MISB MOTION IMAGERY STANDARDS BOARD	MISB ST 1206
STANDARD	
SAR Motion Imagery Metadata	27 February 2014

1 Scope

This Standard defines the content and Local Set Key-Length-Value (KLV) representation of metadata per SMPTE ST 336 [1] necessary to exploit both sequential synthetic aperture radar (SAR) imagery and sequential SAR coherent change products as motion imagery. In addition, background information regarding typical SAR collections and terminology are provided for context.

2 References

2.1 Normative References

The following references and the references contained therein are normative.

[1] SMPTE ST 336:2007, Data Encoding Protocol Using Key-Length-Value
[2] SMPTE RP 210v13:2012, Metadata Element Dictionary
[3] MISB ST 0807.13, MISB KLV Metadata Dictionary, Feb 2014
[4] MISB ST 0801.5, Photogrammetry Metadata Set for Digital Motion Imagery, Feb 2014
[5] MISB ST 0107.2, Bit and Byte Order for Metadata in Motion Imagery Files and Streams, Feb 2014
[6] MISB ST 0603.2, Common Time Reference for Digital Motion Imagery Using Coordinated Universal Time (UTC), Feb 2014
[7] MISB ST 1303, Multi-Dimensional Array Pack, Feb 2014
[8] NGA.SIG.0005_1.0, Spotlight Synthetic Aperture Radar (SAR) Sensor Model Supporting Precise Geopositioning, Version 1.0, Mar 2010

2.2 Informative References

[9] W.G. Carrara, R.S. Goodman and R.M. Majewski, Spotlight Synthetic Aperture Radar Signal Processing Algorithms, Norwood, MA: Artech House, Inc., 1995
[10] MISB ST 0903.3, Video Moving Target Indicator and Track Metadata, Oct 2012
[11] NATO STANAG 4607, Ed. 3, Ground Moving Target Indicator Format (GMTIF), Sep 2010

3 Acronyms

ECEF Earth-Centered Earth-Fixed
GMTI Ground Moving Target Indicator
KLV Key-Length-Value
MDV Minimum Detectable Velocity
PRF Pulse Repetition Frequency
RCS Radar Cross Section
SAR Synthetic Aperture Radar
SARMI SAR Motion Imagery
SRP Scene Reference Point

4 Revision History

Revision	Date	Summary of Changes
Original Draft	02/27/2014	New Release

5 SAR as Motion Imagery Introduction

SAR imagery / SAR coherent change products as motion imagery, herein referred to as SAR motion imagery (SARMI), is defined as a sequence of SAR imagery or SAR coherent change products that support the temporal exploitation of the data contain therein. Typically, the data displayed are observations of the same scene. This definition of motion imagery does not impose any limits or specification on the capture of the motion imagery data. For instance, the input to calculate SAR coherent change product data could be collected at intervals much longer than a second and be temporally disjointed but the resulting data is sequenced in a manner to highlight the temporal changes that occur in the data. The following sections discuss possible SARMI variations.

5.1 SARMI Variations

5.1.1 SAR Imagery as SARMI

This CONOP involves the continuous capture of SAR phase histories using an arbitrary flight trajectory. SAR images are formed from overlapping sets of phase histories illustrated in Figure 1. The sensor parameters, aperture overlap, flight geometry, and available hardware resources determine the frame rate of SAR images.

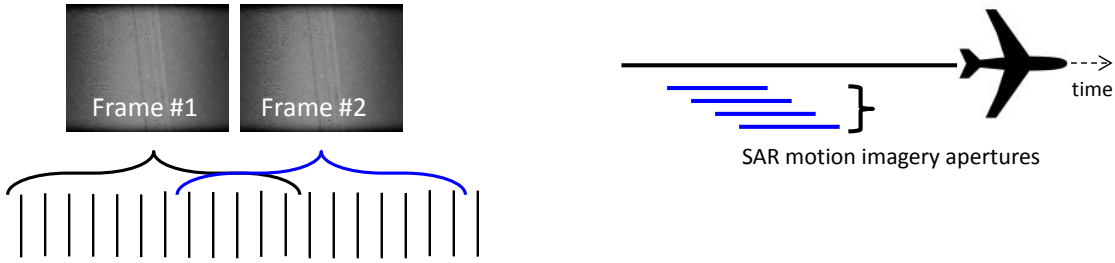


Figure 1: SAR imagery frames are generated from overlapping phase histories and displayed as sequential frames creating SAR Motion Imagery.

For persistent surveillance type collections, the scene center is typically fixed regardless of the sensor's flight path. Latency for this CONOP is a function of the aperture size, which depends on factors such as the platform speed, geometry, wavelength, and cross-range resolution.

5.1.1.1 SARMI with Ground Moving Target Indications

The CONOP in 5.1.1 may be enhanced to include simultaneous Ground Moving Target Indicator (GMTI) detection and tracking of targets in GMTI subapertures formed from the same SAR phase histories illustrated in Figure 2. These detections and tracks may be displayed on the SARMI as overlays to increase the contextual information.

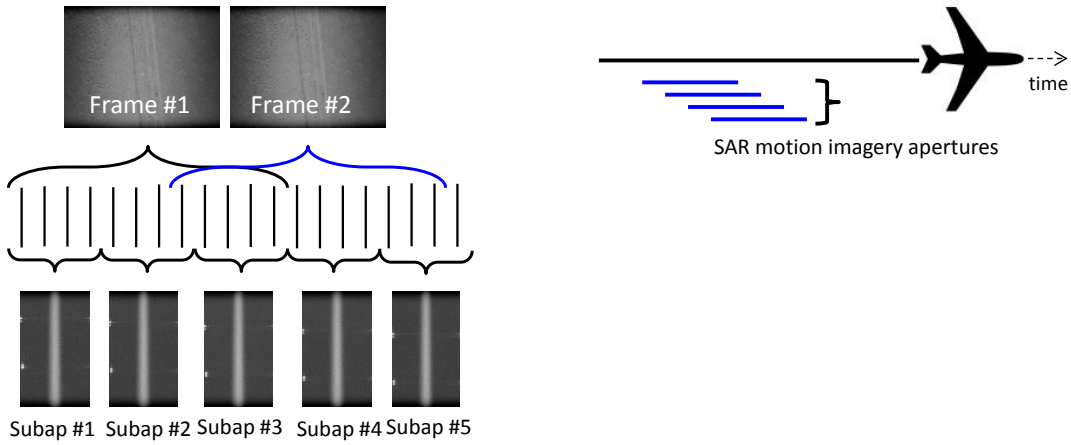


Figure 2: SARMI with simultaneous GMTI generated from the same SAR phase history data.

5.1.2 SAR Coherent Change Product as SARMI

A sequence of SAR coherent change products may be displayed as SARMI. A SAR coherent change product represents some type of change occurring between a frame generated at time t_0 and a subsequent frame generated at time t_{0+} but at a similar geometry. The frame at t_{0+} is registered to the frame at t_0 prior to product generation.

The time duration over which changes may occur is selectable and established by the time delta between frame t_0 and frame t_{0+}. This concept is depicted in Figure 3. Of note, successive coherent change product frames need not overlap temporally. For instance, the initial coherent

change product frame may represent changes over a one-day period while the subsequent change product frames displayed as SARMI may represent several years of change.

