# SAR Processing By Chirp Scaling Algorithm(CSA) Based General Algorithm

2019.11.21

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(referenced of the proceeding published on the 40th Asian Conference On Remote Sensing)

# Contents

- Introduction
- Chirp Scaling Algorithm(CSA) Based General Algorithm
  - Technical functions
  - Flow diagram, formula
  - Azimuth deramping control
- Test Results
- Conclusion

# Introduction

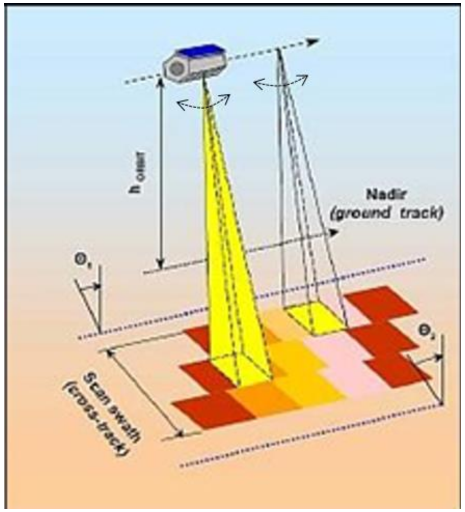
- Current and coming SAR missions
  - KOMPSAT-5, Sentinel-1A, Sentinel-1B, TerraSAR-X, ALOS-2, Cosmo-SkyMed 5G, PAZ, SOACOM-1a, SOACOM-1b, Radarsat-2, Risat-1, KOMPSAT-6

[Fig. 1. KOMPSAT-5 currently in operation and KOMPSAT-6 operational from 2021.Nov.]

- Preference of One general SAR Processing algorithm
  - Low cost for development, maintenance V.S. increment of complexity, processing time
  - Merits of standard SAR processing and standard SAR products

# Introduction

- Multiple SAR systems with multiple operational modes
  - Mono or bi-static and stripmap, scanSAR, TOPS, sliding spotlight, staring spotlight
- Characteristics of SAR observations
  - Multiple beams for subswaths with different hardware parameters
  - Azimuth beam steering

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[Fig. 2. General SAR operations]

# Chirp Scaling Algorithm(CSA) Based General Algorithm

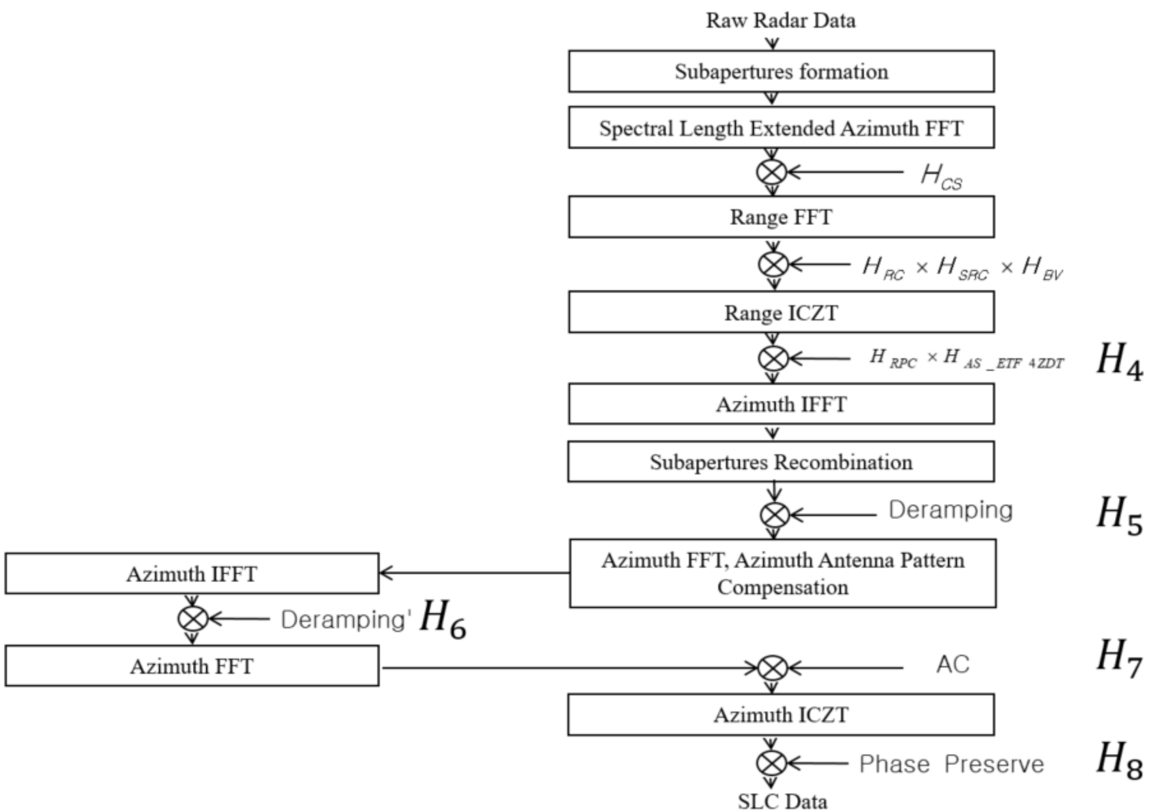
- Application of technical functions
  - Resolution for the Characteristics of SAR observations

