SAND2015-2883C

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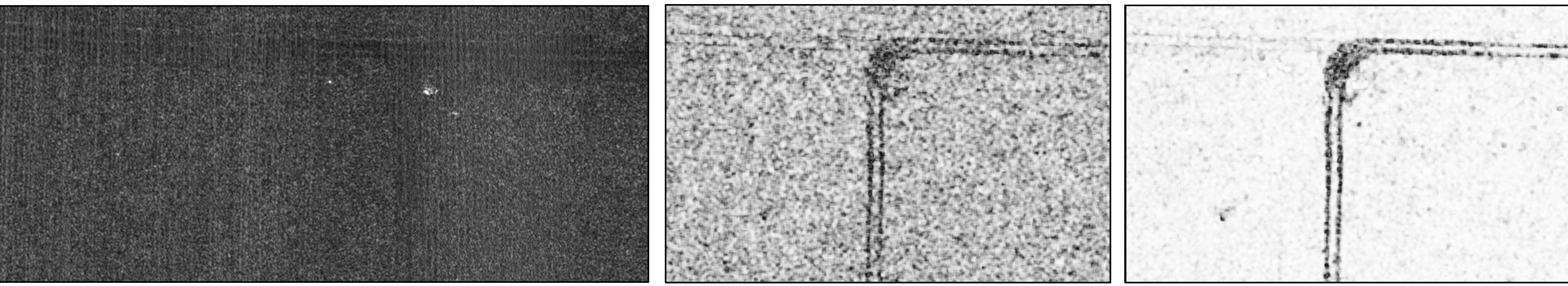

# Application of Equalization Notch to Improve Synthetic Aperture Radar Coherent Data Products


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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration


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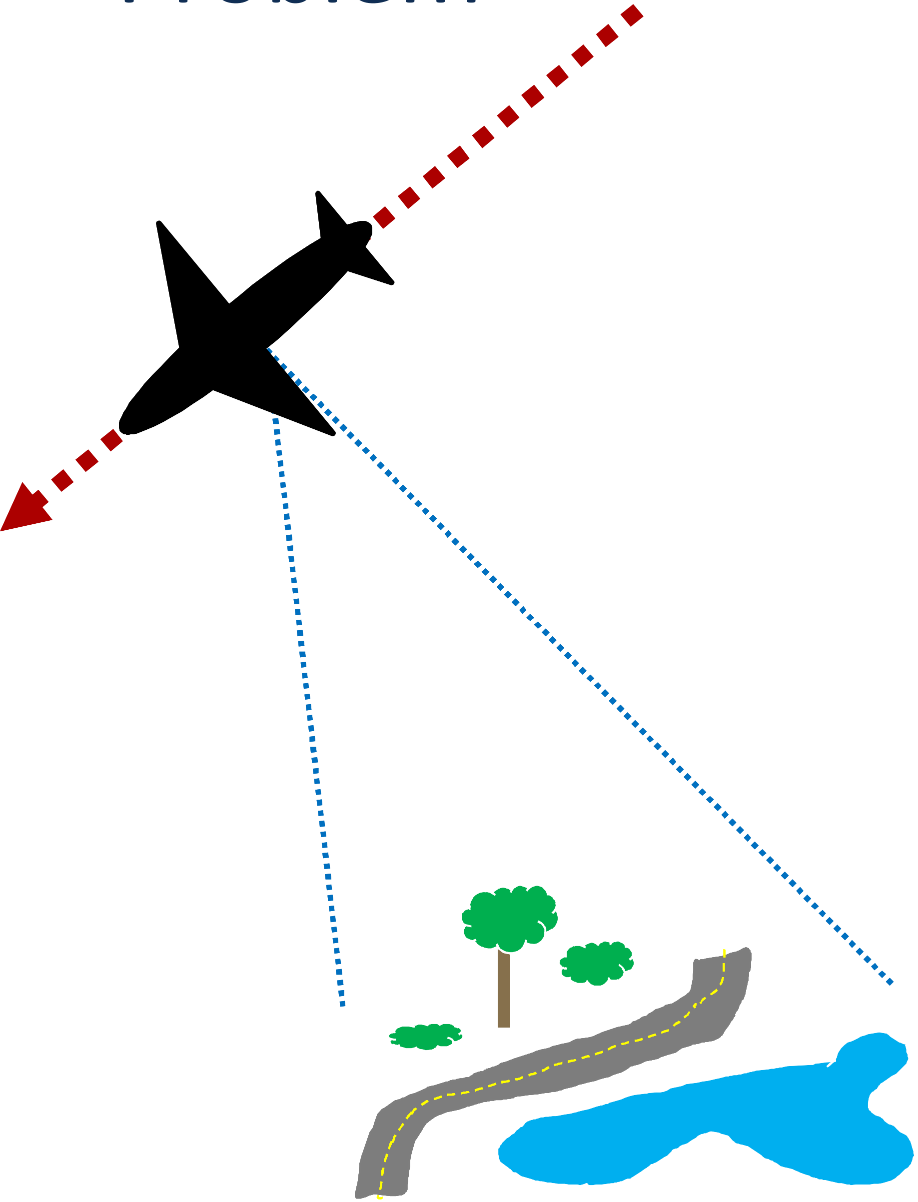
# Motivation

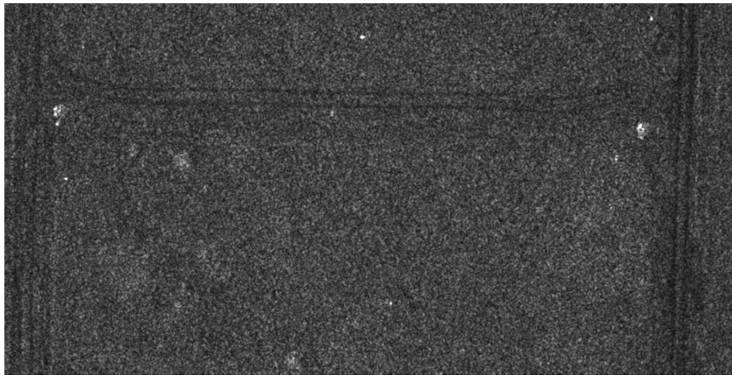
- Interference in radar comes from many potential sources, primarily depending on the radar bandwidth
  - Communications providers searching for more bandwidth at higher frequencies[1]
  - Other radar systems[2]
- For many radar systems it is the coherent data products that are of the most value.
  - IFSAR applications
  - CCD applications
- The challenge becomes what can we do in the presence of interference to maintain the quality of the imagery and coherent data products?

1-Rappaport, T., Roh, W., and Cheun, K., “Mobile's millimeter-wave makeover," IEEE Spectrum 51, 34-58 (Sept. 2014).
2-Meyer, F., Nicoll, J., and Doulgeris, A., “Correction and Characterization of Radio Frequency Interference Signatures in L-Band Synthetic Aperture Radar Data,” IEEE Transactions on Geoscience and Remote Sensing 51(10), 4961-4972 (2013).

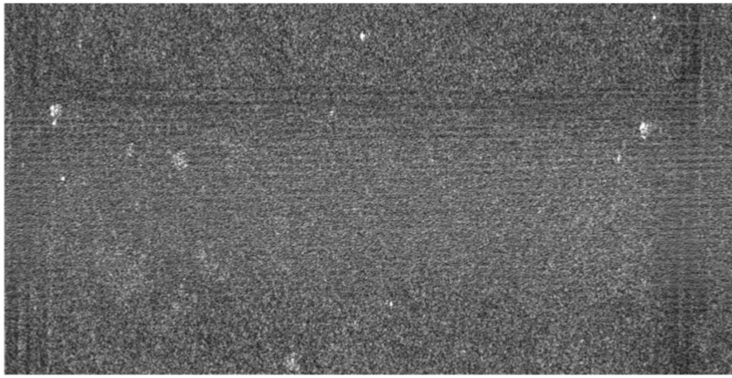
# Problem



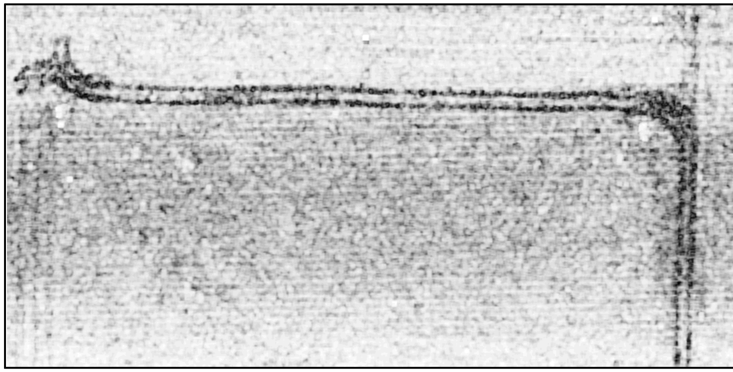
Pass 1



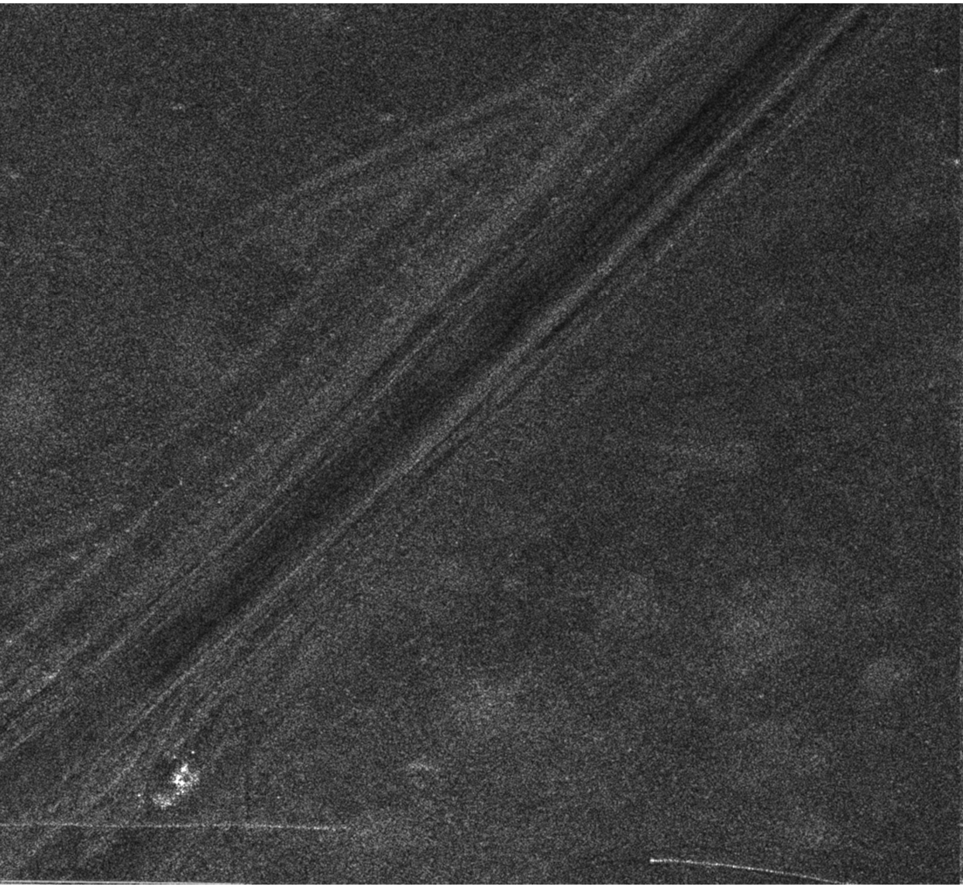
Pass 2



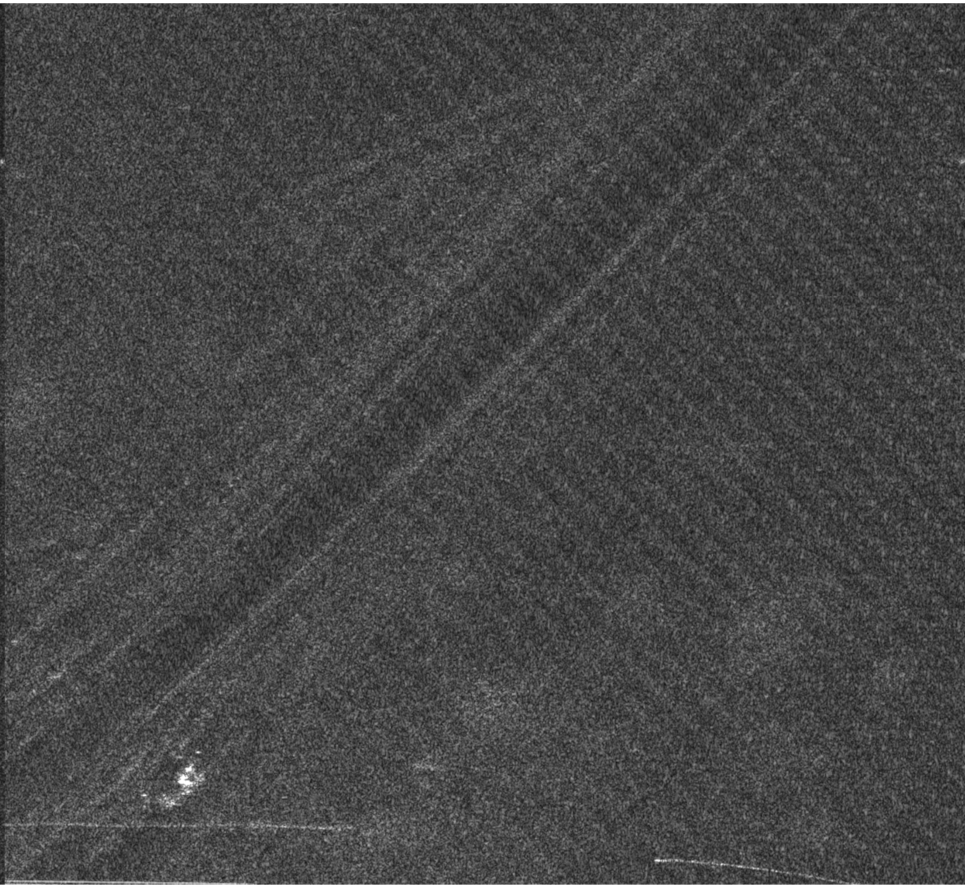
Coherent Change Detection (CCD)



# Interference Effects: Image

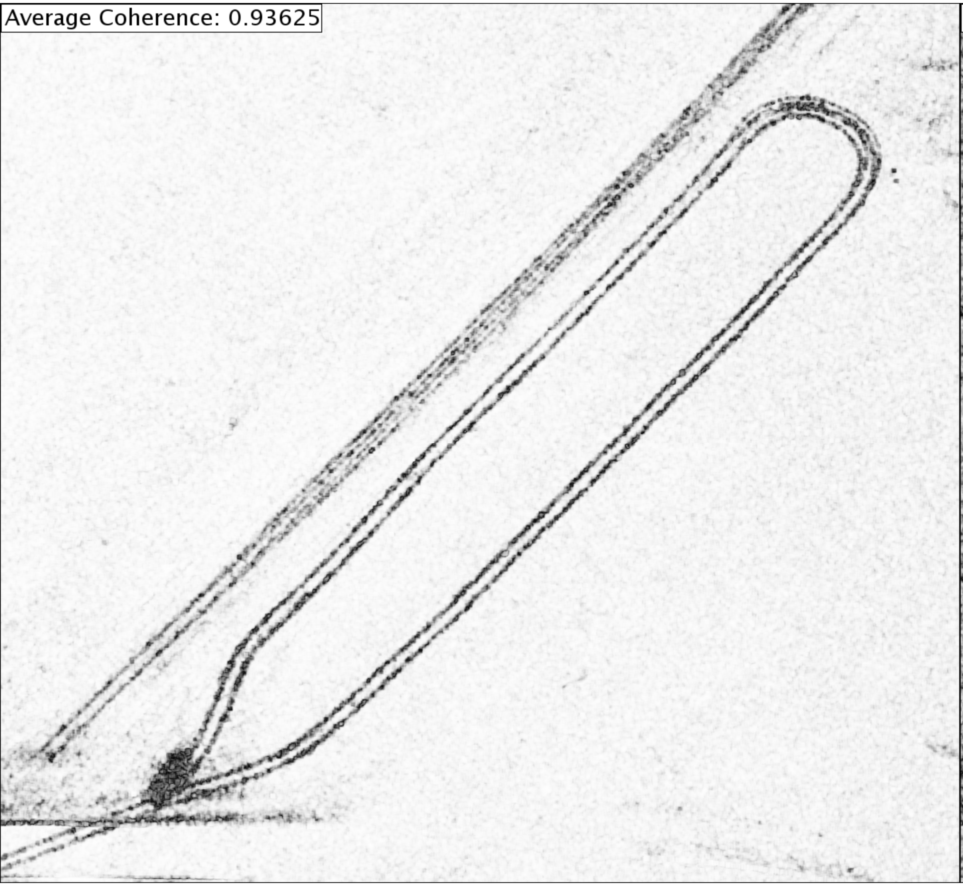


No Interference

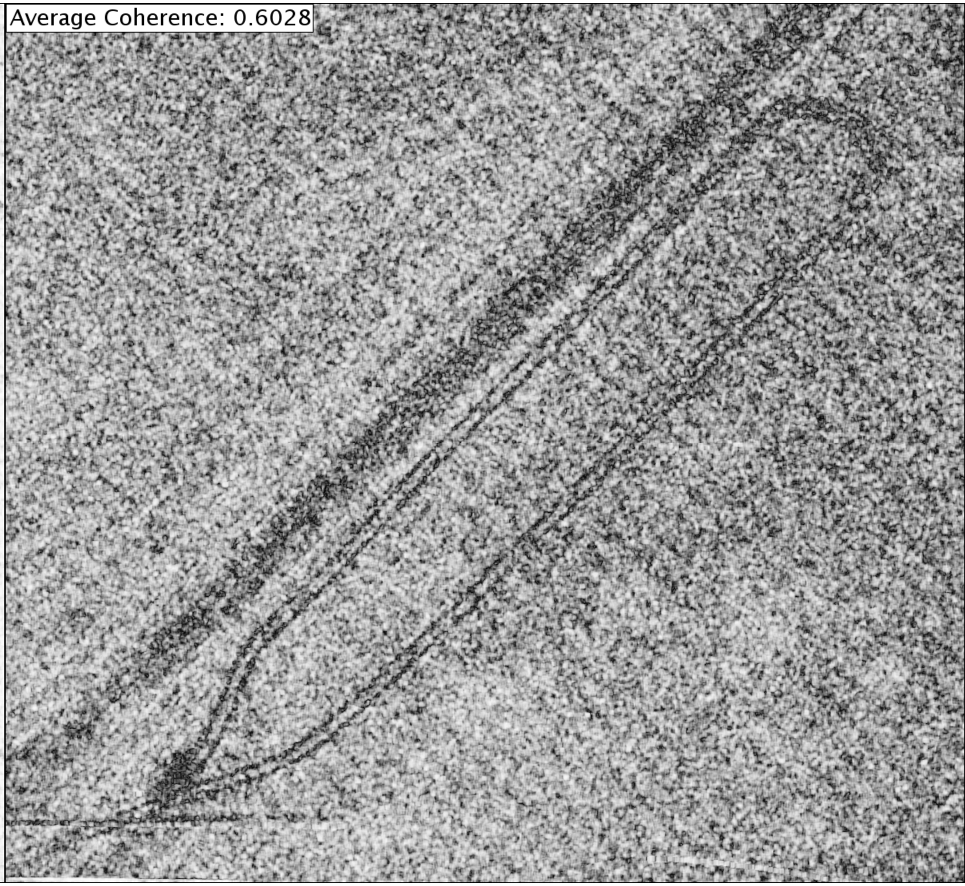


Chirped Interference

# Interference Effects: CCD




No Interference




Chirped Interference



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# Cause for Coherence Loss

$$\mu = \mu_{SNR}\mu_{change}...\mu_x$$

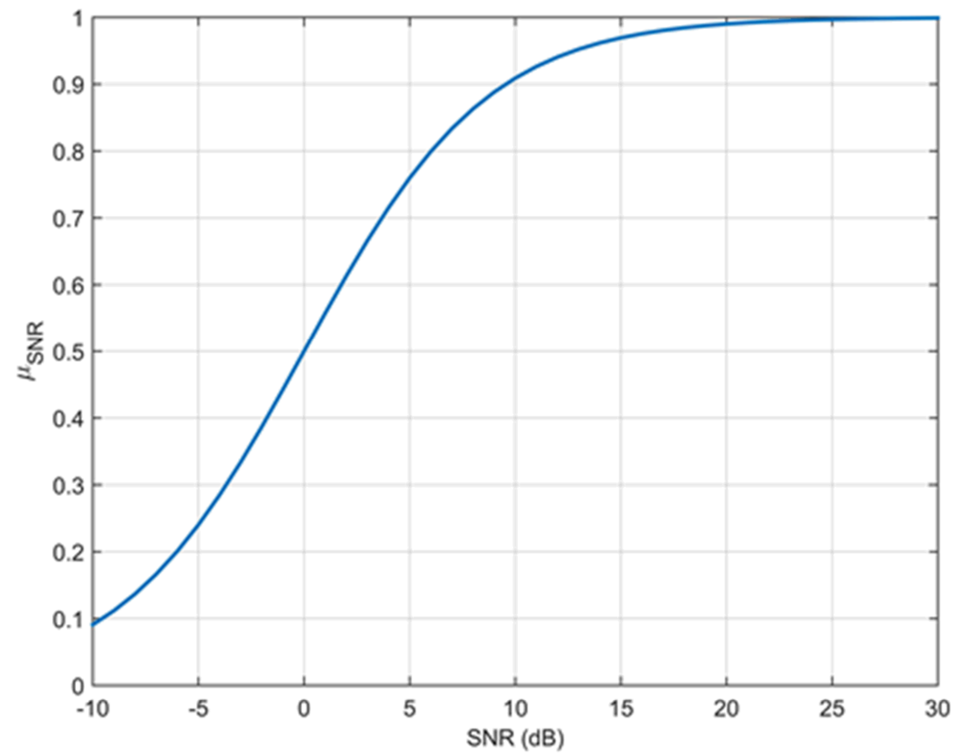
$\mu_{SNR}$ – Thermal noise

$\mu_{change}$ – Temporal change (desired)