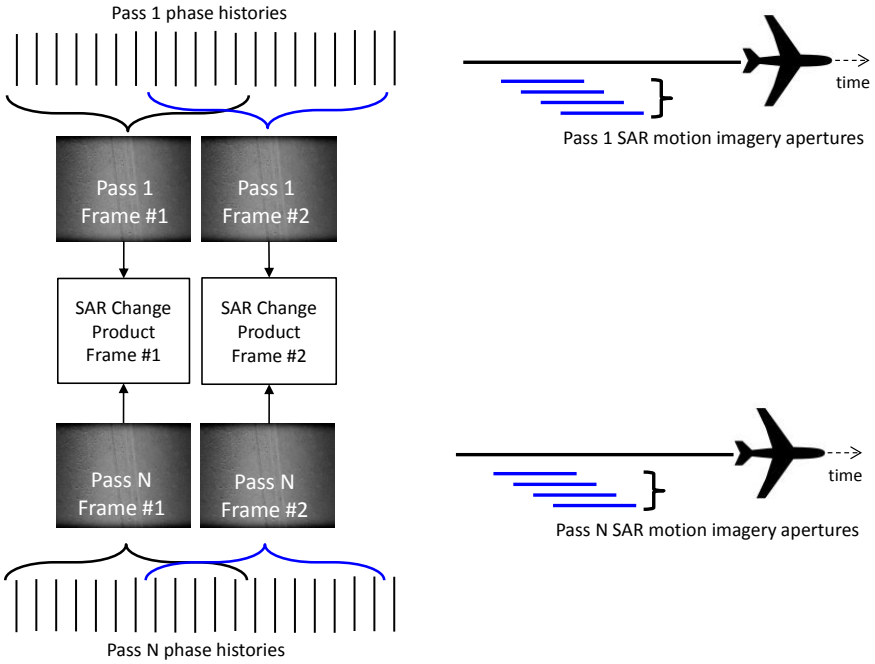


Figure 3: SAR coherent change product displayed as SARMI relies upon pairs of SAR images captured at different times but at similar geometries.

6 SARMI Metadata

The intent of the SARMI metadata local set is to support the SARMI CONOPs described in 5.1.

6.1 Conventions

The SMPTE KLV representation of the SARMI individual metadata elements are defined in [2] and [3].

Requirement	
ST 1206-01	All KLV-encoded metadata shall be expressed in accordance with MISB ST 0107 [5].
ST 1206-02	The SARMI Metadata Local Set 16-byte Universal Label Key shall be 06.0E.2B.34.02.0B.01.01.0E.01.03.03.0D.00.00.00 (CRC 54900).
ST 1206-03	Formatting of SARMI metadata shall be compliant with SMPTE 336 [1] encoding rules for Universal Labels and Local Sets.

6.1.1 Summary of SARMI Metadata Local Set Elements

The SARMI Metadata Local Set is summarized in Table 1.

Table 1: SARMI Metadata Local Set Elements

Tag	Name	Key	Units	Format
1	Grazing Angle	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.00.00.00 (CRC 30335)	Degrees	IMAPB(0,90,2)
2	Ground Plane Squint Angle	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.01.00.00 (CRC 16719)	Degrees	IMAPB(-90,90,2)
3	Look Direction	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.02.00.00 (CRC 6175)	Enumeration	UINT(1)
4	Image Plane	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.03.00.00 (CRC 12079)	Enumeration	UNIT(1)
5	Range Resolution	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.04.00.00 (CRC 43711)	Meters	IMAPB(0,1e6,4)
6	Cross-Range Resolution	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.05.00.00 (CRC 40335)	Meters	IMAPB(0,1e6,4)
7	Range Image Plane Pixel Size	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.06.00.00 (CRC 50399)	Meters	IMAPB(0,1e6,4)
8	Cross-Range Image Plane Pixel Size	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.07.00.00 (CRC 62447)	Meters	IMAPB(0,1e6,4)
9	Image Rows	06.0E.2B.34.01.01.01.01. 0E.01.02.02.06.00.00.00 (CRC 08248)	Numeric	UINT(2)
10	Image Columns	06.0E.2B.34.01.01.01.01. 0E.01.02.02.07.00.00.00 (CRC 22156)	Numeric	UINT(2)
11	Range Direction Angle Relative to True North	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.08.00.00 (CRC 57310)	Degrees	IMAPB(0,360,2)
12	True North Direction Relative to Top Image Edge	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.09.00.00 (CRC 59630)	Degrees	IMAPB(0,360,2)
13	Range Layover Angle Relative to True North	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0A.00.00 (CRC 45502)	Degrees	IMAPB(0,360,2)
14	Ground Aperture Angular Extent	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0B.00.00 (CRC 34446)	Degrees	IMAPB(0,90,2)
15	Aperture Duration	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0C.00.00 (CRC 798)	μ-Seconds	UINT(4)
16	Ground Track Angle	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0D.00.00 (CRC 13358)	Degrees	IMAPB(0,360,2)

17	Minimum Detectable Velocity	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0E.00.00 (CRC 28030)	Meters / Second	IMAPB(0,100,2)
18	True Pulse Repetition Frequency	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.0F.00.00 (CRC 23118)	Hertz	IMAPB(0,1e6,4)
19	Pulse Repetition Frequency Scale Factor	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.10.00.00 (CRC 13596)	Numeric	IMAPB(0,1,2)
20	Transmit RF Center Frequency	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.11.00.00 (CRC 556)	Hertz	IMAPB(0,1e12,4)
21	Transmit RF Bandwidth	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.12.00.00 (CRC 23420)	Hertz	IMAPB(0,1e11,4)
22	Radar Cross Section Scale Factor Polynomial	06.0E.2B.34.02.05.01.01. 0E.01.03.03.06.00.00.00 (CRC 39697)	m^2, m, 1, 1/m, etc.	MDARRAY(...)
23	Reference Frame Precision Time Stamp	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.14.00.00 (CRC 59868)	μ-Seconds	UINT(8)
24	Reference Frame Grazing Angle	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.15.00.00 (CRC 57068)	Degrees	IMAPB(0,90,2)
25	Reference Frame Ground Plane Squint Angle	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.16.00.00 (CRC 34748)	Degrees	IMAPB(-90,90,2)
26	Reference Frame Range Direction Angle Relative to True North	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.17.00.00 (CRC 45196)	Degrees	IMAPB(0,360,2)
27	Reference Frame Range Layover Angle Relative to True North	06.0E.2B.34.01.01.01.01. 0E.01.01.03.3D.18.00.00 (CRC 40125)	Degrees	IMAPB(0,360,2)
28	Document Version	06.0E.2B.34.01.01.01.01. 0E.01.02.05.05.00.00.00 (CRC 56368)	N/A	BER OID

6.2 Metadata Elements for SAR Imagery as SARMI

6.2.1 Grazing Angle

The grazing angle is needed to estimate the height of objects in the SAR imagery as SARMI based on the lengths of shadows. As depicted in Figure 4, the grazing angle is defined as the angle between the line-of-sight vector from the Scene Reference Point (SRP) to the sensor and the ground plane at the SRP. The SRP denotes the scene center for the SAR imagery frames. Technically, the grazing angle from the sensor to each pixel in a SAR image slightly differs. However, a good approximation is to assume the grazing angle to the SRP represents that of the entire image. The grazing angle is <u>not</u> the same as the sensor depression angle. For short slant ranges, the differences are negligible. However, for longer slant ranges, the difference can be

pronounced. For the following derivations, assume the image coordinate system is WGS-84 and ground plane is the plane tangent to the ellipsoid at the SRP.

