Calculation of beta naught and sigma naught for TerraSAR-X data

1 Introduction

The present document describes the successive steps of the TerraSAR-X data absolute calibration. Absolute calibration allows taking into account all the contributions in the radiometric values that are not due to the target characteristics. This permits to minimize the differences in the image radiometry and to make any TerraSAR-X images obtained from different incidence angles, ascending-descending geometries and / or opposite look directions easily comparable and even compatible to acquisitions made by other radar sensors.

The document is organised as follows:

Section 2 focuses on the computation of Beta Naught also called radar brightness (β0). It represents the radar reflectivity per unit area in slant range (Table1).

Section 3 explains how to derive Sigma Naught (σ0) from the image pixel values (or Digital Number (DN)) or from Beta Naught, taking into account the local incidence angle. Sigma Naught is the radar reflectivity per unit area in ground range (Table1).

radar brightness Beta Naught (β^0)	**Radiometric calibration Sigma Naught (σ^0)**
• reflectivity per unit area in slant range • beta naught values are independent from the terrain covered.	• power returned to the antenna from the ground • sigma naught values are directly related to the ground – radiometric calibration

Table 1: Beta Naught and Sigma Naught definitions

2 Beta Naught Computation (Radar Brightness)

The radar brightness β^0 is derived from the image pixel values or digital numbers (DN) applying the calibration factor k_s (1).

$$\beta^0 = k_s \cdot |DN|^2 \qquad \textbf{(1)}$$

Equation (2) converts β^0 to dB,

$$\beta^0{}_{dB} = 10 \cdot log_{10}\left(\beta^0\right) \qquad \textbf{(2)}$$

In the case of detected products (MGD, GEC and EEC), the DN values are directly given in the associated image product. For the SSC products, the DN values are computed from the complex data given in the DLR COSAR format file (.cos file), following (3):

$$DN = \sqrt{I^2 + Q^2} \qquad \textbf{(3)}$$

I and Q are respectively the real and imaginary parts of the backscattered complex signal [2].

The calibration factor k_s (1) also called calFactor is given in the annotation file "calibration" section as shown in Figure 1 and Figure 2. It is processor and product type dependent and might even change between the different beams of a same product type (Figure 2).