$\mu_x$ – Various processing losses[1]

$$\text{SINR}=\frac{\text{signal}}{\text{thermal noise + interference}}$$

$$\mu_{SNR} \rightarrow \mu_{SINR} = \frac{SINR}{SINR+1}$$

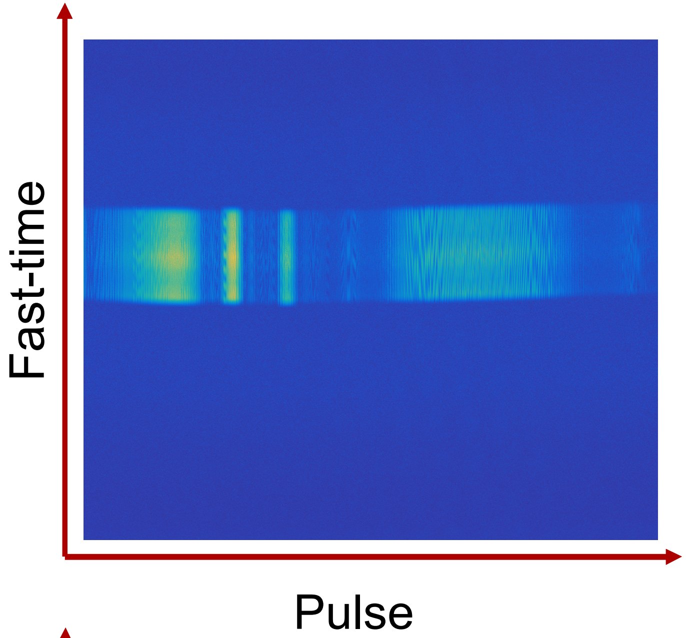


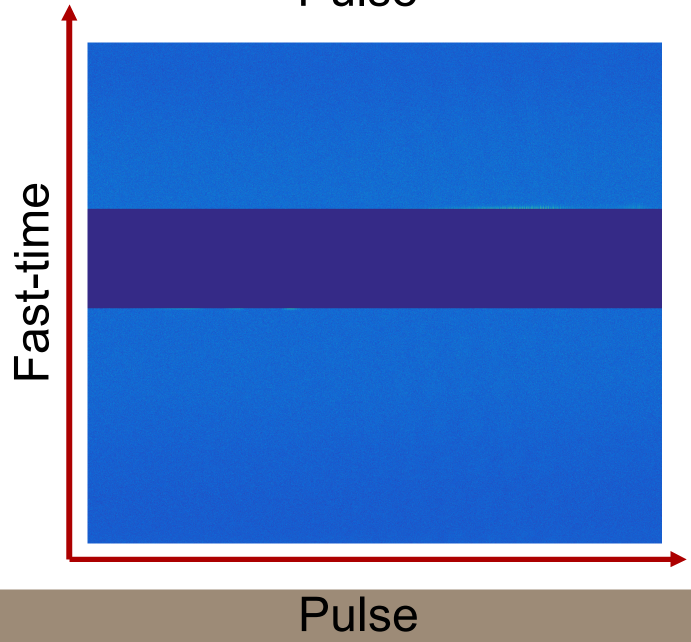

1 - Bickel, D., "SAR image effects on coherence and coherence estimation," Tech. Rep. SAND2014-0369 (2014).

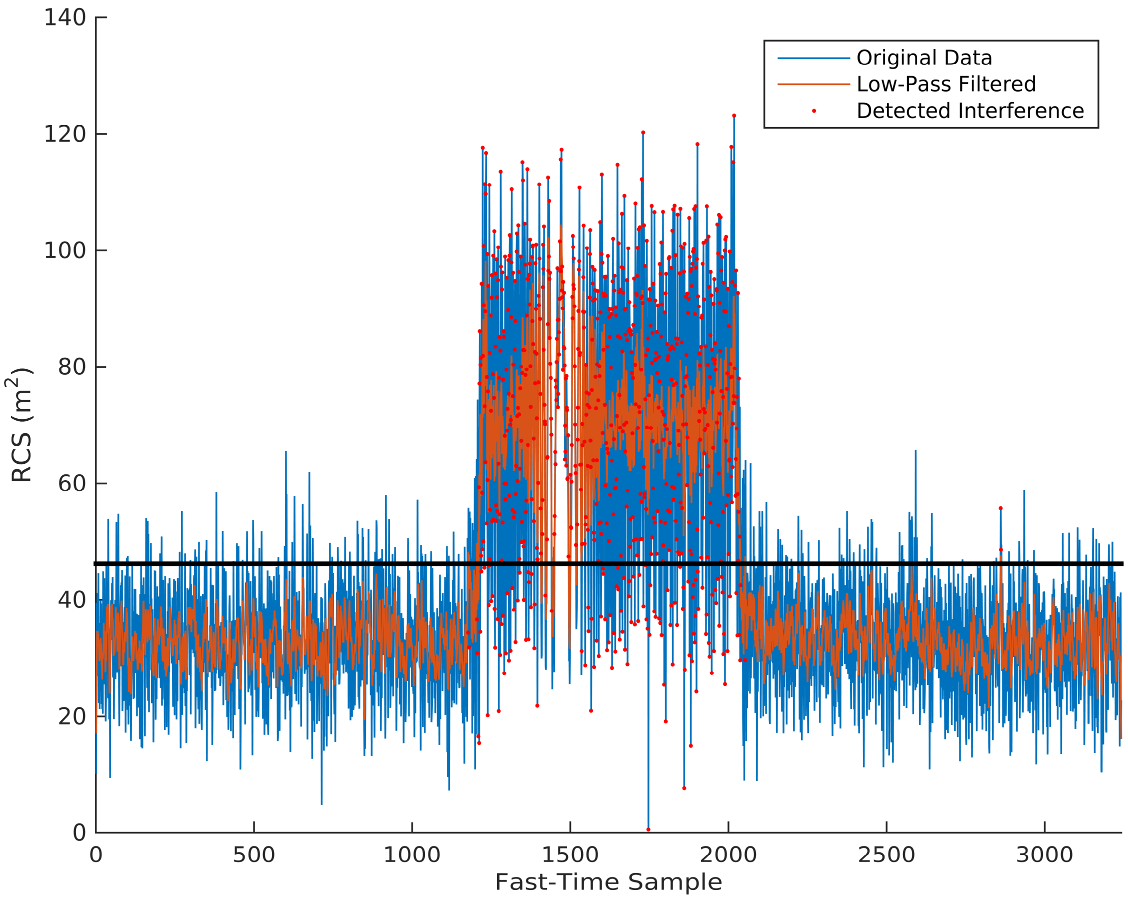
# Interference Mitigation

- There are many existing techniques for mitigating interference.
- One disadvantage for methods that 'sniff' the environment is a lower SNR, which in turn lowers coherence.
- This application requires mitigation techniques compatible with radars utilizing stretch processing.