Define the following:

Antenna Phase Center Position –	$R_a = (X_S, Y_S, Z_S)$
SRP –	$R_{SRP} = (X_{SRP}, Y_{SRP}, Z_{SRP})$
Line-of-Sight vector –	$R_{LOS} = R_a - R_{SRP}$ in the Earth-Centered, Earth-Fixed coordinate frame

The transformation from Geodetic WGS-84 latitude and longitude to the ECEF coordinate frame is one-to-one. The Euclidean distance, $|R_{LOS}|$, between the sensor's antenna phase center and SRP, is the slant range. Denote the ECEF pole vector as *p* defined as

$$p = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

and the square of the second eccentricity of the reference ellipsoid as e^2. Then the vector normal to the reference ellipsoid at the SRP is given in [8] by

$$R_{SRP}^{\perp} = R_{SRP} + (pp^T)R_{SRP}e^2 \qquad \textbf{Equation 1}$$

and the corresponding unit vector is given by

$$u_{R_{SRP}^{\perp}} = \frac{R_{SRP}^{\perp}}{|R_{SRP}^{\perp}|} \qquad \textbf{Equation 2}$$

The grazing angle can thus be computed as

$$\psi = \sin^{-1}\left(\frac{Z_R}{|R_{LOS}|}\right) \qquad \textbf{Equation 3}$$

Where | | denotes the l^2 norm, ⟨ ⟩ represents the inner product, and Z_R is proportional to the inner product of the unit line-of-sight vector and $R_{SRP}^{\perp}$ as illustrated in Figure 4:

$$Z_R = |R_{LOS}|\, cos\left(\frac{\pi}{2} - \psi\right) = |R_{LOS}|\, \langle \frac{R_{LOS}}{|R_{LOS}|}, u_{R_{SRP}^{\perp}} \rangle \qquad \textbf{Equation 4}$$

Thus, the grazing angle is given by

$$\psi = sin^{-1}\left(\frac{Z_R}{|R_{LOS}|}\right) = sin^{-1}\left(\langle \frac{R_{LOS}}{|R_{LOS}|}, u_{R_{SRP}^{\perp}} \rangle\right) \qquad \textbf{Equation 5}$$

With the grazing angle known, the height, *h*, of an object in a SAR frame may be computed by measuring the length, *D*, of its shadow in the direction of RF illumination:

$$h = D\, tan\, \psi \qquad \textbf{Equation 6}$$

Equation 6 assumes the shadow is projected on flat terrain. Significant terrain relief will likely skew the results.

Because of quantization errors that arise from encoding geodetic positions, it is preferable to directly compute the grazing angle according to Equation 5 at the sensor. In the event the grazing angle is not directly computed at the sensor, it may be approximated by using the location of the sensor (latitude, longitude, and altitude above the ellipsoid) and the location of the SRP (latitude, longitude, and elevation above the ellipsoid).

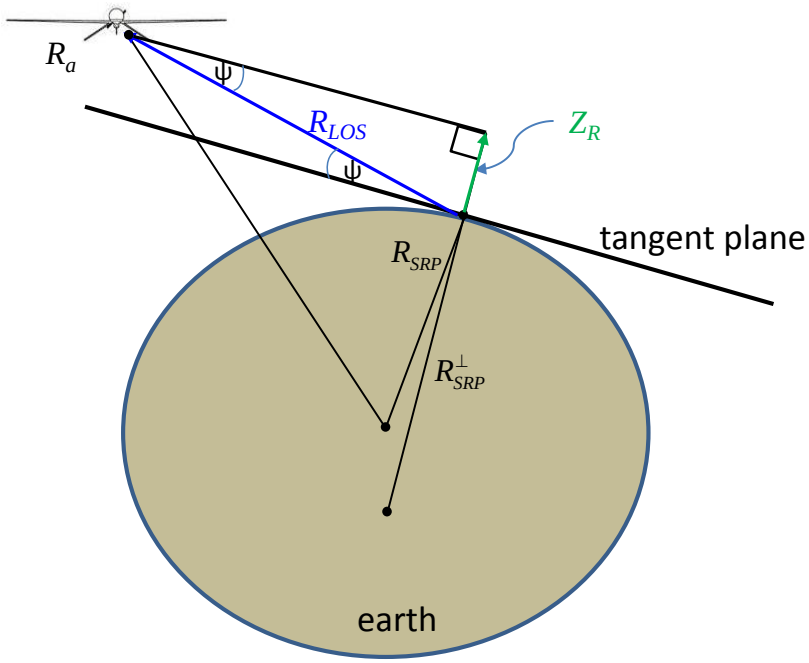


Figure 4: Grazing angle for an elliptical Earth model.

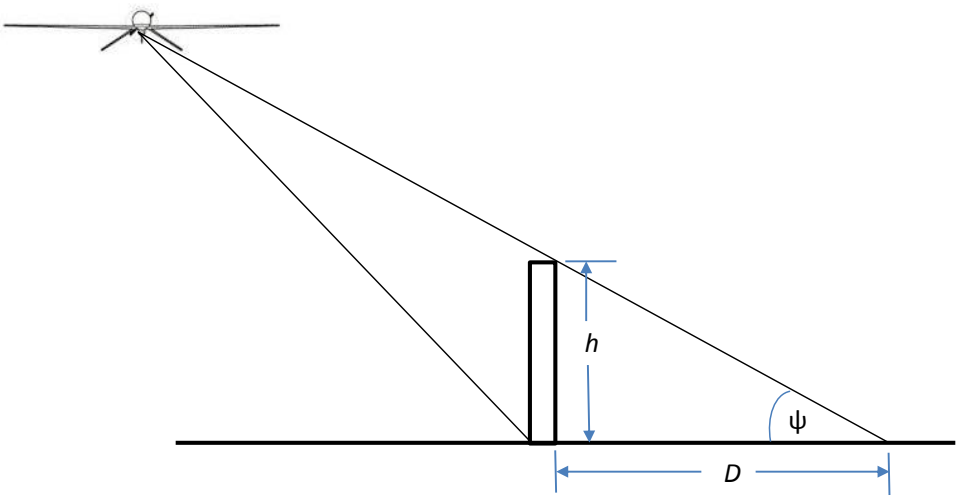


Figure 5: Estimation of height for a wall using shadow length and grazing angle.

6.2.2 Ground Plane Squint Angle

From a collection perspective the squint angle may be expressed as the Doppler cone angle between the ground track vector and the radar's line-of-sight vector or as a ground squint angle,

which is the corresponding angle projected onto the ground plane. Here, the ground plane is the geodetic plane orthogonal to the ellipsoid normal at the SRP, although it may also be defined as the geocentric plane. Most often, the squint angle is defined relative to the sensor velocity vector. However, it is technically defined as the ground-track angle to which the SAR imagery is formed. It can be interpreted as the average velocity vector along the synthetic aperture, or approximated from a single velocity measurement at some position in the aperture, typically the SRP, barring the availability of the ground-track angle. For the ground plane squint angle, forward of broadside is positive and aft of broadside is negative. Many image parameters, such as image orientation with respect to True North, rely on the ground plane squint angle so the computation is outlined below.

Denote the unit vector to the tangential plane to the ellipsoid at the SRP as $u_{R^{\perp}_{SRP}}$ per Equation 2. It follows that the line-of-sight vector projected onto the tangential plane is

$$R^{g}_{LOS} = R_{LOS} - \langle R_{LOS}, u_{R^{\perp}_{SRP}} \rangle \, u_{R^{\perp}_{SRP}} \qquad \textbf{Equation 7}$$

The velocity or ground-track vector projected onto the tangential plane is

$$V^{g}_{a} = V_{a} - \langle V_{a}, u_{R^{\perp}_{SRP}} \rangle \, u_{R^{\perp}_{SRP}} \qquad \textbf{Equation 8}$$

The ground plane squint angle, ϕ, is given by

$$\phi = 90 - \left| cos^{-1}\left(\langle -\frac{R^{g}_{LOS}}{\left|R^{g}_{LOS}\right|}, \frac{V^{g}_{a}}{\left|V^{g}_{a}\right|} \rangle \right) \right| \qquad \textbf{Equation 9}$$

The ground plane squint angle values fall in the interval [-90°, 90°]. The look direction specifies the direction the imagery is collected with respect to the velocity vector illustrated in Figure 6. If the ground plane squint angle is not computed at the sensor, it should be computed using the ground track angle.