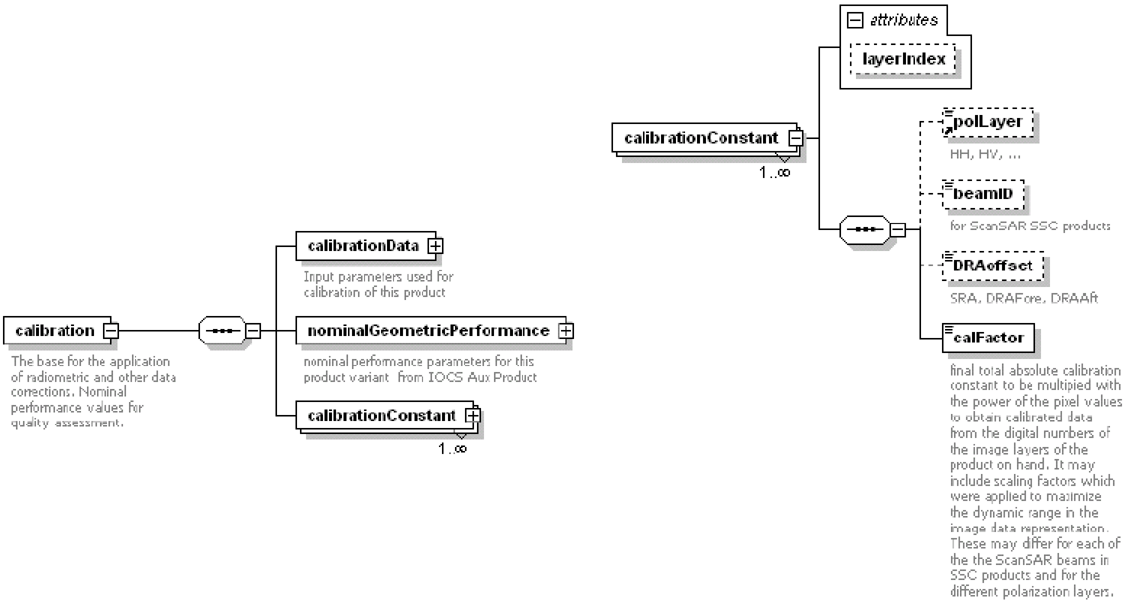

Figure 1: TerraSAR-X data annotation file - section calibration [2]

```
<calibrationConstant layerIndex="1">
        <polLayer>HH</polLayer>
        <beamID>stripFar_012</beamID>
        <DRAoffset>SRA</DRAoffset>
        <calFactor>9.95392054379573598E-06</calFactor>
</calibrationConstant>
<calibrationConstant layerIndex="2">
        <polLayer>HV</polLayer>
        <beamID>stripFar_012</beamID>
        <DRAoffset>SRA</DRAoffset>
        <calFactor>1.99078410875914779E-06</calFactor>
</calibrationConstant>
```


**Figure 2: CalFactor is polarization dependant –
example of a dual polarization TerraSAR-X SM product**

3 Calculation of Sigma Naught (Radiometric Calibration)

Backscattering from a target is influenced by the relative orientation of illuminated resolution cell and the sensor, as well as by the distance in range between them. The derivation of Sigma Naught thus requires a detailed knowledge of the local slope (i.e. local incidence angle) (§4):

$$\sigma^0 = \left(k_S \,.\, |DN|^2 - NEBN\right) .\, \sin\theta_{loc} \qquad \textbf{(4)}$$

- DN or Digital Number is the pixel intensity values (§2),

- k_s is the calibration and processor scaling factor given by the parameter calFactor in the annotated file (§2),

- θ_{loc} is the local incidence angle. It is derived from the Geocoded Incidence Angle Mask (GIM) that is optional for the L1B Enhanced Ellipsoid Corrected (EEC) product ordering. The complete decryption of the GIM is proposed in §3.2.

- NEBN is the Noise Equivalent Beta Naught. It represents the influence of different noise contributions to the signal [1]. The computation of NEBN is described in §3.1.

The equation (4) can also be expressed in terms of Beta Naught, as:

$$\sigma^0 = \beta^0 \;.\, \sin\theta_{loc} - NESZ \qquad \textbf{(5)}$$

NESZ is the Noise Equivalent Sigma Naught (6), i.e. the system noise expressed in Sigma Naught [1].

$$NESZ = NEBN \;.\, \sin\theta_{loc} \qquad \textbf{(6)}$$

NEBN (or NEBZ) contributions are relatively low. NEBZ is specified in [1] between -19dB and -26dB. For this reason the noise influence can often be neglected, depending on the considered application.

In the case NEBN is ignored (5) reduces to the well-known (7) and (8) equations.

$$\sigma^0 = \beta_0 \;.\, \sin\theta_{loc} \qquad \textbf{(7)}$$

$$\sigma^0{}_{dB} = \beta^0{}_{dB} + 10\, log_{10}\left(\sin\theta_{loc}\right) \qquad \textbf{(8)}$$

Beta Naught and Sigma Naught backscattering coefficients from a scene in Solothurn (Switzerland) are shown in Figure 3 and Figure 4. The incidence angle influence is better taken into account in Figure 4, especially in the mountainous zones (scene right-hand side).

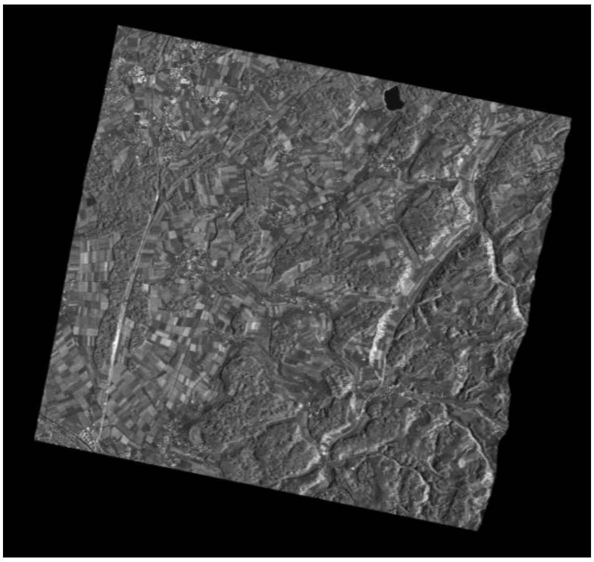

Figure 3: Evolution of the beta naught coefficient on the test site of Solothurn (Switzerland)

