
# PULSE LIMITED WAVEFORMS FROM INTERLEAVED MODE: AN ANALYSIS ON THE ACHIEVABLE SPECKLE REDUCTION

M. Scagliola[1], L. Recchia[1], D. Giudici[1] , M. Kuschnerus[2]

(1) aresys

(2) esa

# Outline

- Speckle, multilooking and range noise
- Interleaved mode
- Incoherent average strategy for LR waveforms
- Correlation model for LR waveforms
- Results for the achievable speckle reduction on LR waveforms
- Conclusions

# Speckle, incoherent average and range noise

***Speckle:*** radar echoes are the incoherent summation of many randomly phased echoes from small scattering regions of the surface. This causes the speckle noise.

***Incoherent average:*** speckle reduction can be achieved by incoherent average, assuming that single look echoes are only partially correlated.

***Range noise:*** the uncertainty on the range measure is function of the number of statistically independent looks (N)

Single look echo:

$$X_s(\tau) = X(\tau) \cdot s(\tau)$$

Multilooked echo:

$$X_{ml}(\tau) = \frac{1}{N_{ML}} \sum_{l=1}^{N_{ML}} X(\tau) \cdot s(\tau)$$

Range noise at the leading edge [1]

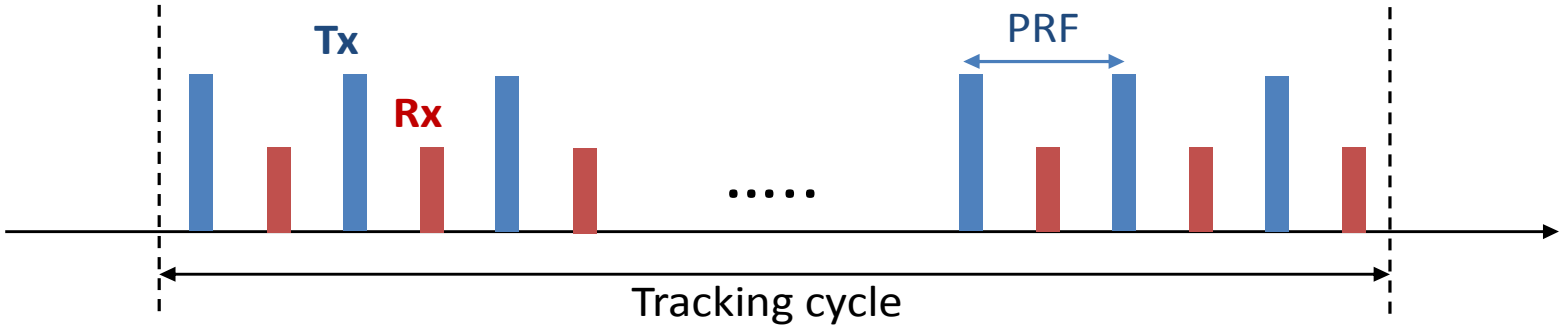
$$\sigma_h = \frac{\sigma_p}{0.8\sqrt{N_g \cdot N}} \left[ 1 + \frac{2}{SNR} \right]$$



[1] Design of the Seasat-A radar altimeter, MacArthur J. L., OCEANS 1976, IEEE

# Interleaved mode

Poseidon4 will be the first altimeter able to operate in a continuous high-rate pulse mode, i.e. interleaved mode, that foresees that between any two transmitted pulses, an echo is received.