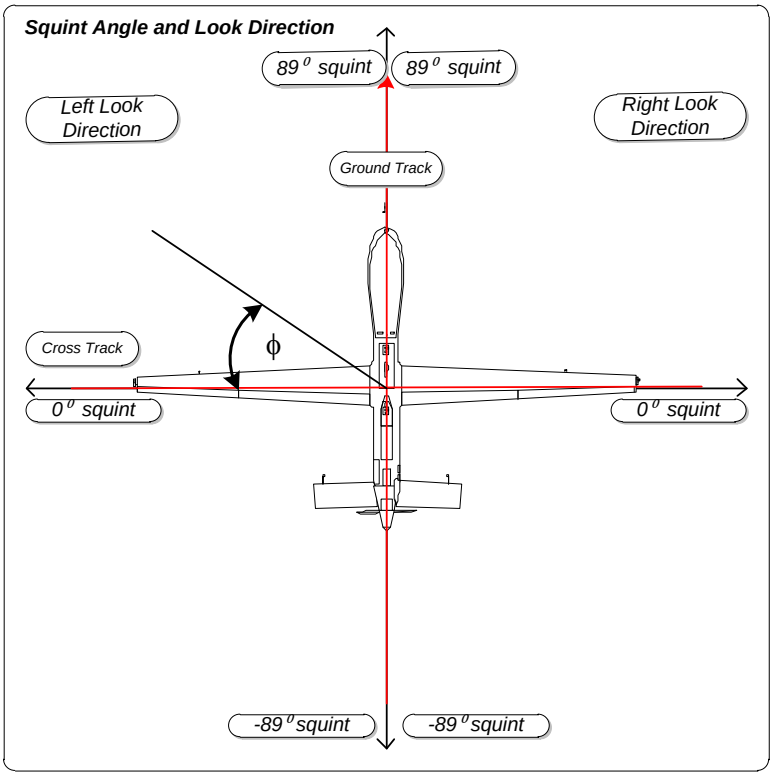


Figure 6: Illustration of squint angle and look direction.

6.2.3 Look Direction

Per Figure 6, the look direction indicates the side of the imaging platform from which the imagery is collected. As such, the sensor look direction with respect to the velocity vector is defined as 0 for Left Look Direction and 1 for Right Look Direction.

Requirement	
ST 1206-04	The Look Direction metadata element and the Ground Plane Squint Angle metadata element shall be present at all times.

6.2.4 Image Plane

SAR images are typically formed either on the slant plane – the plane containing the ground-track vector and the line-of-sight vector to the SRP, or onto the ground plane – the plane tangential to the ellipsoid at the SRP for the WGS-84 image coordinate system as illustrated by Figure 7. The selection of the imaging plane may impact the accuracy of distance measurements. SAR images formed in the slant plane experience a foreshortening in the range dimension, whereby objects projected onto the slant plane will appear shorter than when projected onto the ground plane. As such, the plane in which the SARMI data is formed is defined as 0 for Slant Plane, 1 for Ground Plane, and 2 for Other (self-defined plane).

Foreshortening is proportional to the inverse cosine of the grazing angle; therefore, steeper grazing angles increase range foreshortening. Thus, if a SARMI sensor traverses a circular orbit about a square building situated on flat terrain with sides of length *N*, and provides SAR frames

in the slant plane, the building's dimensions will vary according to the geometry of the sensor with respect to the scene. For instance, for a grazing angle of 60°, the range pixel size in the ground plane is twice the range pixel size in the slant plane. Hence, when the direction of the line-of-sight vector is orthogonal to the front of the building, the width will appear to be *N* wide but the depth will appear to be *N/2*.

Foreshortening in the range dimension leads to inconsistent length measurements and is highly undesirable for geospatial analysis. Therefore, it is recommended for SARMI applications, that frames be projected onto the ground plane during image formation. For high-relief terrain where geo-location becomes crucial, it is desirable to orthorectify the slant plane SAR frames to a Digital Elevation Model (DEMs), if available.

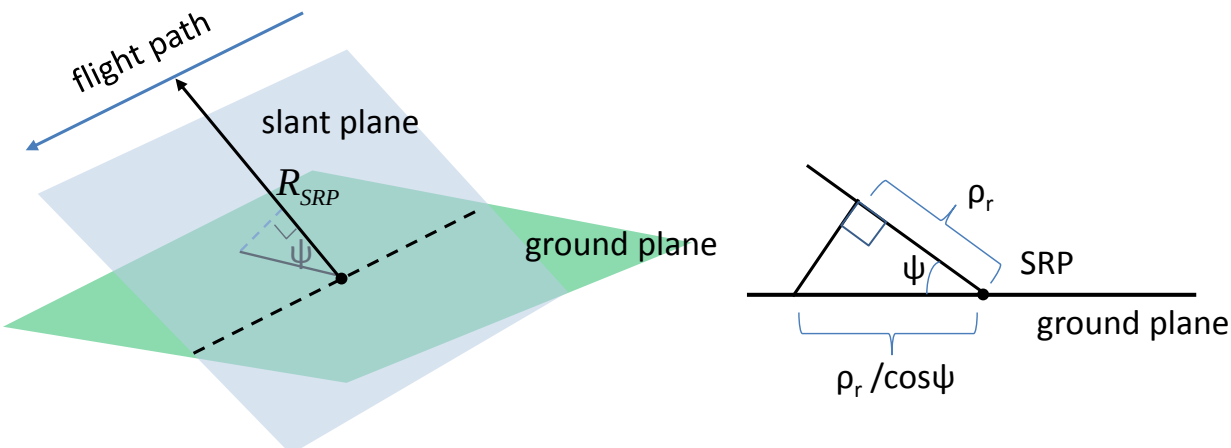


Figure 7: Range resolution and pixel size dimensions elongate by the inverse of the cosine of the grazing angle.

6.2.5 Range and Cross-Range Resolution

Range resolution is a measurement of spatial resolution, where two targets in close proximity in range may be resolved from one another. Theoretical resolution is important as it is an indicator of the maximum image quality. Most literature sources define the range resolution in the slant plane. Range resolution in the slant plane is defined by the RF bandwidth of the waveform, *B*, and is independent of sensor range:

$$\rho_r = \frac{K_r c}{2B} \qquad \textbf{Equation 10}$$

where *c* is the speed of light and K_r is the main lobe broadening factor. The range resolution in the ground plane may be computed by dividing Equation 10 by the cosine of the grazing angle or the range resolution may be directly specified in the ground plane.

Cross-range resolution is a measurement of spatial resolution where two targets in close proximity in cross-range may be resolved from one another. The cross-range resolution is range dependent. For slant ranges, R_S, much larger than the aperture length, *L*, it is approximated by

$$\rho_a \approx \frac{K_a R_S \lambda_C}{2L \sin \phi_{dc}} \approx \frac{K_a \lambda_C}{2\Delta\theta}$$ **Equation 11**

where K_a is the main lobe broadening factor in the cross-range dimension, λ_C is the wavelength at the center RF frequency, ϕ_{dc} is the Doppler cone squint angle, and $\Delta\theta$ is the angle swept by the synthetic aperture in the slant plane. The cross-range resolution is not affected by the choice of imaging plane. Although Equation 10 and Equation 11 define resolution in the down range and cross-range directions, these directions may not correspond to rows and columns in a SARMI frame. For example, the SAR frames may undergo rotation to fix their frame of reference, or the frames could be chipped at arbitrary rotation angles.

Both range and cross-range resolution measurements include amplitude weighting. Also, even though both measurements allow 0 as a valid value, it should not be used as it is meaningless in practical applications.

6.2.6 Range and Cross-Range Image Plane Pixel Size

Knowledge of the pixel dimensions and the number of pixels traversed enables the measurement of the Euclidean distance between any two arbitrary points in a SAR image. Pixel dimensions are specified in the range and cross-range directions of an image plane. The pixel size is a relative quantity that reflects the amount of oversampling the image undergoes during image formation. As in the case of range resolution, the range image plane pixel size in the slant plane is shorter than the range image plane pixel size in the ground plane by a factor given by the inverse of the cosine of the grazing angle. The cross-range image plane pixel size reflects the size of a pixel in the SAR image in the cross-range dimension.

