Radiometric Calibration of TerraSAR-X Data

Beta Naught and Sigma Naught Coefficient Calculation

Introduction

The present document describes 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 minimise 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 1 focuses on the computation of Beta Naught also called radar brightness (β^0). It represents the radar reflectivity per unit area in slant range.

Section 2 explains how to derive Sigma Naught (σ^0) 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.

1. 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).

$$\beta^0 = k_s \cdot \left| DN \right|^2 \tag{1}$$

Equation (2) converts β^0 to dB,

$$\beta^0{}_{dB} = 10 \bullet log_{10}\left(\beta^0\right) \tag{2}$$

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):

$$DN = \sqrt{I^2 + Q^2} \tag{3}$$

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 TerraSAR-X data delivery package annotation file “calibration” section as shown in Figure 1. It is processor and product type dependent and might even change between the different beams of a same product type (Figure 2).

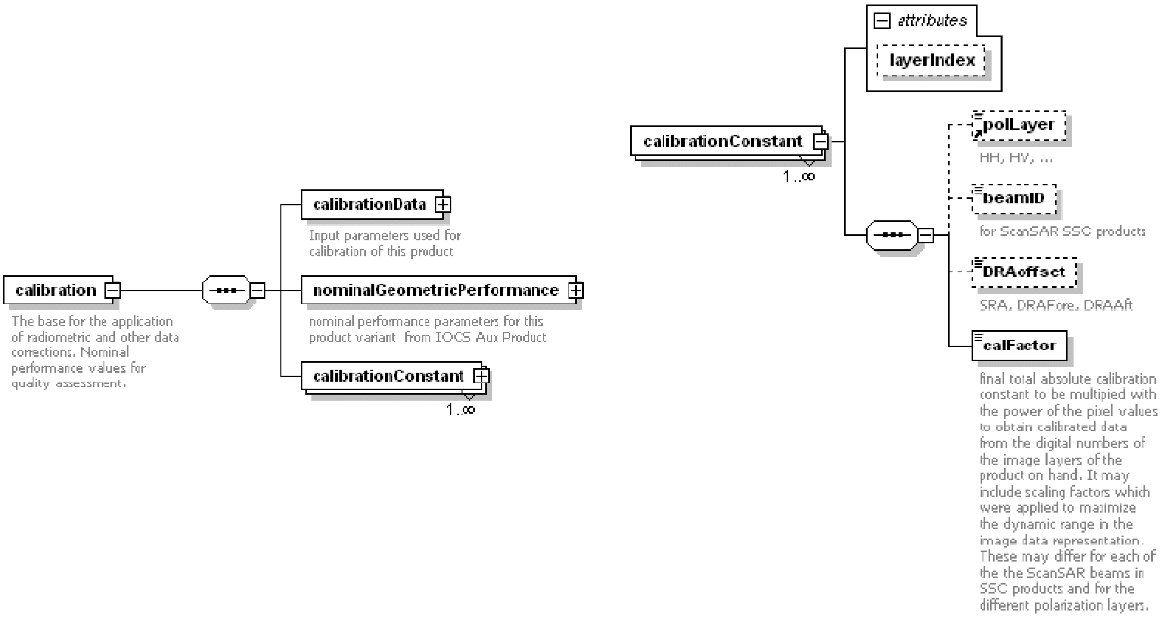

Figure 1 TerraSAR-X data annotation file: section calibration [2]

```
<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 polarisation dependant: example of a dual polarisation TerraSAR-X StripMap product

2. Calculation of Sigma Naught (Radiometric Calibration)