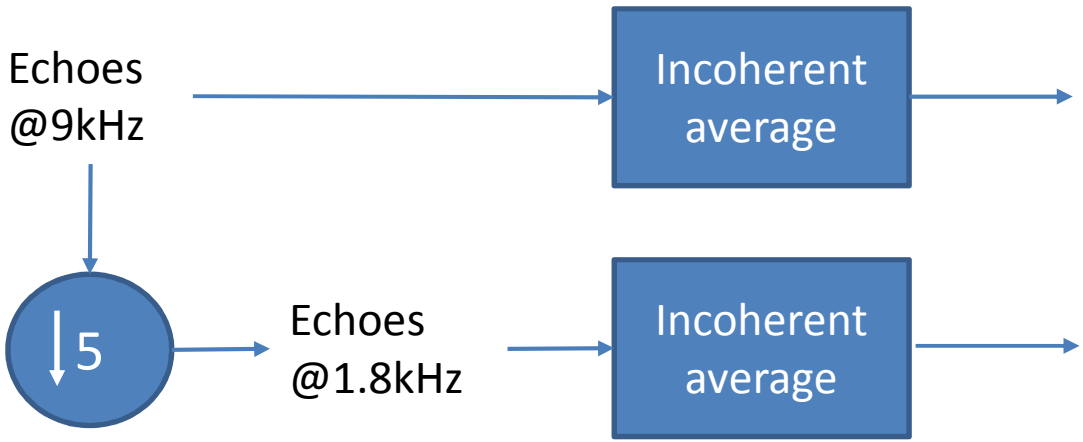

Just like a Pulse Limited altimeter but at a much higher rate (~9 kHz for Ku-band)

- simultaneous production of low-resolution mode measurements on-board as well as the processing of high-resolution echoes on-ground
- higher number of single looks waveforms in high-resolution mode w.r.t. closed burst mode

# Incoherent average strategy for LR waveforms

| | Walsh limit | Conventional LRM instrument | Interleaved mode instrument |
|---|---|---|---|
| **PRF** | ~ 1.8 kHz | ~ 2 kHz | ~ 9 kHz |
| | Successive echoes are partially correlated | | Higher number of single look echoes but more correlated |

Two possible strategies for incoherent average [2]:




***Incoherent average of all pulses @9kHz***: waveforms not statistically equivalent to conventional LRM instrument but higher speckle reduction expected

***Incoherent average of decimated pulses @1.8kHz:***
waveforms statistically equivalent to conventional LRM instrument

***Objective: quantifying the higher speckle reduction achievable @9kHz***



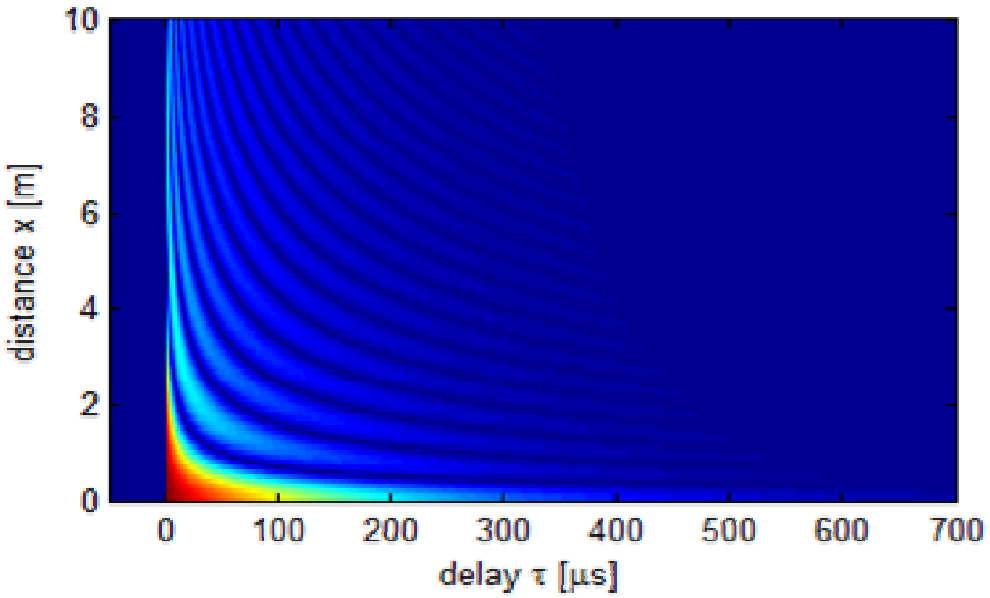
[2] JASON-CS SAR MODE ERROR BUDGET STUDY REVIEW OF STATE OF KNOWLEDGE FOR SAR ALTIMETRY OVER OCEAN, EUM/RSP/REP/14/749304, 21 NOVEMBER 2013, VERSION 2.2

