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SENSOR INDEPENDENT COMPLEX DATA (SICD)

Volume 1

Design & Implementation Description Document

Specification of the design of SICD data products
for SAR complex images.

(2011-09-28)

Version 1.0

NATIONAL CENTER FOR GEOSPATIAL INTELLIGENCE STANDARDS

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FOREWORD

The suite of Sensor Independent Complex Data (SICD) standardization documents describe the implementation of SICD products for complex image data generated by Synthetic Aperture Radar (SAR) systems and their data processing elements.

A SAR complex image is an intermediate data product. The real utility is in the products and measurements that may be derived from it. The quality of the pixel array (resolution, SNR, etc.), along with the set of metadata provided, are critical in generating the derived products. The "sensor independence" of the SICD product refers to the ability of the allowed pixel array and metadata options to accurately describe the image products from many sensors and data processing systems. Sensor independence does NOT mean that all products have the same format for the pixel array or the same set of metadata parameters.

The SICD documentation has been organized into three volumes and a set of XML implementation artifacts. The three volumes are summarized below. The collection of SICD XML artifacts includes the schema documents that define the correct implementation of the XML metadata document included in a given product.

Volume 1 Design & Implementation Description Document

Contains the description needed by producers of SAR complex image products to design a SICD product and the set of metadata that describe it.

Volume 2 File Format Description Document

Defines the placement of SICD data products in the allowed image file formats. Also provides the description needed by users of SICD products to read and properly extract the SICD data components from a SICD product file.

Volume 3 Image Projections Description Document

Describes the SICD sensor model and the correct projections from image location to ground point and from ground point to image location for all SICD products.

A companion suite of standardization documents, collectively known as Sensor Independent Derived Data (SIDD), describes standardized products and measurements that may be derived from SICD.

The SICD and SIDD documentation and associated XML artifacts are available on the National System for Geospatial-Intelligence (NSG) Standards Registry (https://nsgreg.nga.mil).

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1 Introduction

Synthetic Aperture Radar (SAR) systems are capable of high fidelity ground imaging using many types of platforms and a variety of radar technologies. The platforms carrying SAR systems range from low flying aircraft to earth orbiting satellites. The radar systems can operate in a wide range of collection geometries. The radar operating frequencies range from several hundred megahertz to tens of gigahertz. The SAR image resolution can vary from many meters to a fraction of a meter. The imaged area can vary in size from a fraction of a square kilometer to hundreds of square kilometers. The majority of SAR systems use a single radar platform to transmit and receive (monostatic imaging) although a relatively small number of systems use a pair of radar platforms operating as separate transmitter and passive receiver (bistatic imaging).

These systems all employ the fundamental SAR imaging principles. Resolution in range is achieved by controlling the bandwidth of the radar waveform. Resolution in cross range is achieved by coherently processing observations from a span of viewing angles to effectively synthesize an array with fine angular resolution. The range resolution (ΔR) is inversely proportional to the bandwidth (BW) of the radar waveform. The azimuth resolution (ΔA), expressed as a distance in cross range, is a function of the center frequency of the transmitted waveform (f_{CTR}) and the variation in viewing angle ($\Delta\theta$) to a given point being imaged. The basic expressions for ΔR and ΔA are given in the equations below.

$$\Delta R = \frac{c}{2 \bullet BW} \qquad \Delta A = \frac{c}{2 \bullet f_{CTR} \bullet \Delta\theta}$$

The majority of SAR imaging systems operate in one of two common SAR ground imaging modes. The first is known as Spotlight mode. In the Spotlight mode, the scene being imaged is illuminated throughout the collection period. The second is known as Stripmap mode. In the most common Stripmap mode, the scene being imaged is a strip of ground that is oriented parallel to the trajectory of the platform. The radar is controlled to illuminate the portion of the strip at broadside. Individual ground points are imaged as they pass through the radar beam. A more general form of the Stripmap mode allows for the strip being imaged to be at an arbitrary orientation relative to the ground track. The radar control required for this mode is more complex due to the dynamic nature of the radar imaging geometry. This more general form of stripmap mode is referred to as Dynamic Stripmap.

A Synthetic Aperture Radar (SAR) and its associated data processing systems are capable of producing many types of image products. The image formation processing exploits the coherent nature of the collected SAR signals to form the image. The initial image formed is usually a two-dimensional complex pixel grid that represents the radar reflectivity of the scene that was imaged. The complex pixel values contain information about both the amplitude and phase of the reflected radar signals. The mapping of the three-dimensional scene reflectivity to the two-dimensional image is a function of both the SAR imaging

geometry and the image formation processing. For most complex images, the spatial sampling of the image is closely related to the natural coordinates of the radar imaging geometry (for example, range and cross range).

The SAR complex images have great utility in that many other image products may be derived from them. The derived products include human viewable images that are accurately geo-located. The complex image retains information regarding the amplitude and phase of the scene reflectivity within the processed frequency band and the span of viewing angles. Many useful products that exploit the phase of the scene reflectivity may be derived from the complex image. For example, a pair of complex images taken at different times may be used to detect small scale changes in the scene that are not noticeable in the viewable products.

The Sensor Independent Complex Data (SICD) product has been developed to store and transmit complex image products from a wide range of SAR sensors and data processing systems. A SICD product contains the complex image pixel data and a set of metadata describing both the radar collection and the image formation processing. The SICD product accommodates images with the following attributes.

(1) Accommodates images from many sensors including both airborne and spaceborne SAR sensors. Full support for monostatic images and limited support for bistatic images.

(2) Support images collected with any of the common imaging modes including Spotlight mode, side looking Stripmap mode or Dynamic Stripmap.

(3) Support images formed using any image formation algorithm. Enable precise exploitation with images formed with the primary image formation algorithms.

(4) Enable products from new sensors to be readily understood and exploited using existing tools.

What Is Meant By "Sensor Independent" Complex Image Products?

A SAR complex image is an intermediate data product. The real utility is in the products and measurements that may be derived from it. The quality of the pixel array (resolution, SNR, etc.) along with the set of metadata provided are critical in generating the derived products. The "sensor independence" of the SICD product refers to the ability of the allowed pixel array and metadata options to accurately describe the image products from many sensors and data processing systems. Sensor independence does NOT mean that all products have the same format for the pixel array or the same set of metadata parameters.

The SICD product pixel array allows for only a limited number of pixel formats and pixel array orientations. The pixel format options allow for file size versus dynamic range to balanced while limiting the number of possibilities an exploitation application must be able to interpret. The orientation of the pixel array is also limited so that an exploitation application will not need to be capable of handling all possible orientations. Variety in the input array orientation does not add utility to any derived product.

All SICD products are supplied with metadata that may logically be divided into two types: (1) product identification parameters and (2) SAR science parameters. The product identification parameters identify the SAR platform that collected the image, the time and date of the collection, etc. The product identification parameters may also include parameters related to the tasking request that initiated the collection. The SAR science parameters are those used to describe the collection and processing of the complex image. In general, the SAR science parameters are those used along with the image pixel array to produce the derived data products.

