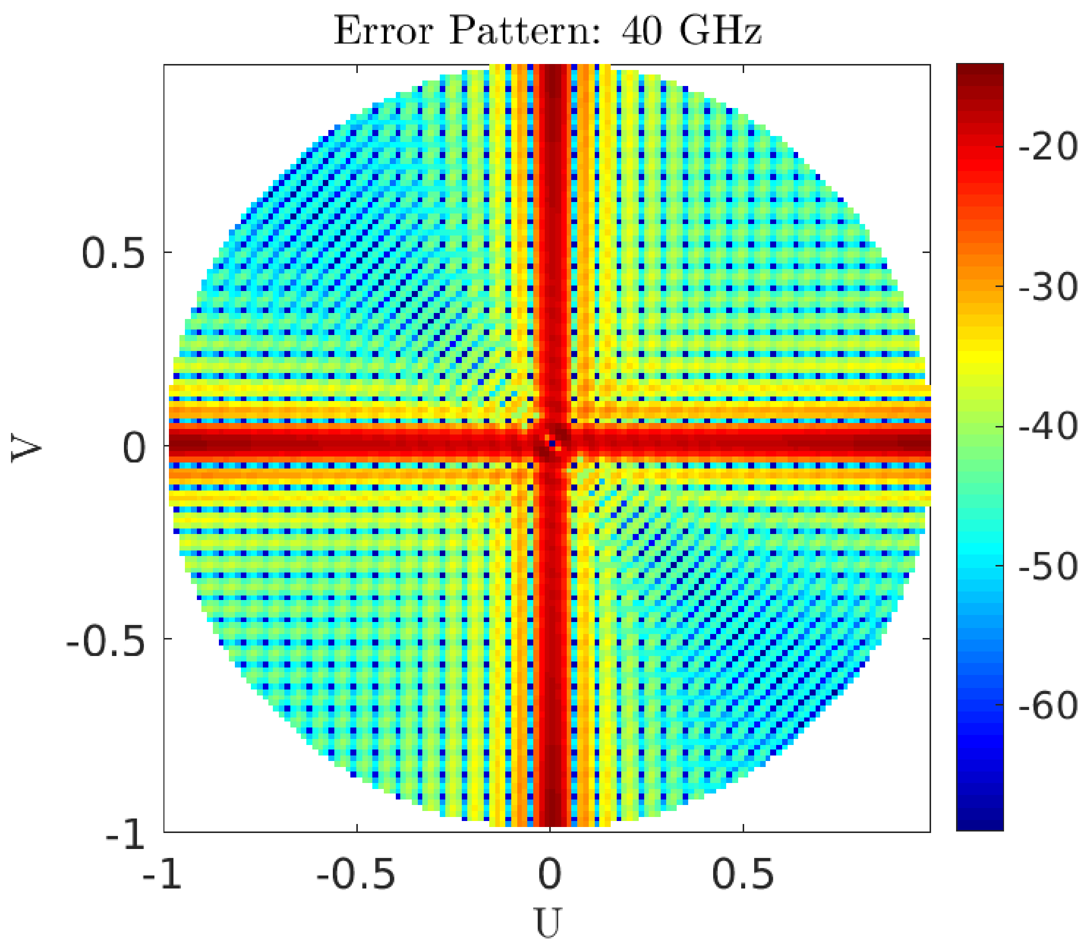
U and V Cuts

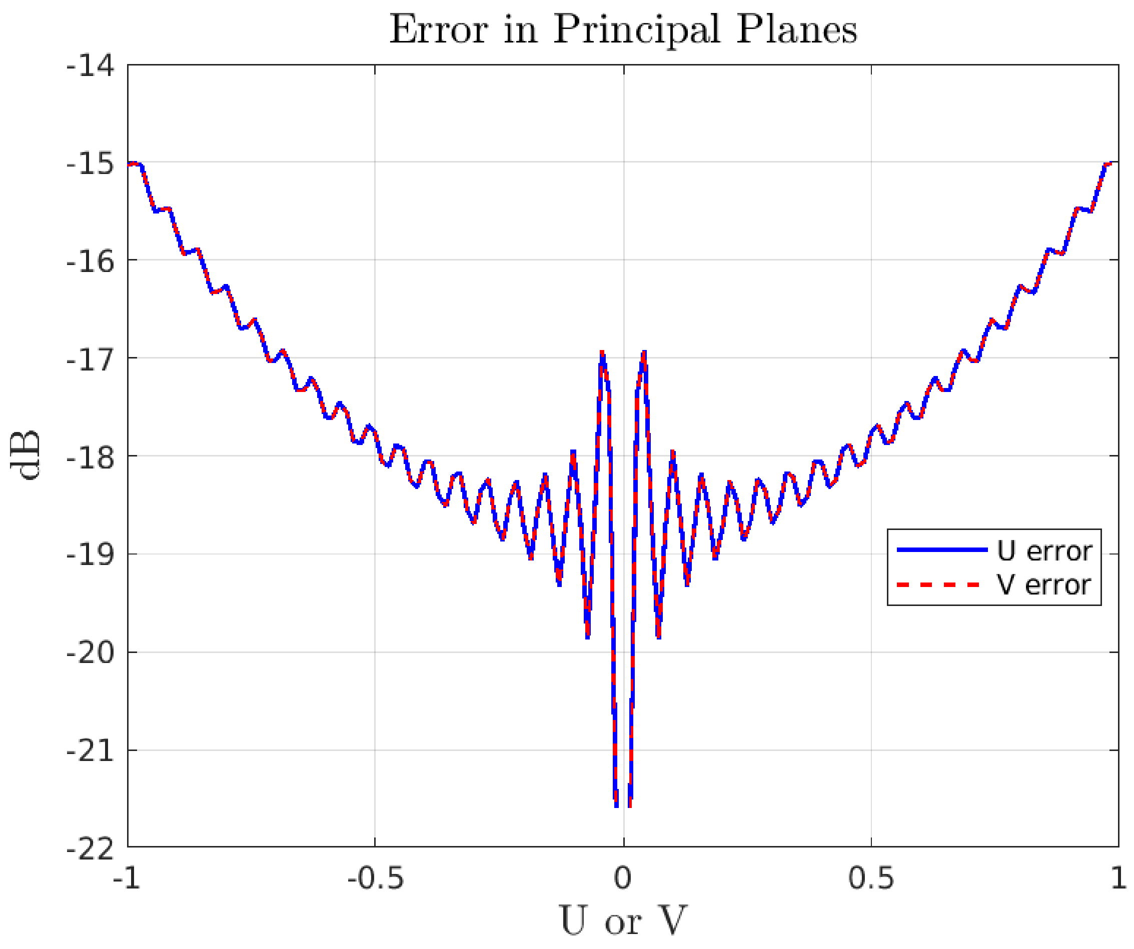




- ***The sidelobe nulls (red) in the ideal pattern go to zero (<-300 dB)***
- ***The depth of the sidelobe nulls in the perturbed pattern is limited***

