Lab Exercise I: SAR image focusing

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Basics:
A SAR scene of the European ERS mission, given as raw data in uncompressed form (dimension: 2048×2048), has to be focused. All parameters needed for the SAR image compression are summarized in table 1. The focusing is conducted by correlating the raw data with a reference function in range ("range chirp") and azimuth direction ("azimuth chirp"), respectively.

Basic contents of the source code for focusing are already available in a MATLAB file ("SAR_focusing_tutorial_temp.m"):

- Loading of raw data/ definition of sensor parameters
- Routines for displaying the raw data, azimuth/range chirps, and the compressed image.
- "Multi looking": The spatial resolution of the ERS data is different in azimuth and range. Hence, a box car filter, having a size of 5x1 pixels, can be applied to the focused data in order to provide approximately "quadratic" pixels.

Problem:
In the course of this tutorial, two core elements are to be integrated into the source code for enabling SAR image focusing:

- A.) Definition of reference functions in azimuth and range direction.
    - Definition of signal chirps: fill the vectors „azimuth_chirp" and „range_chirp" with values. Keep in mind, that the chirps of duration t_a und τ_c do not fully cover the vectors, i.e. the chirps have to be positioned centrally within both vectors.
    - Transform both reference functions to the frequency domain (MATLAB command **fft**)
    - Define the chirps for correlation in frequency domain (MATLAB command **conj**).
- B.) Correlation of raw data with reference functions in frequency domain. Correlating the data is conducted line-by-line in azimuth and range direction, respectively, following the scheme:
    - Selection and Fourier-Transform of raw data line.
    - Multiply with reference chirp in frequency domain.
    - Inverse Fourier-Transformation (**ifft**) and sorting of values (**fftshift**).
    - Entry focused data line in new image.
    - Continue with next raw data line …

Control:
Apply the MATLAB code to the test dataset (matrix „Test_Image.mat", dimension: 1100× 1700 pixels) for checking the correctness of programming. If your code is free from errors, you should be able to read the content of the resulting image (dimension: 1100×1700 pixels, 220×1700 pixels after multi-looking).

	Parameters		Value	Unit
Parameters for range compression	Range sampling frequency	f_s	18.962468 * 10^6	s^{-1}
	Chirp rate	K_r	4.18989015 * 10^{11}	s^{-2}
	Chirp length	τ_c	37,12 * 10^{-6}	s
Parameters for azimuth compression	Satellite velocity	V_{sat}	7098.0194	m/s
	Wavelength	λ	0.05656	m
	Range to target at broadside time t = 0	R_0	852358.15	m
	Aperture time	t_a	0.6	s
	Pulse repetition frequency	PRF	1679.902	s^{-1}

Table 1: ERS sensor parameters

Required formulas:

Range Chirp: $u(\tau) = \exp(i \cdot \pi \cdot K_r \cdot \tau^2)$ for $-\frac{\tau_c}{2} < \tau < \frac{\tau_c}{2}$

with step width $\Delta\tau = \frac{1}{f_s}$

Azimuth Chirp: $u(t) = \exp(i \cdot \pi \cdot K_a \cdot t^2)$ for $-\frac{t_a}{2} < t < \frac{t_a}{2}$

with step width $\Delta t = \frac{1}{PRF}$

Frequency modulation rate in azimuth (FM rate): $K_a = -2\frac{V_{sat}^2}{\lambda R_0}$

MATLAB commands in source code:

- Fourier transform (FT): `y = fft(x)`
- Inverse fourier transform (IFT): `y = ifft(x)`
- Sort data in space domain after IFT: `y = ifftshift(x)`
- Complex conjugatet: `zc = conj(z)`
- Round up to next integer: `ceil(x)`
- Scale and display data
  - `imagesc(data)`: plot matrix as image
  - `abs(data)`: amplitude, `real(data)` real part of complex number; `imag(data)` imaginary part of complex number
  - `colormap('gray')`: display data using gray values
  - `caxis ([0 max])`: define interval of values which covers gray values on the visualized image; Image „Test_Image“: `max` = 2.1807*10^8, Image „ERS“: `max` = 10000