The product identification parameters are grouped as a single block within the metadata structure. The product identification parameters include a minimal set of required "text-based" fields. Optional fields may also be included that are needed by the systems that store and disseminate the image products. The product identification parameters are NOT sensor independent. Product identification parameters (both the number and their definition) are ALWAYS specific to the SAR sensor and the tasking, processing and product dissemination systems. They are, however, readily identified in all products independent of the SAR system that produced the product.

The SAR science parameters provided with an image are also dependent on the SAR system that produced the image (i.e. both the SAR sensor and the image formation processor). The SAR science parameters include required data blocks and may also include a number of optional data blocks. The required blocks are common to all images and are needed for fundamental exploitation. For advanced SAR systems, many additional parameters may be provided via the optional data blocks. The optional parameters, when available, allow for the full exploitation of a well-calibrated SAR sensor/image formation processing system.

The SICD products are "sensor independent" in that SAR science parameters are selected from an independent set of parameters. Parameter definitions are independent of both the sensor and the image formation processor. Sensor independence means that a parameter has the same definition for all sensors and processing systems that choose to include it.

SICD Design Documents

The SICD product design description documents are contained in this and several other documents. The set of additional documents is listed in Table 1-1.

Table 1-1 Applicable Documents

Number	Title	Date
---	Sensor Independent Complex Data, Volume 2, File Format Description Document, V1.0	22 April 2011
---	SICD_schema_V1.0.1_2013_02_25.xsd	25 February 2013

1.1 Product Design & Definition

A SICD product contains a single SAR complex image and a set of metadata that describes how the data was collected, how the data was processed and the parameters needed for exploitation. The image data is a single two-dimensional grid of complex valued pixels. The image data has been processed such that the fundamental 2-dimensional impulse response varies smoothly across the image. Such an image will have a smoothly varying amplitude and phase response across the image prior to any spatially variant image-based processing that may be applied (e.g. image patch-based focus corrections).

A SAR imaging collection may be characterized across multiple dimensions. The dimensions include the time span of the collection, the collected RF bandwidth and the dimensions of the area that was imaged. Additionally, a particular platform may simultaneously collect multiple radar channels (e.g. multiple polarizations). A SICD product will contain only a single image. Multiple images from the same collection are placed in separate SICD products. The SICD metadata will describe the image data contained in the product with respect to which radar channel, the portion of the collection time that was processed and the portion of the RF bandwidth that was processed. Optional metadata may be included to also describe the entire collection (all channels collected, total area imaged, etc.).

The SICD product definition for a particular SAR sensor and data processing system starts with an assessment of the collection types, collection modes and image formation processing algorithms used to produce the complex image products. Also to be considered are the derived image products to be produced and the types of exploitation to be supported. From these considerations, a set of metadata parameters are selected from the available SICD metadata parameters. This set of metadata parameters is referred to as a metadata profile. The metadata profile includes both the product identification parameters and the SAR science parameters. The metadata profile will include all required parameters, conditional parameters (as appropriate) and the optional parameters that may apply.

1.2 SICD Data Components

A SICD product consists of a pair of data components. The first component is a block of complex image pixel data. The image pixel block is described in Sections 1.2.1 and 1.2.2 below. The second component is a block of metadata expressed using the eXtensible Markup Language (XML), Version 1.0. The metadata contains the selected set of parameters that describe the imaging collection and the data processing that formed the image. A description of the XML implementation and a complete list of metadata parameters is contained in Sections 2, 3 and 4 below. The precise XML implementation is defined in the SICD XML Schema.

1.2.1 Image Pixel Array

The SICD image pixel data block is a single two-dimensional array of complex numbers. The image pixel array contains NumRows rows by NumCols columns. The SICD image array size limits have not been established. The following are estimated values that are not expected to be exceeded in any current or foreseeable products.

NumRows:	1 to 1,000,000
NumCols:	1 to 1,000,000
Number of Pixels:	1 to 100,000,000,000 (e.g. 100,000 x 1,000,000)

The SICD image pixel data may be stored in one of three allowed formats. The selected pixel format is specified by parameter PixelType. The allowed pixel types are as follows.

PixelType = RE32F_IM32F

Each pixel is stored as a pair of numbers that represent the real and imaginary components. Each component is stored in a 32-bit IEEE floating point format (4 bytes per component, 8 bytes per pixel).

PixelType = RE16I_IM16I

Each pixel is stored as a pair of numbers that represent the real and imaginary components. Each component is stored in a 16-bit signed integer in 2's complement format (2 bytes per component, 4 bytes per pixel).

PixelType = AMP8I_PHS8I

Each pixel is stored as a pair of numbers that represent the amplitude and phase components. Each component is stored in an 8-bit unsigned integer (1 byte per component, 2 bytes per pixel).

The real and imaginary or amplitude and phase components of a given pixel are interleaved such that they are stored in adjacent bytes. For real and imaginary components, the real component is stored first. For amplitude and phase components, the amplitude component is stored first. For a given image, all pixels are stored in the same pixel format. The binary numbers are stored with the Most Significant Byte (MSB) first (referred to as "Big Endian"). The Big Endian byte order is required for placement in a NITF 2.1 container file.

The size of the image pixel array is determined as follows. The number of bytes per pixel is denoted by parameter BytesPerPixel (where BytesPerPixel = 2, 4 or 8). The adjacent pixels within a row are stored in adjacent bytes within the file. The NumCols pixels of the first row in the image array are stored in the first bytes in the file. The total size of the image array is as follows.

$$\text{Pixel Array Size (bytes)} = \text{Bytes_Per_Pixel} \bullet \text{NumCols} \bullet \text{NumRows}$$

1.2.2 Image Arrays: Full Image & Sub-Image

The image pixel array contained in a SICD product may be the initial image array as produced by the image formation processing system or a sub-image extracted from the initial image. The initial image is referred to as the "full image". A sub-image, sometimes referred to as an "image chip", is a single two-dimensional portion of the full image. The full image pixel array is NumRowsFI rows by NumColsFI columns. An example full image array is shown in Figure 1.2-1. The rows of the full image pixel array are indexed as follows.

Full image row index: row = 0, 1, 2, . . . , NumRowsFI – 1.

Full image column index: col = 0, 1, 2, . . . , NumColsFI – 1.