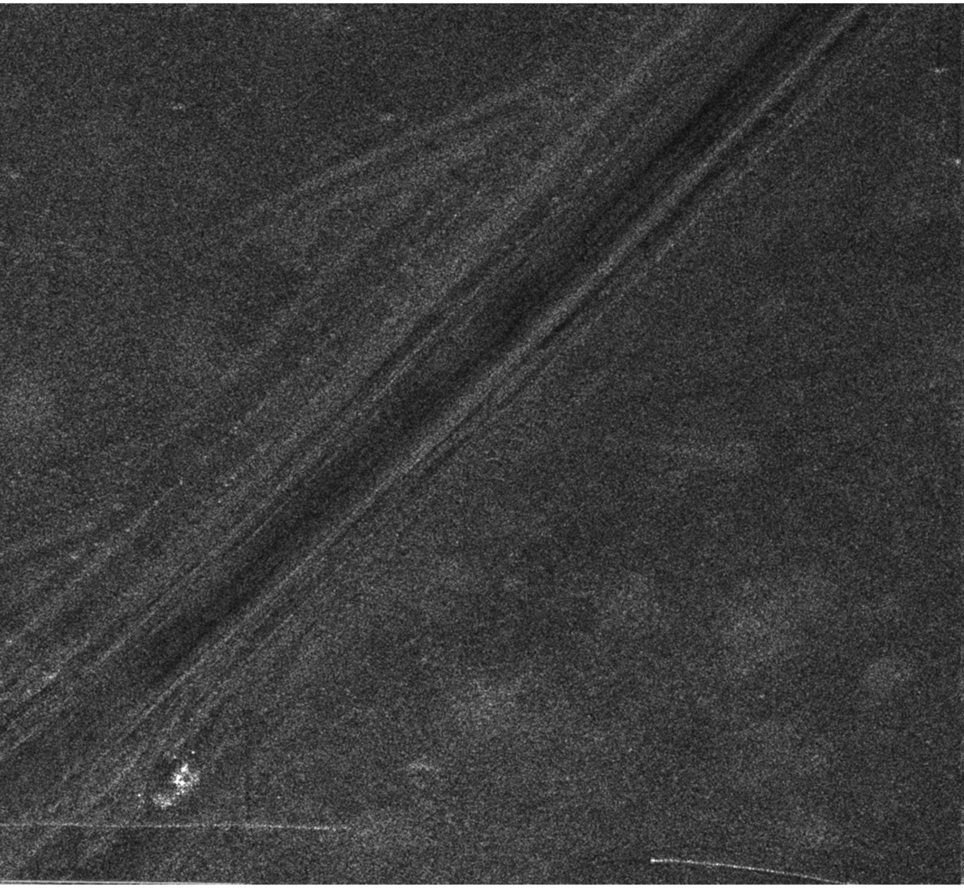
# Interference Mitigation - Notch



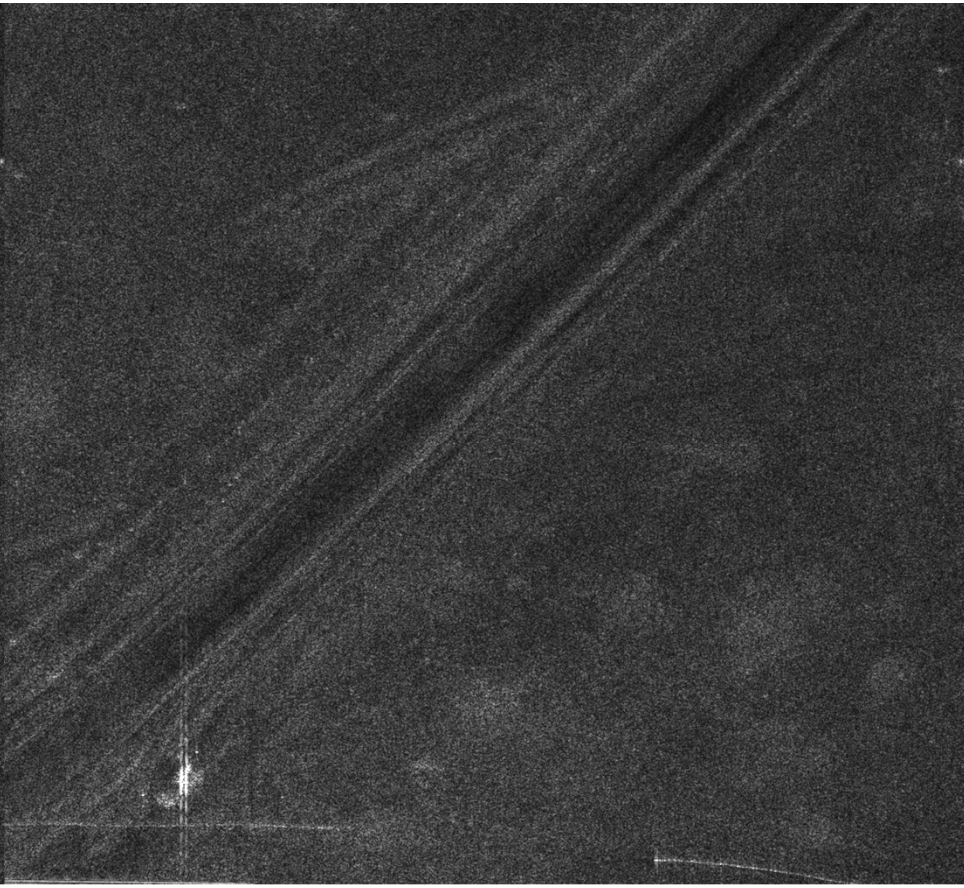



# Notch Example

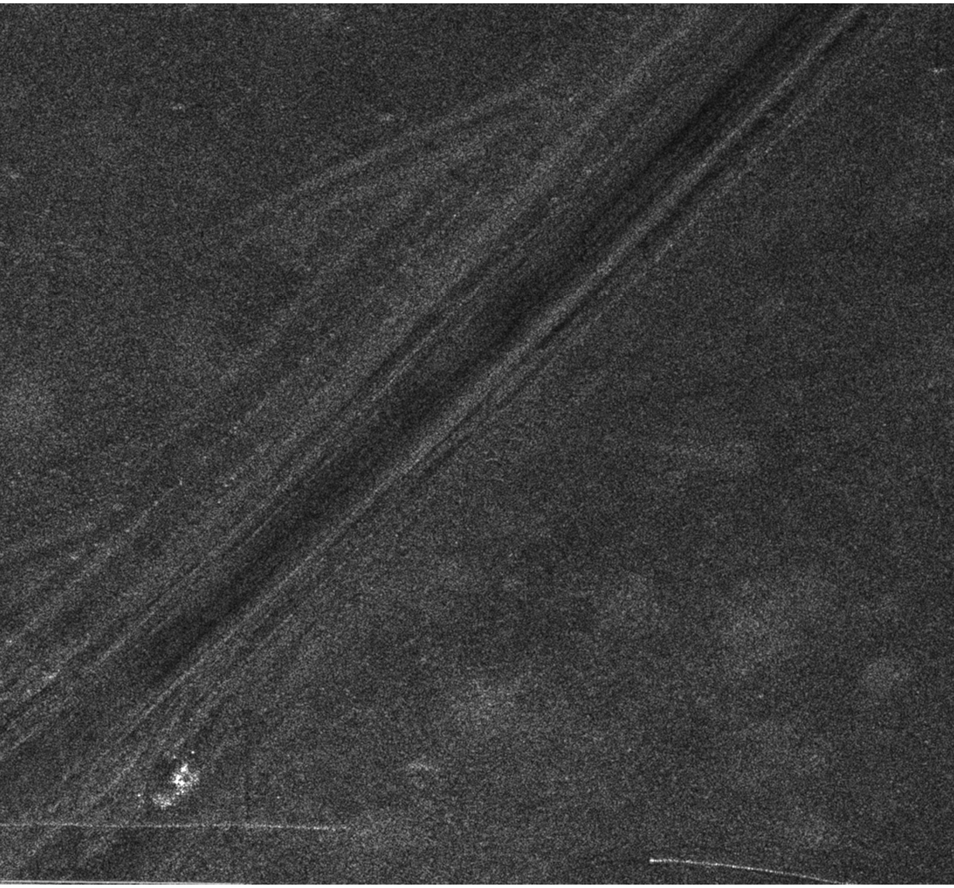


0% of Samples Notched

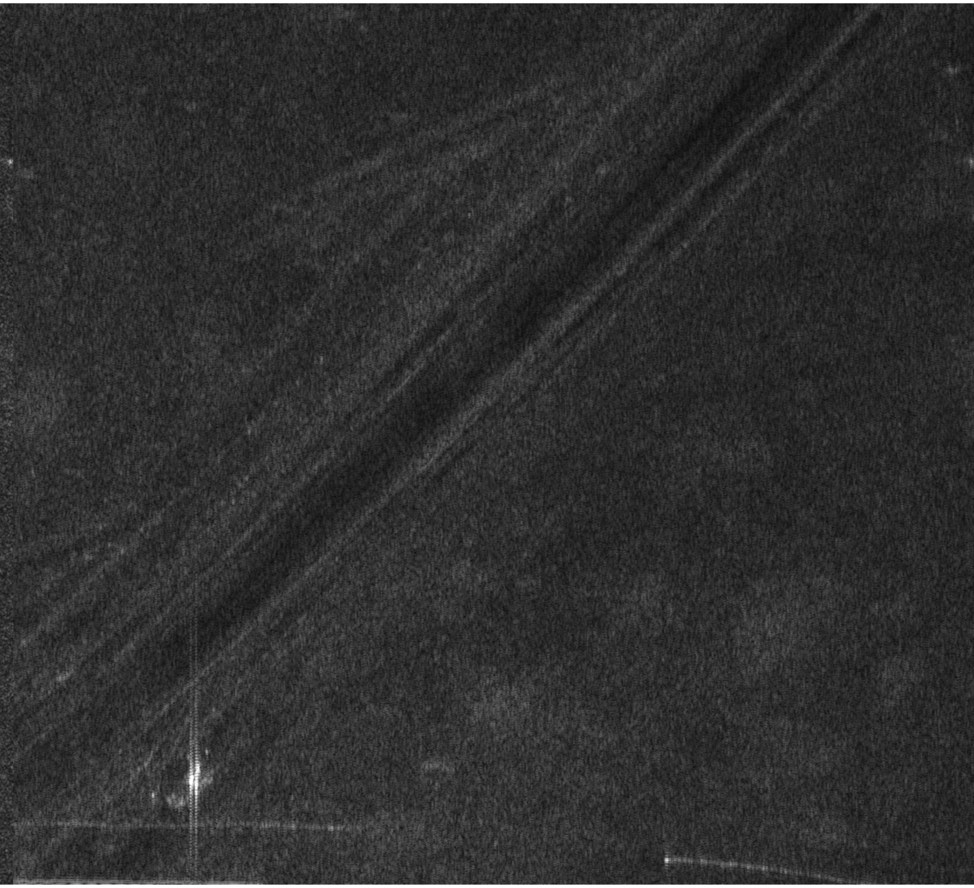


5% of Samples Notched

# Notch Example

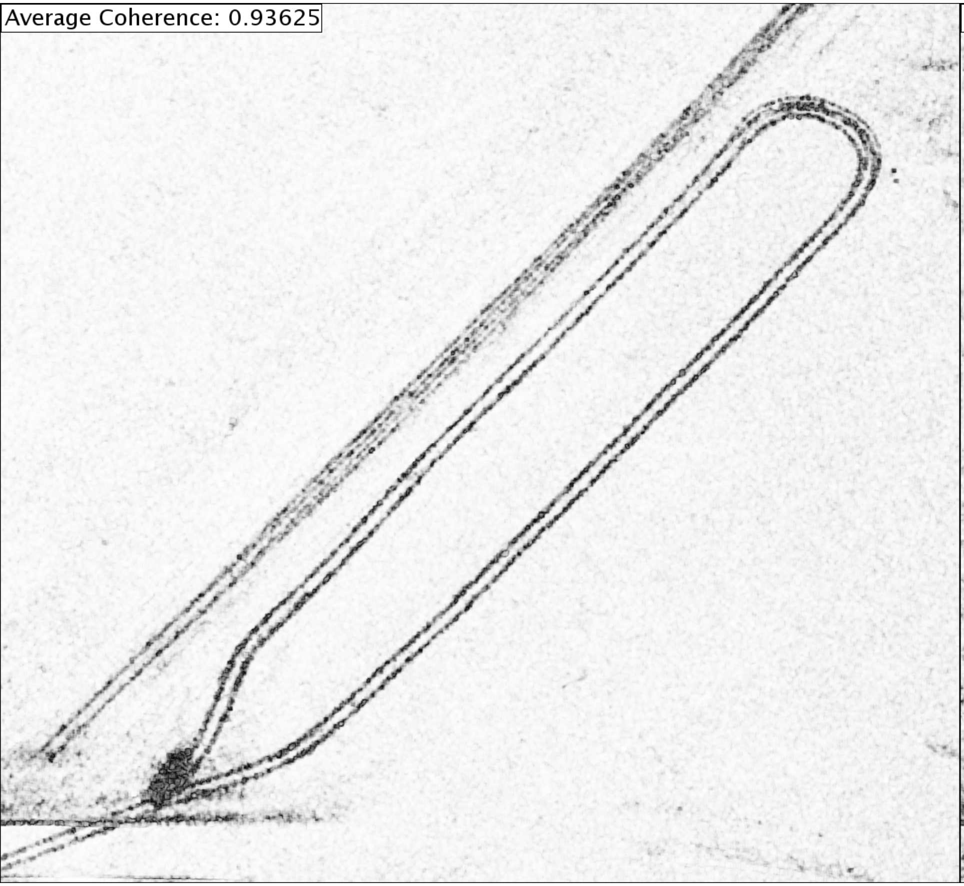


0% of Samples Notched

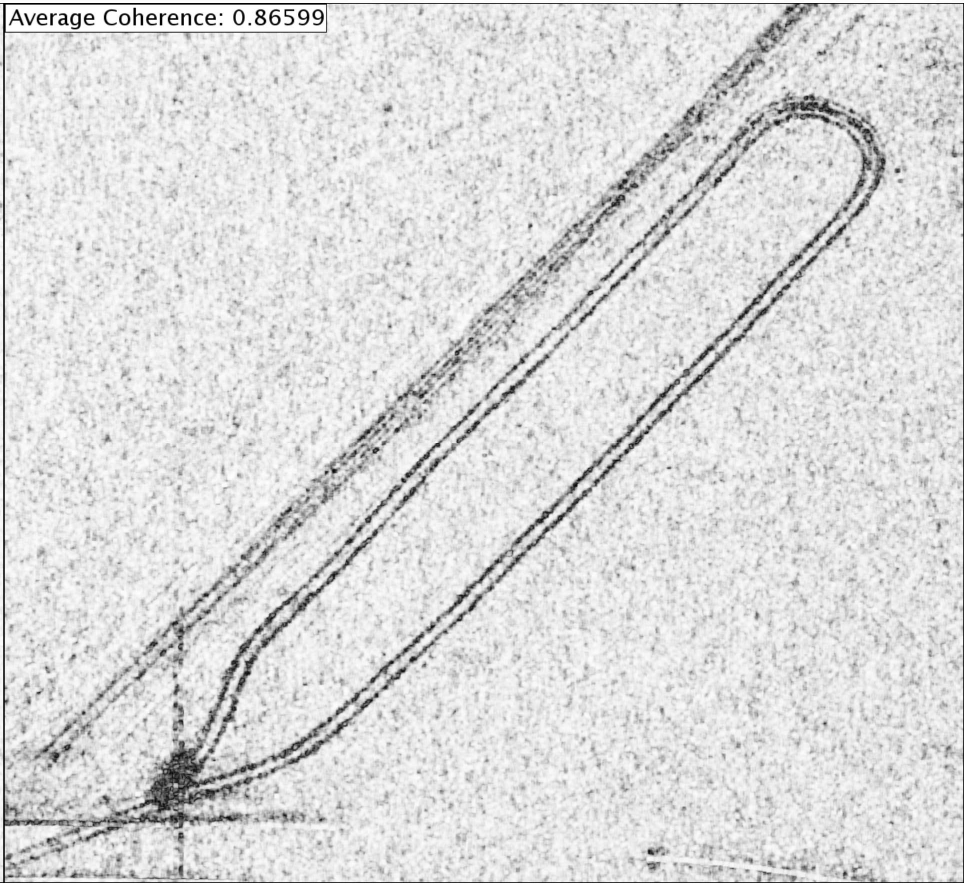


25% of Samples Notched

# Notch Example




0% of Samples Notched




5% of Samples Notched



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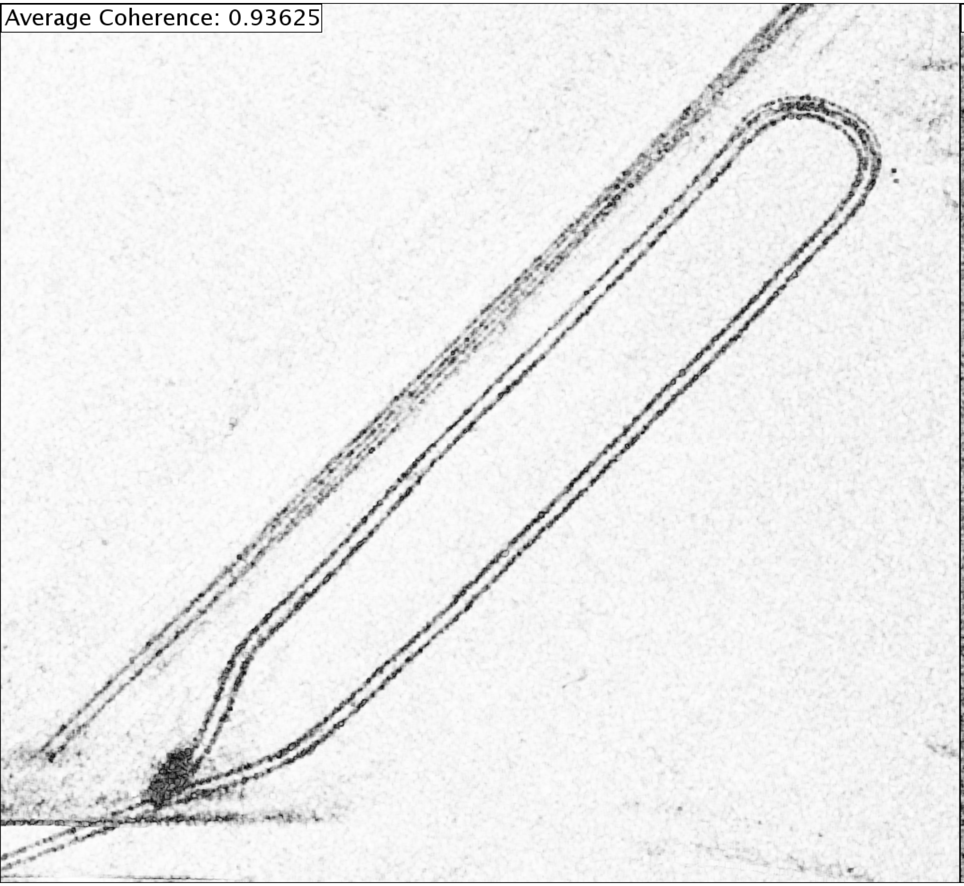
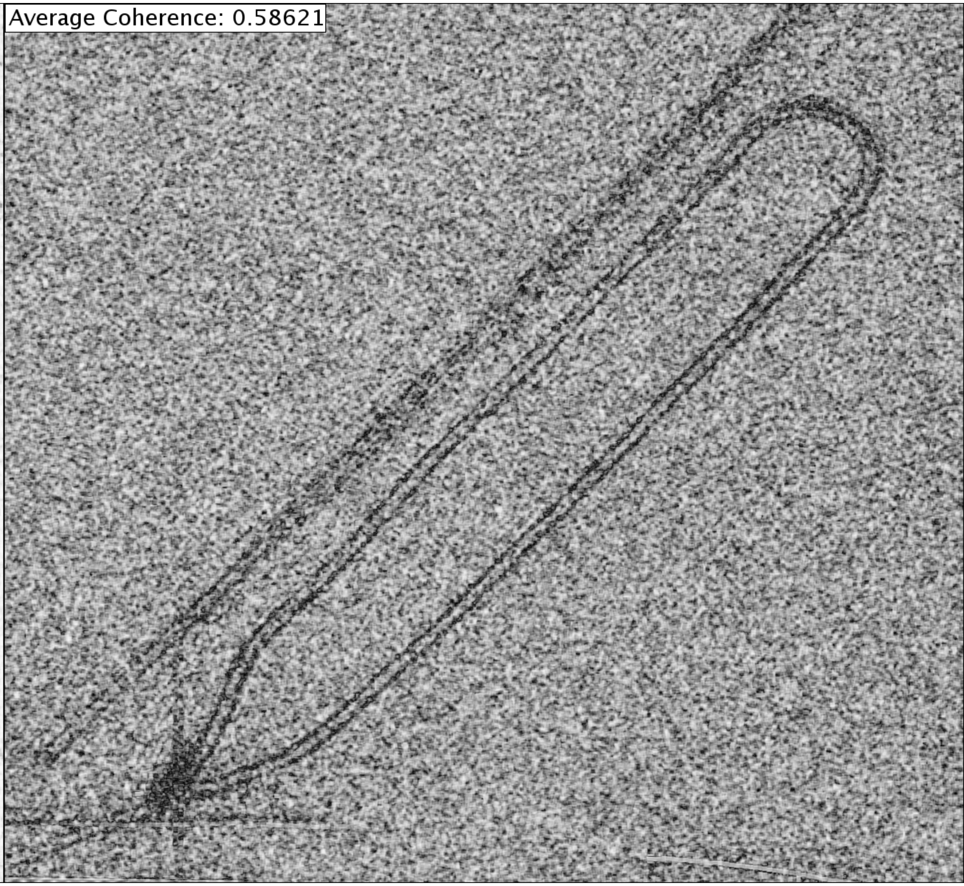
# Notch Example




0% of Samples Notched




25% of Samples Notched



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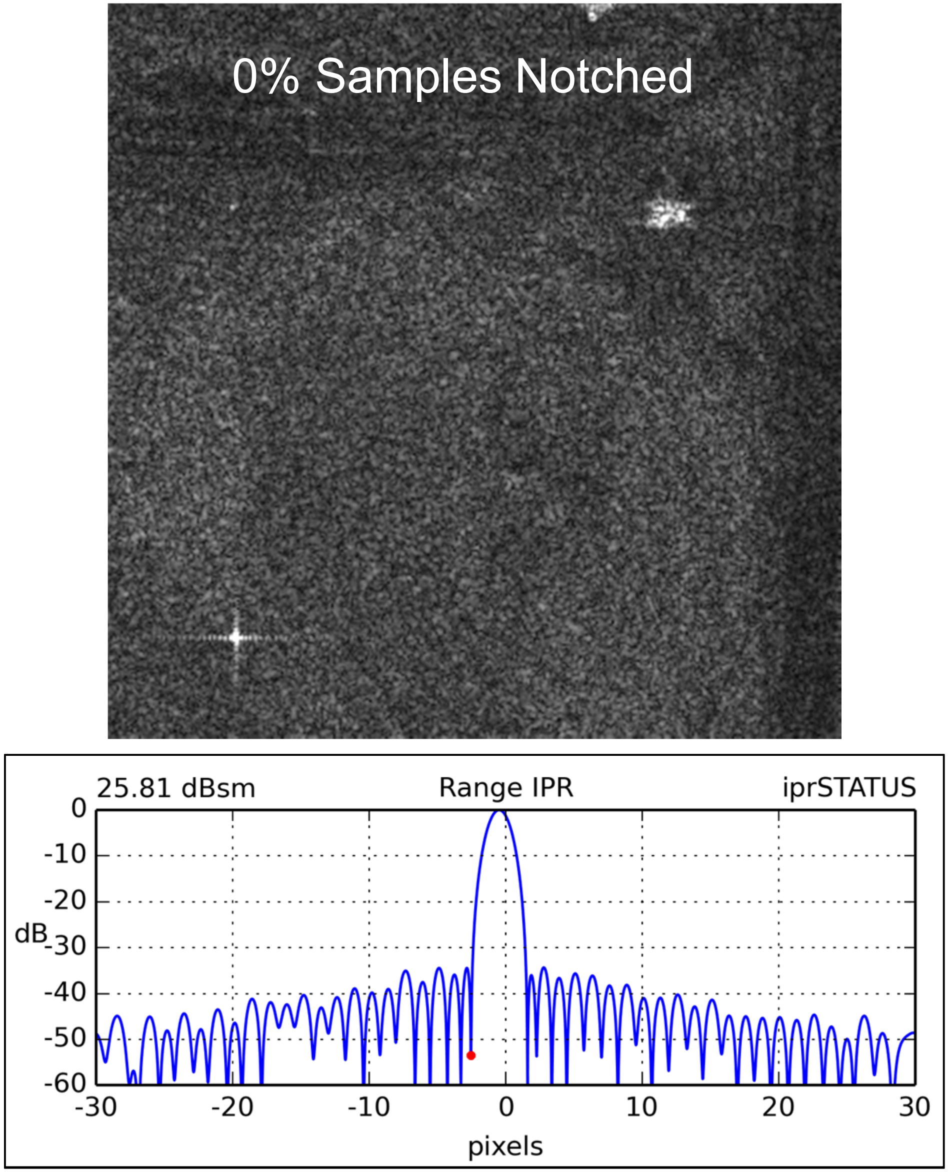
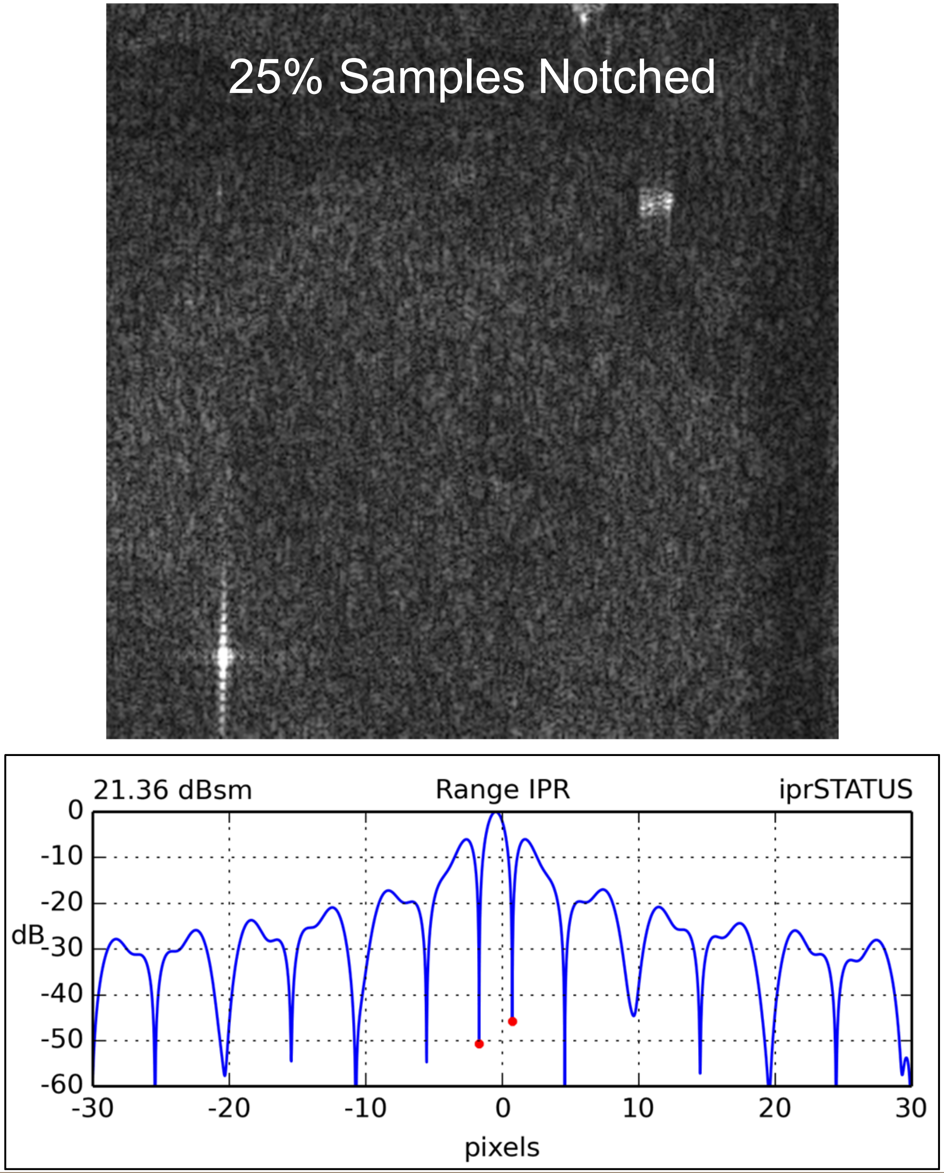
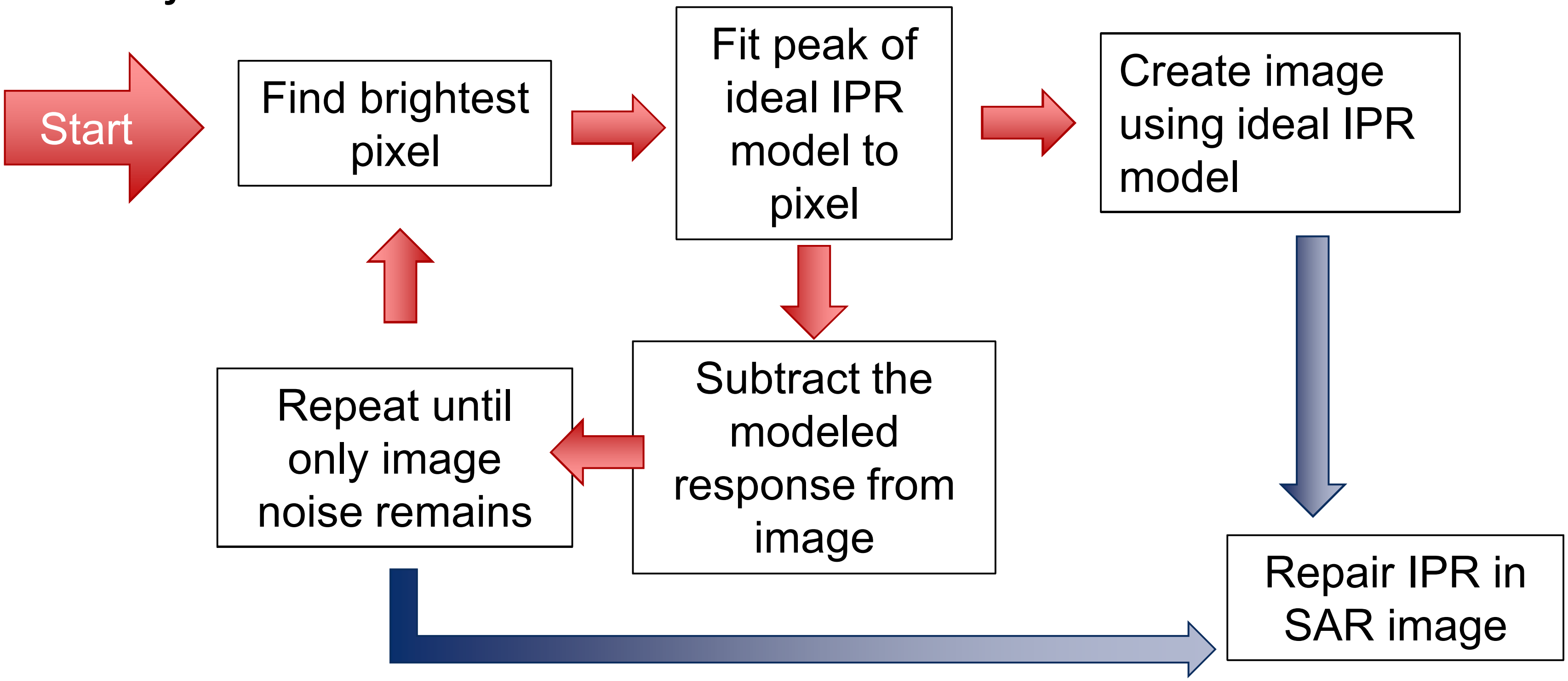
# Notching Effect