The ratio of range / cross-range image plane pixel size to range / cross-range resolution sans amplitude weights is the oversampling ratio. Also, even though both measurements allow 0 as a valid value, it should not be used as it is meaningless in practical applications.

6.2.7 Image Rows and Columns

For SARMI, the number of image rows and columns combined with range and cross-range pixel sizes give the swath size of the image patch. Pixels are assumed to appear in row-major order. Image rows correspond to the height of the image and image columns correspond to the number of pixels in a row [4]. Also, even though both measurements allow 0 as a valid value, it should not be used as it is meaningless in practical applications.

6.2.8 Range Direction Angle Relative to True North

When estimating the height of objects based on the lengths of their shadows, it is particularly important to measure the shadow in the direction of the sensor line-of-sight vector, which does not necessarily align with any of the image axes. Inferring the shadow direction by merely examining shadows in an image may be misleading, as complicated structures can create unusual shadows. Note that for typical SARMI applications, whereby the SAR frames are rotating due to sensor motion, the shadow direction is usually fixed. On the other hand, if image post-processing were to fix the frame of orientation in the SARMI data for applications such as chipping, or

extracting an arbitrarily oriented chip from a larger frame because of bandwidth constraints, the shadow angle would change from frame-to-frame and could rotate in a complete circle.

The key to determining the shadow direction lies in knowing the down range direction as the image may undergo a rotation during image formation or feature extraction. For SARMI, define γ as the angle of the down range direction with respect to True North as

$$\gamma = GTA + \phi \qquad \textbf{Equation 12}$$

for both left/right-looking cases, where *GTA* is the desired ground track angle or path of the radar with respect to True North as defined at the SRP and ϕ is the ground squint. This is illustrated in Figure 8. The ground track and ground squint angles are relative to True North at the SRP, which may differ significantly from True North at the sensor while operating near the Earth's poles. The *GTA* also differs from the sensor heading, as the heading of airborne sensors may be affected by platform crabbing.

As Equation 12 only depends on telemetry, to define the down range direction with respect to the image pixels, the direction of True North with respect to the image as described in 6.2.9 is also required.

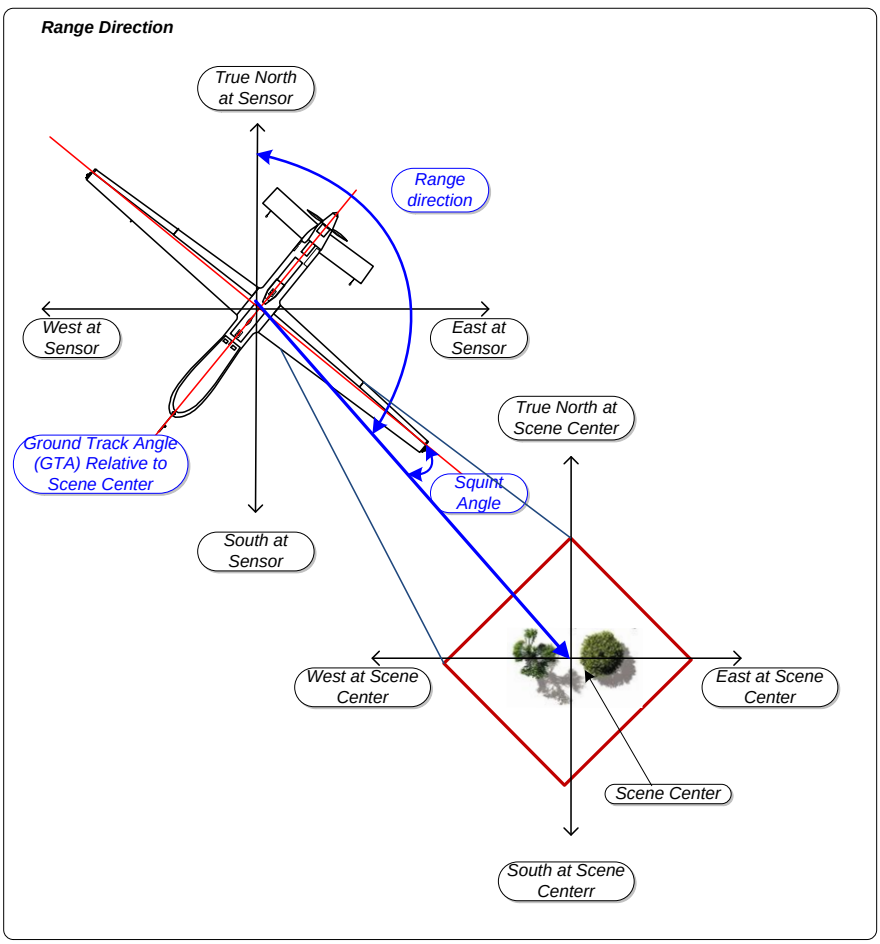


Figure 8: The down range direction relative to True North depends on the sensor's Ground Track Angle and Ground Plane Squint Angle relative to the SRP.

6.2.9 True North Direction Relative to Top Image Edge

The True North direction relative to top image edge angle may be computed by knowing the down range direction relative to True North based on sensor telemetry and the True North direction with respect to pixels in the image. True North direction with respect to pixels in the image is defined relative to the top edge of the image as measured in a counter-clockwise fashion assuming the origin (0,0) is the top-left corner of the image as depicted in Figure 9. Hence, regardless of the image orientation, the range direction with respect to True North may be computed from the ground track and ground squint angles. It is important that these quantities be defined at the SRP rather than at the sensor location as the difference between True North at the SRP and sensor location increases closer to the poles. The angle between True North and the image itself will always be the same value if the SAR motion imagery orientation is fixed or will vary from frame-to-frame if the orientation varies from frame-to-frame.

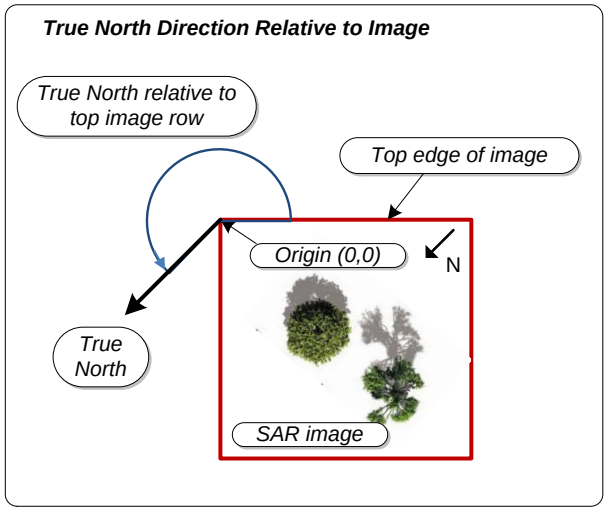


Figure 9: Example of the True North direction relative to the top image edge.

With the down range direction relative to True North at the SRP and direction of North relative to pixels in an image defined, the down range direction in an image may be computed with respect to its pixels through the relation as the direction of True North relative to the top image edge minus the range direction relative to True North. This is shown pictorially in Figure 10.