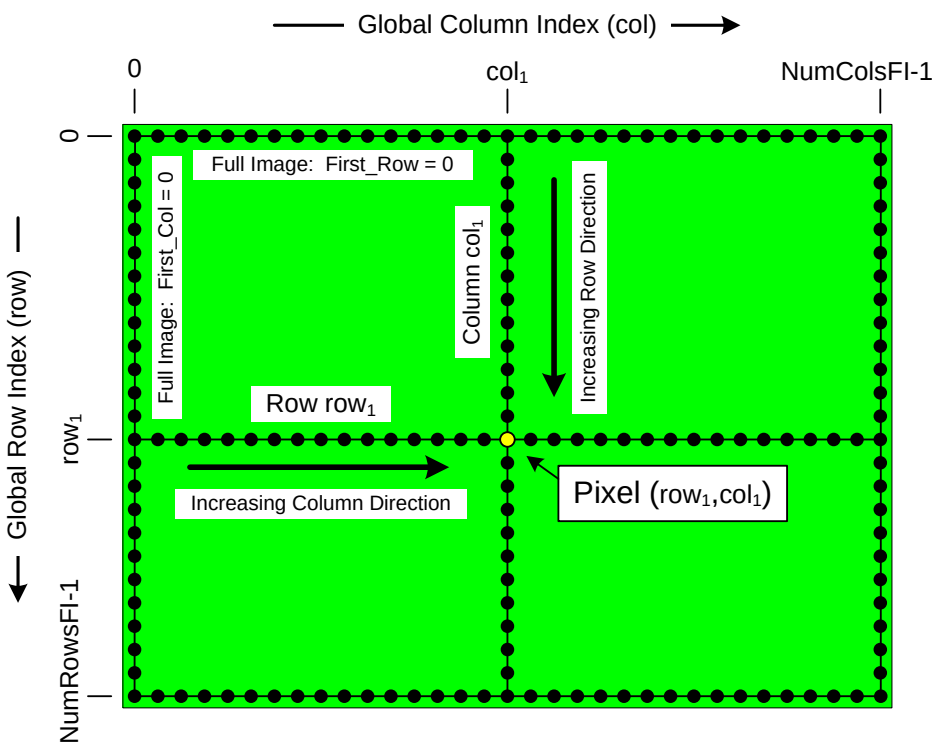


Figure 1.2-1 Full Image Pixel Array

Global image indices (row, col) address the elements of the pixel array.

Image pixel indices (row, col) are referred to as the "global" image indices. The first row of the full image is indexed row = 0. The first column of the full image is indexed col = 0. Parameters NumRowsFI and NumColsFI are contained in the XML metadata for all image products.

Image size parameters NumRows and NumCols always denote the size of the image pixel array contained in the product file. The correct exploitation of a sub-image is dependent upon the relative position of the sub-image within the full image array. An example sub-image array and the full image array from which it was extracted are shown in Figure 1.2-2. The first row of the sub-image (indexed $row_S = 0$) is extracted from row = FirstRow of the full image. The first column of the sub-image (indexed $col_S = 0$) is extracted from col = FirstCol of the full image. FirstRow and FirstCol are contained in the XML metadata for all image products. For a full image product, parameters FirstRow = 0 and FirstCol = 0.

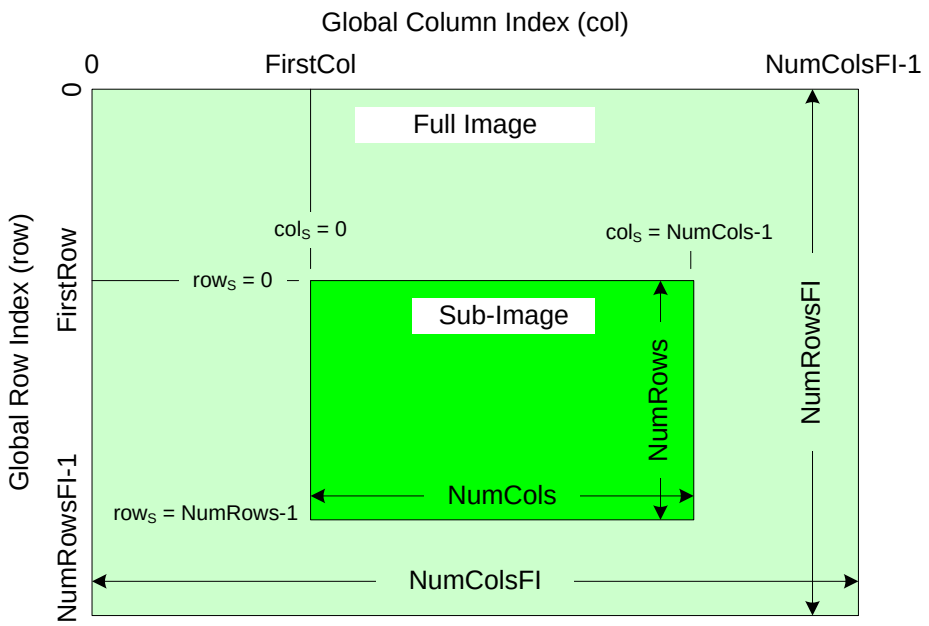


Figure 1.2-2 Full Image & Sub-Image Pixel Arrays

The sub-image pixel array relative position in the full image array is given by parameters FirstRow and FirstCol.

1.3 Container File Formats

A single container file format has been selected for SICD product files. The format is the National Imagery Transmission Format, Version 2.1 (referred to as NITF 2.1). The NITF 2.1 standard is described in MIL-STD-2500C, National Imagery Transmission Format, Version 2.1, dated 01 May 2006. A detailed description of the SICD data component placement into the NITF 2.1 file components is provided in the Sensor Independent Complex Data File Format Description Document. See Table 1-1 above. This document contains the description needed by the producers of SICD products to properly place the SICD data components into the product file. It also contains the description needed by users of SICD products to read and properly extract the SICD data components from the product file.

The mapping of SICD data components to NITF 2.1 file components is shown in Figure 1.3-1. The example shows a product file with the image pixel array stored in two Image Segments. The parameters contained in the XML data are used to populate fields in the File Header, the Image Sub-Headers and the DES Sub-Header.