# To Repair IPR of Point-Like Objects

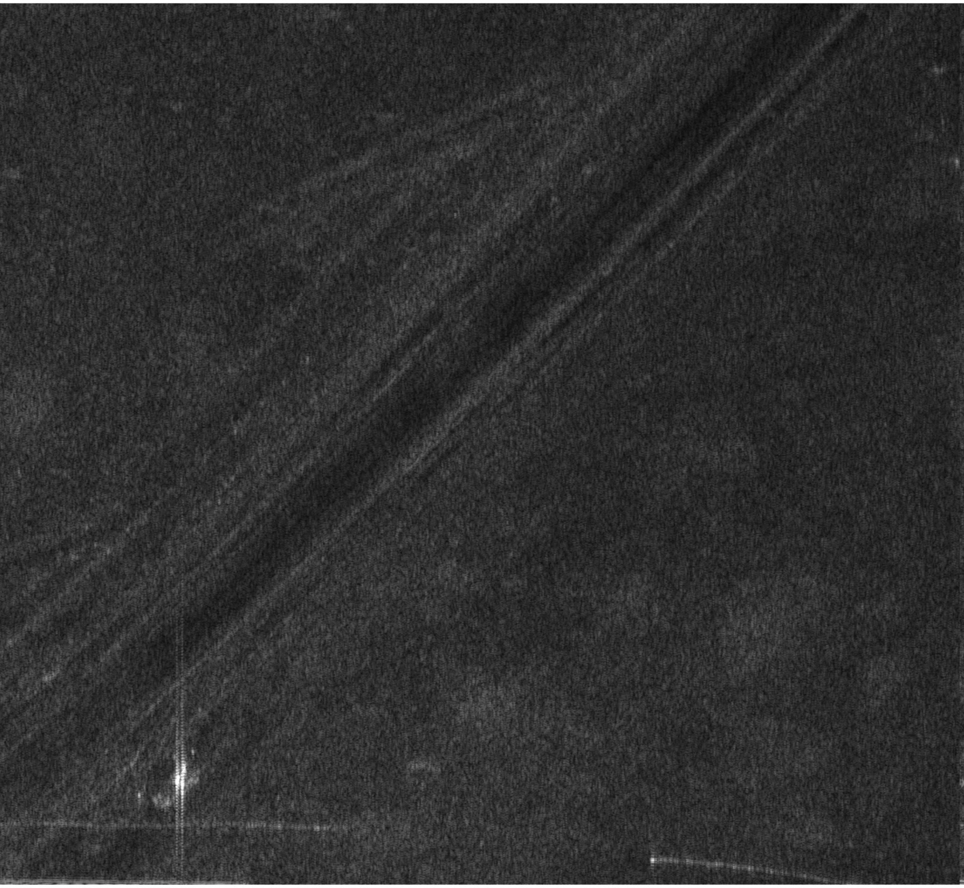
- Wahl et al.[1] used CLEAN[2] to improve the IPR of point-like objects



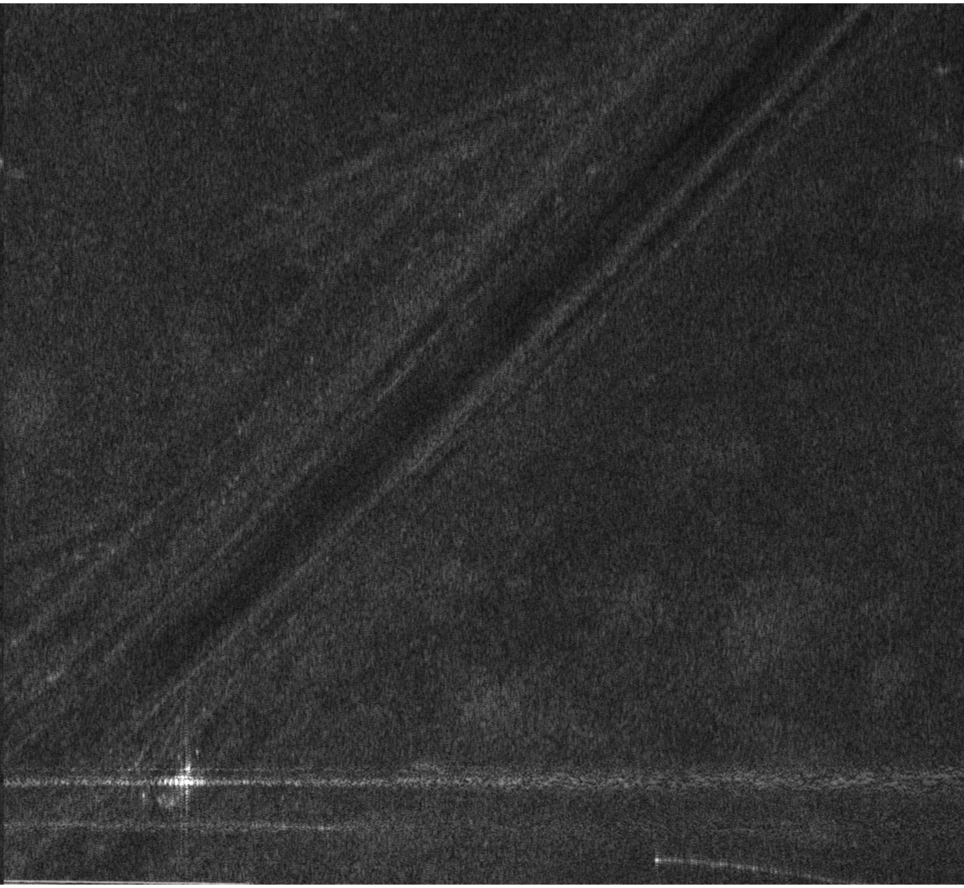

Not designed for distributed targets, like terrain.

1-D. Wahl, D. A. Yocky, C. V. Jakowatz, P. Thompson, I. Erteza, and N. Doren, “Interesting aspects of spotlight-mode image formation for an L/S-band high-resolution SAR," in *Proceedings of the Workshop on Synthetic Aperture Radar Technology*, Redstone Arsenal, AL, 2002.
2-J. Tsao and B. Steinberg, “Reduction of sidelobe and speckle artifacts in microwave imaging; the CLEAN technique,” IEEE Transactions on Antennas and Propagation, vol. 36, no. 4, pp. 543-556, Apr. 1988.

# Interference Mitigation Example

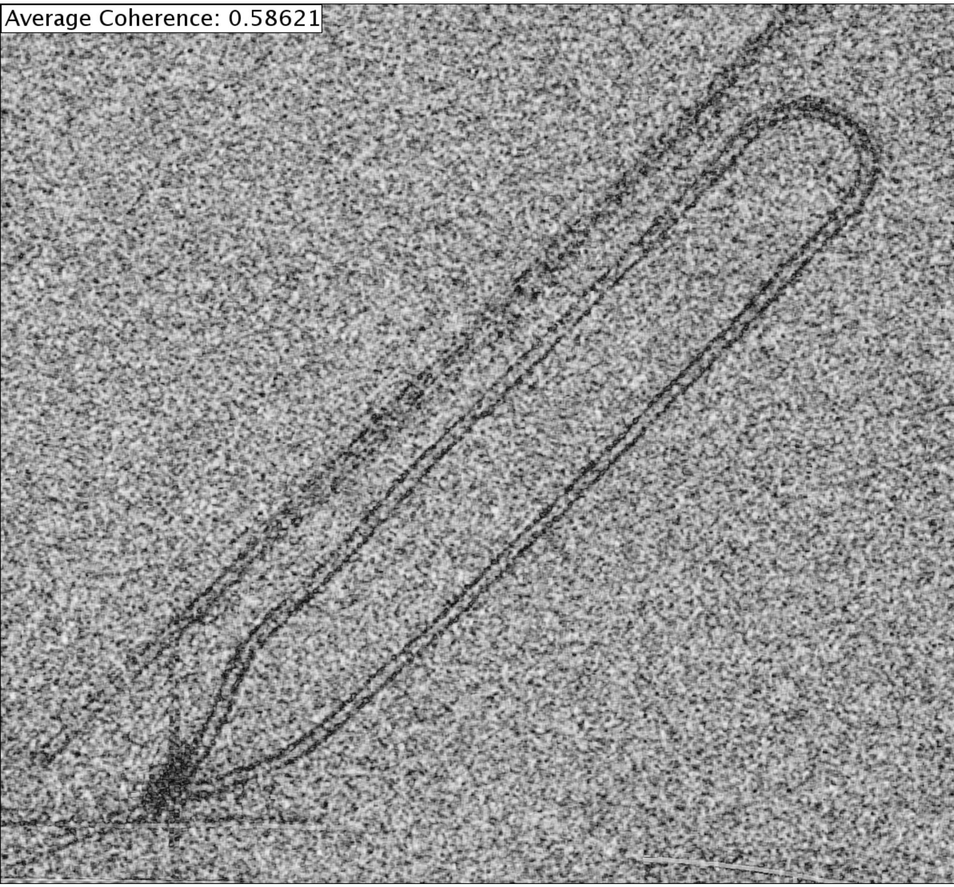


25% of Samples Notched

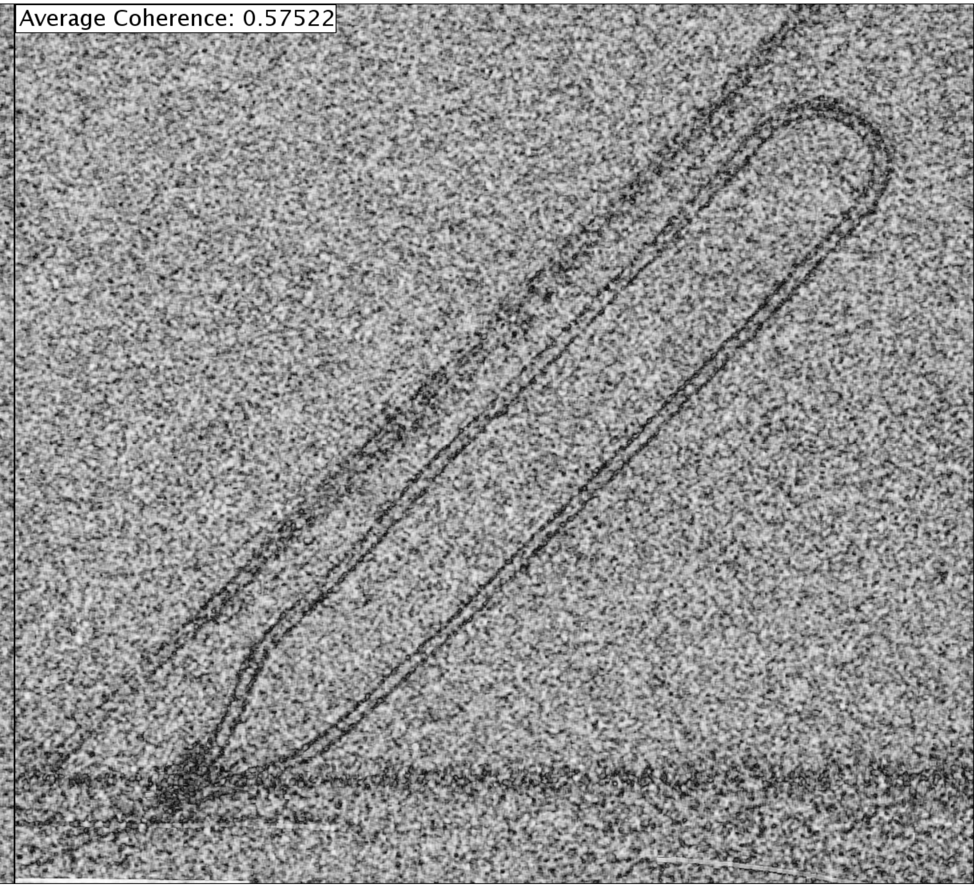


CLEAN Applied

# Interference Mitigation Example




25% of Samples Notched




CLEAN Applied



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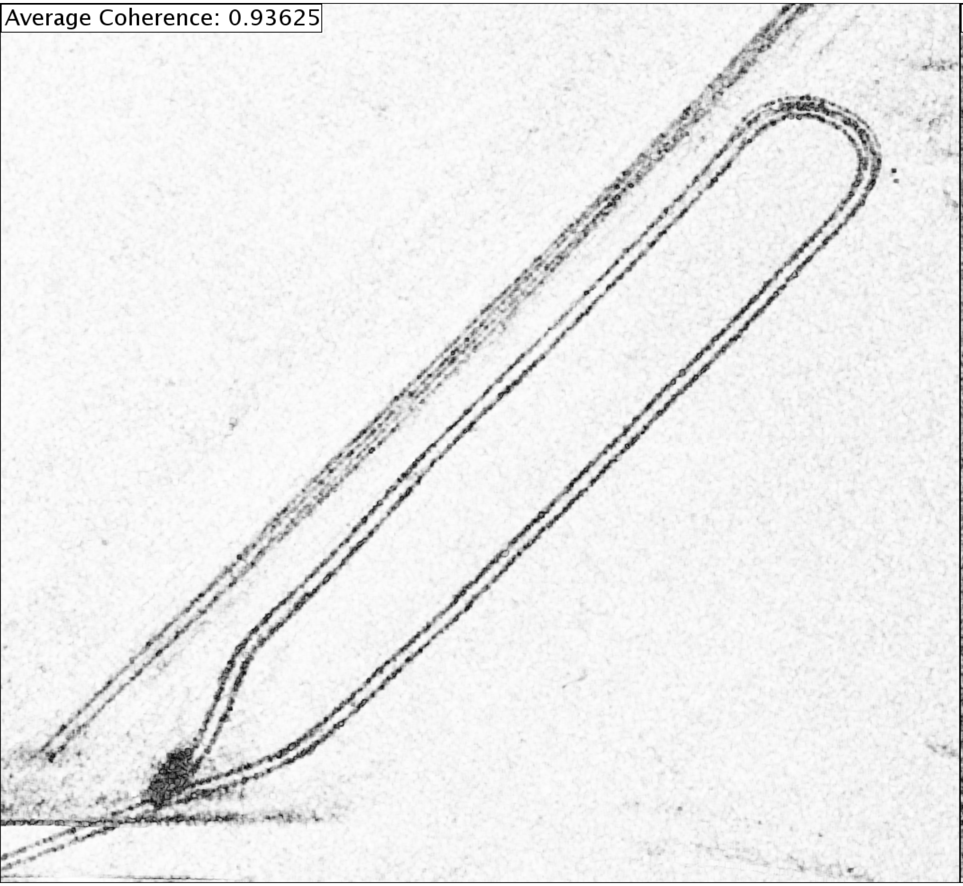
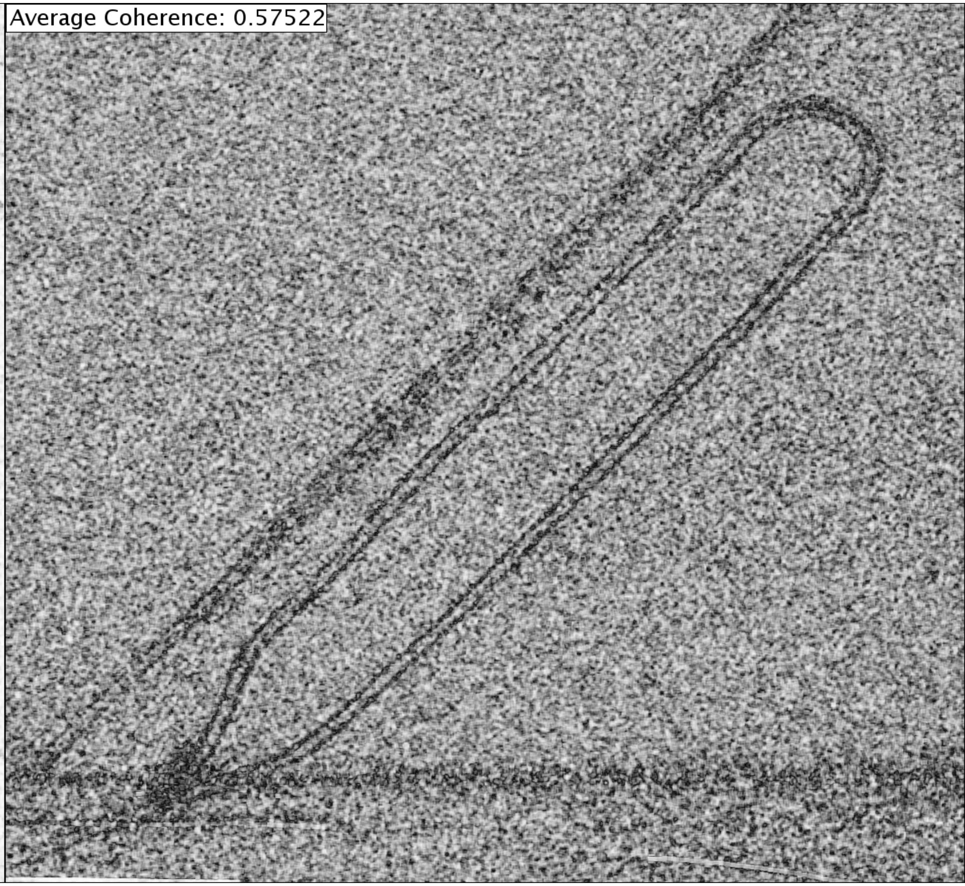
# Interference Mitigation Example




0% of Samples Notched




CLEAN Applied



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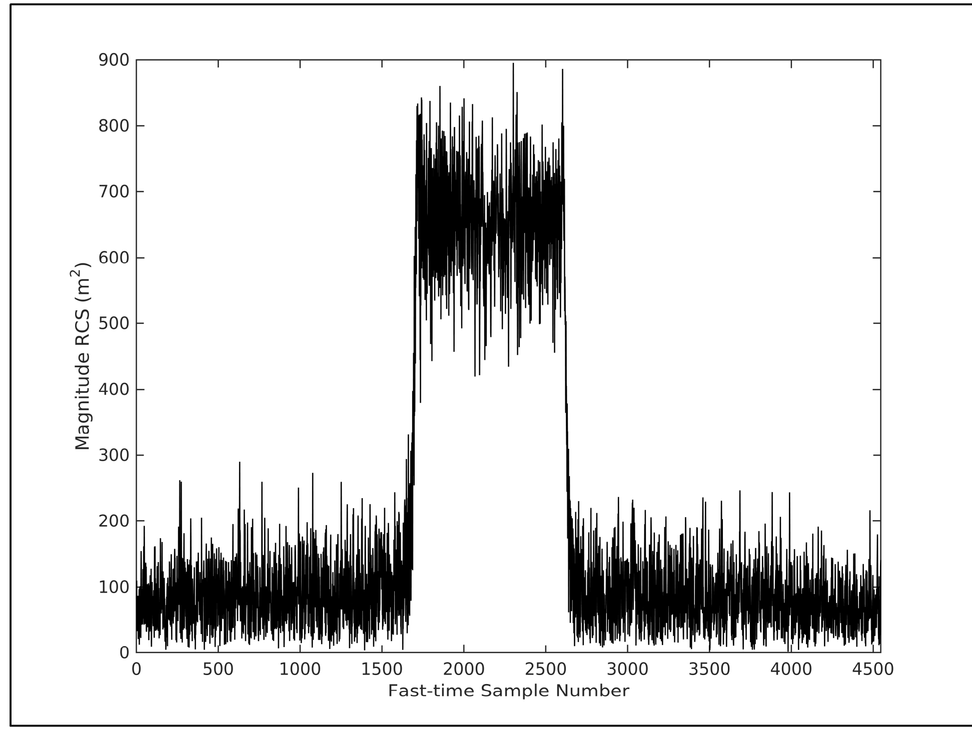
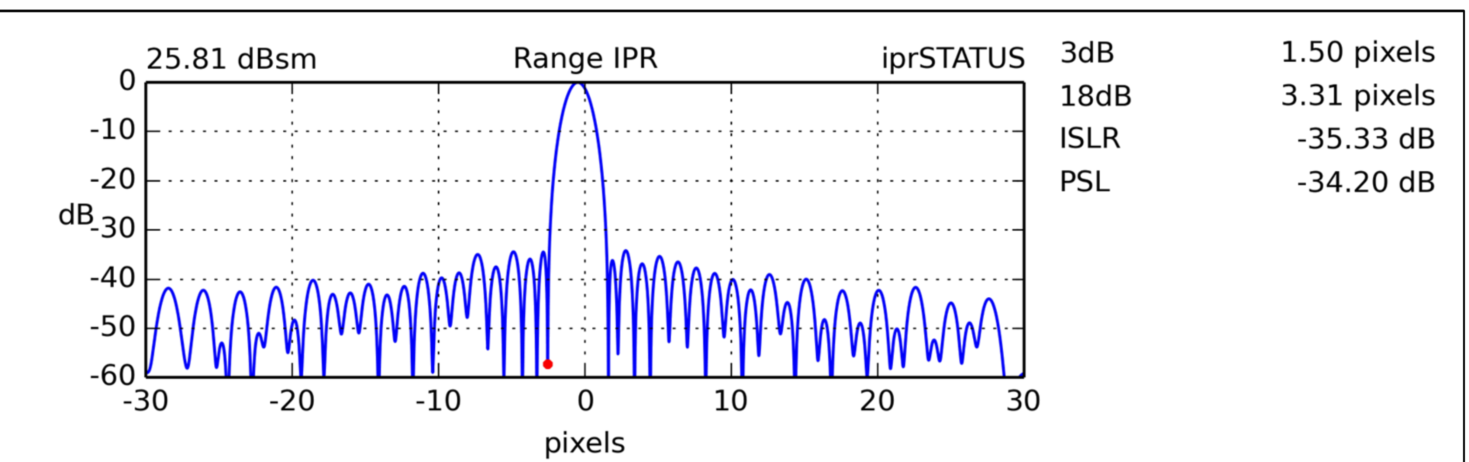
# Equalization Notch