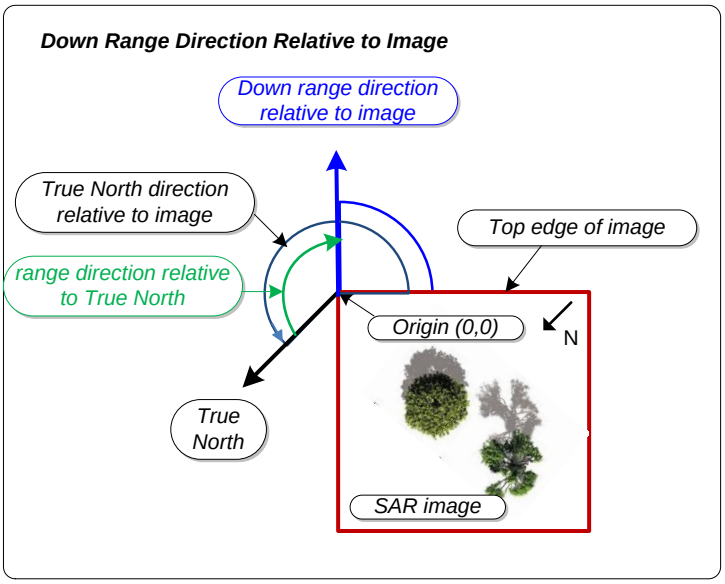


Figure 10: Down range direction in an image is determined by the direction of True North relative to the image and the range direction with respect to True North.

6.2.10 Range Layover Angle Relative to True North

The range layover relative to True North is in the direction perpendicular to the sensor ground track angle at the aperture center as depicted in Figure 11. Hence, for a left-looking sensor, the layover angle is the ground track angle plus ninety degrees. Conversely, for a right-looking sensor, the range layover angle is the ground track angle minus ninety degrees.

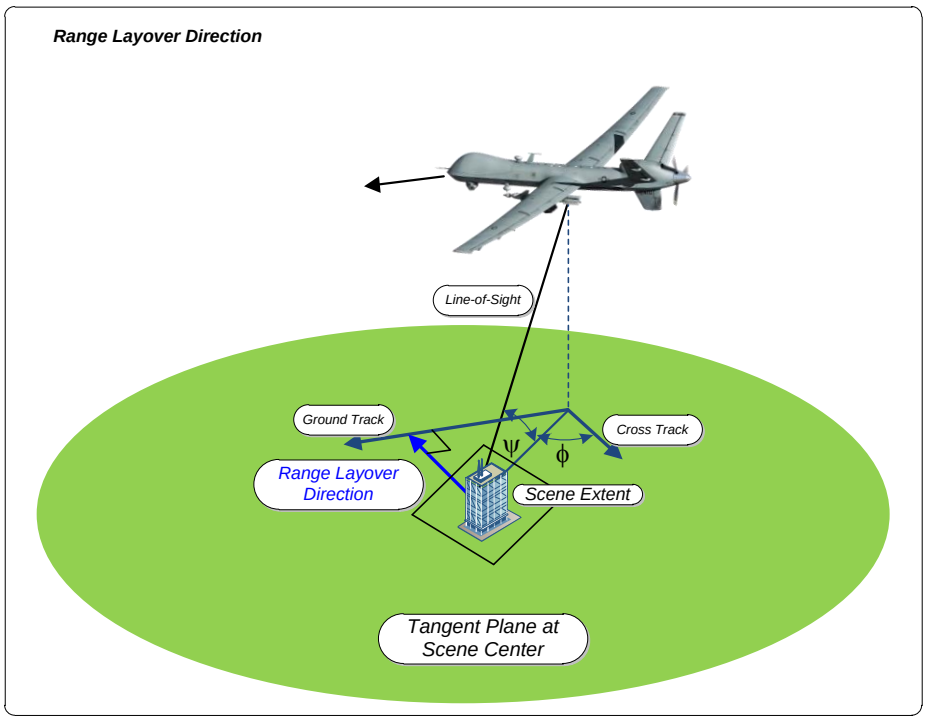


Figure 11: Illustration of range layover direction.

6.2.11 Ground Aperture Angular Extent

The aperture angular extent, $\Delta\theta$, is the angle swept in cross-range as the sensor traverses the synthetic aperture used to generate a single SAR image. It may be defined in the slant plane, in which case it is the angle between the line-of-sight vector at the first pulse and the line-of-sight vector at the last pulse forming the aperture. The aperture angular extent may also be defined in the ground plane, $\Delta\theta_g$, giving a sense of the physical geometry and angular distance flown to cover a single SAR image as depicted in Figure 12. Given the cross-range resolution, ρ_a, the angular extent in the ground plane may be approximated from the angular extent in the slant plane obtained from the cross-range resolution in Equation 11 and projected onto the ground

$$\Delta\theta_g \approx \frac{K_a \lambda_C}{2\rho_a \cos\psi} \qquad \textbf{Equation 13}$$

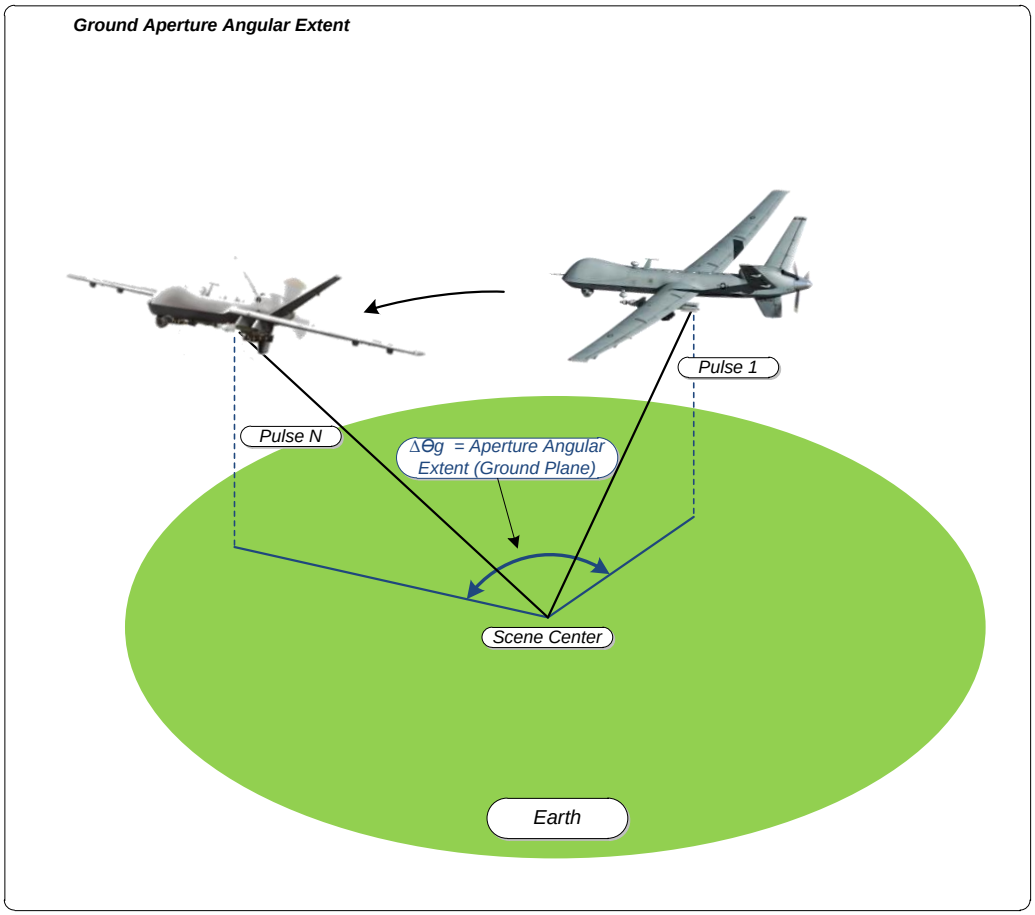


Figure 12: Aperture angular extent in the slant and ground planes.