# Correlation model for LR waveforms

Exploiting the single look echo cross-product impulse response in [3], we can compute the echo correlation coefficient as function of the delay τ and of the along orbit displacement x

$$R(\tau,x)=\frac{\overline{\psi(\tau)\psi(\tau,x)^*}}{\overline{\psi(\tau)\psi(\tau)^*}}=\frac{\Pi(\tau,x)}{X(\tau)}$$

**Mean echo cross-product**
over
**Mean echo power**




ENL is defined as the estimate of the effective number of statistically independent looks

$$ENL = N^2 / \sum_{n=0}^{N-1}\sum_{m=0}^{N-1} R_{n,m}$$

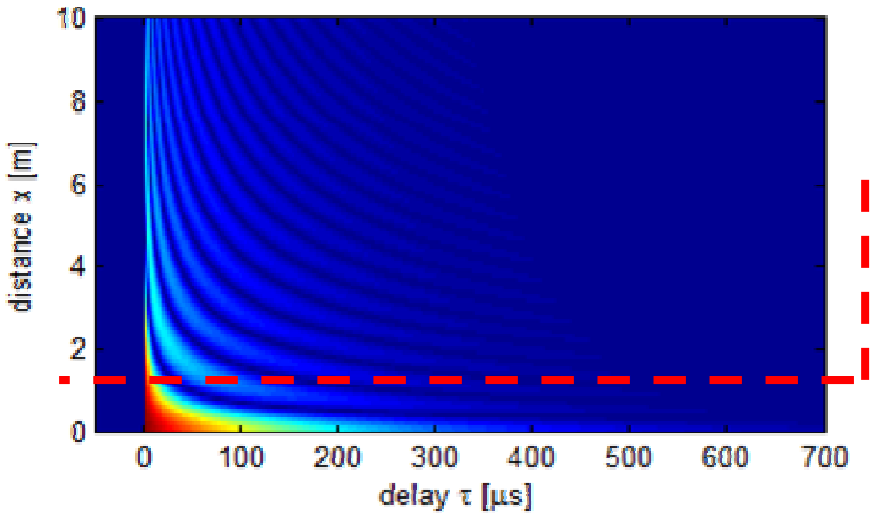
**Higher is the ENL and lower is the speckle**

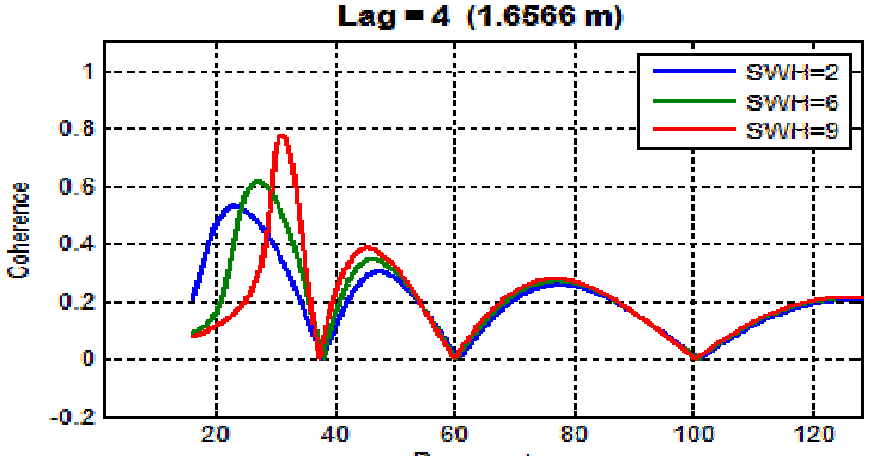


[3] Giles, K., D. J. Wingham, N. Galin, R. Cullen, W. Smith, 2012: Precise estimates of ocean surface parameters from Cryosat. *OSTST 2012, Venice, 27-28 Sept 2012,*