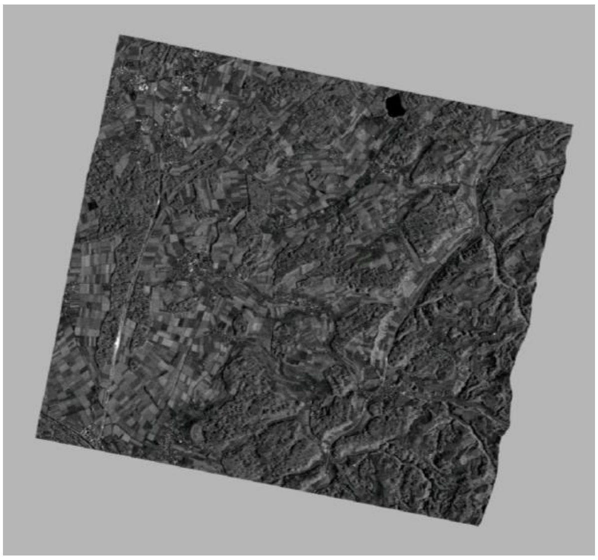

Figure 4: Evolution of the sigma naught coefficient on the test site of Solothurn (Switzerland)

Figure 5 shows the values of the Sigma Naught backscattering coefficient according to the land cover. The considered subset is extracted from the precedent figures (area located in the north of Figure 3 and Figure 4).

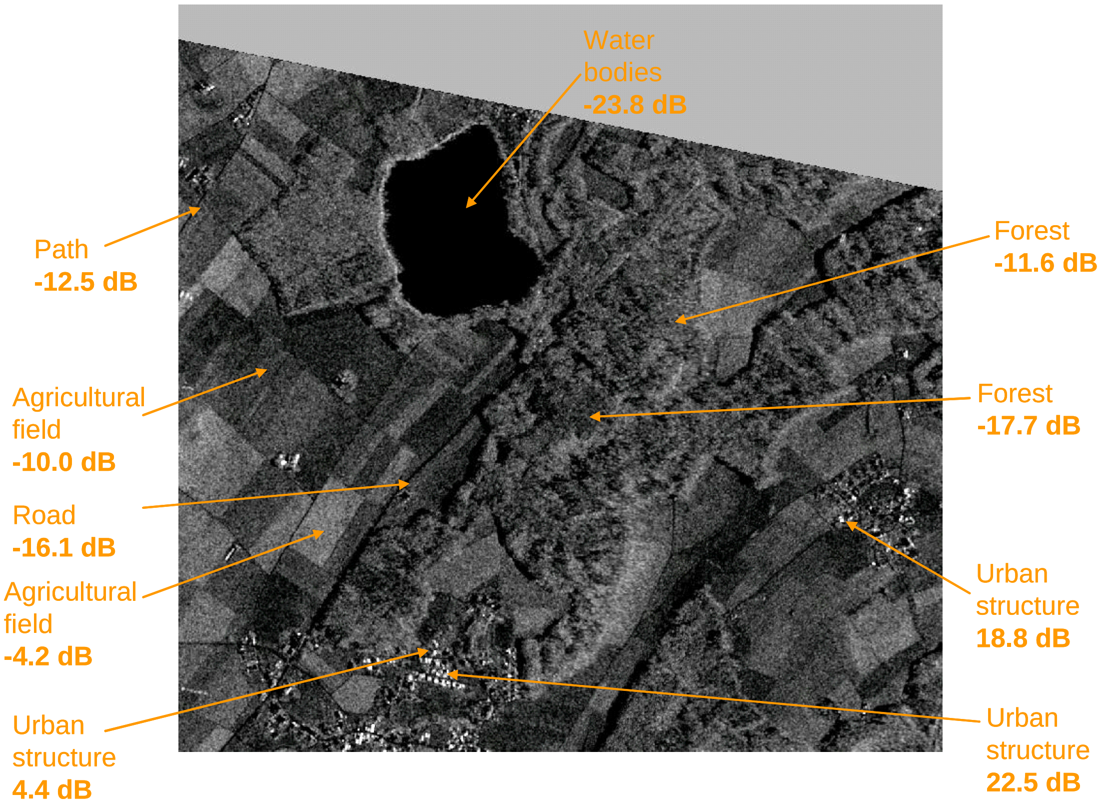

Figure 5: Sigma Naught values in dB – subset of the Solothurn test site (Switzerland)

Reflectivity from water bodies (under low wind conditions), roads and from different vegetated areas (forest, agricultural fields) are comparable to the NEBZ values announced in [1].