6.2.12 Aperture Duration

The synthetic aperture duration is the length of the coherent processing period or the time interval the radar beam illuminates the scene as shown in Figure 12. This time is a function of both flight geometry and RF carrier frequency. The aperture duration is the dominant contributor to latency due to physically flying the aperture. It, however, accounts for neither the SAR image

formation time, which is small for real-time SARMI, nor the data transmission time from the sensor to the end-user, which may be large when utilizing BLOS data links. The aperture duration may be computed from the slant range, swept aperture angle, sensor speed, and Doppler cone angle by

$$T_a = \frac{|R_S|\Delta\theta}{|V_s|\,sin\,\phi_{dc}} \qquad \textbf{Equation 14}$$

6.2.13 Ground Track Angle

The ground track angle is the heading over ground the sensor travels as illustrated in Figure 13. It is important to note that the ground track angle is assumed to be with respect to the SRP rather than the sensor location. While this differentiation may seem insignificant, the difference between the coordinate system at the SRP and the platform becomes pronounced near the poles. The ground track angle may either be the desired, ideal ground track angle or the actual ground track angle, depending on the sensor.

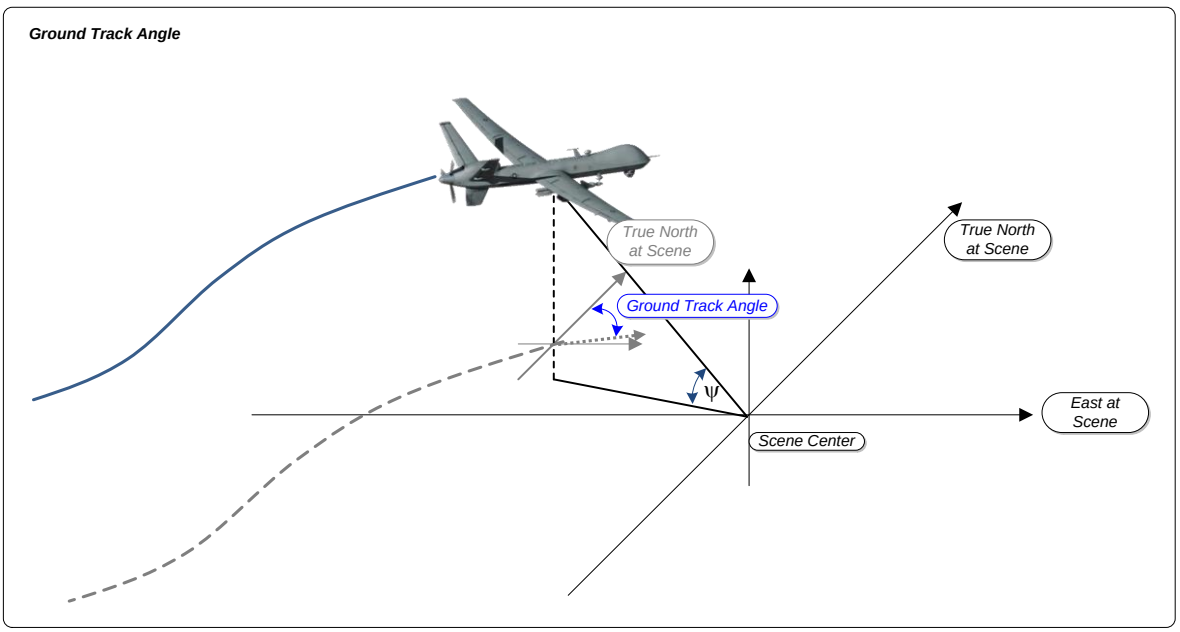
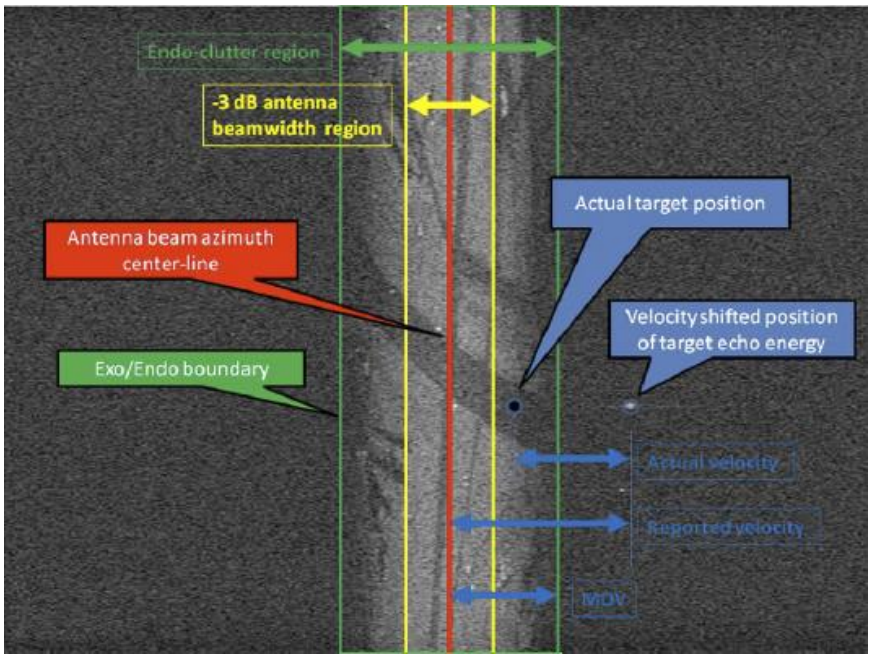


Figure 13: The ground track angle is relative to the scene center.

6.2.14 Minimum Detectable Velocity

SARMI is essentially a form of Ground Moving Target Indicators (GMTI) displayed on full-resolution Endo-clutter SAR frames rather than the classic 'blips' on a range-Doppler image. The GMTI radial velocity is the projection of the mover's velocity vector upon the radar's line-of-sight vector to the target. Hence, the radial velocity is not only a function of target velocity, but also scene geometry. The Minimum Detectable Velocity (MDV) is defined as the radial velocity when a target located at the antenna beam's cross-range center line transcends from the Endo-clutter (visible SAR image) boundary into Exo-clutter (not visible) as illustrated in Figure 14Figure 1. Technically, the MDV could change within a SAR image. However, for simplicity,

assume the MDV is constant over the SAR coherent processing interval. Estimation of the MDV using aforementioned SARMI metadata requires additional *a priori* knowledge of sensor parameters. Hence, it is desirable to specify the MDV explicitly.



Source: A.W. Doerry, "Performance Limits for Exo-Clutter Ground Moving Target Indicator (GMTI) Radar," Sandia National Laboratories Report, Albuquerque, NM, SAND2010-5844, Unlimited Release, pp.54.

Figure 14: The Minimum Detectable Velocity is a function of RF parameters and target / sensor geometry.

The MDV is asymmetric about broadside and may be computed from sensor telemetry and basic RF parameters. Let ψ be the grazing angle as defined in Equation 5, ϕ_n be the ground plane squint angle relative to the nose of the aircraft, ϕ_ε be the magnitude of the antenna beam maximum pointing error, θ_{bwaz} be the -3dB antenna beam width, and K_{exo} be the ratio of the Endo/Exo-clutter boundary distance from the beam center to half the nominal cross-range beam width. Define

$$\varphi_{fore} \approx max\left(|\phi_n| - K_{exo}\frac{\theta_{bwaz}}{2\,cos\,\psi} - \phi_\varepsilon, 0\right) \qquad \textbf{Equation 15}$$

and

$$\varphi_{aft} \approx min\left(|\phi_n| + K_{exo}\frac{\theta_{bwaz}}{2\,cos\,\psi} + \phi_\varepsilon, \pi\right) \qquad \textbf{Equation 16}$$

MDV may then be simplified as the maximum of the MDV forward of broadside and the MDV aft of broadside [9]

$$MDV \approx max\left(\left|v_s \cos\psi\left(\cos\varphi_{fore} - \cos|\phi_n|\right)\right|, |v_s|\cos\psi\left(\cos\varphi_{aft} - \cos|\phi_n|\right)\right) \qquad \textbf{Equation 17}$$

where v_s is the sensor velocity.