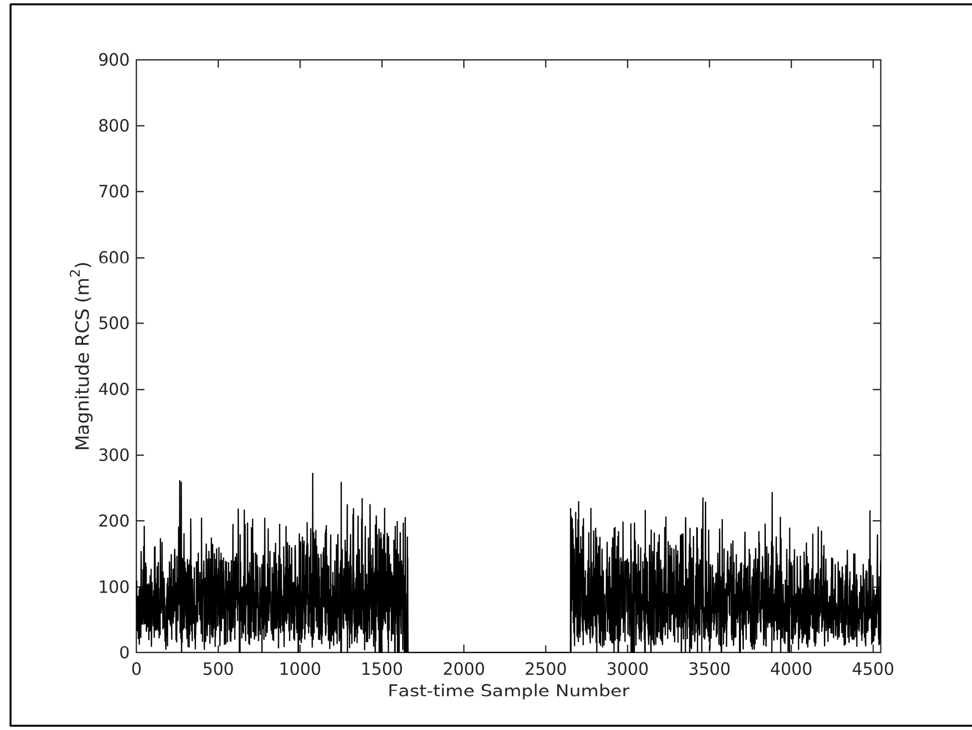
IPR in the presence of interference – not affected.

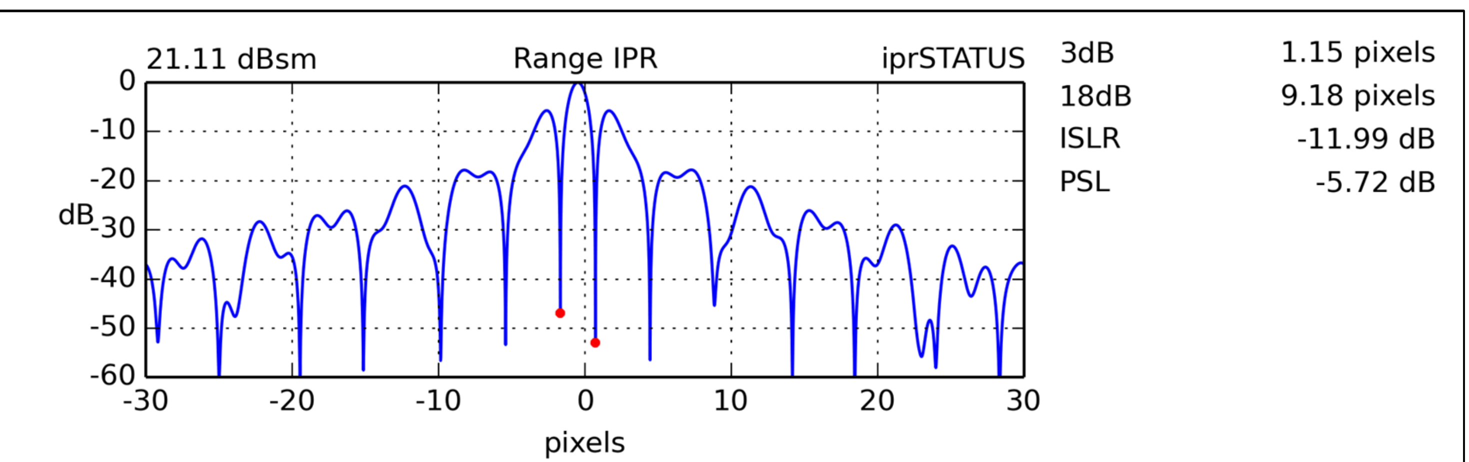


# Equalization Notch

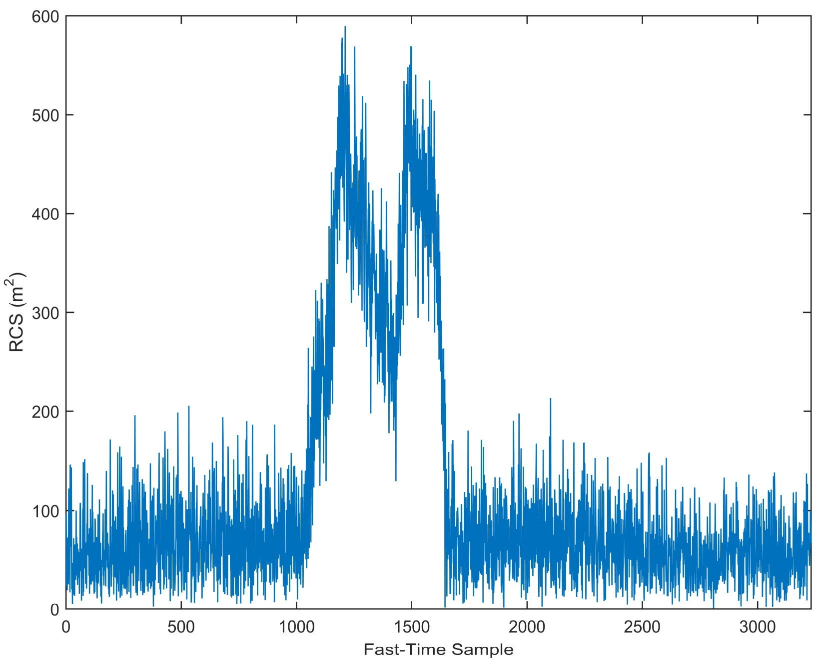
Applying a notch to phase history distorts the IPR.



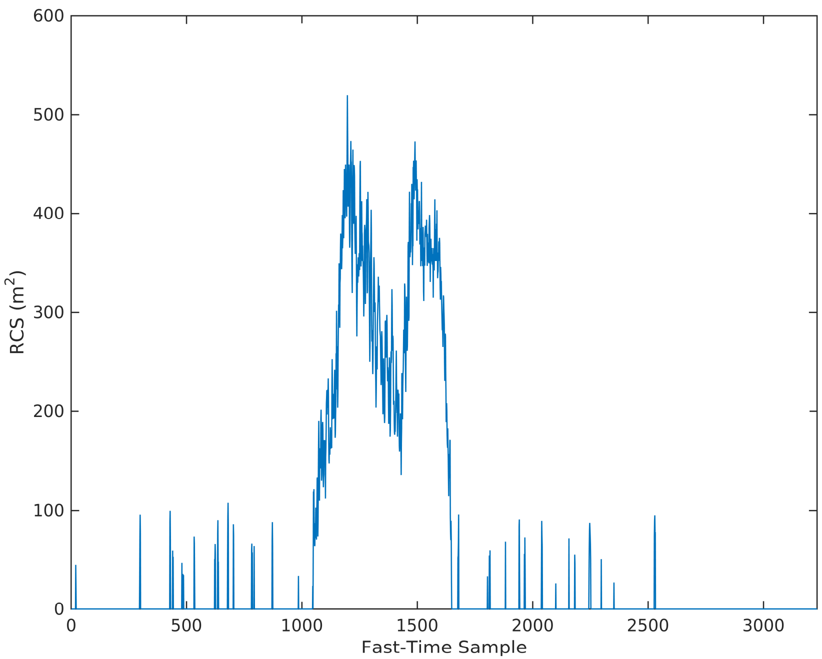



# Equalization Notch


$$\text{Weighting} = \frac{(\text{Signal} + \text{Interference}) - \text{Estimated Interference}}{(\text{Signal} + \text{Interference})}$$

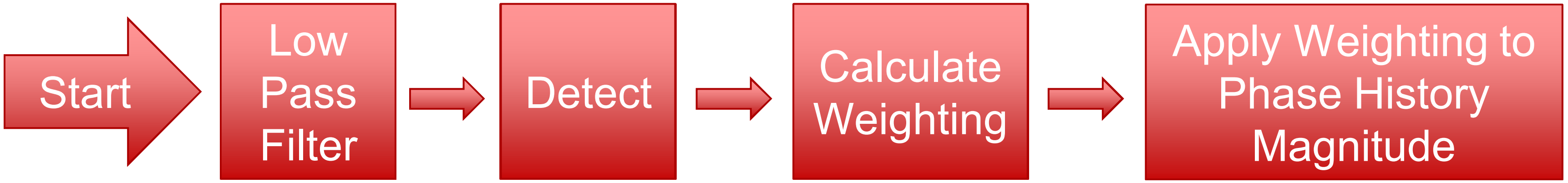



Signal and Interference

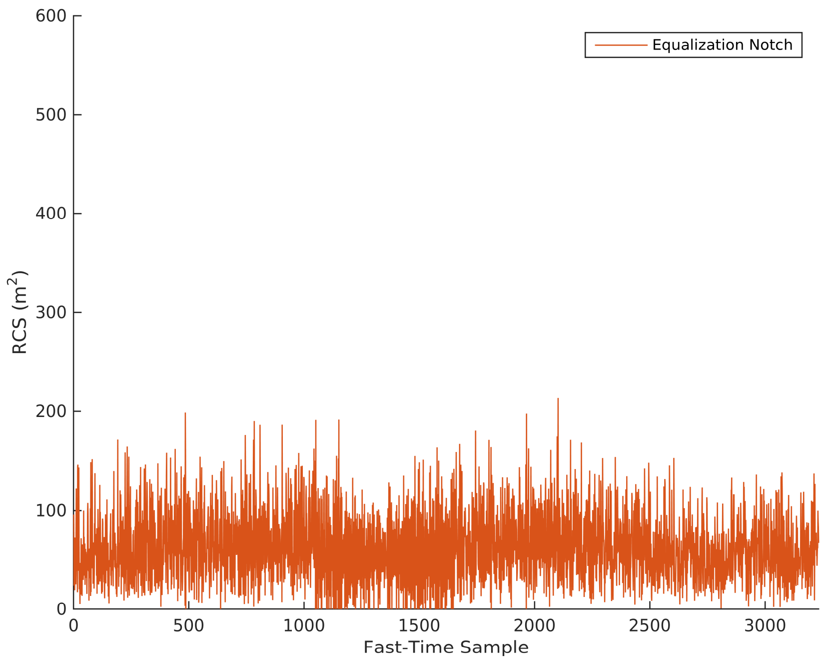



Estimated Interference

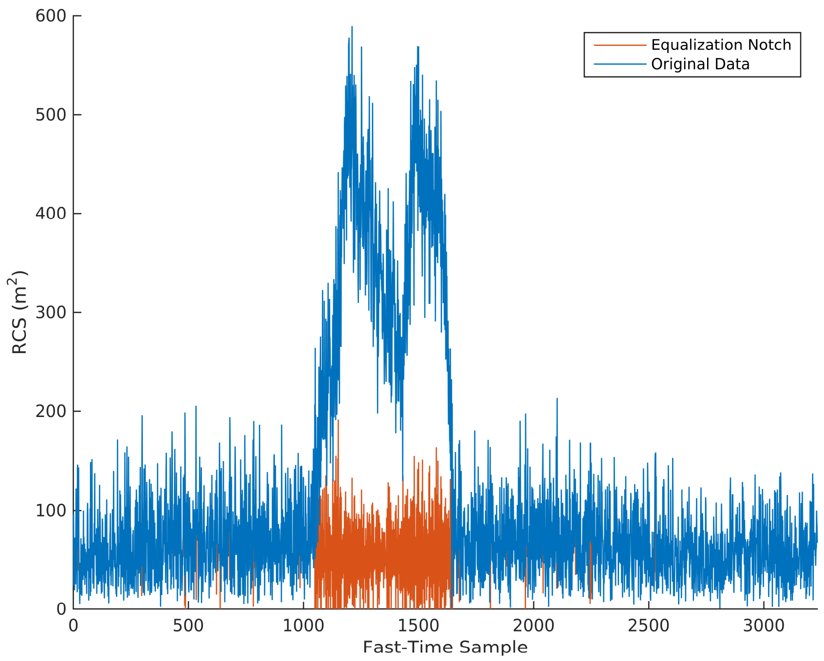
# Equalization Notch




$$\text{Weighting} = \frac{(\text{Signal} + \text{Interference}) - \text{Estimated Interference}}{(\text{Signal} + \text{Interference})}$$



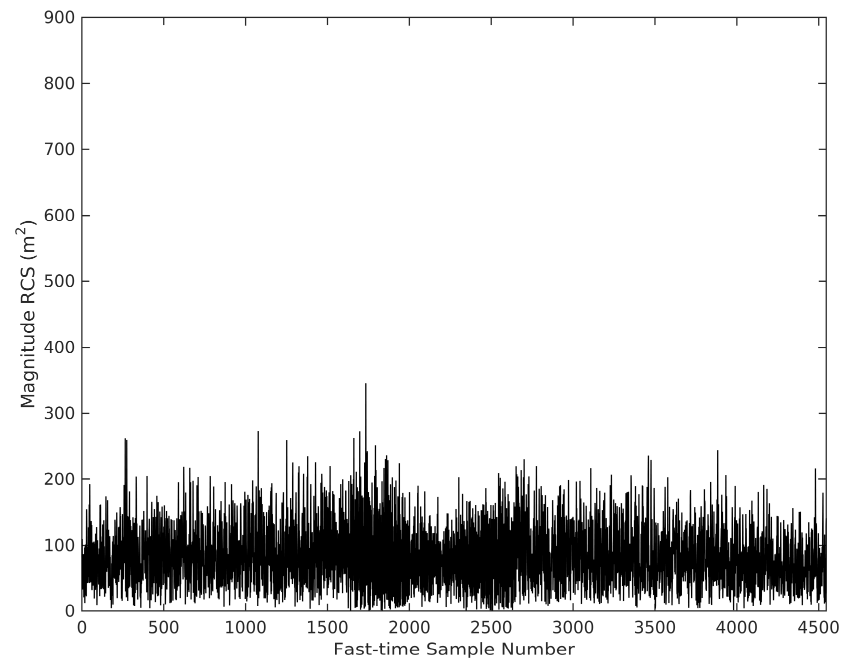

Corrected Signal and Interference

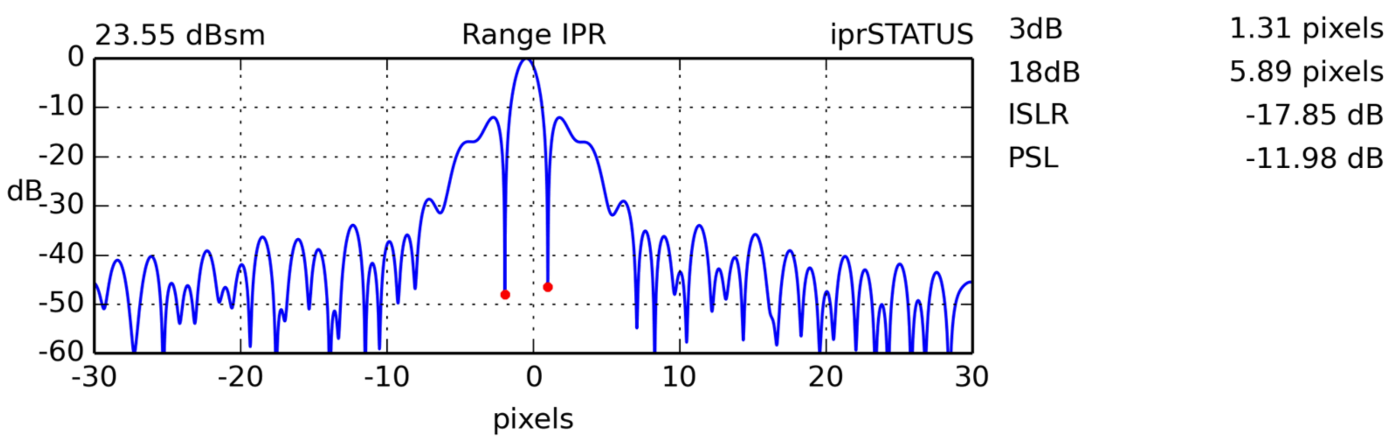



Before/After Comparison

# Equalization Notch

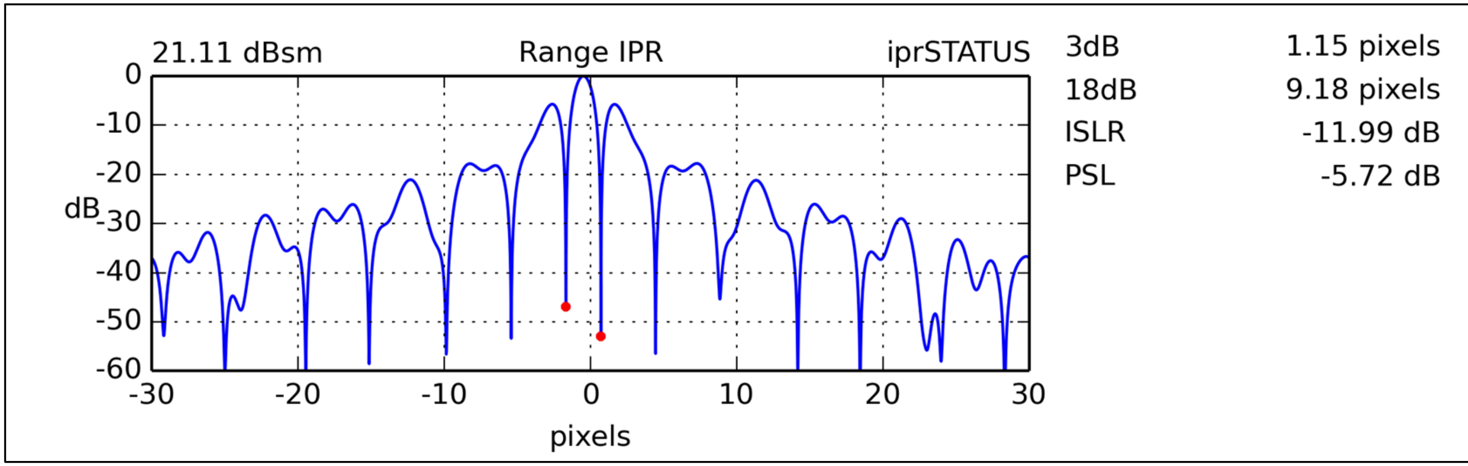
Reduced sidelobe level is an improvement.