NEBN computation is detailed in the following subsection, NEBZ can then be deducted using (6).

3.1 Noise equivalent beta naught (NEBN) ESTIMATION

3.1.1 Annotation file "noise" section description

The Noise Equivalent Beta Naught (NEBN) is annotated in the section "noise" of the TerraSAR-X data delivery package annotation file in forms of polynomial scaled with k_S (

Figure 6) [2]. Those polynomials describe the noise power as a function of range considering major noise contributing factors (e.g. elevation antenna pattern, transmitted power and receiver noise) and are computed at defined azimuth time tags (see <numberOfNoiseRecords> tab), and are function of range time.

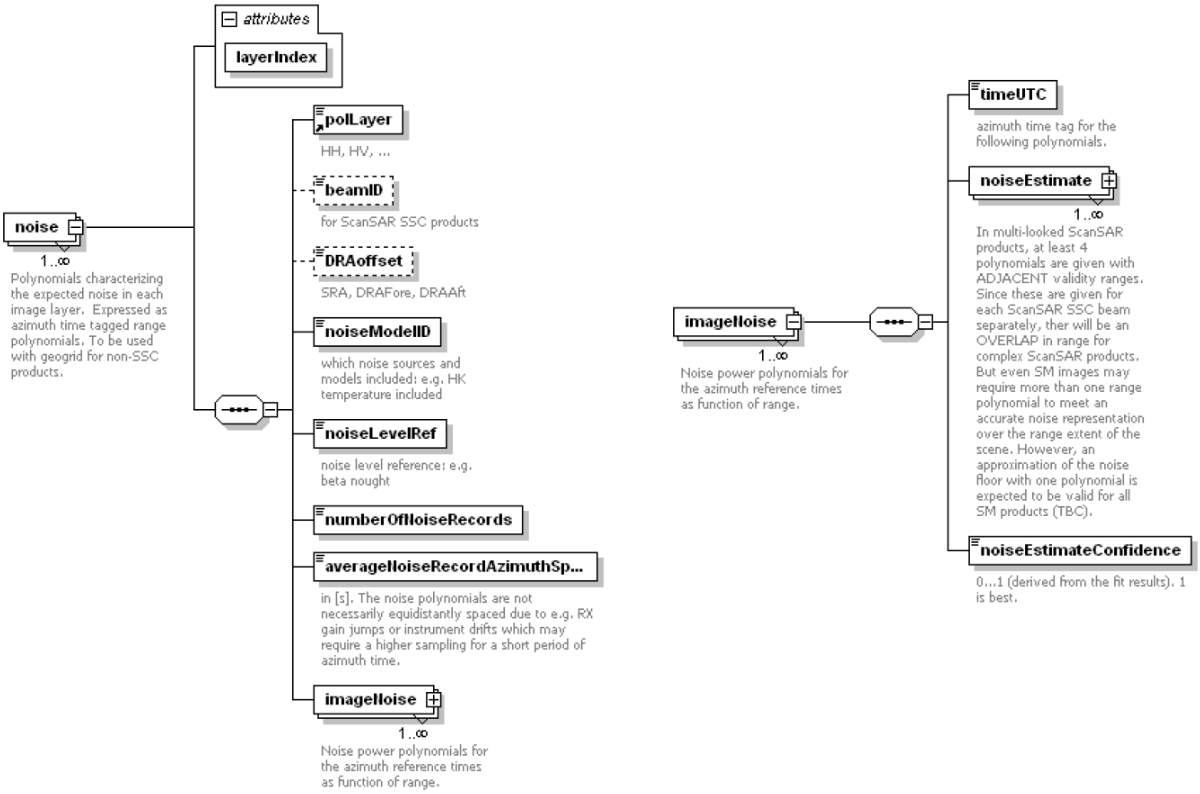

Figure 6: Annotation file Noise section and imageNoise subsection [2]

The polynomial parameters are given in the “imageNoise” subsection (

Figure 6) [2].