[Table. 1. Applied technical functions]

| Multi-SAR characteristics | Dealing Technique | Description |
|---|---|---|
| Multiple beams | Inverse Chirp-z transformation | Control image pixel resolution (azimuth, range) |
| Azimuth steering | Spectral length extension, Deramping | Azimuth bandwidth handling under Nyquist criteria |

# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Algorithm flow diagram




- The range processing flow of the proposed algorithm, until $H_{RPC}$ at marked as $H_4$, is that of the CSA of the reference (Ian G. Cumming, Frank H. Wong, 2005).

[Fig. 3. Flow diagram of Chirp Scaling algorithm based General SAR Processing Algorithm]

# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Algorithm formula
  - Azimuth Scaling

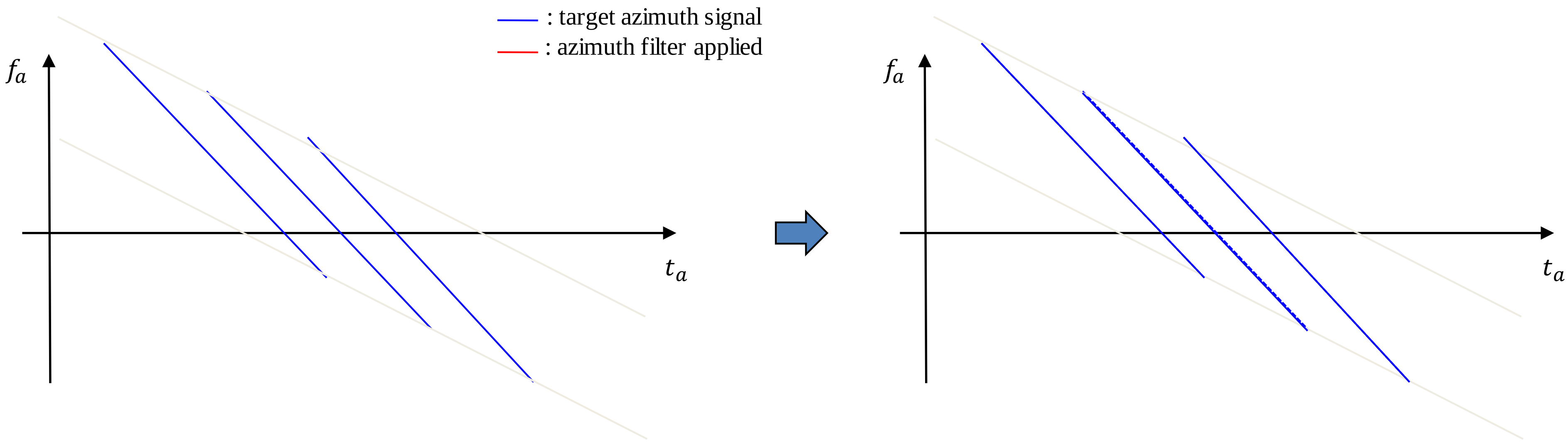
$$H_4(f_a, r) = H_{AS\_ETF4ZDT} = M_1(w_\eta) \cdot exp\left[-j\frac{\pi}{K_{scl}(r)} f_a^2\right]$$

$$here, K_{scl}(r) = -\frac{2v_{eff}^2(r)}{\lambda r_{scl}(r)},\ r_{scl}(r) = r$$

$$M_1(w_\eta) = \exp[j\{2\left(\frac{2\pi}{\lambda} + \frac{w_r}{c}\right) R_{r2}(\eta^*) + w_\eta \eta^*\}]$$

$$R_{r2}(\eta) = c_4\eta^4 + (c_3 + 4c_4t_1)\eta^3 + (c_2 + 3c_3t_1 + 6c_4t_1^2)\eta^2$$

$M_1(w_\eta)$ is referred to the reference, (Jae Chul Yoon).