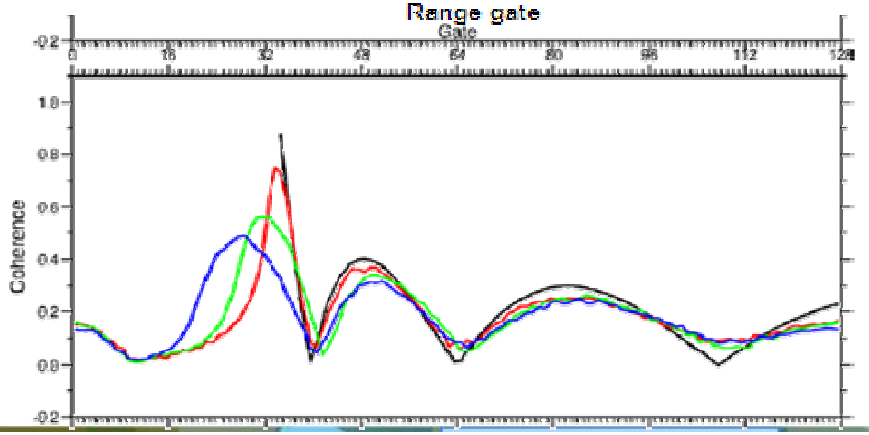
# Verification of the correlation model

The correlation model has been verified by comparison with the results in [4], where the coherence as function of the delay delay τ and of the lag between CryoSat pulses has been measured from CryoSat FBR data




Aresys' model




CryoSat data [3]

***The matching between the theoretical coherence and the experimental one allows to verify the correcteness of the Aresys model***

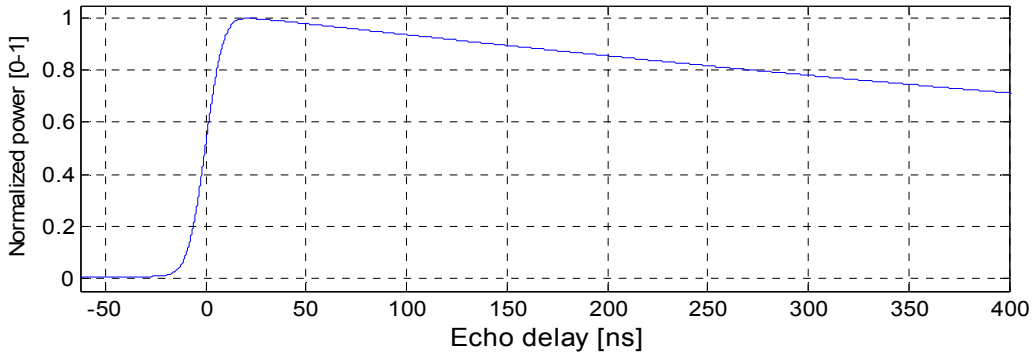


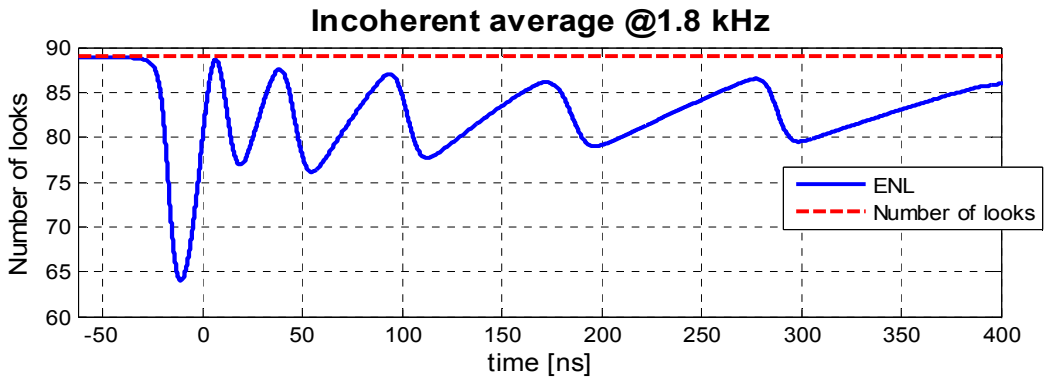
[4] W.Smith, R. Scharroo, Pulse-to-pulse correlation in CryoSat SAR echoes from ocean surfaces: implications for optimal pseudo-LRM waveform averaging. 20 years of progress in radar altimetry symposium