- <timeUTC> time corresponds to the azimuth time (sensor flight track) at which the noise estimation is made
- The <noiseEstimation> tab contains the following parameters:
  - ValidityRangeMin and validityRangeMax that define the validity range of the computed polynomial.
  - ReferencePoint
  - PolynomialDegree is the degree of the polynomial computed for the noise description.
  - Coefficients are the polynomial coefficient.

The noise polynomial is derived from the previous parameters applying (9):

$$NEBN = k_S \cdot \sum_{i=0}^{deg} coeff_i \cdot (\tau - \tau_{ref})^i \;,\; \tau \in \left[\tau_{min}, \tau_{max}\right] \qquad \textbf{(9)}$$

where:

- *deg* is polynomialDegree
- $coeff_i$ is coefficient exponent="i"
- τ_{ref} is referencePoint
- τ_{min} and τ_{max} are validityRangeMin and validityRangeMax, respectively

NEBN is estimated in the following subsection in the case of the dataset of Solothurn presented in Figure 3 to Figure 5.

3.1.2 NEBN evaluation: application to a SpotLight L1B Enhanced Ellipsoid Corrected product

The parameters of the acquisition are given at the beginning of the <imageNoise> section (Figure 7),


```
<polLayer>HH</polLayer>
<beamID>spot_047</beamID>
<DRAoffset>SRA</DRAoffset>
<noiseModelID>LINEAR</noiseModelID>
<noiseLevelRef>BETA NOUGHT</noiseLevelRef>
<numberOfNoiseRecords>3</numberOfNoiseRecords>
<averageNoiseRecordAzimuthSpacing>7.30946004390716553E-01</averageNoiseRecordAzimuthSpacing>
```


Figure 7: <imageNoise> section – TerraSAR-X SpotLight scene acquisition parameters

An extract of the <sceneInfo> section is here copied in order to allow the comparison of the noise estimation record time s and of the scene acquisition duration (Figure 8).


```
<sceneInfo>
	<sceneID>C22_N116_A_SL_spot_047_R_2008-02-08T17:16:46.949859Z</sceneID>
<start>
	<timeUTC>2008-02-08T17:16:46.949859Z</timeUTC>
	<timeGPS>886526220</timeGPS>
	<timeGPSFraction>9.49859023094177246E-01</timeGPSFraction>
</start>
<stop>
	<timeUTC>2008-02-08T17:16:48.411751Z</timeUTC>
	<timeGPS>886526222</timeGPS>
	<timeGPSFraction>4.11751002073287964E-01</timeGPSFraction>
</stop>
<rangeTime>
	<firstPixel>4.24852141657393149E-03</firstPixel>
	<lastPixel>4.29714751188355320E-03</lastPixel>
</rangeTime>
```


Figure 8: Extract of the <sceneInfo> section – TerraSAR-X SpotLight scene acquision duration

The different <noiseEstimate> are then displayed (Figure 9). The validityRangeMin>, <validityRangeMax>, <referencePoint>, <polynomialDegree> and <coefficient exponent are given for each <noiseEstimate>. The noise has been estimated three times in the case of the considered dataset (cf. <numberOfNoiseRecords> in Figure 7)