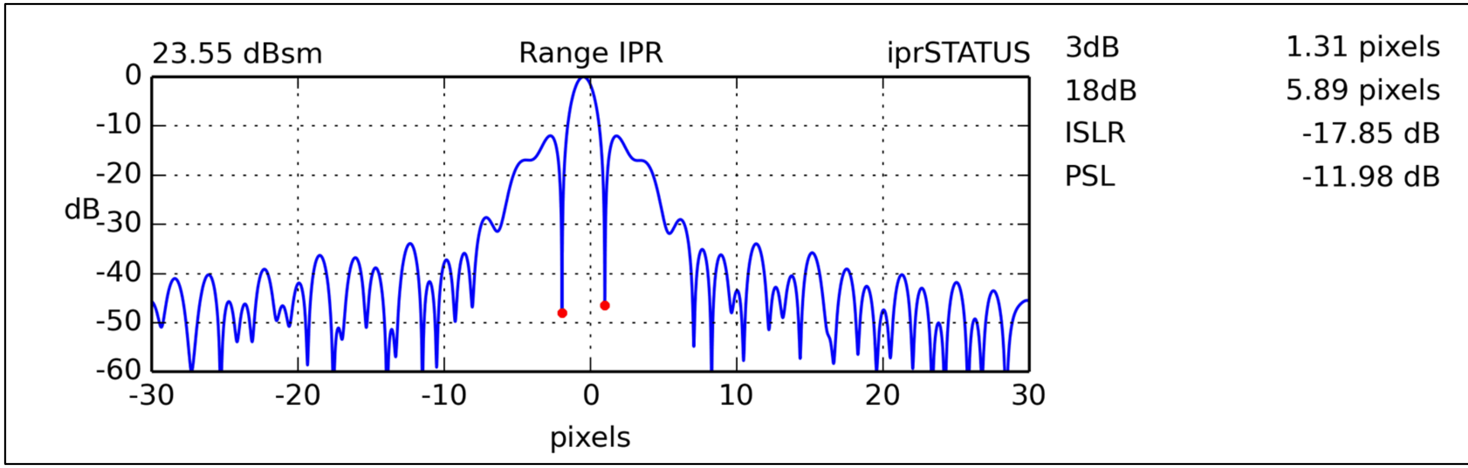



# Equalization Notch

Notch:



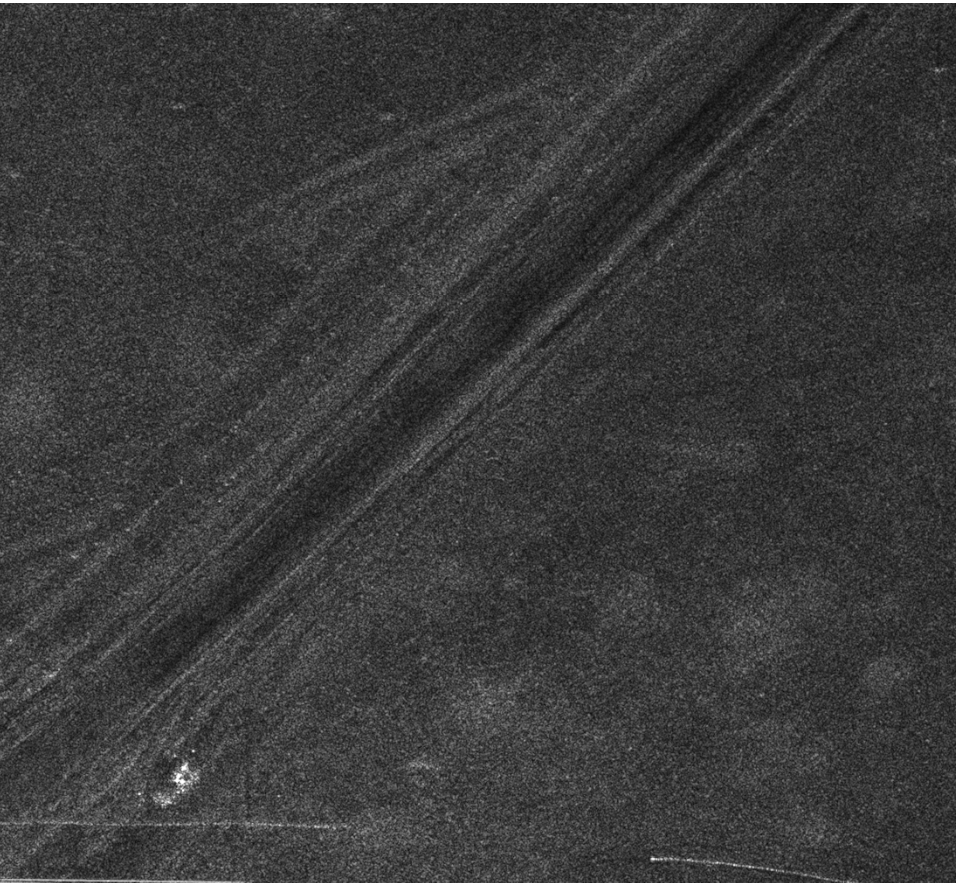

Equalization Notch:



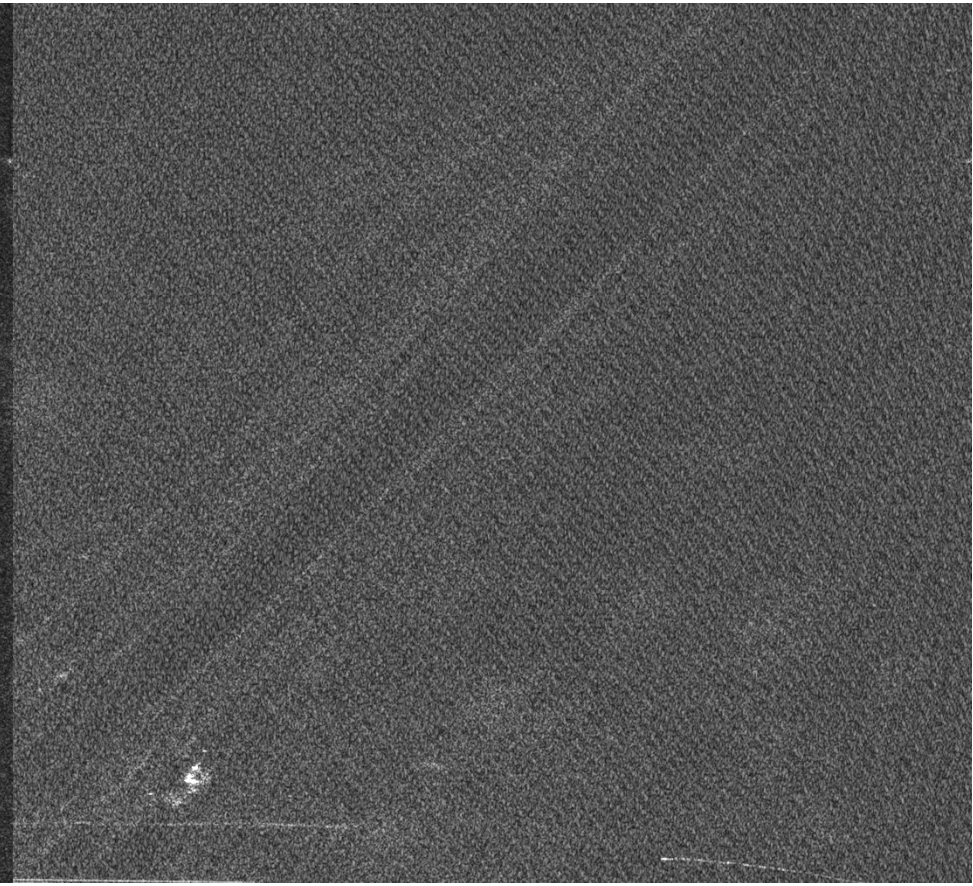
# Real Data, Example 1

Interference Source: synthetic asynchronous 300MHz chirp bandwidth centered at 16.8GHz with PRF 10Hz and duty factor 20%.

| Example 1 Parameters | |
|---|---|
| Center Frequency | 16.8GHz |
| Resolution | 0.1524m (6”) |
| Image Oversample Factor | 1.5 |
| Window Function | Taylor, n=4, -35dB SLL |



No Interference



With Interference

# Real Data, Example 1

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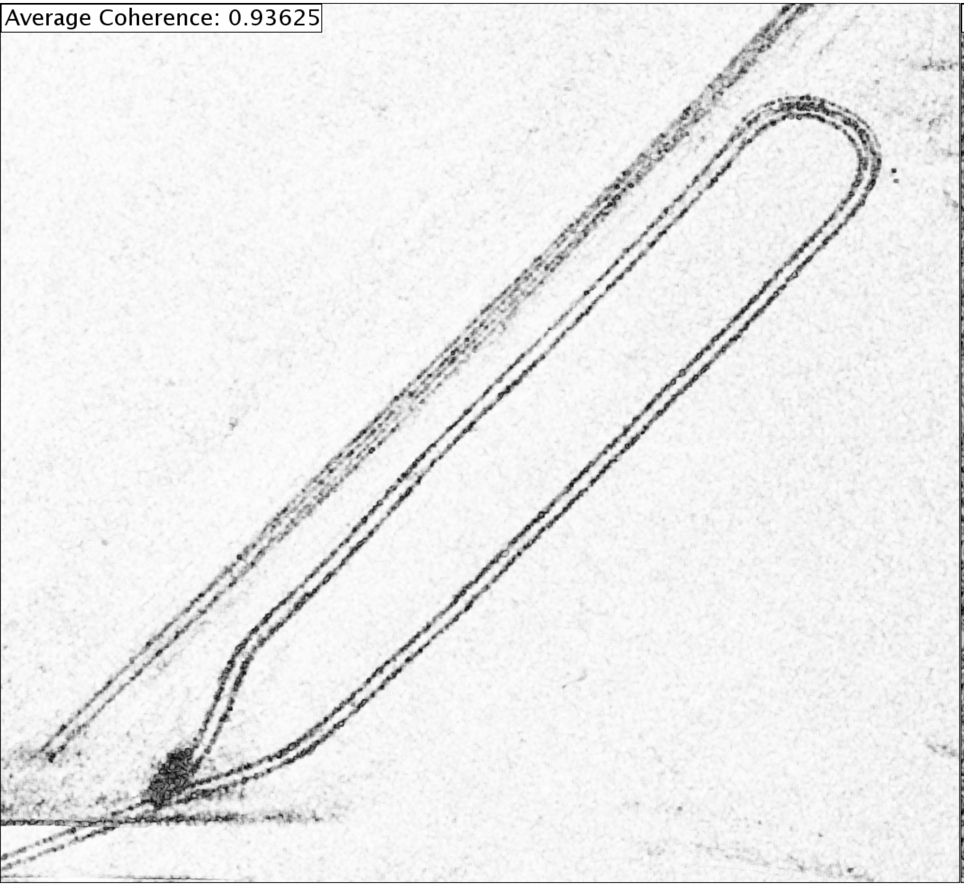
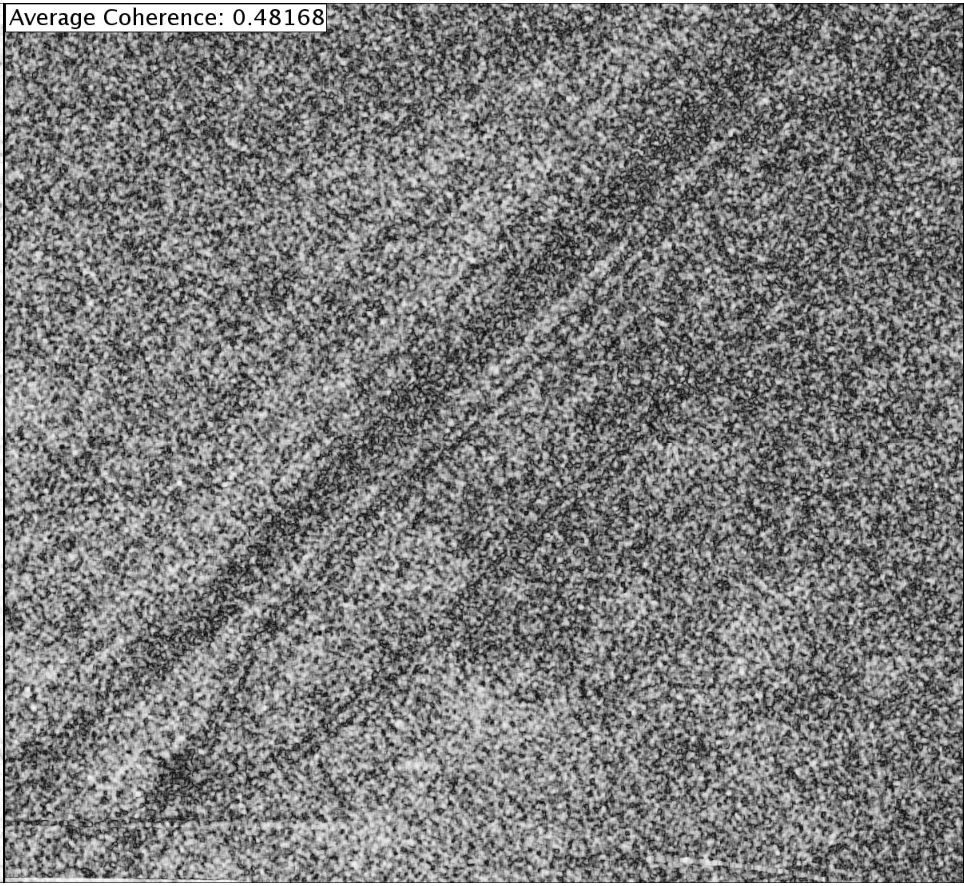



CCD without Interference




CCD with Interference

# Real Data, Example 1

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|---|---|
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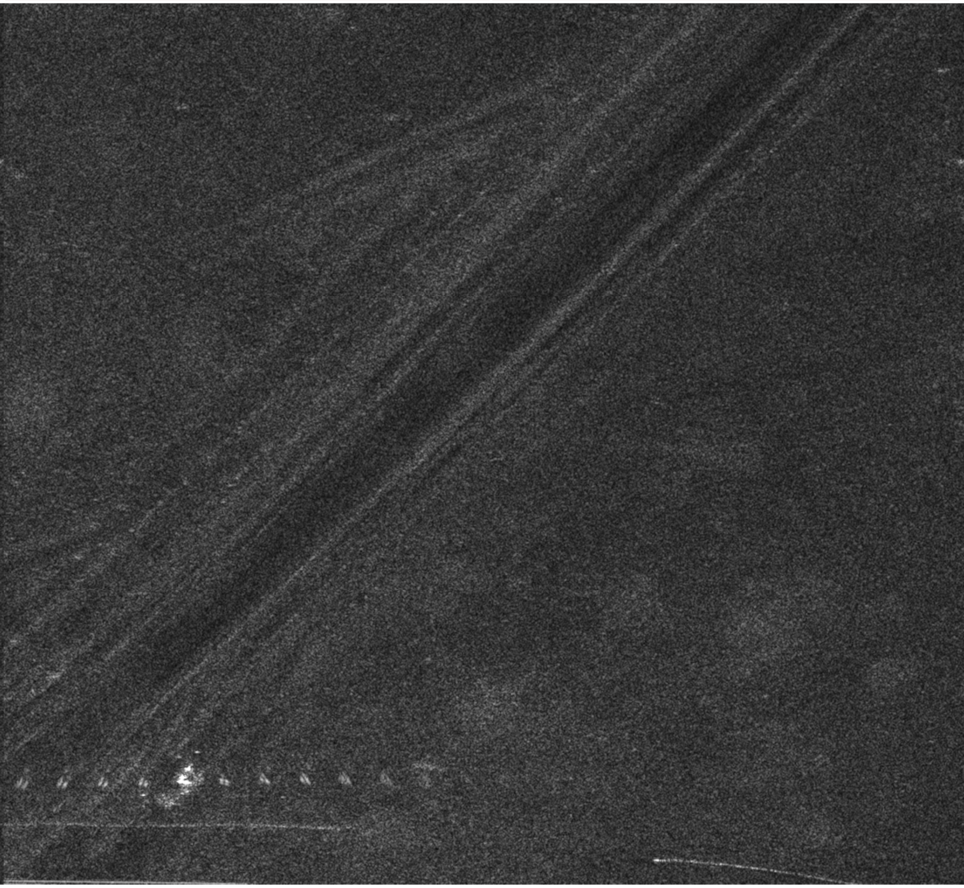
| Resolution | 0.1524m (6”) |
| Image Oversample Factor | 1.5 |
| Window Function | Taylor, n=4, -35dB SLL |

Standard Notch



Equalization Notch

# Real Data, Example 1

Interference Source: synthetic asynchronous 300MHz chirp bandwidth centered at 16.8GHz with PRF 10Hz and duty factor 20%.