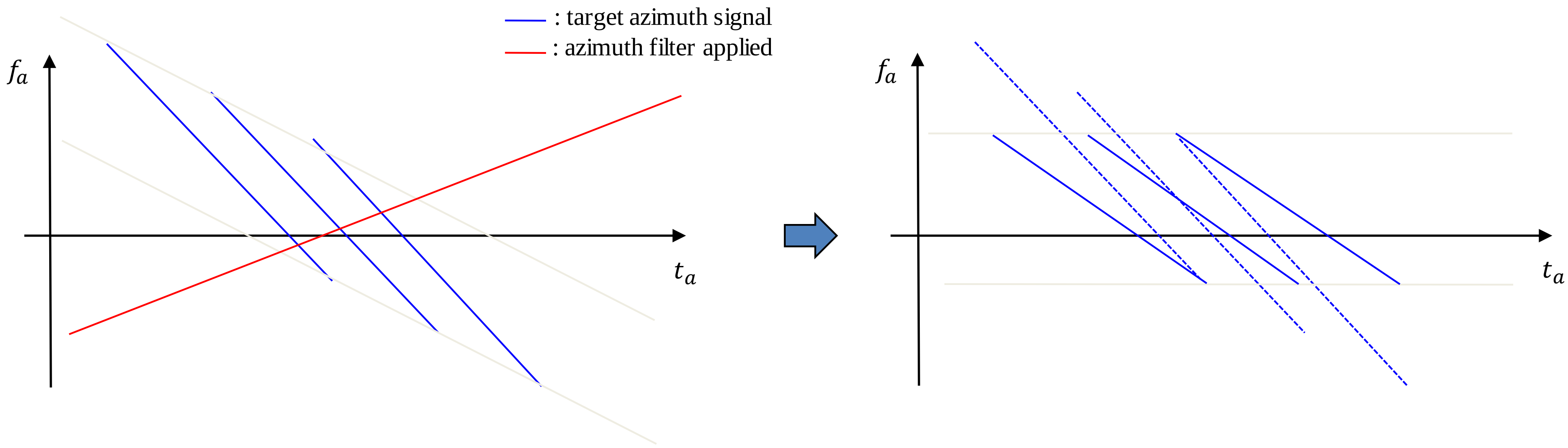


# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Algorithm formula
  - Azimuth Deramping1

$$H_5(t_a,r) = exp\left[-j\pi K_{rot\_geometry} \cdot (t_a - t_{mid})^2\right]$$

$here, K_{rot\_geometry}(r) = K_{rot1}(r) = -\frac{2v_{eff}^2(r)}{\lambda r_{rot\_geometry}}$ and $r_{rot\_geometry}$ is the geometrical beam rotation distance.



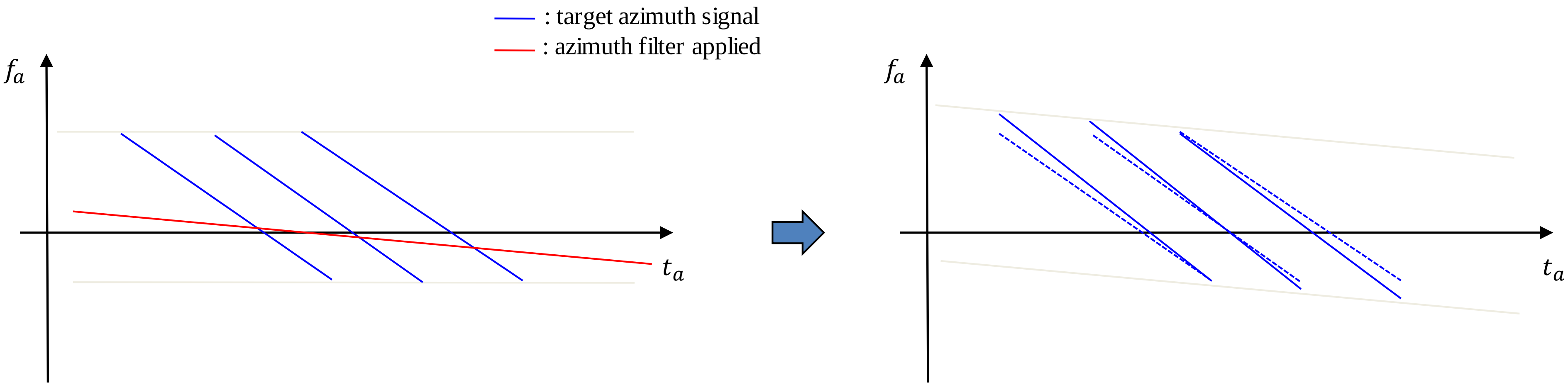
# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Algorithm formula
  - Azimuth Deramping2