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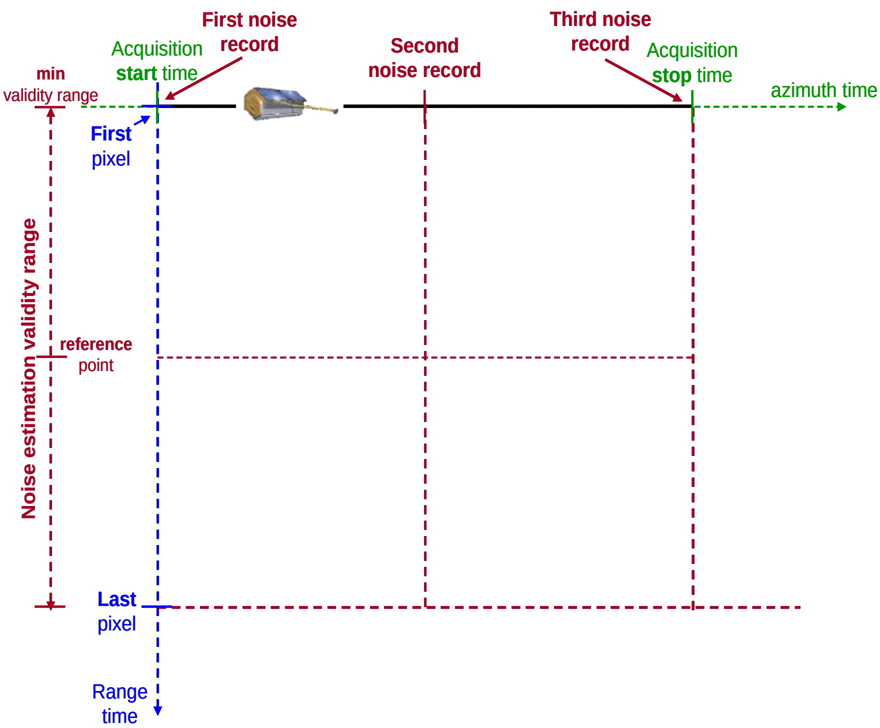
```xml
<imageNoise>
	<timeUTC>2008-02-08T17:16:46.949859Z</timeUTC>
	<noiseEstimate>
		<validityRangeMin>4.24852141657393149E-03</validityRangeMin>
		<validityRangeMax>4.29715357877005506E-03</validityRangeMax>
		<referencePoint>4.27283749767199371E-03</referencePoint>
		<polynomialDegree>3</polynomialDegree>
			<coefficient exponent="0">7.31891288570141569E+02</coefficient>
			<coefficient exponent="1">3.59583194738081144E+06</coefficient>
			<coefficient exponent="2">2.62234025007967133E+11</coefficient>
			<coefficient exponent="3">1.80700987913142070E-03</coefficient>
	</noiseEstimate>
	<noiseEstimateConfidence>5.00000000000000000E-01</noiseEstimateConfidence>
</imageNoise>
<imageNoise>
	<timeUTC>2008-02-08T17:16:47.680805Z</timeUTC>
	<noiseEstimate>
		<validityRangeMin>4.24852141657393149E-03</validityRangeMin>
		<validityRangeMax>4.29715357877005506E-03</validityRangeMax>
		<referencePoint>4.27283749767199371E-03</referencePoint>
		<polynomialDegree>3</polynomialDegree>
			<coefficient exponent="0">7.34534937627067279E+02</coefficient>
			<coefficient exponent="1">3.47245661681551347E+06</coefficient>
			<coefficient exponent="2">2.49510234647123260E+11</coefficient>
			<coefficient exponent="3">1.74501285382171406E-03</coefficient>
	</noiseEstimate>
	<noiseEstimateConfidence>5.00000000000000000E-01</noiseEstimateConfidence>
</imageNoise>
<imageNoise>
	<timeUTC>2008-02-08T17:16:48.411751Z</timeUTC>
	<noiseEstimate>
		<validityRangeMin>4.24852141657393149E-03</validityRangeMin>
		<validityRangeMax>4.29715357877005506E-03</validityRangeMax>
		<referencePoint>4.27283749767199371E-03</referencePoint>
		<polynomialDegree>3</polynomialDegree>
			<coefficient exponent="0">7.39705864286483120E+02</coefficient>
			<coefficient exponent="1">3.73953473187694838E+06</coefficient>
			<coefficient exponent="2">2.39043547247924896E+11</coefficient>
			<coefficient exponent="3">1.87924871242650844E-03</coefficient>
	</noiseEstimate>
	<noiseEstimateConfidence>5.00000000000000000E-01</noiseEstimateConfidence>
</imageNoise>
```


Figure 9: <imageNoise> section - <noiseEstimate>

Before estimating NEBN in the case of the considered acquisition, the configuration of the NEBN records can be illustrated in Figure 10. The acquisition start and stop times correspond to the first and last noise records, respectively. As well each noise estimation validity range is defined by the duration of the acquisition in range.

Figure 10: Noise estimation configuration

NEBN is now computed in the case of the proposed xml file. The degree of the considered polynomial is 3 (Figure 9), (9) reduces (10), yielding to:



$$NEBN = k_S \, . \, \left[coeff_0 \, . \, (\tau - \tau_{ref})^0 + coeff_1 \, . \, (\tau - \tau_{ref})^1 + coeff_2 \, . \, (\tau - \tau_{ref})^2 + coeff_3 \, . \, (\tau - \tau_{ref})^3 \right] \quad \textbf{(10)}$$

where $\tau \in \left[\tau_{min} , \tau_{max} \right]$

Looking at the displayed xml file, the values of the different main parameters of the noise estimation can clearly be identified.