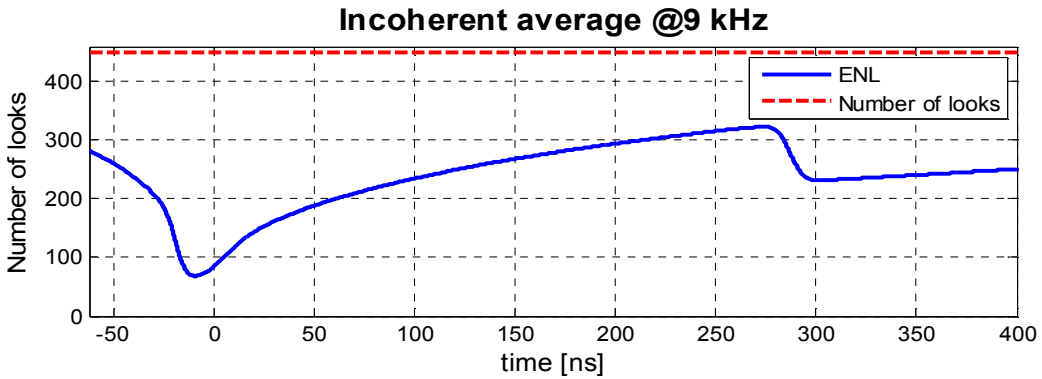
# Achievable speckle reduction on LR waveforms

The achievable ENL in case of Low Resolution waveforms by averaging echoes at ~9 kHz or at ~1.8 kHz is here shown:

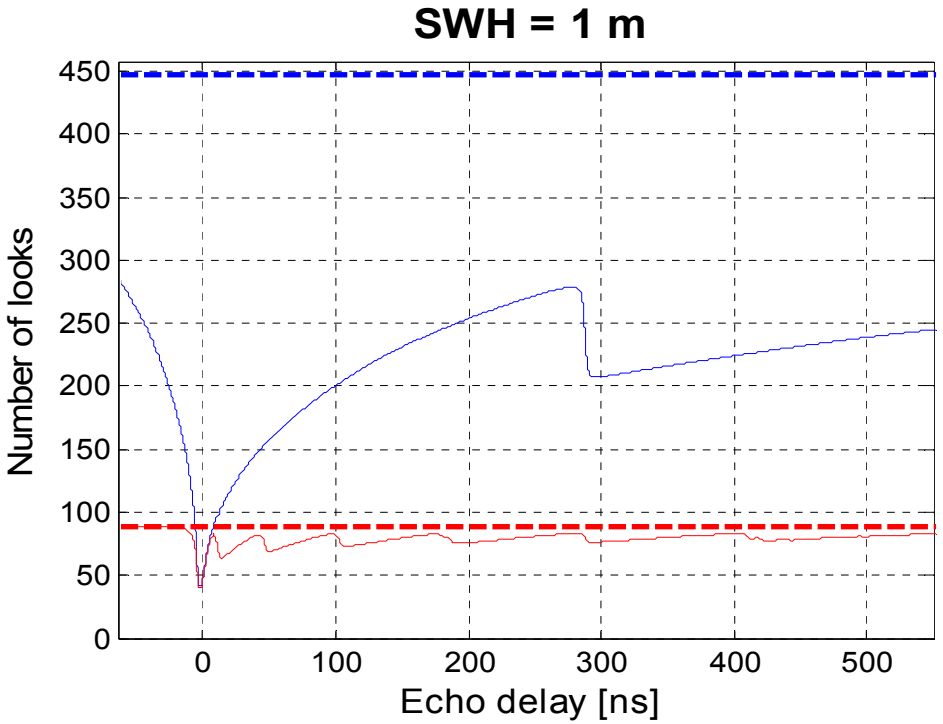
- the ENL @1.8 kHz approaches the number of averaged echoes
- the ENL @9 kHz is far from the number of averaged echoes (echoes highly correlated)
- Oscillations of the ENL as function of τ can be noticed in both the cases