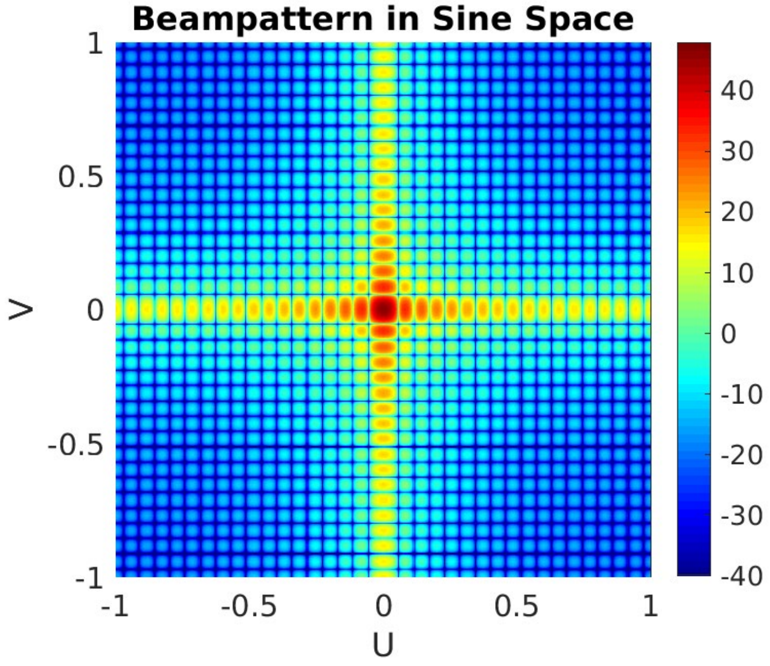
Error Pattern

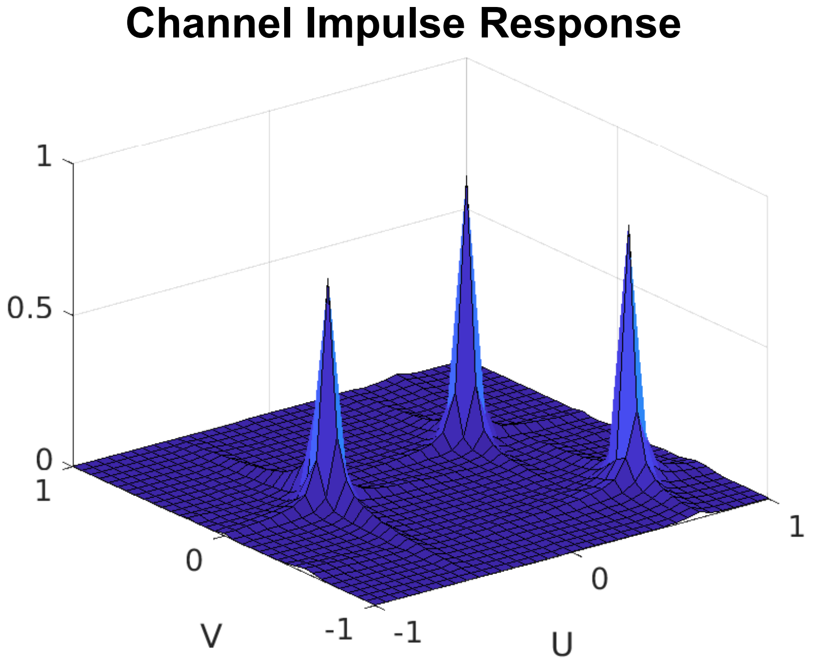


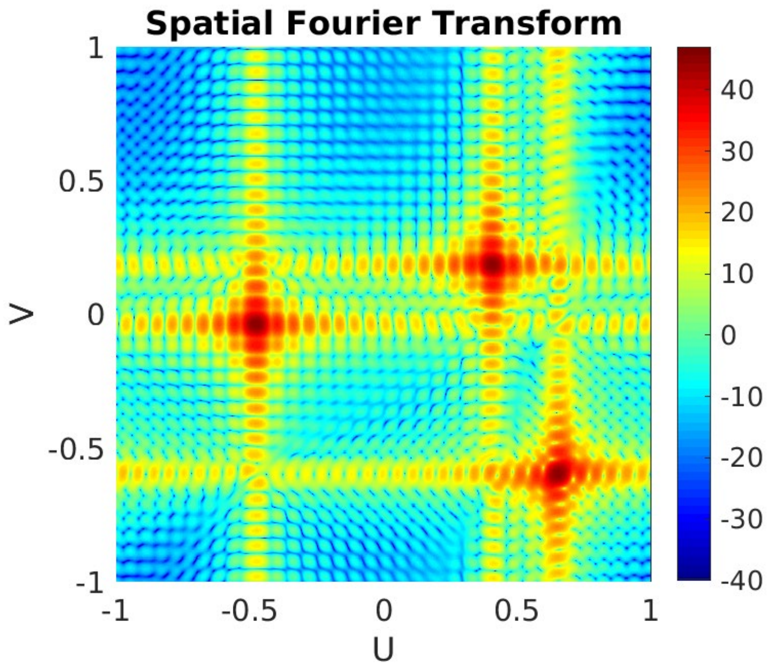


- ***Error pattern = ideal array response – perturbed array response***
- ***There is no error exactly at arry boresight (u=0, v=0)***