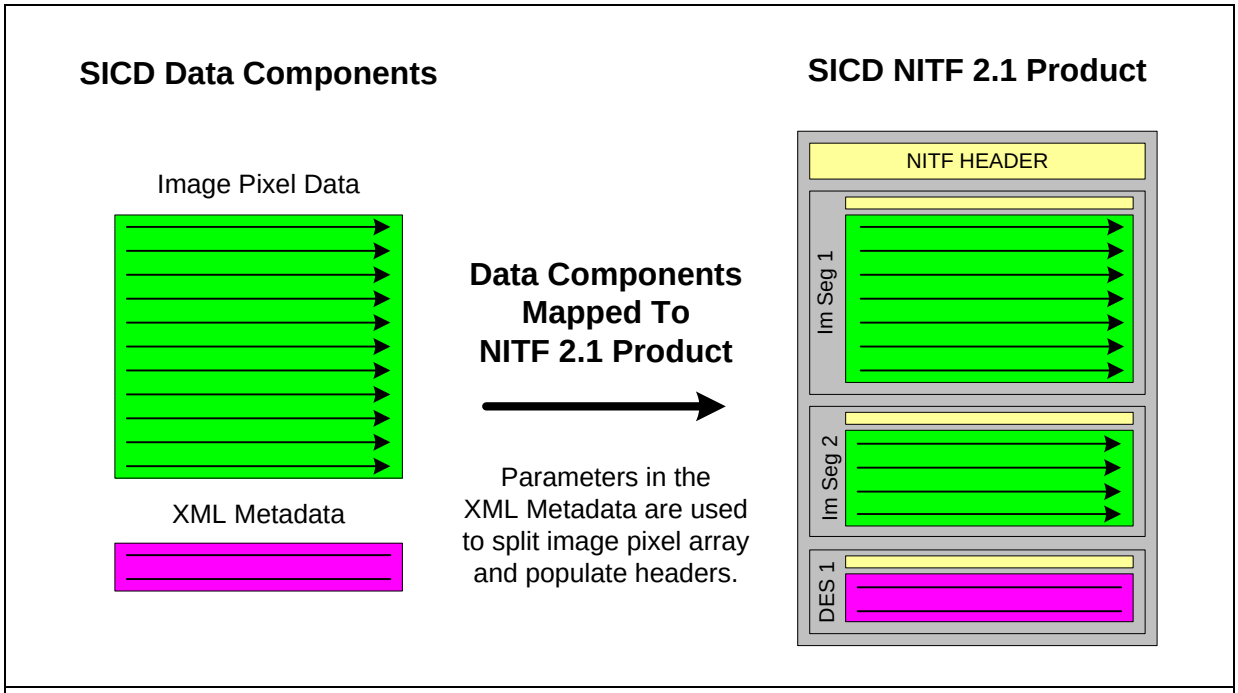


Figure 1.3-1 SICD NITF 2.1 Product
SICD data components mapped to NITF 2.1 file components.

1.4 Program Specific Implementation Documentation

For the SAR sensor and data processing system that will generate SICD products, a Program Specific Implementation Document should be developed to document the selected metadata profile. The implementation document will serve as a guide for those developing the products as well as for users of the products. The metadata profile will specify the product identification parameters as well as the selected SAR science parameters.

The SICD implementation document should address a number of implementation specific items. This list below is provided as a guide for developing implementation documents.

(1) Identify the SAR platforms for which the image products will be produced and a brief description of their attributes. The description may include imaging modes, number of collected channels, etc.

(2) Identify the Image Formation Algorithms (IFAs) that are used to produce the products. Proper exploitation is highly dependent upon the IFA used to produce the image.

(3) Specify the product identification metadata parameters to be included and the guidance for each parameter. Product identification parameters are selected from the Collection & Image Creation Information Parameters. See Table 3-1.

(4) Specify product file naming conventions. Product file names will usually identify the SAR platform and the specific imaging collection. For collections with multiple receive channels, the channel(s) used to form the image may also be identified.

(5) Specify the implementation specific values for the header and sub-headers of the SICD container file. These parameters are explicitly identified in the SICD File Format Description Document. See Table 1-1 above.

(6) Specify the set of SAR science parameters that are included. Parameters that will only be included in some products should be identified and the criteria for including them (e.g. for a particular collection mode or IFA).

(7) For products that use a reference frequency when specifying frequency values, the values of the reference frequency indices and the reference frequencies should be specified. See Table 3-7 below.

(8) If the Matched Collection Parameters block is to be included, the types of matched collections to be identified are selected. The criteria for match selection and the optional match parameters to be included (if any) are specified. See Table 3-13 below.

2 SICD XML Metadata

2.1 XML Metadata Structure

2.1.1 Field Name

The "Field Name" column lists the whole path to a particular field in the XML metadata tree. The tree structure is denoted "xxx.yyy.zzz" where "xxx" is the parent tag of "yyy" and "yyy" is the parent tag of "zzz". A particular child tag is only valid if it has been placed in the proper location within the parent tag. For every instance of a tag in the file, there will also be an instance of its child tags. Below is an XML example of "xxx.yyy.zzz". Note: zzz holds a double value in the example below.

```
<xxx>
    <yyy>
        <zzz>3.14159</zzz>
    </yyy>
</xxx>
```

2.1.2 Required vs. Optional

The Required / Optional (Req / Opt) column outlines the usage rules of a particular field. There are three options: "R", "O", and "C". The "R" value means that the field must appear in the XML tree. The "O" value means that the field is optional. The "C" value means the field is conditional and is only included based upon the values of other fields. There is one more caveat to the rules for this column usage. If a tag is marked as "R" and its parent tag is marked as "O" or "C", then the tag is only required if its parent tag is included.

2.1.3 Types

The "Type" column defines the XML Type of parameter contained in a particular field. The parameter types are listed in Table 2-1.

Table 2-1 XML Parameter Types

Type	Meaning	Example XML Parameter
TXT	Value is a string of characters	Field: SICD.CollectionInfo.CollectorName Value: "SARPlatformIdentifier"
ENU	Value can be a string of characters or an integer. There is a certain allowed set of character strings or integer values.	Field: SICD.CollectionInfo.CollectType Value: (must be 1 of the 2 below) "MONOSTATIC" or "BISTATIC"
BOOL	Value is a Boolean type. The Boolean type is used to specify true or false.	Field: SICD.PFA.Comp.Applied Value: "false"
INT	Value is an integer. It may be a positive or negative value with an optional positive sign ("+") when positive.	Field: SICD.ImageData.NumRows Value: 1000

DBL	Value is a floating point number. An IEEE double precision (64bit) floating point type. It may be a positive or negative value with an optional positive sign ("+") when positive. The value is represented in the scientific notation (The E notation) with 16 digits of precision. a * 10^b = a.000000000000000Eb The coefficient *a* is any real number (called the mantissa) and exponent *b* is an integer.	CollectDuration is: 0.44444 seconds Field: SICD.Timeline.CollectDuration Value: 4.444400000000000E-01
XDT	Value represents the dateTime XML type. The dateTime form is: "YYYY-MM-DDThh:mm:ss.s+" • YYYY indicates the year • MM indicates the month • DD indicates the day • "T" indicates the start of the required time section • hh indicates hour • mm indicates minute • ss indicates second • s+ indicates fractional seconds * The seconds should be followed by a Z to indicate the time is in UTC (Coordinated Universal Time) *All components are required.	Field: SICD.ImageCreation.DateTime Value: 2008-08-06T20:27:55.123456Z
RC	Identifies a parent tag that consists of a required row and column component. The values of each component are integers, "INT". • "Row" represents row • "Col" represents column	Field: SICD.ImageData.SCPPixel.Row Value: 500 Field: SICD.ImageData.SCPPixel.Col Value: 500
CMPLX	Identifies a parent tag that consists of a required real and imaginary component. The values of each component are floating point type, "DBL". • "Real" represents the real part. • "Imag" represents the imaginary part.	Field: SICD.ImageFormation.PolarizationCalibration.Distortion.F1.Real Value: 1.050000000000000E00 Field: SICD.ImageFormation.PolarizationCalibration.Distortion.F1.Imag Value: 8.010000000000000E-01
XYZ	Identifies a parent tag that consists of a x, y and z component. The values of each component are floating point type, "DBL". • "X" represents the x component • "Y" represents the y component	Field: SICD.Grid.Row.UVectECF.X Value: 4.444400000000000E01 Field: SICD.Grid.Row.UVectECF.Y Value: 4.444400000000000E01 Field: SICD.Grid.Row.UVectECF.Z