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|---|---|
| Center Frequency | 16.8GHz |
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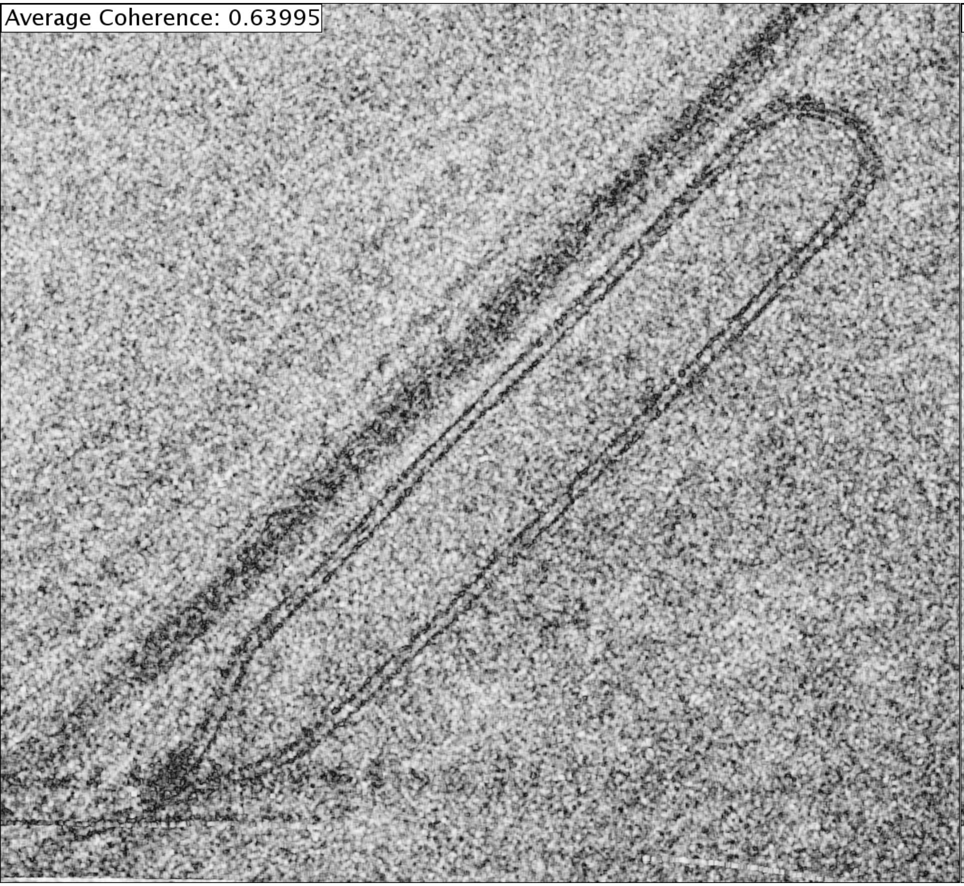
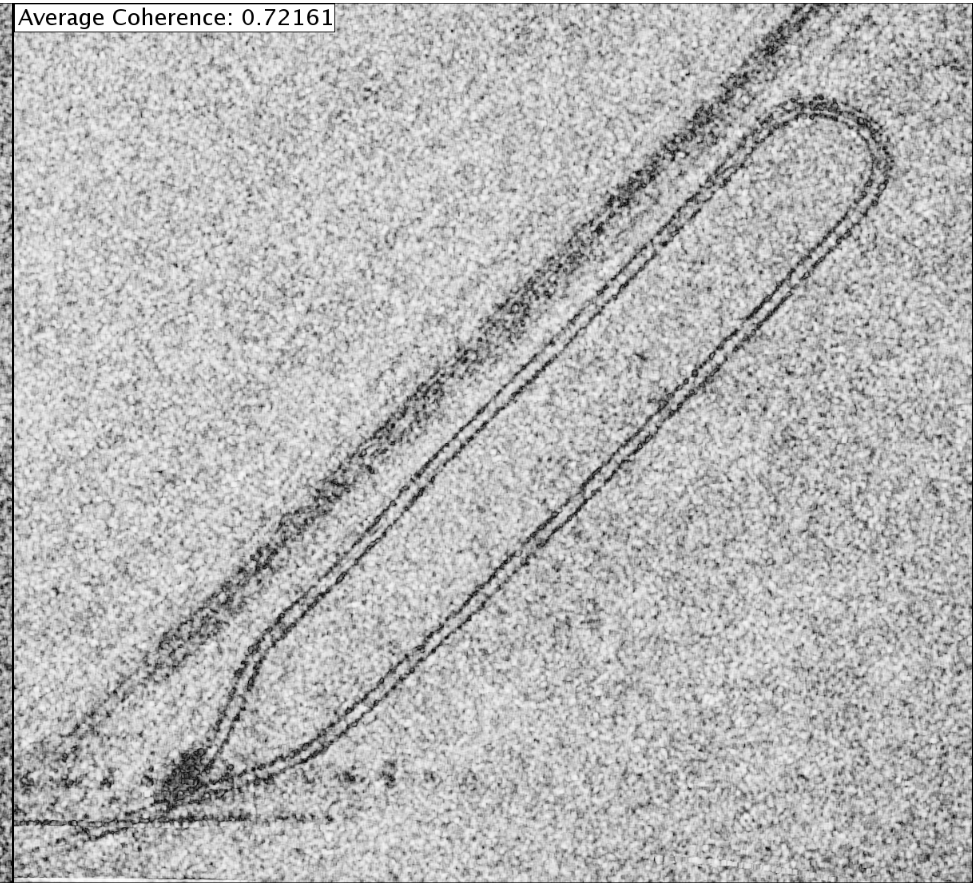



Standard Notch CCD

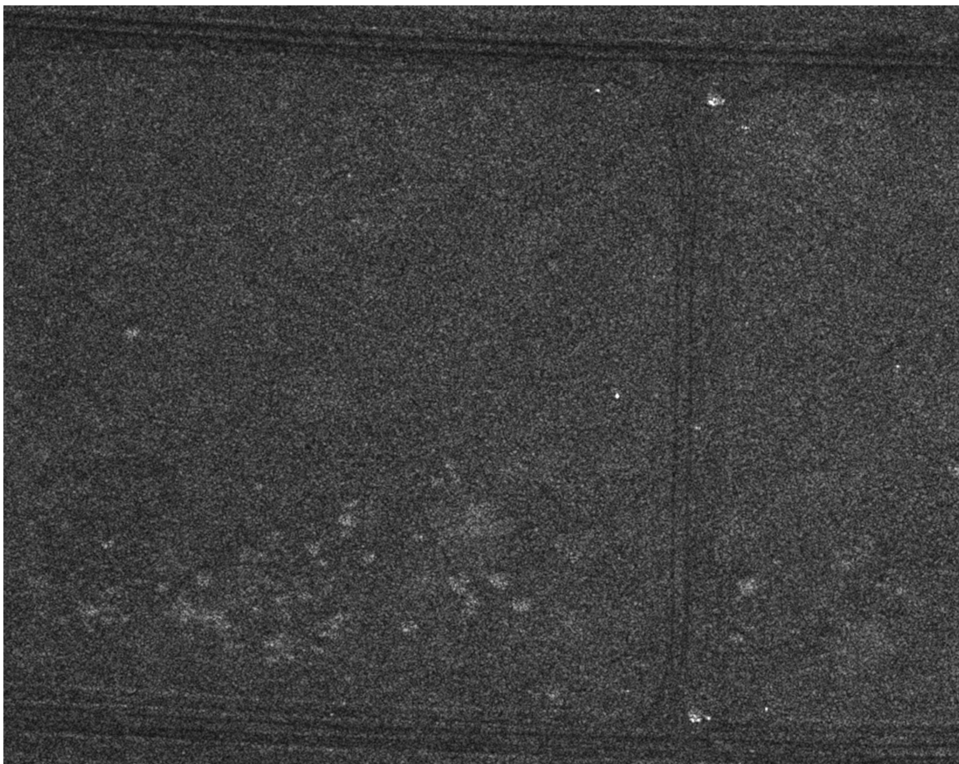



Equalization Notch CCD

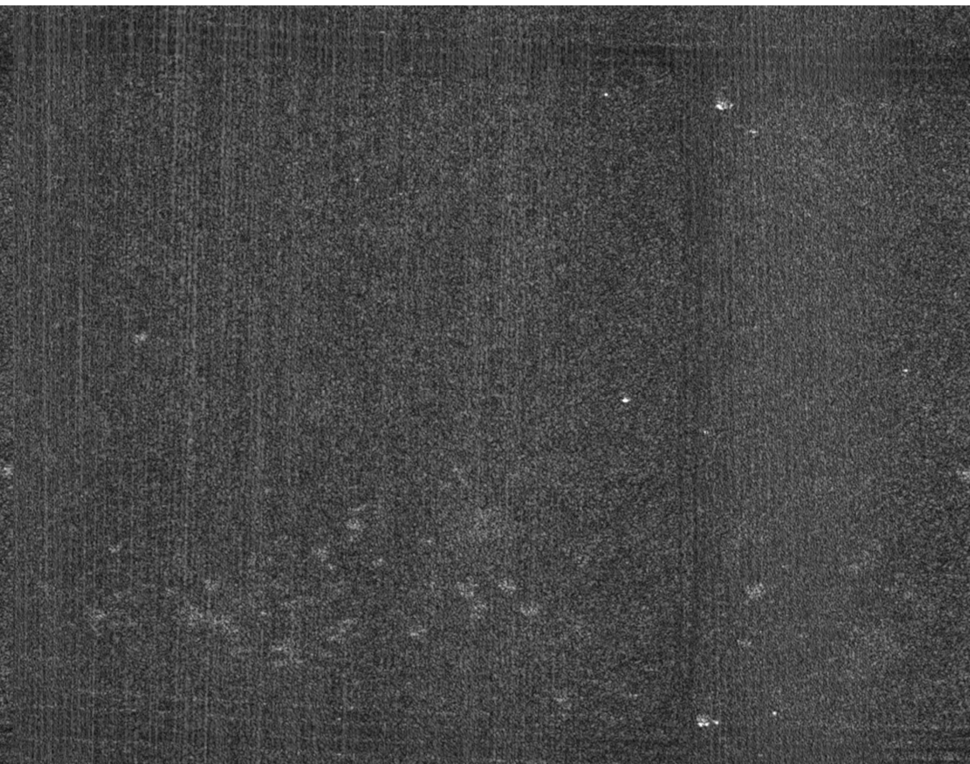
# Real Data, Example 2

300MHz chirp bandwidth interference source centered at 16.8GHz. SIR -4dB.

| Example 1 Parameters | |
|---|---|
| Center Frequency | 16.8GHz |
| Resolution | 0.1524m (6”) |
| Image Oversample Factor | 1.5 |
| Window Function | Taylor, n=4, -35dB SLL |



No Interference

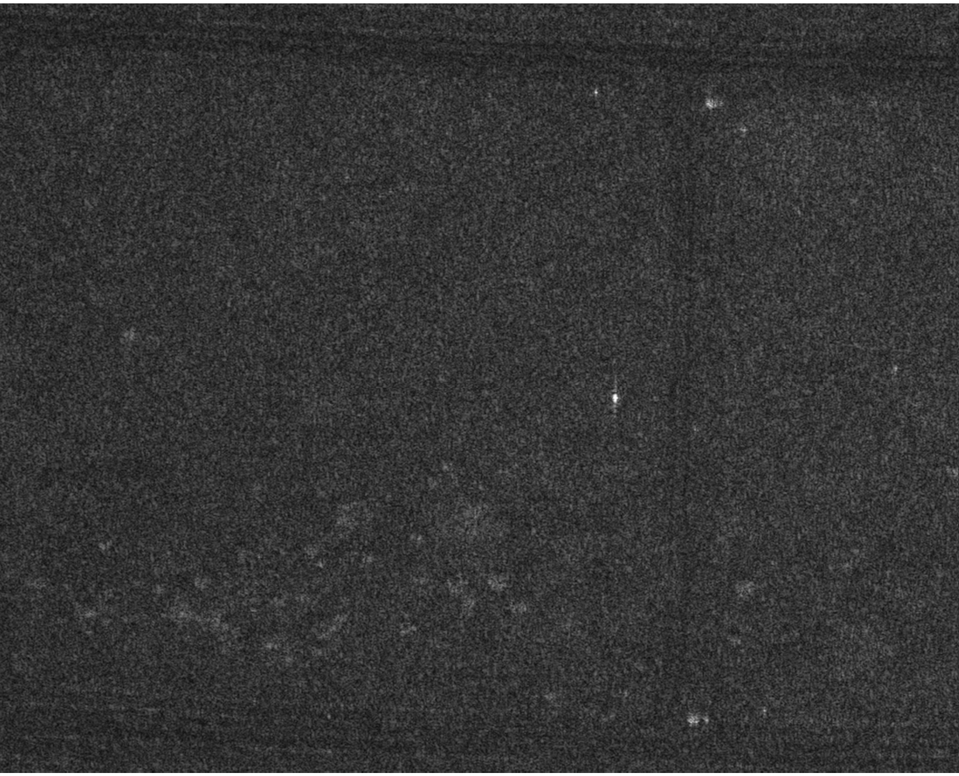


With Interference

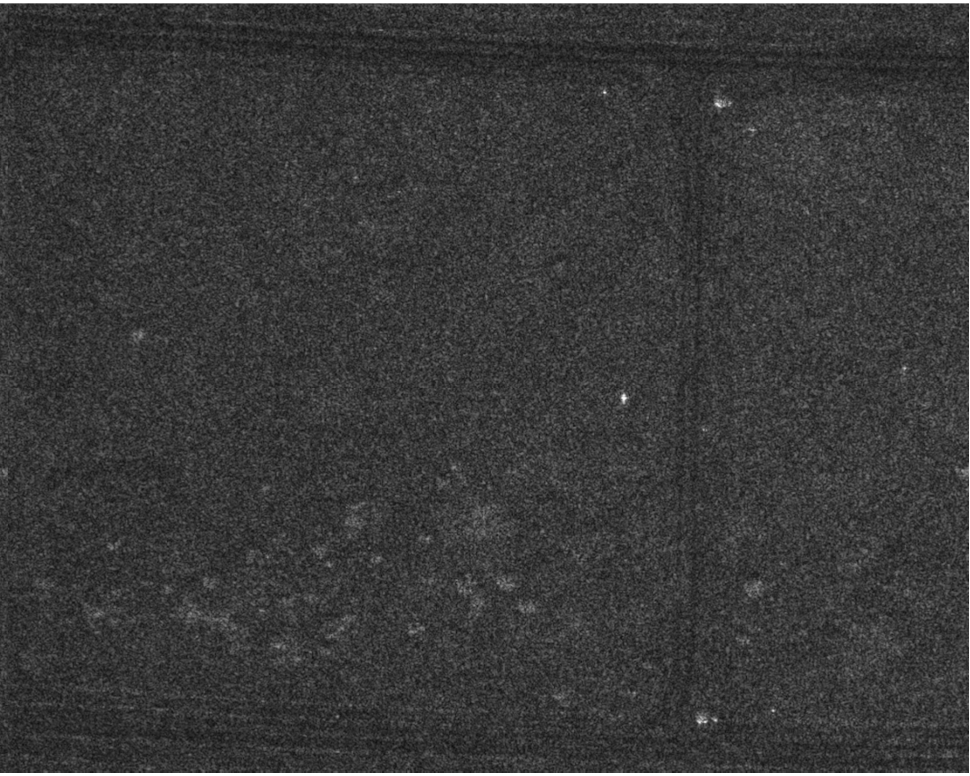
# Real Data, Example 2

300MHz chirp bandwidth interference source centered at 16.8GHz. SIR -4dB.

| Example 1 Parameters | |
|---|---|
| Center Frequency | 16.8GHz |
| Resolution | 0.1524m (6”) |
| Image Oversample Factor | 1.5 |
| Window Function | Taylor, n=4, -35dB SLL |



Standard Notch



Equalization Notch

# Real Data, Example 2

300MHz chirp bandwidth interference source centered at 16.8GHz. SIR -4dB.

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|---|---|
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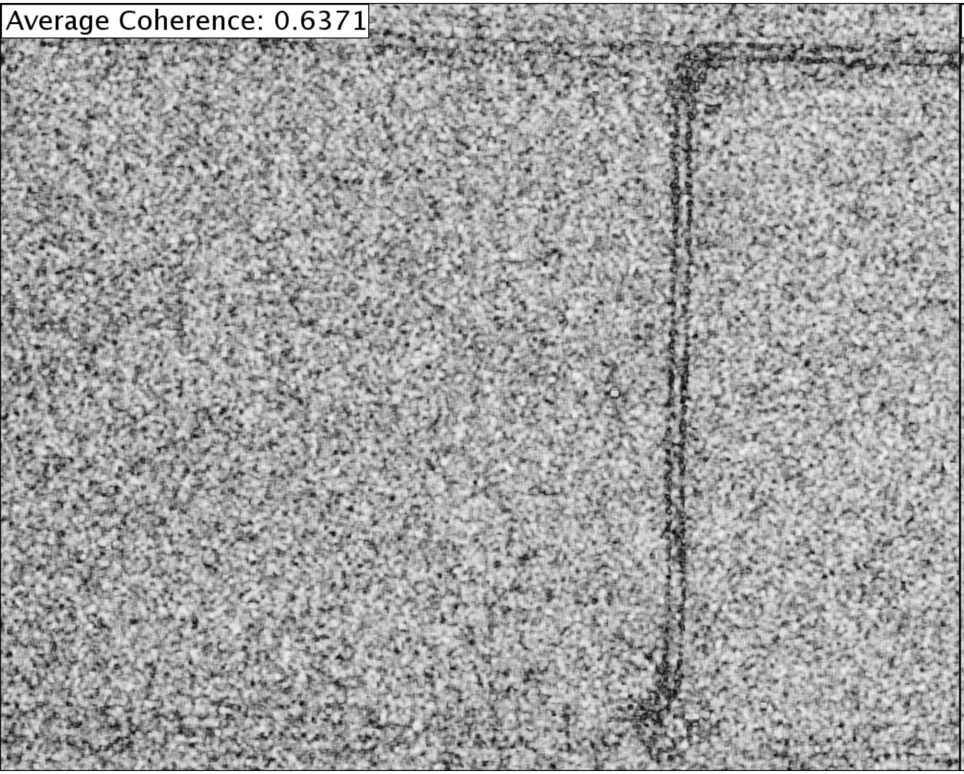
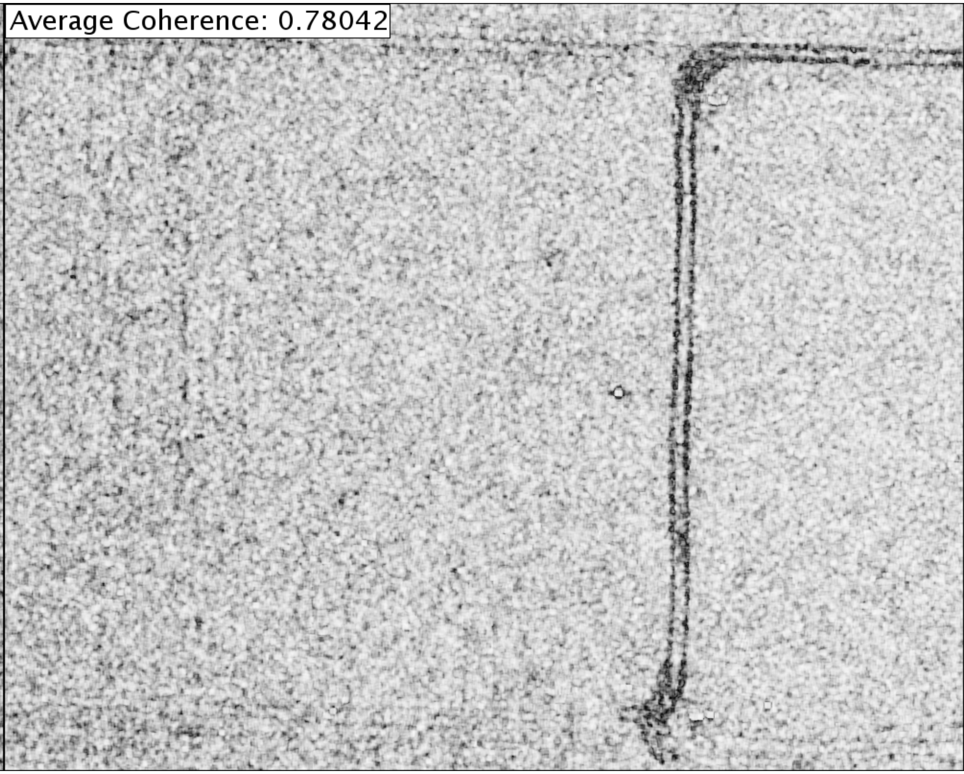
| Resolution | 0.1524m (6”) |
| Image Oversample Factor | 1.5 |
| Window Function | Taylor, n=4, -35dB SLL |