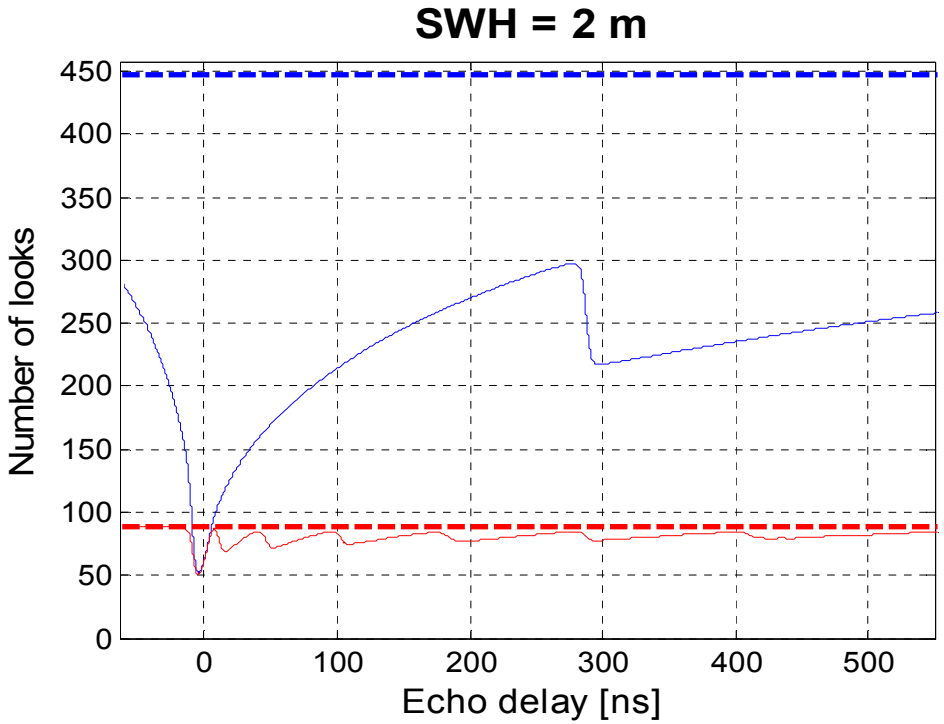


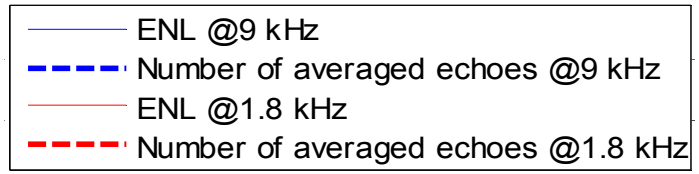



# SWH = 1 m and SWH = 2 m

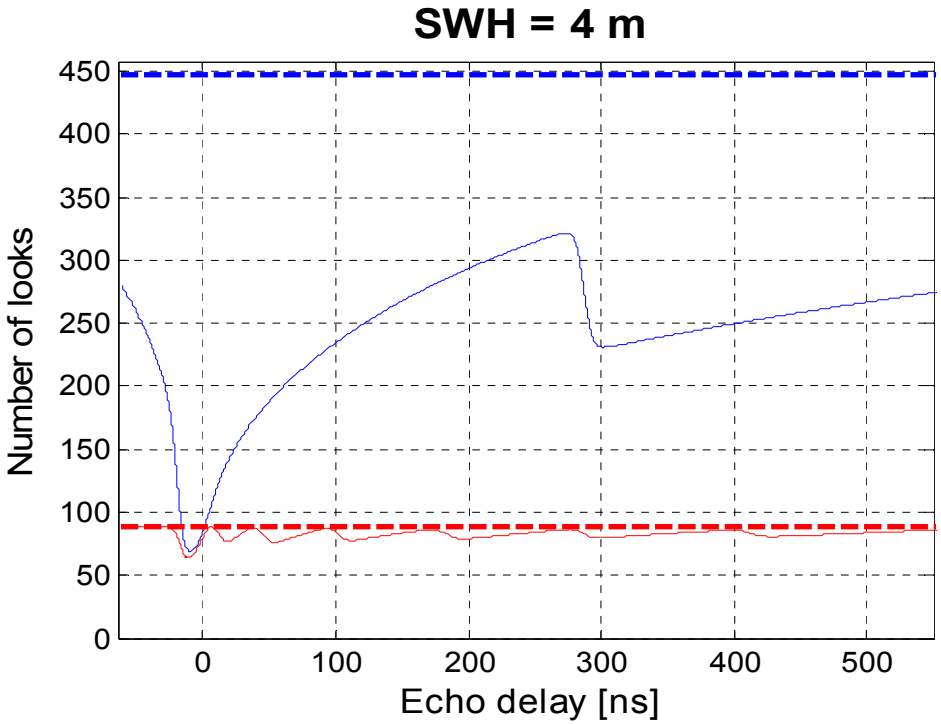


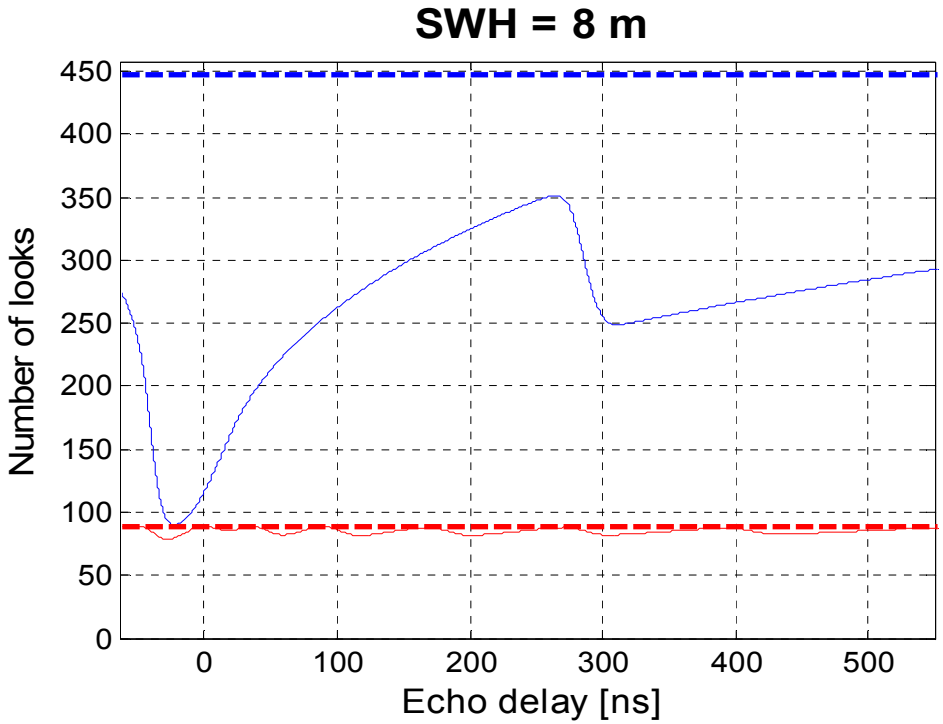




- the ENL is comparable around the leading egde, i.e same speckle
- the ENL @9 kHz is higher for the trailing edge, i.e. higher speckle reduction



# SWH = 4 m and SWH = 8 m




- the ENL @9 kHz increases as the SWH increases
- At high SWH, the ENL @9 kHz is higher than the ENL @1.8 kHz also around the leading edge

ENL @9 kHz
Number of averaged echoes @9 kHz
ENL @1.8 kHz
Number of averaged echoes @1.8 kHz

# Conclusions

- It has been evaluated the theoretical speckle reduction on Low Resolution waveforms that is achievable by interleaved mode acquisition in Sentinel-6/Poseidon-4

- By incoherent average of all the echoes at high pulse rate (~9 kHz), going beyond the Walsh limit, we have that
  - a higher speckle reduction is achieved, even if the echoes are highly correlated
  - the speckle reduction is more effective in the trailing edge of the waveform
  - the speckle reduction increases as the SWH increases

- Incoherent average of all the available echoes has been verified to be the best strategy from the speckle reduction point of view

# Sentinel-6 Poseidon-4 L1b Simulator

The analysis here shown has been developed in the framework of activities for the provision to ESA of the *Sentinel-6 Poseidon-4 L1b Simulator*, a model-based simulator for Level1 altimeter products

***To correctly simulate the LR waveforms, the speckle has to be injected with the proper statistical properties.***

For more details, please refer to FUT_002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