6.2.15 True Pulse Repetition Frequency

The pulse repetition frequency (PRF) is defined as the time interval between successively transmitted pulses. Each pulse corresponds to a unique sensor along-track position over the synthetic aperture. For SARMI, assume the PRF is fixed during the collection phase for a single SAR image. Note that the effective PRF of as a result frame formation may be significantly less than the true system PRF.

6.2.16 Pulse Repetition Frequency Scale Factor

The PRF scale factor is used to indicate when the effective PRF of a SAR image differs from that of the true system PRF described in 0. The effective PRF is useful for determining the location of ambiguous returns in range and/or cross-range that may appear in SARMI data. The effective PRF is defined as

$$Effecitve\ PRF = PRF * PRF\ Scale\ Factor \qquad \textbf{Equation 18}$$

6.2.17 Transmit RF Center Frequency

The transmit RF center frequency is the center frequency of the RF band when linear FM waveforms are employed. For most chirped waveform SARMI systems, the set of transmitted frequencies is fixed for every pulse. For systems that adjust the transmitted frequency band during the synthetic aperture, the RF center frequency is the frequency at the center of the band defined by the minimum overall RF starting frequency and the maximum overall RF ending frequency during the synthetic aperture.

6.2.18 Transmit RF Bandwidth

The RF bandwidth dictates the range resolution in the slant plane independent of aperture size. The transmit RF bandwidth may be defined by a single, fixed waveform or a sequence of waveforms, such as a step chirp waveform. The transmit RF bandwidth is defined as the difference between the maximum and minimum transmit frequencies for a single or sequence of waveforms, if applicable.

6.2.19 Radar Cross Section Scale Factor Polynomial

To determine the Radar Cross Section (RCS) for a pixel in a SARMI frame, the RCS scale factor is defined as a quantity that relates pixel power for an ideal point scatterer to the RCS in square meters. This relationship is expressed as a bivariate polynomial that is a function of the image pixel coordinates as follows

$$RCSSFPoly(xrow, ycol) = \sum_{m=0}^{M} \sum_{n=0}^{N} cRCS(m,n) * xrow^{m} ycol^{n} \qquad \textbf{Equation 19}$$

where $cRCS(m,n)$ denotes the bivariate polynomial coefficients where m is the row index and n is the column index of the two-dimensional polynomial. The bivariate polynomial provides a

maximum of $(M+1)*(N+1)$ coefficients defined by the radiometric polynomial. The resulting pixel RCS is defined as the product of the RCS scale factor at the pixel with the pixel power:

$$RCS_{target}(m^2) = RCSSFPoly(xrow, ycol) * P_{peak}(xrow, ycol) \qquad \textbf{Equation 20}$$

The two-dimensional array containing the polynomial coefficients is formatted in KLV using MISB ST 1303 [7]. The MISB ST 1303 MDARRAY parameters for the RCS scale factor polynomial coefficients are:

MDARRY(Radar Cross Section Scale Factor Polynomial Coefficients (06.0E.2B.34.01.01.01.01.0E.01.01.03.3D.13.00.00), 2, $M+1$, $N+1$, IMAPB, 0, 1e6)

6.3 Metadata for SAR Coherent Change Products as SARMI

6.3.1 Reference Frame Precision Time Stamp

SAR coherent change product is formed from two complex SAR images collected at different periods of time. The process of forming a SAR coherent change product involves registering a complex SAR image to a reference complex SAR image collected at nearly the same geometry. Typically, the reference SAR image is collected earlier in time, but this need not be the case. Without loss of generality, assume the reference SAR image is collected at an earlier point in time as compared to the current SAR image.

In the optimal case where both SAR images are collected at the exact same geometry, coherence naturally degrades over time due to environmental effects such as wind or rain. Therefore, the elapsed time between the reference SAR image and the current SAR image is of particular interest to analysts. The reference frame time stamp provides the information necessary for analysts to calculate the time delta between SAR images utilized to create the SAR coherent change product.

The reference frame time is expressed as a precision time stamp defined in [5]. The reference frame precision time stamp is a critical metadata component for all SAR coherent change products as SARMI.

6.3.2 Reference Frame Grazing Angle

The reference frame grazing angle is defined as the angle between the line-of-sight vector from the SRP to the sensor and the ground plane at the SRP for the collected reference frame. The compliment for the current SAR image used in the creation of the SAR coherent change products is defined in 6.2.1.

6.3.3 Reference Frame Ground Plane Squint Angle

The reference frame squint angle may be expressed as the Doppler cone angle between the ground track vector and the radar's line-of-sight vector or as a ground squint angle, which is the corresponding angle projected onto the ground plane. Here, the ground plane is the geodetic plane orthogonal to the ellipsoid normal at the SRP of the reference plane although it may also

be defined as the geocentric plane. The compliment for the current SAR image used in the creation of the SAR coherent change products is defined in 6.2.2.

6.3.4 Reference Frame Range Direction Angle Relative to True North

The reference frame range direction angle relative to True North is the down range direction angle of the reference SAR image used in the creation of the SAR coherent change products. The compliment for the current SAR image used in the creation of the SAR coherent change products is defined in 6.2.8.

6.3.5 Reference Frame Range Layover Angle Relative to True North

The reference frame range layover angle relative to True North is the direction angle perpendicular to the sensor ground track angle at the aperture center of the reference SAR image used in the creation of the SAR coherent products. The compliment for the current SAR image used in the creation of the SAR coherent change products is defined in 6.2.10.

6.4 Metadata for SARMI Local Set

6.4.1 Document Version

The document version identifies the version of ST 1206 used in the implementation.

Requirement	
ST 1206-05	The SARMI Document Version shall be included in all SAR Motion Imagery Metadata Local Set instantiations.

7 Standards Support for SARMI Attributes

7.1 Feature Exploitation

The previous sections elaborate on basic metadata necessary for fundamental geospatial exploitation of SARMI data. There are more advanced geospatial exploitation applications that may be applied to SARMI data. SARMI may be exploited to exhibit temporal changes in amplitude that may indicate activity. Furthermore, coherent change products as SARMI data my exhibit tracklets that temporally create tracks, such as the entrance of a vehicle into the scene.

The Standards supporting these features already exist within the MISB domain. For signatures and tracks in SARMI, MISB ST 0903 [10] on Video Moving Target Indictors supports two-dimensional target chips and signature masks, as well as track attributes including the start and end times, location, velocity, and speed.

7.2 Simultaneous SARMI and GMTI

Some SARMI sensors have the capability to operate simultaneously in SAR/GMTI modes. This refers to a SAR sensor that has a constant PRF, whereby the same pulses transmitted and

received over the synthetic aperture are used to both process a SAR imagery frame and detect moving targets. Data collected for the SAR imagery may be partitioned into sub-apertures to meet the coherent processing interval requirements of the MTI modes. This does not refer to a system whereby SAR and GMTI pulses are interleaved, as the de-interleaved GMTI pulses may utilize different waveforms or waveform parameters than those used to create the SAR imagery.

Moving target detection is performed on the sequence of range-Doppler images processed from pulses along portions of the synthetic array. Each GMTI detection may be characterized by range, range-rate, cross-range angle (for multi-channel radars), RCS, and possibly other attributes of it response. These properties are typically the input state variables to a tracking algorithm, which provides the positions and the velocities of targets over multiple coherent processing intervals. The algorithm may also exploit features in target signatures for tracking high valued targets in heavily contested environments.

MISB ST 0903 handily supports this SAR/GMTI construct, as it permits the definition of sub-aperture start and end times for each target over a SARMI aperture. The modifications necessary to MISB ST 0903 include radar truncation packs that convey location measurements to each target within a MTI sub-aperture as well as a subset of the radar target metadata from Table 2-4.1 in NATO STANAG 4607 [11], such as range-rate and radar cross section to enable feature-aided tracking on the ground. The proposed metadata to be passed via these radar truncation pack structures are used in conjunction with the SARMI level parameters discussed within this Standard.