Backscattering from a target is influenced by the relative orientation of the 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), as shown in (4):

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

where:

- k_s is the calibration and processor scaling factor given by the parameter calFactor in the annotated file (§1),
- DN is the pixel intensity values (§1),
- 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 §2.1.
- 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 §2.2.

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

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

where:

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

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

NESZ 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 equation (5) reduces to the equations (7) and (8),

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

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

Figure 3 and 4 show the evolution of Beta Naught and Sigma Naught backscattering coefficients from a scene in Solothurn (Switzerland). It can be observed that the incidence angle influence is better taken into account in Figure 4, especially in mountainous areas.

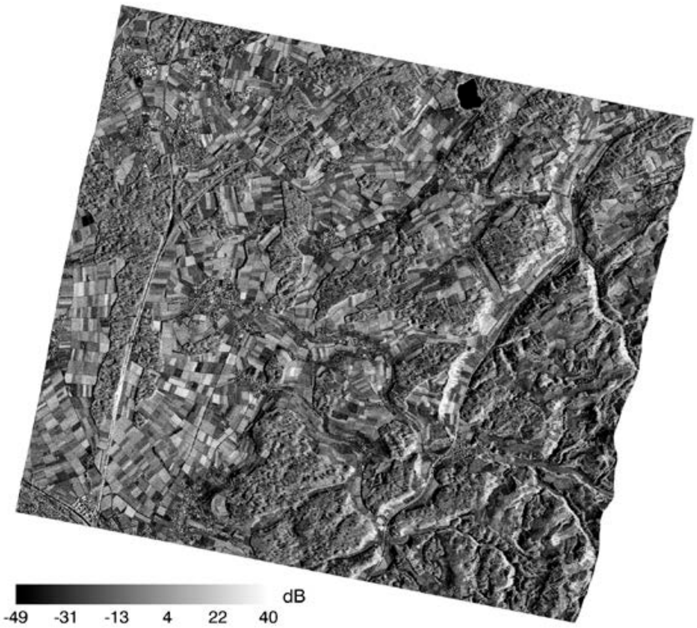

Figure 3: Evolution of the Beta Naught coefficient (expressed in dB) on the test site of Solothurn (Switzerland)