The computation of NEBN is detailed for the first noise record; the same method should be applied for the other <noise estimation> tabs.

The values of the parameters required for NENB estimation (10) are extracted from Figure 9:

$\tau_{min} = 4.2485214165\,7393149E-03$

$\tau_{max} = 4.2971535787\,7005506E-03$

$\tau_{ref} = 4.2728374976\,7199371E-03$

$coeff_0 = 7.31891288\,570141569E+02$

$coeff_1 = 3.59583194\,738081144E+06$

$coeff_2 = 2.62234025\,007967133E+11$

$coeff_3 = 1.80700987\,913142070E-03$

The value of the calibration constant is also extracted from the studied xml file (§2).

$k_S = 1.05930739\,668874399E-05$

NEBN is now computed for three different values of τ, knowing that $\tau_{min} \leq \tau \leq \tau_{max}$. The following simple cases are considered:

- $\tau = \tau_{min}$
- $\tau = \tau_{max}$
- $\tau = \tau_{ref}$

	$\tau = \tau_{min}$	$\tau = \tau_{max}$	$\tau = \tau_{ref}$
$\tau - \tau_{ref}$	$\tau_{min} - \tau_{ref}$ = -2.43160811E-05	$\tau_{max} - \tau_{ref}$ = 2.43160811E-05	$\tau_{ref} - \tau_{ref}$ = 0.
NEBN	k_s x 799.5063313 = 8.4692297046E-03	k_s x 974.379413828 = 1.0327746928E-02	k_s x 731.891288570141 = 7.75297855555E-03
$NEBN_{dB}$	10 x log_{10}[abs(NEBN)] = -20.721 dB	10 x log_{10}[abs(NEBN)] = -19.860 dB	10 x log_{10}[abs(NEBN)] = -21.105 dB

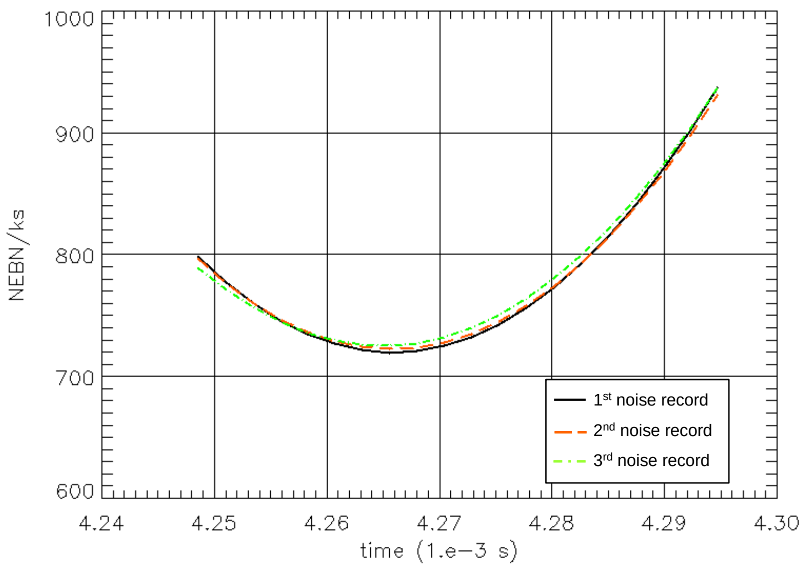
Table 2: NEBN estimation at different time in range

Figure 11 shows the evolution of the NEBN contributions according to different range time values τ ($\tau_{min} \leq \tau \leq \tau_{max}$). The variation of NEBN for the first noise estimation is represented by the black solid line. The orange dash- and the green dot-dash lines show the evolution of NEBN for the second and the last noise record, respectively.

Figure 11 : Noise contribution at the three time tags in azimuth (real values) – the black solid line represents the first noise record, the orange dash line represents the second noise record and the green dot-dash line the third noise record

Figure 12 shows the evolution of the noise, converted in dB.