Array Response Convolves CIR

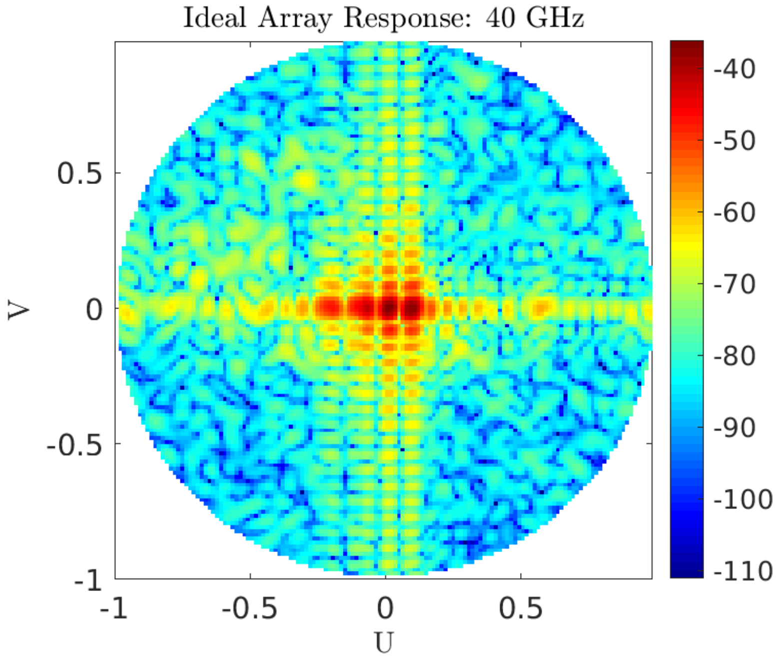




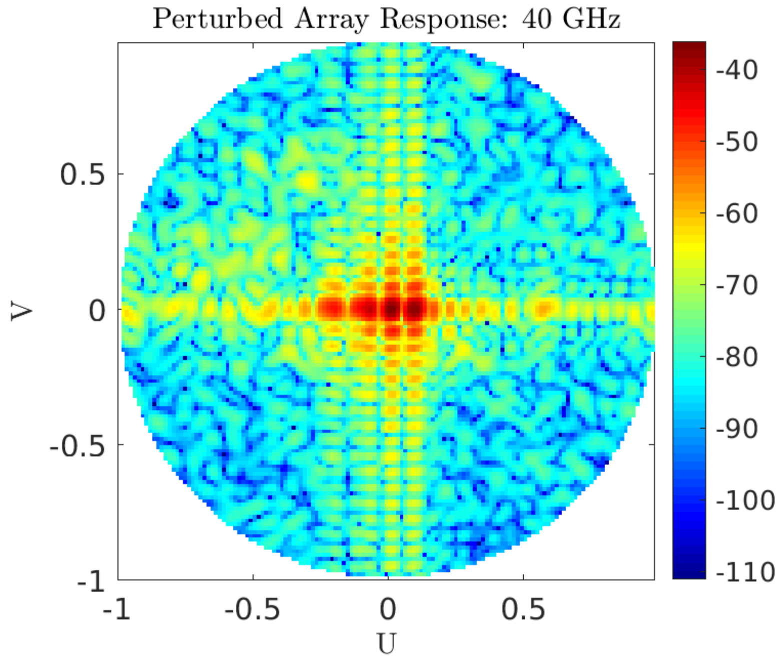


Measured Data

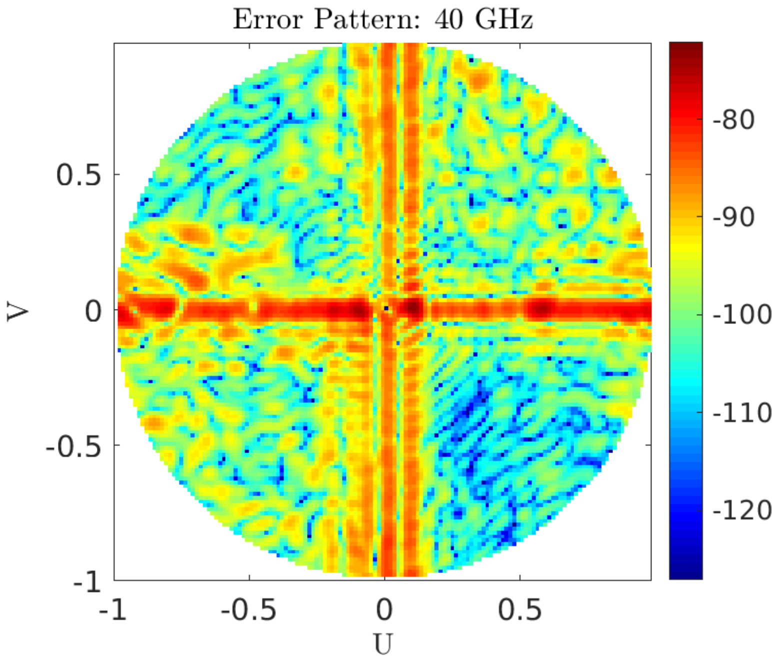
Data processed with ideal lattice



Data processed with perturbed lattice



Difference



- ***Perturbations in the array manifold will manifest in the principal plane sidelobes of discrete scatterers***
- ***In high dynamic range systems, if a signal source is strong enough, these errors will be visible***

Observations

- The analysis presented was for a narrowband sinusoidal tone
  - In wideband systems that perform a temporal IFFT these errors will also appear in the delay domain

- Position errors are linearly related to distance traveled by the robot tip relative to a reference location

- Position errors are correlated across the aperture

- The choice of initial starting point and sampling trajectory will affect how correlated and how large the total errors are
  - Is it better to start the sampling trajectory from center of the array?
  - Will a random walk to all array positions decorrelate the errors?

Generalization and Corrective Action

- A comparable analytical framework also applies to synthetic aperture radar deployed on a moving platform
- If the actual sampling lattice is perturbed from ideal, what corrective action can be performed to bring the image back into focus?
  - With a sensor available that estimates actual sample positions
  - Without a sensor
- Where do the interests of the Synthetic Aperture TWG align?