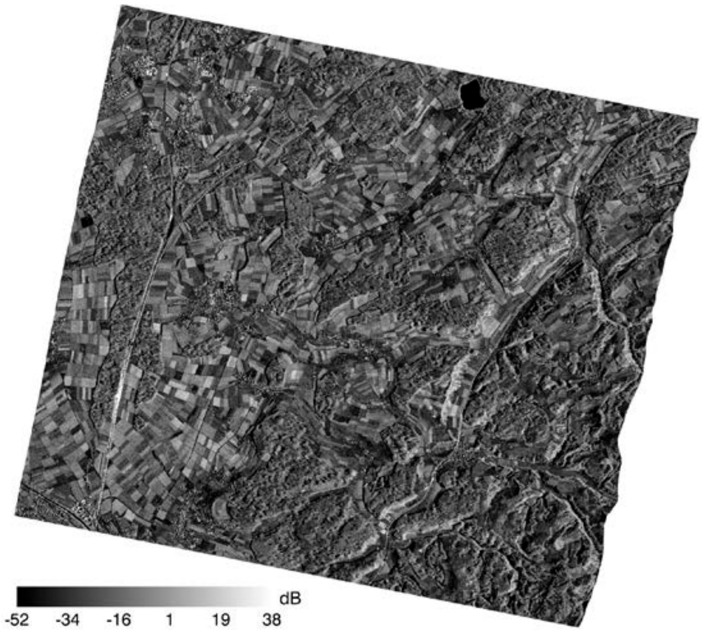

Figure 4: Evolution of the Sigma Naught coefficient (expressed in dB) on the test site of Solothurn (Switzerland)

Figure 5 shows the values of the Sigma Naught backscattering coefficient according to the land cover. The considered subset is extracted from Figure 4.

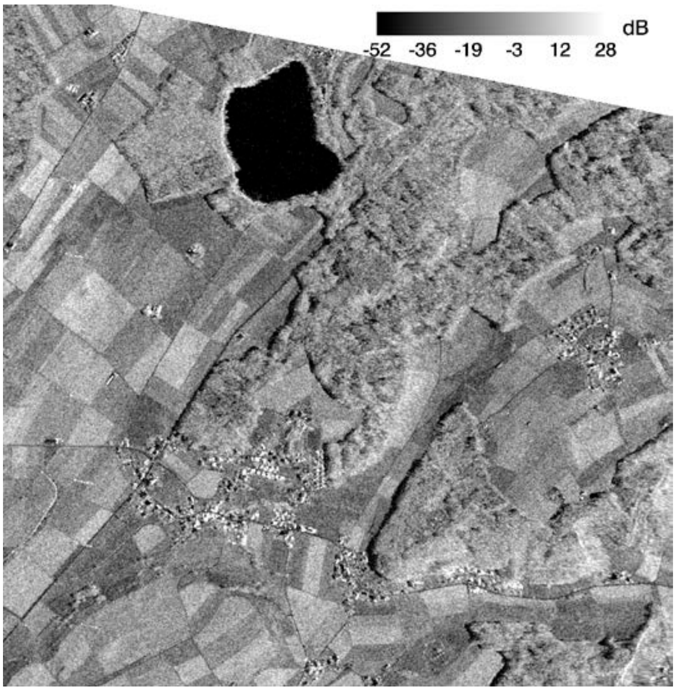

Figure 5: Sigma Naught values expressed in dB - subset of the Solothurn test site (Switzerland)

Reflectivity from water bodies (under low wind conditions), roads and from different vegetated areas (forest, agricultural fields) are smaller than -19dB and often comparable to the noise level [1].

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

2.1. Noise Equivalent Beta Naught (NEBN) estimation

2.1.1. Annotation file “noise” section description

The 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.

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):

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

where:

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

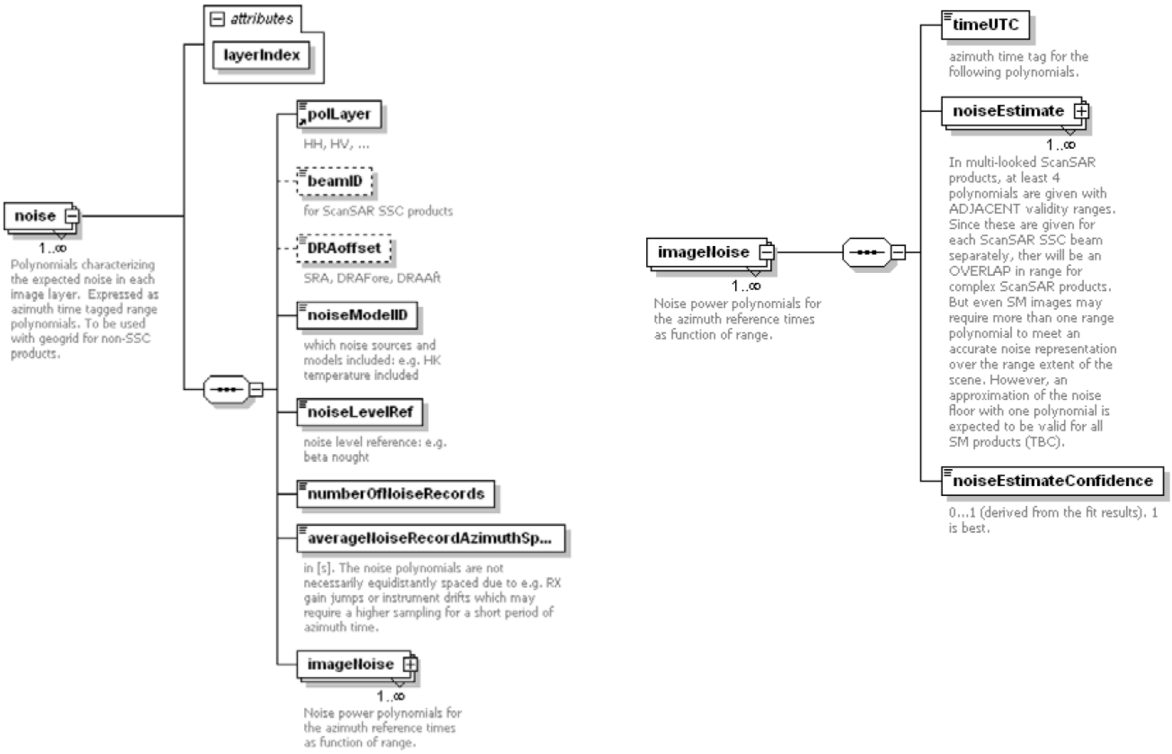

Figure 6: Annotation file noise section and imageNoise subsection [2]

As an example NEBN is estimated in the following subsection in the case of the dataset of Solothurn presented in Figures 3 to 5.

2.1.2. 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 times and of the scene acquisition duration (Figure 8).