$$H_6(t_a,r) = exp\left[-j\pi\left(K_{rot2}(r) - K_{rot\_geometry}\right)\cdot(t_a - t_{mid})^2\right]$$

$here, K_{rot2}(r) = -\frac{2v_{eff}^2(r)}{\lambda r_{rot2}(r)}$ is the azimuth deramping Doppler rate and $r_{rot2}(r) = r\cdot\xi$.

$\xi$ is to be set in accordance of the azimuth beam steering scheme with the beam hardware parameters.

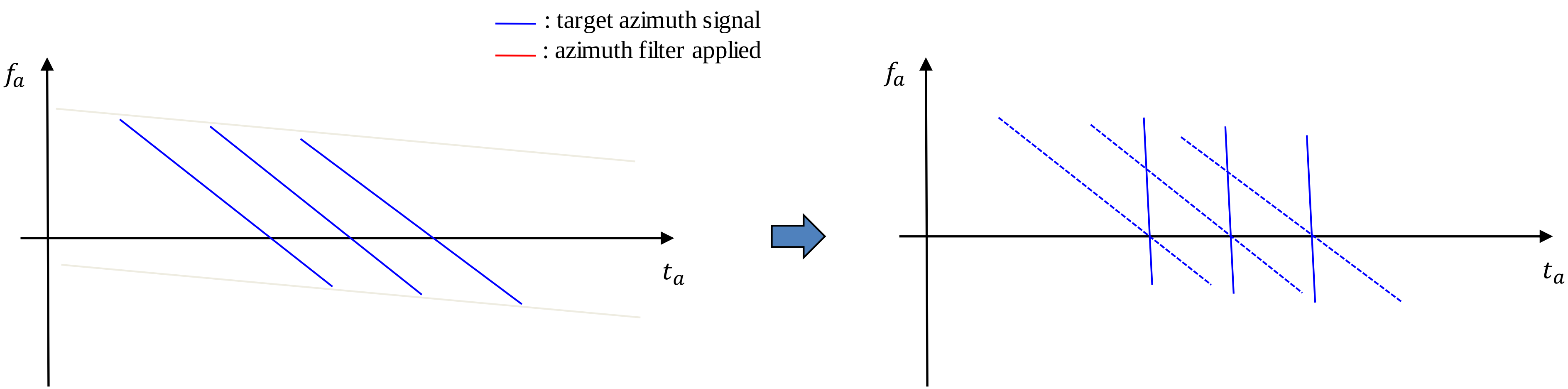


# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Algorithm formula
  - Azimuth compression

$$H_7(f_a, r) = \exp\left[j \frac{\pi}{K_{eff}(r)} f_a^2\right]$$

Here, $K_{eff}(r) = K_{scl}(r) - K_{rot2}(r)$.



# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Azimuth deramping2 ($K_{rot2}(r)$) control
  - Conditions
    1. Azimuth time span of the processed scene is not extended too long compared to the azimuth time domain of the original raw data
    2. Azimuth bandwidth of any target is larger than 0 Hz after deramping by $H_6$
  - $\xi$ setting
    - For stripmap or scanSAR or TOPS : $\xi = \frac{r_{rot\_geometry}}{r_{mid}}$
    - For sliding spotlight or staring spotlight or any in between them : optimization of $\xi$ among the two conditions above
      - First Condition
        (The constant value, 1.25 can be adjusted for tuning the processing. )

$\xi = 1 + \frac{\Delta t_{a0}}{\gamma_1 \cdot T_a - \Delta t_{a0}}, \gamma_1 > 0$ $T_a$ is the total azimuth time length of the raw data, $\Delta t_{a0}$ is the processed azimuth scene length in seconds. Here, the range $\frac{\Delta t_{a0}}{T_a} < \gamma_1 < 1.25$ can be used then, allowed $\xi$ range is found.

$$\xi_{\min\_\gamma_1} = -\infty < \xi < 1 + \frac{\Delta t_{a0}}{1.25 \cdot T_a - \Delta t_{a0}} = \xi_{\max\_\gamma_1}$$

# Chirp Scaling Algorithm(CSA) Based General Algorithm

- Azimuth deramping2 ($K_{rot2}(r)$) control
  - $\xi$ setting
    - For sliding spotlight or staring spotlight or any in between them : optimization of $\xi$ among the two conditions above
      - Second Condition
        (The constant value 0.75 can be adjusted for tuning the processing. )

$\xi = \frac{v_{eff}(r_{mid})\cdot T_{obs}}{v_{eff}(r_{mid})\cdot T_{obs} - \gamma_2\cdot\theta_{az}\cdot r_{mid}}, \gamma_2 > 0$ $T_{obs}$ is a target observation duration in seconds, $\theta_{az}$ is the 3dB azimuth beam width in radians. Here, the range $1 < \gamma_2 < 0.75\cdot\frac{B_{a\_Target}}{B_{FOV}}$ can be used then, allowed another ξ range is found.

$$\xi_{\min\_\gamma_2} = \frac{v_{eff}(r_{mid})\cdot T_{obs}}{v_{eff}(r_{mid})\cdot T_{obs} - \theta_{az}\cdot r_{mid}} < \xi < \frac{1}{1-0.75} = \xi_{\max\_\gamma_2}$$

Where, $B_{a\_Target} = \frac{2v_{eff}^2(r_{mid})}{\lambda r_{mid}}\cdot T_{obs}$, $B_{FOV} = \frac{2v_{eff}^2(r_{mid})}{\lambda r_{mid}}\cdot\frac{\theta_{az}\cdot r_{mid}}{v_{eff}(r_{mid})}$.

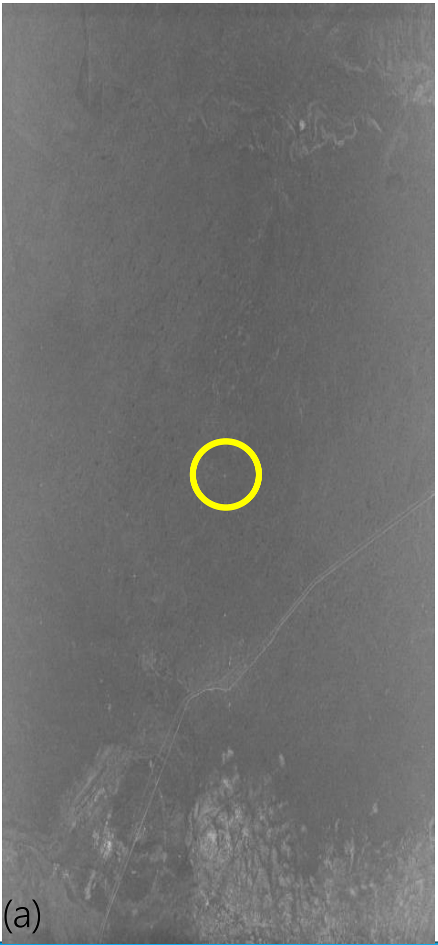
# Chirp Scaling Algorithm(CSA) Based General Algorithm

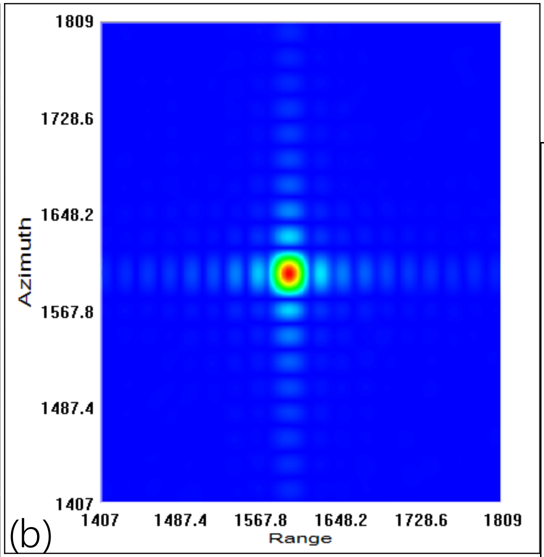
- Azimuth deramping2 ($K_{rot2}(r)$) control
  - $\xi$ setting
    - For sliding spotlight or staring spotlight or any in between them : optimization of $\xi$ among the two conditions above
      - Apply optimization rule among the two conditions