	• "Z" represents the z component	Value: 4.444400000000000E01
LLH	Identifies a parent tag that consists of a geodetic latitude, longitude and height above ellipsoid component. The values of each component are floating point type, "DBL". • "Lat" represents the latitude point • "Lon" represents the longitude point • "HAE" represents the height point	Field: SICD.GeoData.SCP.LLH.Lat Value: 4.444400000000000E01 Field: SICD.GeoData.SCP.LLH.Lon Value: 4.444400000000000E01 Field: SICD.GeoData.SCP.LLH.HAE Value: 4.444400000000000E01
LL	Identifies a parent tag that consists of a geodetic latitude and longitude component. The values of each component are floating point type, "DBL". • "Lat" represents the latitude point • "Lon" represents the longitude point	Field: SICD.GeoData.ImageCorners.ICP.Lat Attribute: "index = 1:FRFC" Value: 4.444400000000000E01 Field: SICD.GeoData.ImageCorners.ICP.Lon Attribute: "index = 1:FRFC" Value: 4.444400000000000E01
POLY	Identifies a parent tag that consists of a set of coefficients for a one-dimensional polynomial function. The values of each component are floating point type, "DBL". • "Coef" represents a coefficient A one-dimensional polynomial input variable 1 (Var1). Variable 1 of order1=M, where M equals the maximum value of the exponent1 attribute. The parent tag POLY will have an order1 attribute. Each component "Coef" will have an exponent1 attribute. The attribute represents the exponents of that coefficient. Zero coefficients may be omitted. Total number of possible coefficients is: (M + 1) $Z(Var1) = \sum_{m=0}^{M} c_m \bullet (Var1)^m$	M = 2 Parent Tag: SICD.Timeline.IPP.Set.IPPPoly Attribute: "order1 = 2" Field: SICD.Timeline.IPP.Set.IPPPoly.Coef Attribute "exponent1 = 0" Value: 4.444400000000000E01 Field: SICD.Timeline.IPP.Set.IPPPoly.Coef Attribute "exponent1 = 1" Value: 4.444400000000000E01 Field: SICD.Timeline.IPP.Set.IPPPoly.Coef Attribute "exponent1 = 2" Value: 4.444400000000000E01

2D_POLY	Identifies a parent tag that consists of a set of coefficients for a two-dimensional polynomial function. The values of each component are floating point type, “DBL”. • “Coef” represents a coefficient Two-dimensional polynomial inputs variable 1 (Var1) and variable 2 (Var2). Variable 1 of order1= M, where M equals the maximum value of the exponent1 attribute. Variable 2 of order2= N, where N equals the maximum value of the exponent2 attribute. The parent tag POLY will have an order1 and order2 attribute. Each component “Coef” will have an exponent1 and exponent2 attribute. The attributes represent the exponents of that coefficient. Total number of possible coefficients is: (M + 1) * (N + 1) $Z(Var1, Var2) = \sum_{m=0}^{M}\sum_{n=0}^{N} c_{m,n} \bullet (Var1)^{m} \bullet (Var2)^{n}$ *If a coefficient has a zero value it may be omitted.	M = 2 and N = 1 Parent Tag: SICD.Grid.TimeCOAPoly Attribute: “order1 = 2”, “order2 = 1” Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 0” “exponent2 = 0” Value: 4.444400000000000E01 Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 0” “exponent2 = 1” Value: 4.444400000000000E01 Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 1” “exponent2 = 0” Value: 4.444400000000000E01 Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 1” “exponent2 = 1” Value: 4.444400000000000E01 Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 2” “exponent2 = 0” Value: 4.444400000000000E01 Field: SICD.Grid.TimeCOAPoly.Coef Attribute: “exponent1 = 2” “exponent2 = 1” Value: 4.444400000000000E01
XYZ_POLY	Identifies a parent tag that consists of a x, y and z component. Each component is a POLY type. Each parent tag, X,Y,Z will have the order1 attribute. Each component “Coef” will have the exponent1 attribute.	M = 1 Parent tag: SICD.Position.GRPPoly.X Parent tag: SICD.Position.GRPPoly.Y Parent tag: SICD.Position.GRPPoly.Z All have an attribute: “order1=1” Field: SICD.Position.GRPPoly.X.Coef Attribute: “exponent1 = 0”

	• "X.Coef" represents a x component coefficient • "Y.Coef" represents a y component coefficient • "Z.Coef" represents a z component coefficient A one-dimensional polynomials with same input variable 1 (Var1). Total number of possible coefficients is: 3 x (M + 1) . $\mathbf{V}(\text{Var1}) = \begin{bmatrix} X(\text{Var1}) \\ Y(\text{Var1}) \\ Z(\text{Var1}) \end{bmatrix} = \begin{bmatrix} \sum_{m=0}^{M} cx_m \bullet (\text{Var1})^m \\ \sum_{m=0}^{M} cy_m \bullet (\text{Var1})^m \\ \sum_{m=0}^{M} cz_m \bullet (\text{Var1})^m \end{bmatrix}$ *If a coefficient has a zero value it may be omitted.	Value: 4.444400000000000E01 Field: SICD.Position.GRPPoly.X.Coef Attribute: "exponent1 = 1" Value: 4.444400000000000E01 Field: SICD.Position.GRPPoly.Y.Coef Attribute: "exponent1 = 0" Value: 4.444400000000000E01 Field: SICD.Position.GRPPoly.Y.Coef Attribute: "exponent1 = 1" Value: 4.444400000000000E01 Field: SICD.Position.GRPPoly.Z.Coef Attribute: "exponent1 = 0" Value: 4.444400000000000E01 Field: SICD.Position.GRPPoly.Z.Coef Attribute: "exponent1 = 1" Value: 4.444400000000000E01

2.1.4 Description

The "Description" column explains the meaning of a particular field or block. A block groups its following fields under the same section. An example is parameter SICD.SCP (See Table 3-3). The fields ECF and LLH represent the earth center fixed and geodetic coordinates of the Scene Center Point.

- SICD.GeoData.SCP → Is a Block
- SICD.GeoData.SCP.ECF → ECF is a parameter under the SCP, representing SCP information
- SICD.GeoData.SCP.LLH → LLH is a parameter under the SCP, representing SCP information.

2.1.5 Units

The "Units" column defines the measurement units assigned to a particular field. Units are seconds (sec), meters (m), seconds per meter (sec/m), meters per second (m/sec), Hertz (Hz), Hertz per second (Hz/sec), degrees (deg), decimal degrees (dd), cycles (cyc), cycles per meter (cyc/m), cycles per meter squared (cyc/m**2, etc), radians (rad), radians per second (rad/sec), radians per second squared (rad/sec**2, etc), samples per second (samples/sec) and decibel (dB).

2.1.6 Rpt

The “Repeatable” column indicates if a tag may be repeated. There are two values: “Y” and “N”. “Y” means that a tag may appear more than once and “N” means that a tag may appear only once.