```xml
<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

The different <noiseEstimate> are then shown in 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)

```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>

Finally Figure 10 schematises the configuration of the NEBN records. The acquisition start and stop times correspond to the first and last noise records, respectively. Further each noise estimation validity range is defined by the duration of the acquisition in range.

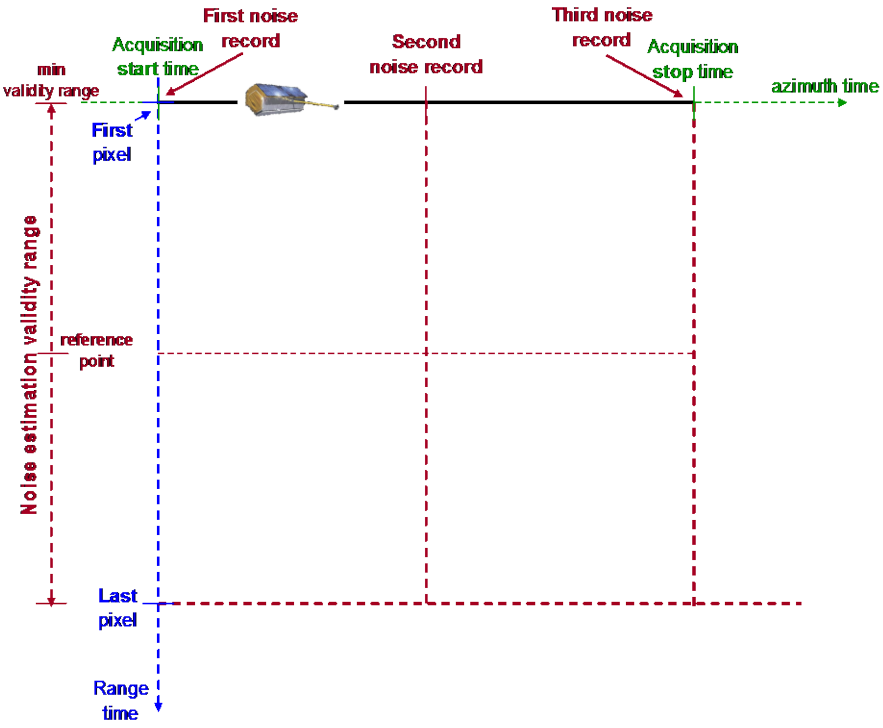

Figure 10: Noise estimation configuration

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

$$\begin{aligned} NEBN = k_S \,.\, \Big[& coeff_0 \,.\, (\tau - \tau_{ref})^0 + coeff_1 \,.\, (\tau - \tau_{ref})^1 \\ & + coeff_2 \,.\, (\tau - \tau_{ref})^2 + coeff_3 \,.\, (\tau - \tau_{ref})^3 \Big] \end{aligned} \qquad \textbf{(10)}$$

where:

- $\tau \in [\tau_{min}, \tau_{max}]$

Looking at the displayed xml file (Figure 9), 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 NEBN estimation (10) are extracted from Figure 9:

$\tau_{min} = 4.24852141657393149E-03$

$\tau_{max} = 4.29715357877005506E-03$

$\tau_{ref} = 4.27283749767199371E-03$

$coeff_0 = 7.31891288570141569E+02$

$coeff_1 = 3.59583194738081144E+06$

$coeff_2 = 2.62234025007967133E+11$

$coeff_3 = 1.80700987913142070E-03$

The value of the calibration constant is also extracted from the studied xml file (§1).

$k_S = 1.05930739668874399E-05$

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 in Table 1:

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

	$\tau = \tau_{min}$	$\tau = \tau_{max}$	$\tau = \tau_{ref}$
$\tau - \tau_{ref}$	$\tau_{min} - \tau_{ref}$ $= -2.431608E-05$	$\tau_{min} - \tau_{ref}$ $= 2.431608E-05$	$\tau_{ref} - \tau_{ref}$ $= 0$
NEBN	$k_S \times 799.5063313$ $= 8.469229E-03$	$k_S \times 974.379413828$ $= 1.032775E-02$	$k_S \times 731.891289$ $= 7.752978E-03$
$NEBN_{dB}$	$10 \times log_{10}[abs(NEBN)]$ $= -20.721dB$	$10 \times log_{10}[abs(NEBN)]$ $= -19.860\,dB$	$10 \times log_{10}[abs(NEBN)]$ $= -21.105\,dB$