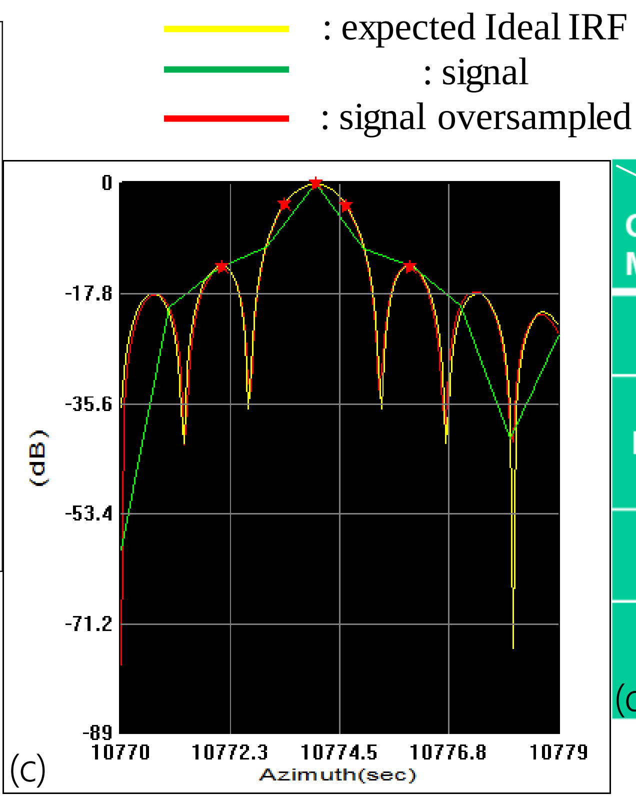
In the case of $\xi_{\max\_\gamma_2} \leq \xi_{\max\_\gamma_1}$ then, $\xi = \frac{\xi_{\min\_\gamma_2} + \xi_{\max\_\gamma_2}}{2}$. In the case of $\xi_{\max\_\gamma_2} > \xi_{\max\_\gamma_1}$ and $\xi_{\min\_\gamma_2} + \Delta\xi_{one\ third\_\gamma_2} \leq \xi_{\max\_\gamma_1}$ then, $\xi = \frac{\xi_{\min\_\gamma_2} + \Delta\xi_{one\ third\_\gamma_2} + \xi_{\max\_\gamma_1}}{2}$. In the case of $\xi_{\max\_\gamma_2} > \xi_{\max\_\gamma_1}$ and $\xi_{\min\_\gamma_2} + \Delta\xi_{one\ third\_\gamma_2} > \xi_{\max\_\gamma_1}$ then, $\xi = \xi_{\min\_\gamma_2} + \Delta\xi_{one\ third\_\gamma_2}$. Here, let $\Delta\xi_{one\ third\_\gamma_2} = \frac{\xi_{\max\_\gamma_2} - \xi_{\min\_\gamma_2}}{3}$.