2.1.7 Attribute

The “Attribute” column is used to associate name=value pairs with elements. It is part of an element and provides additional information about that element. There are several different types of attributes. SICD is using the Enumeration and ID type. Enumeration type allows a specific list of values that the attribute must match. The values are listed in the table along with the attribute. ID type allows a unique identifier for each element. The identifier being used can either have an integer dataType or a string dataType. The string dataType allows a user to add sensor specific metadata parameters. The allowed values and ranges for the specified parameter are also defined in this column

The attributes that are Enumeration Type from the Attribute column in Tables 3-1 through 3-15:

- index = “1:FRFC”, …, “4:LRLC”

The attributes that are ID types from the Attribute column in Tables 3-1 through 3-15:

- name = “xxx” , string
- index = “x”, integer
- size= “x”, integer
- order1 = “M”, integer
- order2 = “N”, integer
- exponent1= “0 to M”
- exponent2= “0 to N”

Example XML of Attributes “size” and “index”

Field: SICD.Grid.Row.WgtFunct.Wgt, Attribute: size= “x” and index=“x”

```
<WgtFunct size=“4”>
    <Wgt index= “1”> value here </Wgt>
    <Wgt index= “2”> value here </Wgt>
    <Wgt index= “3”> value here </Wgt>
    <Wgt index= “4”> value here </Wgt>
</WgtFunct>
```

3 XML Metadata Parameter List

The SICD metadata parameters are divided into blocks of related parameters. Blocks are marked as Required, Optional or Conditional. Required blocks may contain both optional and conditional parameters. Some blocks contain fields that permit sensor specific parameter additions called Parameters.

3.1 XML Metadata Block Summary

(1) Collection & Image Creation Information Required

Parameters that identify the collection including specific platform(s) and imaging collection. Includes product classification and release parameters as applicable. See parameters listed in Table 3-1.

(2) Image Data Parameters Required

Parameters that describe the image pixel array. Includes the dimensions of the image pixel array in the product, the original full image pixel array and areas of zero-filled pixels if applicable. See parameters listed in Table 3-2.

(3) Image Geographic Reference Parameters Required

Parameters that describe the geographic coordinates of the region covered by the image. Geographic coordinates are of the SCP (Scene Center Point) and the image corner points are included. See parameters listed in Table 3-3.

(4) Image Grid Parameters Required

Parameters that describe the spatial sampling represented by the sample grid. Includes the type of sample grid, the sample spacings and resolutions. Includes parameters describing the two-dimensional spatial frequency domain. See parameters listed in Table 3-4.

(5) Collection Timeline Parameters Required

Parameters that describe the imaging collection timeline. Includes the collection start time, collection duration and the radar pulse repetition interval / inter-pulse period parameters. See parameters listed in Table 3-5.

(6) Reference Position Parameters Required

Parameters that describe the platform and ground reference positions in ECF coordinates versus time. Includes the effective Aperture Reference Point position and the Ground

Reference Point position. The individual transmit and receive phase center positions are optional parameters. See parameters listed in Table 3-6.

(7) Radar Collection Parameters Required

Parameters that describe the radar collection including area covered by the collection and the finest SAR resolutions that may be achieved. Transmitted waveform parameters include the transmitted bandwidth and polarization(s). Receive parameters include the number of channels and the polarization(s). Transmitted frequency values may be expressed as offsets from a reference frequency. See parameters listed in Table 3-7.

(8) Image Formation Parameters Required

Parameters that describe the image formation processing parameters that produced the image. Parameters indicate which receive channel(s) were processed. Parameters describe the portion of the collection time and bandwidth processed. See parameters listed in Table 3-8.

(9) SCP Center Of Aperture Parameters Required

Parameters that describe the Center of Aperture time and collection geometry for the Scene Center Point (SCP). Parameters include the ARP position and velocity, the imaging side of track and range to the SCP. Parameters provided to support search and discovery. See parameters listed in Table 3-9.

(10) Radiometric Parameters Optional

Parameters that enable the conversion of pixel power level to radar reflectivity parameters. Parameters may be included to convert pixel power to common clutter reflectivity parameters (such as σ_0) or point target radar cross section. See parameters listed in Table 3-10.

(11) Antenna Parameters Optional

Parameters that describe the transmit and receive antenna patterns. An option is also included to describe an effective two-way antenna for monostatic operation. Parameters include antenna orientation, mainlobe pointing and beam shape as a function of time. See parameters listed in Table 3-11.

(12) Error Estimation Parameters Optional

Parameters that describe the errors in radar collection parameters (e.g. position and velocity) that allow estimation of image geolocation parameters. See parameters listed in Table 3-12.

(13) Collection Match Parameters Optional

Parameters that describe other known collections that are matched to the collection from which this image was produced. See parameters listed in Table 3-13.

(14) Range & Azimuth Compression Parameters Conditional

Parameters that describe the images formed using simple Range & Azimuth Compression – the simplest image formation algorithm. The resulting image is a simple range, Doppler image. See parameters listed in Table 3-14.

(15) Polar Format Algorithm Parameters Conditional

Parameters that describe the image formation processing for images formed using the Polar Format Algorithm. Parameters include the image formation plane used, the focus plane used, the mapping of platform position to polar angle, and transmitted frequency to aperture frequency scale factors. See parameters listed in Table 3-15.

(16) Range Migration Algorithm Parameters Conditional

Parameters that describe the image formation processing for images formed with any one of several Range Migration Algorithms. Parameters include the reference slant plane and portion of the spatial frequency domain processed. Parameters commonly used for imaging near closest approach may be used when applicable. See parameters listed in Table 3-16.

3.2 XML Metadata Parameter Lists

Table 3-1 Collection & Image Creation Information Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD				-		
CollectionInfo	R		This block contains general information about the collection.	-	N	
CollectorName	R	TXT	Radar platform identifier. For Bistatic collections, list the Receive platform.	-	N	
IlluminatorName	O	TXT	Radar platform identifier that provided the illumination. For Bistatic collections, list the transmit platform.	-	N	
CoreName	R	TXT	Collection & imaging data set identifier. Uniquely identifies imaging collections per Program Specific Implementation Doc.	-	N	
CollectType	O	ENU	Collection type identifier. Monostatic collections include single platform collections with unique transmit and receive apertures.	-	N	Allowed values: “MONOSTATIC”, “BISTATIC”.
RadarMode	R			-	N	
ModeType	R	ENU	Radar imaging mode.	-	N	Allowed Values: “SPOTLIGHT”, “STRIPMAP”, “DYNAMIC STRIPMAP”.
ModeID	O	TXT	Radar imaging mode per Program Specific Implementation Document.	-	N	
Classification	R	TXT	Contains the human-readable banner. Contains classification, file control & handling, file releasing, and/or proprietary markings. Specified per Program Specific Implementation Document.	-	N	Default value: “UNCLASSIFIED”

Table 3-1 Collection & Image Creation Information Parameters							
Field Name			Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
		CountryCode	O	TXT	List of country codes for region covered by the image.	-	Y	
		Parameter	O	TXT	Free format field that can be used to pass forward the radar collection information.	~	Y	name = "xxx", name is a descriptive identifier for this information
SICD								
	ImageCreation		O		This block contains general information about the image creation.		N	
		Application	O	TXT	Name and version of the application used to create the image.	-	N	
		DateTime	O	XDT	Date and time the image creation application processed the image (UTC).	-	N	
		Site	O	TXT	The creation site of this SICD product	-	N	
		Profile	O	TXT	Identifies what profile was used to create this SICD product.	-	N	