Table 1: 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 NENB for the second and the last noise record, respectively

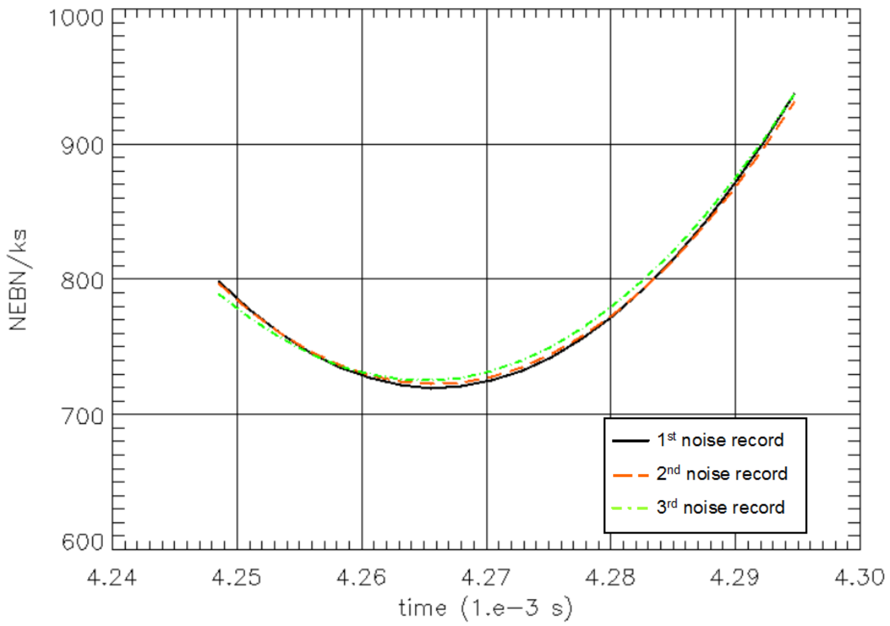

Figure 11 : Noise contribution at the three time tags in azimuth (real values)

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

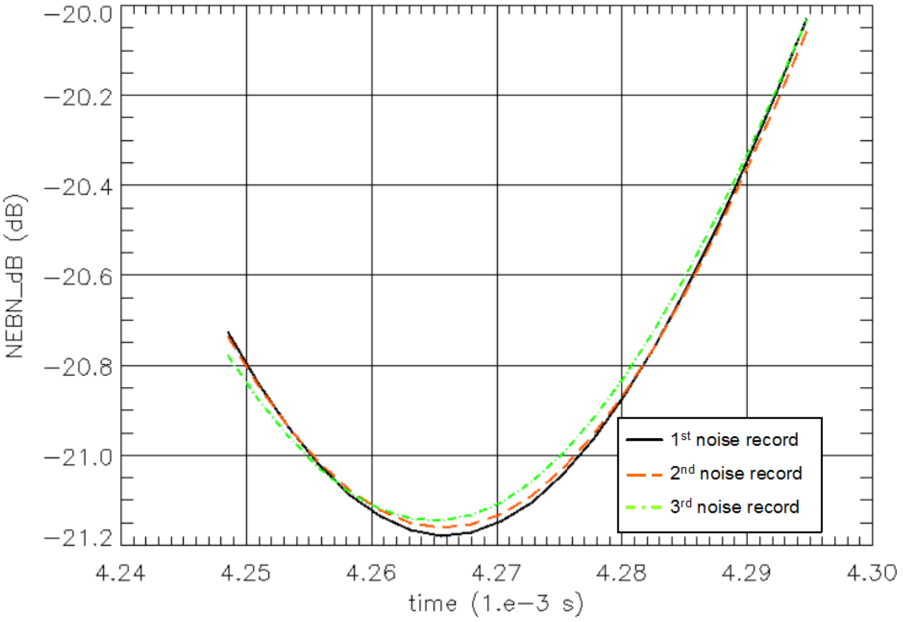

Figure 12 : Noise contribution at the three time tags in azimuth (dB values)

The same procedure for the noise estimation should be applied to all TerraSAR-X products (all imaging modes and polarisation channels). 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 applied 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 GIM which is available for the TerraSAR-X L1B EEC product.

2.2. Geocoded Incidence Angle Mask (GIM) decryption

The local incidence angle is the angle between the radar beam and the normal to the illuminated surface. As mentioned before this parameter can be ordered optionally with L1B EEC products, as 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 indicating 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)

2.2.1. Extraction of the local incidence angle

θ_i: local incidence angle (in deg), GIM representing the pixel value of the GIM,

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

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

Note: GIM *mod* 10 ("GIM modulo 10") represents the remainder of the division of GIM by 10.

2.2.2. 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:

$$\mathrm{LS} = \mathrm{GIM}\ mod\ 10 \qquad (12)$$

References

[1] Fritz, T., Eineder, M.: “TerraSAR-X Basic Product Specification Document”, TX-GS-DD-3302, Issue 1.9

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

Abbreviations

DN	Digital Number
EEC	Enhanced Ellipsoid Corrected
GEC	Geocoded Ellipsoid Corrected
GIM	Geocoded Incidence angle Mask
MGD	Multi Look Ground Range Detected
NEBN	Noise Equivalent Beta Naught
NESZ	Noise Equivalent Sigma Zero

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