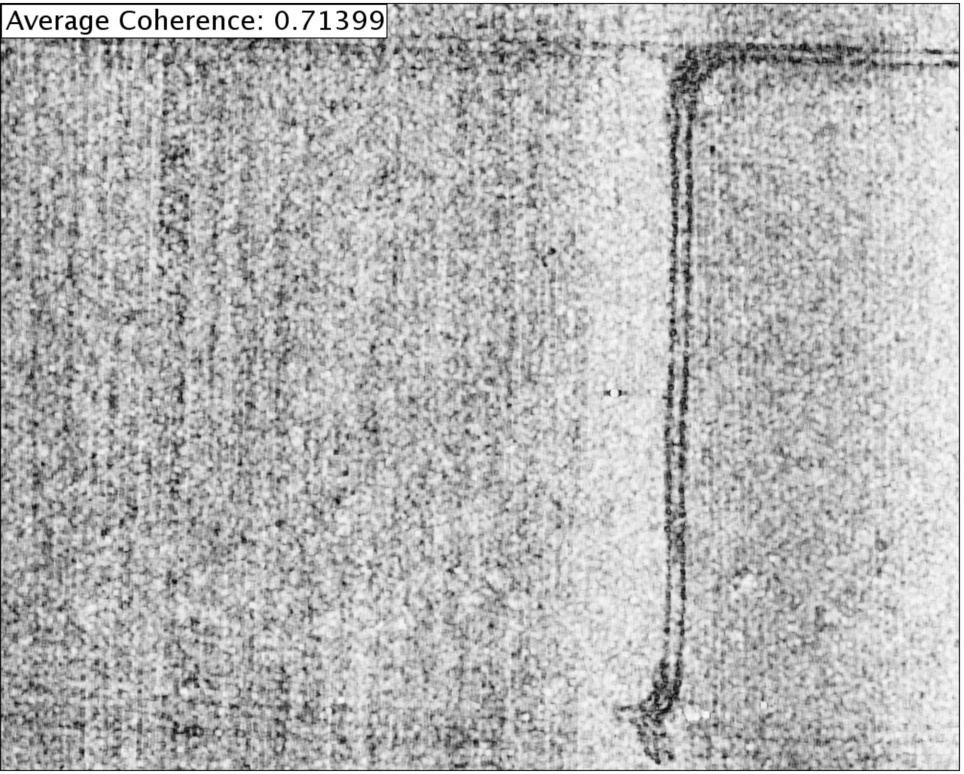

Standard Notch CCD



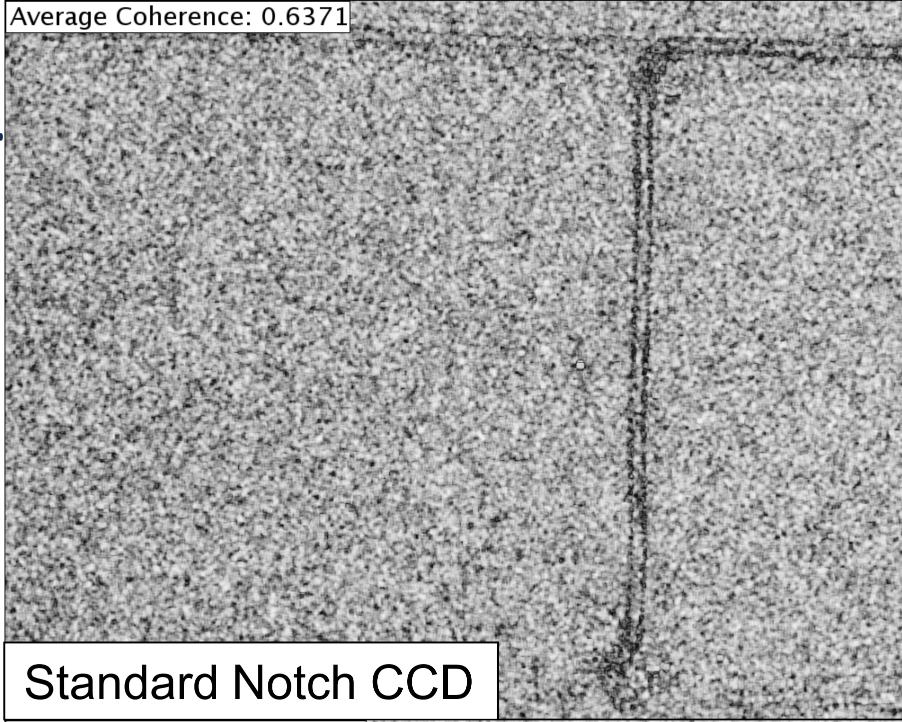

Equalization Notch CCD

# Real Data, Example 2

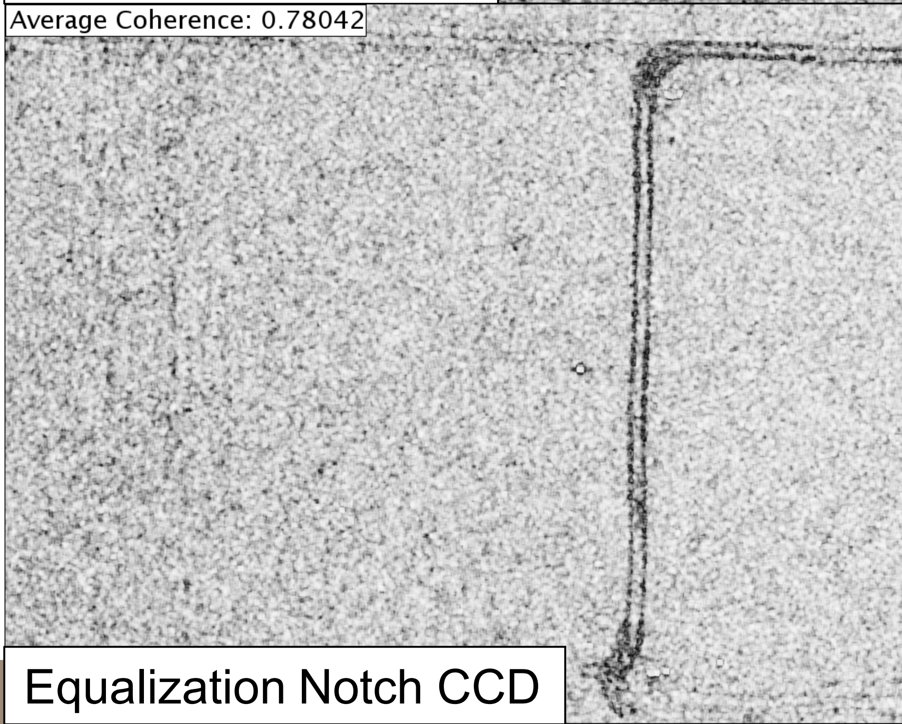
Chirped interference centered at 16.8GHz with 300MHz bandwidth. SIR -4dB.




CCD with Interference




Standard Notch CCD




Equalization Notch CCD

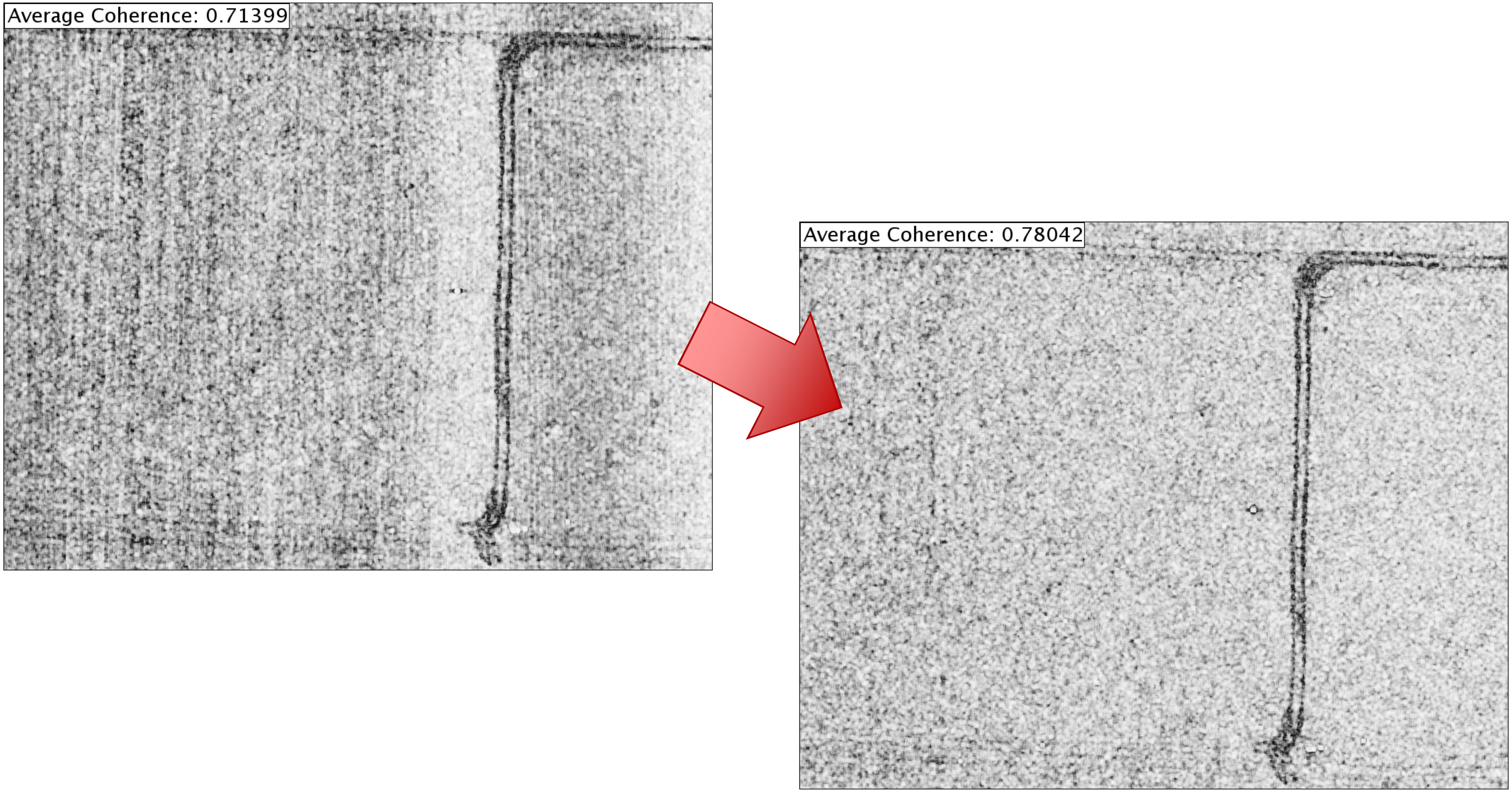
# Conclusions

- Mitigation method, not the interference creates IPR distortions.
- IPR distortions and interference artifacts reduce quality of image and coherent data products.
- Equalizing the magnitude of the phase history can improve the IPR and coherent data product over notching techniques.

# Future Work

- Quantify interference mitigation method performance against probability of detecting change for CCD.
- Explore additional mitigation strategies to improve image quality and coherence.

# Questions?





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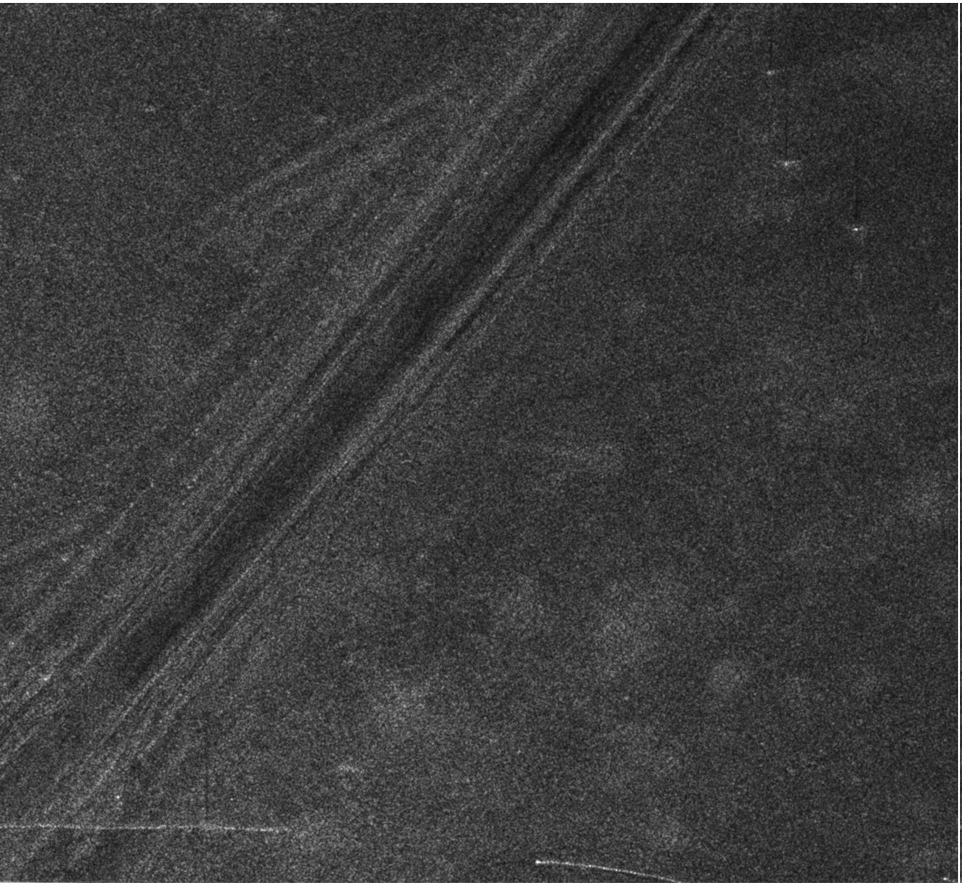
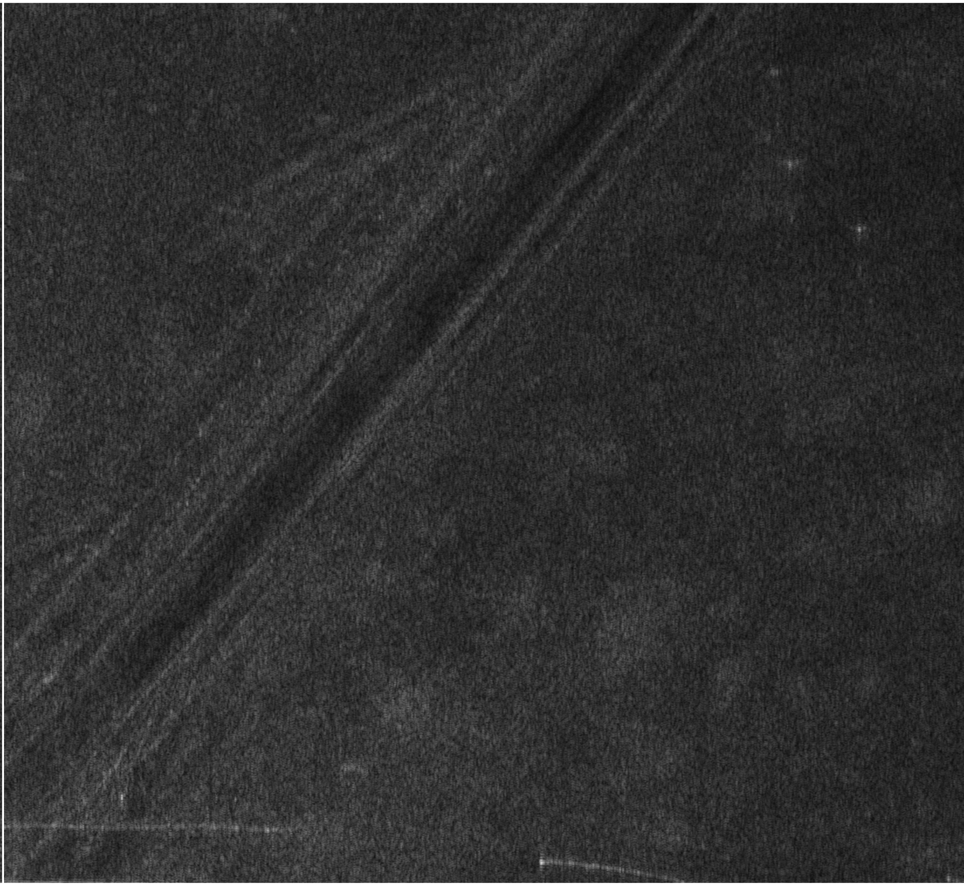
# Equalization Notch – Limit

# Notching Both Images

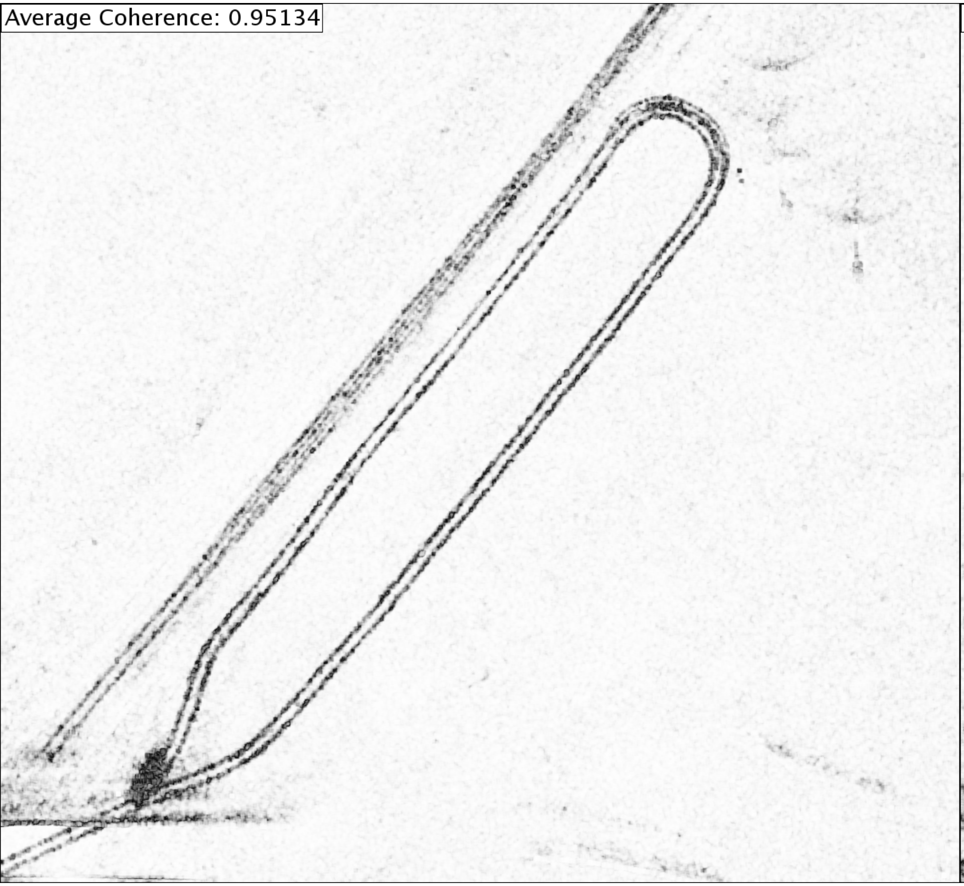


0% samples notched

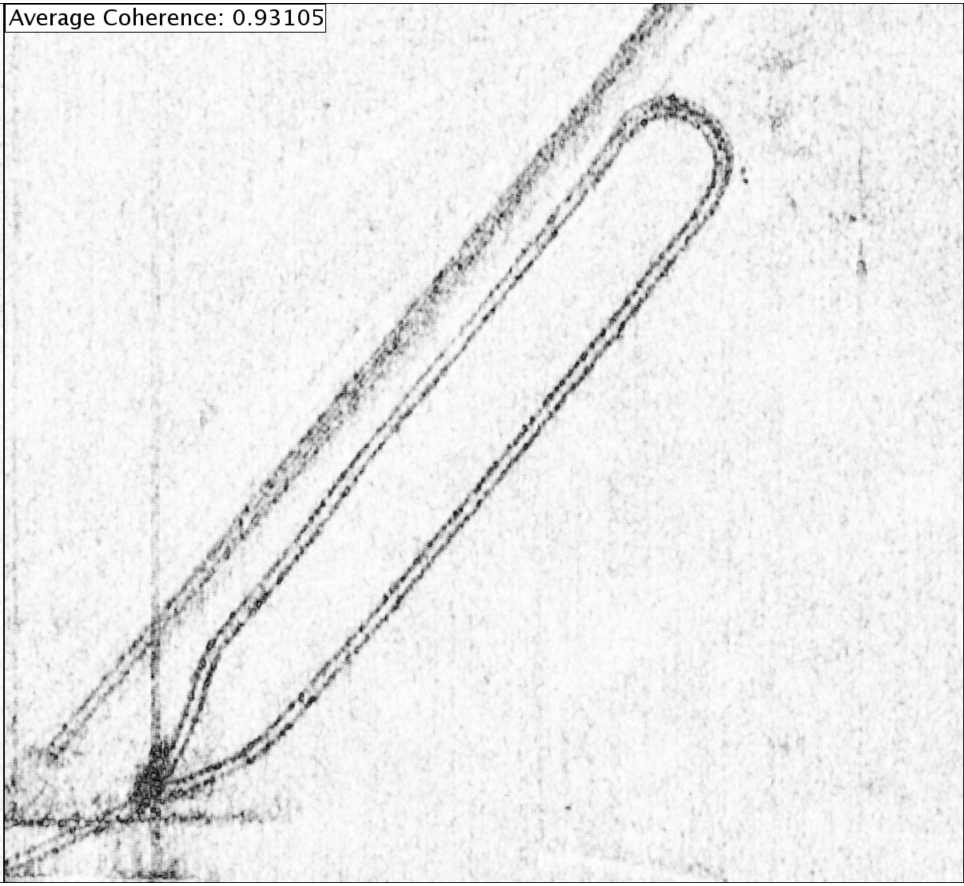


25% samples notched

# Notching Both Images




0% samples notched




25% samples notched, in both images