Table 3-2 Image Data Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
ImageData	R		This block describes image pixel data	-	N	
PixelType	R	ENU	Indicates the pixel type and binary format of the data. PixelType = “RE32F_IM32F”: - Real & Imaginary components. Each component a 32 bit IEEE FP. PixelType = “RE16I_IM16I”: - Real & Imaginary components. Each component a 16 bit signed integer, 2’s complement. PixelType = “AMP8I_PHS8I”: - Amplitude & Phase components. Each component an 8 bit unsigned integer.	-	N	Allowed values: “RE32F_IM32F”, “RE16I_IM16I” or “AMP8I_PHS8I”
AmpTable	O		Amplitude lookup table for PixelType = “AMP8I_PHS8I”. Attribute “size” equals the number of amplitude entries (always equal to 256).	-	N	size = “256”
Amplitude	R	DBL	Amplitude table entries. Values indexed by n = 0, 1, 2, . . ., 255.	-	Y	index = “0” to “255”
NumRows	R	INT	Number of rows in the product. Includes zero filled pixels (if present).	-	N	
NumCols	R	INT	Number of columns in the product. Includes zero filled pixels (if present).	-	N	
FirstRow	R	INT	Global row index of the first row in the product (non-negative integer value). Set equal to 0 in full image product.	-	N	
FirstCol	R	INT	Global column index of the first column	-	N	

Table 3-2 Image Data Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
			in the product. Non-negative integer value. Set equal to 0 in the full image product.			
FullImage	R		Original full image product	-	N	
NumRows	R	INT	Number of rows in the original full image product. Includes zero filled pixels (if present).	-	N	
NumCols	R	INT	Number of columns in the original full image product. Includes zero filled pixels (if present).	-	N	
SCPPixel	R	RC	Scene Center Point pixel global row & column index. Located near the center of the full image.	-	N	
ValidData	O		Indicates the full image includes both valid data and some zero filled pixels. Simple polygon encloses the valid data (may include some zero filled pixels for simplification). Vertices in clockwise order. Attribute “size” = NumVertices. NumVertices $\geq$ 3.	-	N	size =”x”
Vertex	R	RC	Polygon vertex pixel global row & column index. Vertices indexed n = 1, 2, . . ., NumVertices. Vertex 1 determined by: (1) minimum row index, (2) minimum column index if 2 vertices with minimum row index. 1st and last vertices of polygon connect.	-	Y	index = “1” to “x”

Table 3-3 Image Geographic Reference Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
GeoData	R		This block describes the geographic coordinates of the region covered by the image.	-	N	
EarthModel	R	ENU	Identifies the earth model used for latitude, longitude and height parameters. All height values are Height Above The Ellipsoid (HAE).	-	N	Allowed Values: “WGS_84”
SCP	R		Scene Center Point (SCP) in full (global) image. This is the precise location	-	N	
ECF	R	XYZ	Scene Center Point position in ECF coordinates.	m	N	
LLH	R	LLH	Scene Center Point geodetic latitude, longitude and height. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd dd m	N	
ImageCorners	R		Image corners points projected to the ground/surface level. Points may be projected to the same height as the SCP if ground/surface height data is not available. The corner positions are approximate geographic locations and not intended for analytical use.	-	N	
ICP	R	LL	Image Corner Point (ICP) data for the 4 corners in product. ICPs indexed x = 1, 2, 3, 4, clockwise. x = 1 ⇔ First row, First column x = 2 ⇔ First row, Last column x = 3 ⇔ Last row, Last column x = 4 ⇔ Last row, First column	dd	Y	index = “1:FRFC” or “2:FRLC” or “3:LRLC” or “4:LRFC”

Table 3-3 Image Geographic Reference Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
ValidData	O		Indicates the full image includes both valid data and some zero filled pixels. Attribute “size” = NumVertices. Include with SICD.ImageData.ValidData.	-	N	size =”x”
Vertex	R	LL	Valid data points projected to the ground/surface level. Points may be projected to the same height as the SCP if ground/surface height data is not available. The vertex positions are approximate geographic locations and not intended for analytical use. Vertices indexed n = 1, 2, . . ., NumVertices. Vertices in same order as SICD.ImageData.ValidData.Vertex. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0		Y	index = “1” to “x”
GeoInfo	O		Parameters describing geographic features. Note: The GeoInfo block may be used as a block within itself.	-	Y	name = "xxx", name is a descriptive identifier for this information
Desc	O	TXT	Used to specify a name and description of a geographic feature.	-	Y	name = "xxx", name is a descriptive identifier for this information
Point	O	LL	Used to specify a single point. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd	N	
Line	O		Used to specify a “linear” feature with connected line segments. The size attribute represents the number or endpoints (NumEndpoints)	-	N	size = “x”
Endpoint	R	LL	Line segment endpoints indexed x = 1, 2, .., NumEndpoints. NumEndpoints ≥ 2.	dd	Y	index = “x”

Table 3-3 Image Geographic Reference Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
Polygon	O		Used to specify an area with a polygon. The size attribute represents the number or endpoints (NumEndpoints)	-	N	size = “x”
Vertex	R	LL	Polygon vertices indexed clockwise x = 1, 2, . , NumVertices. NumVertices $\geq$ 3. 1st and last vertices of polygon connect. -90.0 $\leq$ Lat $\leq$ 90.0, -180.0 $\leq$ Lon $\leq$ 180.0	dd	Y	index = “x”

Table 3-4 Image Grid Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
Grid	R		This block of parameters describes the image sample grid.	-	N	
ImagePlane	R	ENU	Defines the type of image plane that the best describes the sample grid. Precise plane defined by Row Direction and Column Direction unit vectors.	-	N	Allowed values: “GROUND”, “SLANT”, and “OTHER”.
Type	R	ENU	Defines the type of spatial sampling grid represented by the image sample grid. Row coordinate first, column coordinate second. RGAZIM: Grid for a simple range, Doppler image. Also, the natural grid for images formed with the Polar Format Algorithm. RGZERO: A grid for images formed with the Range Migration Algorithm. Used only for imaging near closest approach (i.e. near zero Doppler). XRGYCR & XCTYAT – Slant plane grids for images formed with the Range Migration Algorithm. Used for any imaging geometry. PLANE – Arbitrary plane with orientation other than the specific XRGYCR & XCTYAT above.	-	N	Allowed values: “RGAZIM”, “RGZERO”, “XRGYCR”, “XCTYAT” and “PLANE”. RGAZIM <=> Range & azimuth relative to the ARP at a reference time. RGZERO <=> Range from ARP trajectory at zero Doppler and “azimuth” aligned with the strip being imaged. XRGYCR <=> Orthogonal slant plane grid oriented range and cross range relative to the ARP at a reference time. XCTYAT <=> Orthogonal slant plane grid with X oriented cross track. PLANE <=> Uniformly sampled in an arbitrary plane along directions U & V.