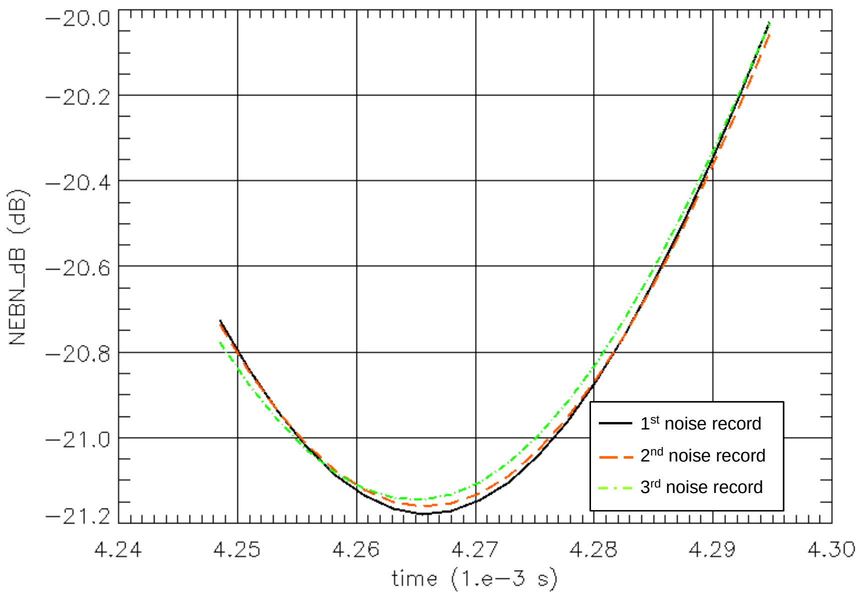
Figure 12 : Noise contribution at the three time tags in azimuth (dB values) - the black solid line represents the first noise record, the orange dash line represents



the second noise record and the green dot-dash line the third noise record

The same procedure for the noise estimation should be applied to all TerraSAR-X products, whatever imaging modes and polarisation channel is available.

The noise is normally estimated at different defined time tags. In the case the NEBN value is



desired at a time where it has not been estimated previously, linear interpolation can be necessary in order to evaluate the noise at the desired time.

The last subsection of the document focuses on the estimation of the local incidence angle in from the Geocoded Incidence angle Mask which is available for the TerraSAR-X L1B Enhanced Ellipsoid Corrected (EEC) product.

3.2 Geocoded Incidence Angle Mask (GIM) decryption

The local incidence angle is the angle formed between the radar beam and the normal to the illuminated surface. As mentioned before this information can be ordered optionally with L1B Enhanced Ellipsoid Corrected (EEC) products, as Geocoded Incidence angle Mask (GIM).

The GIM provides information about the local incidence angle for each pixel of the geocoded SAR scene and about the presence of layover and shadow areas. The GIM product shows the same cartographic properties as the geocoded output image with regard to output projection and cartographic framing. The content of the GIM product is basically the local terrain incidence angle and additional flags indicate whether a pixel is affected by shadow and/or layover or not.

The following coding of the incidence angles into the GIM product is specified [1]:

- Incidence angles are given as 16bit integer values in tenths of degrees, e.g. 10,1° corresponds to an integer value of 1010.
- The last digit of this integer number is used to indicate shadow and/or layover areas as follows:

  1………….. indicates layover (ex. 1011)

  2………….. indicates shadow (ex. 1012)

  3………….. indicates layover and shadow (ex. 1013)

3.2.1 Extraction of the local incidence angle

θ_i : local incidence angle (in deg)

$$\theta_{loc} = \frac{(GIM - (GIM \ mod \ 10))}{100} \quad \textbf{(11)}$$

The resulting incidence angle is in degree (float value).

Remark: $GIM \ mod \ 10$ ("GIM modulo 10") represents the remainder of the division of GIM by 10.

3.2.2 Extraction of the layover and shadow identifiers

The shadow areas are determined via the off-nadir angle, which in general increases for a scan line from near to far range. Shadow occurs as soon as the off-nadir angle reaches a turning point and decreases when tracking a scan-line from near to far range. The shadow area ends where the off-nadir angle reaches that value again, which it had at the turning point.

Applying (12) yields to the extraction of the Layover and Shadow (LS) information:

$$LS = GIM \ mod \ 10 \quad \textbf{(12)}$$

GIM is the pixel value of GIM

4 References

[1] Fritz, T., Eineder, M.: TerraSAR-X Basic Product Specification Document, TX-GS-DD-3302, Issue 1.5, February 2008

[2] Fritz, T.: TerraSAR-X Level 1b Product Format Specification, TX-GS-DD-3307, Issue 1.3, December 2007

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