# Test Results

- K-5 Stripmap mode processing test



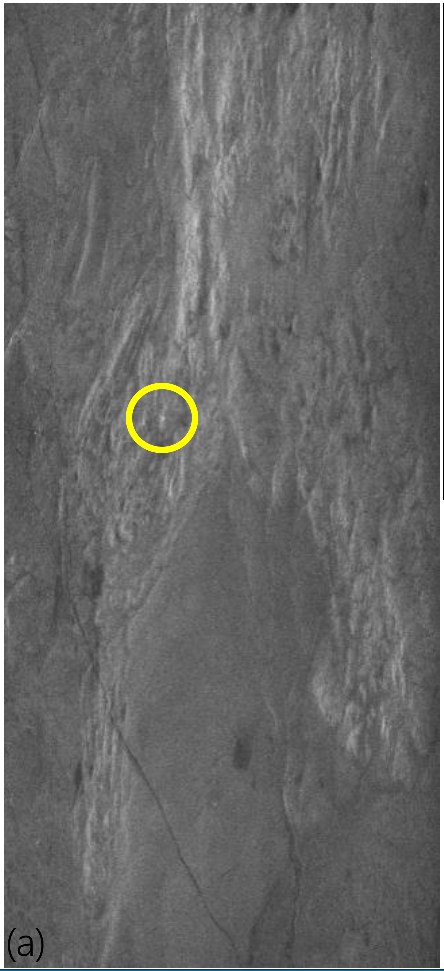

| Mode / Quality Measure | K5-ST |
|---|---|
| ξ | -29209.460 |
| Azimuth Resolution (Meter) | 2.102 |
| Azimuth PSLR(dB) | -13.319 |
| Azimuth ISLR(dB) | -10.124 |

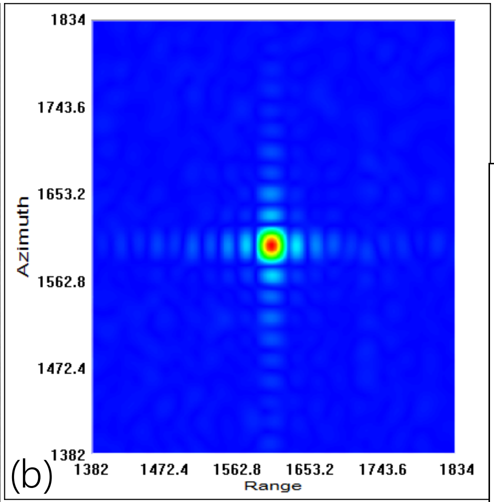
(d)

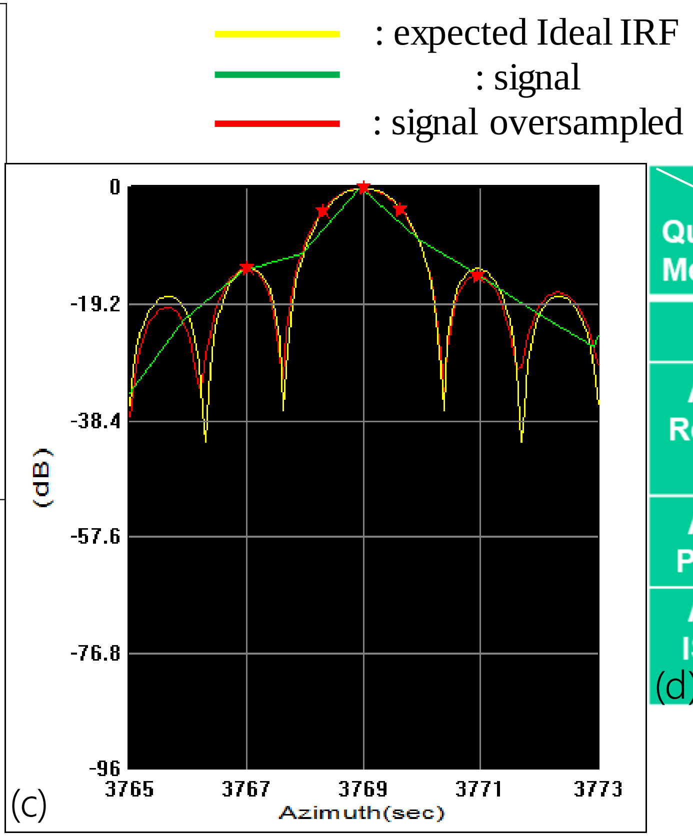
[Fig. 4. Corner reflector measurement
(a) Processed image,
(b) Contour plot,
(c) Azimuth IRF,
(d) Quality measurement]

# Test Results

- K-5 Sliding spotlight mode processing test



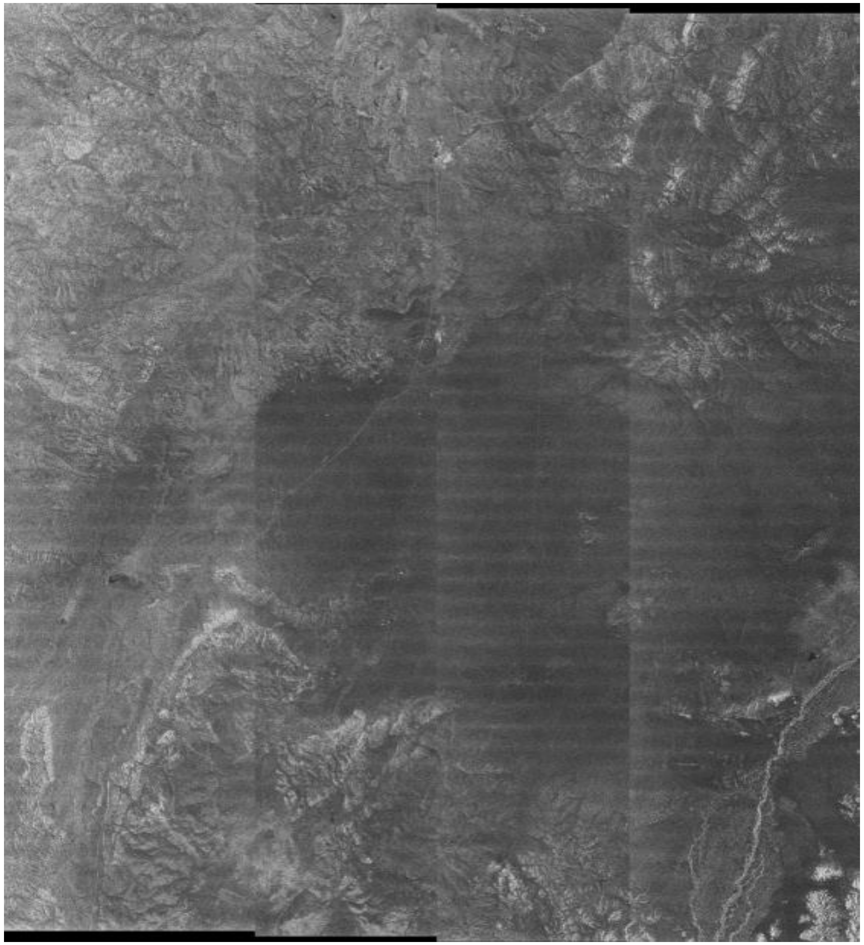

| Mode / Quality Measure | K5-HR |
|---|---|
| ξ | 2.032 |
| Azimuth Resolution (Meter) | 0.858 |
| Azimuth PSLR(dB) | -13.233 |
| Azimuth ISLR(dB) | -10.464 |

(d)

[Fig. 5. Corner reflector measurement
(a) Processed image,
(b) Contour plot,
(c) Azimuth IRF,
(d) Quality measurement]

# Test Results

- K-5 ScanSAR mode processing test



[Fig. 6. K-5 ScanSAR mode Processed image

# Test Results

- Sentinel-1A TOPS mode processing test

[Fig. 7. Sentinel-1A TOPS mode Processed image

# Conclusion

- Conclusion
  - "One general SAR Processing algorithm" has been developed successfully.
  - It can be applied properly to all kinds of SAR observations, mono or bi-static and stripmap, scanSAR, TOPS, sliding spotlight, staring spotlight and any in between them.

- Future Work
  - Applying Replica for the internal calibration.

- References

  - Dong Hyun Kim, Do Chul Yang, Ho Ryung Jung and Dong Han Lee, Oct. 2019. SAR processing by chirp scaling algorithm(CSA) based general algorithm. The 40th Asian Conference On Remote Sensing.
  - Dong Hyun Kim. Method and system for inverse Chirp-z transformation. Republic of Korean Patent Application No. 10-1687658.
  - Ian G. Cumming, Frank H. Wong, 2005. Digital Processing of Synthetic Aperture Radar Data. Artech House Inc., pp. 283-322.
  - Jae Chul Yoon. Method for SAR Processing. European Patent Application No. 14 160 447.0.
  - Pau Prats, Member, IEEE, Rolf Scheiber, Josef Mittermayer, Member, IEEE, Adriano Meta, Member, IEEE, and Alberto Moreira, Fellow, IEEE, Febru. 2010. Processing of Sliding Spotlight and TOPS SAR Data Using Baseband Azimuth Scaling. IEEE Trans. Geosci. Remote Sens., vol. 48, no. 2, pp. 770-780.

# Q&A

THANKS FOR YOUR ATTENTIONS