Table 3-4 Image Grid Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
TimeCOAPoly	R	2D_POLY	Time of Center Of Aperture (t_COA) polynomial as a function of image coordinates. The polynomial is a function of image row coordinate (variable 1) and column coordinate (variable 2). Note: Coefficient (0,0) is the SCP COA time.	s, s/m, s/m^2, s/m^3, etc.	N	order1 = "M" order2 = "N"
Parameters are provided for the Row Direction and the Column Direction. Row Direction ⇔ Increasing Row Index Direction. Column Direction ⇔ Increasing Column Index Direction.						
Row Direction Parameters						
Row	R		Parameters describing increasing row direction image coordinate.	-	N	
UVectECF	R	XYZ	Unit vector in the increasing row direction (ECF) at the SCP pixel.	-	N	
SS	R	DBL	Sample spacing in the increasing row direction. Precise spacing at the SCP.	m	N	
ImpRespWid	R	DBL	Half power impulse response width in the increasing row direction. Measured at the SCP.	m	N	
Sgn	R	ENU	Integer sign of the exponent in the DFT to transform the row dimension to spatial frequency dimension (Krow).	-	N	Allowed values: "-1" or "+1"
ImpRespBW	R	DBL	Spatial bandwidth in Krow used to form the impulse response in the row direction. Measured at the center of support for the SCP.	cyc/m	N	

Table 3-4 Image Grid Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
KCtr	R	DBL	Center spatial frequency in the Krow dimension. Corresponds to the zero frequency of the DFT in the row direction.	cyc/m	N	
DeltaK1	R	DBL	Minimum row offset from KCtr of the spatial frequency support for the image.	cyc/m	N	
DeltaK2	R	DBL	Maximum row offset from KCtr of the spatial frequency support for the image.	cyc/m	N	
DeltaKCOAPoly	O	2D_POLY	Offset from KCtr of the center of support in the row spatial frequency (Krow). The polynomial is a function of image row coordinate (variable 1) and column coordinate (variable 2).	cyc/m, $*/m^2$, $*/m^3$,. etc.	N	order1 = “M” order2 = “N”
WgtType	O		Parameters describing aperture weighting type applied in the spatial frequency domain (Krow) to yield the impulse response in the row direction.	-	N	
WindowName	R	TXT	Type of aperture weighting applied in the spatial frequency domain (Krow) to yield the impulse response in the row direction.	~	N	Example: “UNIFORM”, “TAYLOR”, “UNKNOWN” “HAMMING”
Parameter	O	TXT	Free format field that can be used to pass forward the weighting parameter information.	~	Y	name = "xxx", name is a descriptive identifier for this information
WgtFunct	O		Sampled aperture amplitude weighting function applied in Krow to form the SCP impulse response in the row direction. Attribute “size” equals the number of weights (NW). 2 ≤ NW	-	N	size = “x”

Table 3-4 Image Grid Parameters									
Field Name					Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
				Wgt	R	DBL	Sampled amplitude values that span the ImpRespBW of the SCP. Weights indexed n = 1 to NW.	-	Y	index = “x”
Column Direction Parameters										
		Col			R		Parameters describing increasing column direction image coordinate.	-	N	
			UVectECF		R	XYZ	Unit vector in the increasing column direction (ECF) at the SCP pixel.	-	N	
			SS		R	DBL	Sample spacing in the increasing column direction. Precise spacing at the SCP.	m	N	
			ImpRespWid		R	DBL	Half power impulse response width in the increasing column direction. Measured at the SCP.	m	N	
			Sgn		R	ENU	Integer sign of the exponent in the DFT to transform the column dimension to spatial frequency dimension (Kcol).	-	N	Allowed values: “ -1” or “+1”
			ImpRespBW		R	DBL	Spatial bandwidth in Kcol used to form the impulse response in the column direction. Measured at the center of support for the SCP.	cyc/m	N	
			KCtr		R	DBL	Center spatial frequency in the Kcol dimension. Corresponds to the zero frequency of the DFT in the column direction.	cyc/m	N	
			DeltaK1		R	DBL	Minimum column offset from KCtr of the spatial frequency support for the image.	cyc/m	N	
			DeltaK2		R	DBL	Maximum column offset from KCtr of the spatial frequency support for the image.	cyc/m	N	

Table 3-4 Image Grid Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
DeltaKCOAPoly	O	2D_POLY	Offset from KCtr of the center of support in the column spatial frequency (Kcol). The polynomial is a function of image row coordinate (variable 1) and column coordinate (variable 2).	cyc/m, $*/m^2$, $*/m^3$,. etc	N	order1 = “M” order2 = “N”
WgtType	O	TXT	Parameters describing aperture weighting type applied in the spatial frequency domain (Kcol) to yield the impulse response in the row direction.	-	N	
WindowName	R	TXT	Type of aperture weighting applied in the spatial frequency domain (Kcol) to yield the impulse response in the row direction.	~	N	Example: “UNIFORM”, “TAYLOR”, “UNKNOWN” “HAMMING”
Parameter	O	TXT	Free format field that can be used to pass forward the weighting parameter information.	~	Y	name = "xxx", name is a descriptive identifier for this information
WgtFunct	O		Sampled aperture amplitude weighting function applied in Kcol to form the SCP impulse response in the column direction. Attribute “size” equals the number of weights (NW). 2 ≤ NW	-	N	size = “x”
Wgt	R	DBL	Sampled amplitude values that span the ImpRespBW of the SCP. Weights indexed n = 1 to NW.	-	Y	index = “x”

Table 3-5 Collection Timeline Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
Timeline	R		This block describes the imaging collection timeline.	-	N	
CollectStart	R	XDT	Collection date and start time (UTC). Time reference for times measured from collection start (i.e. slow time t = 0).	-	N	
CollectDuration	R	DBL	Duration of collection period.	sec	N	
IPP	O		Describes Inter-Pulse Period (IPP) parameters. The size attribute represents the number of IPP sets.	-	N	size = “x”
Set	R		Identifies a set, x, of IPP parameters. Minimum of 1 set of parameters required. Sets indexed x = 1, 2, … number of sets.	-	Y	index= “x”
TStart	R	DBL	Start time for the period relative to Collection Start.	sec	N	
TEnd	R	DBL	End time for the period relative to Collection Start.	sec	N	
IPPStart	R	INT	Starting IPP index for the period described.	-	N	
IPPEnd	R	INT	Ending IPP index for the period described.	-	N	
IPPPoly	R	POLY	IPP index polynomial coefficients yield IPP index as a function of time t (variable 1), starting TStart to TEnd.	-	N	order1 = “M”

Table 3-6 Reference Position Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
Position	R		This block describes the platform and ground reference positions verse time.		N	
ARPPoly	R	XYZ_POLY	Aperture Reference Point (ARP) position polynomial in ECF as a function of time t (variable 1). Time t = 0 at Collection Start.	m, m/sec, etc.	N	
GRPPoly	O	XYZ_POLY	Ground Reference Point (GRP) position polynomial in ECF as a function of time t (variable 1). Time t = 0 at Collection Start.	m, m/sec, etc.	N	
TxAPCPoly	O	XYZ_POLY	Transmit Aperture Phase Center (APC) polynomial in ECF as a function of time t (variable 1). Time t = 0 at Collection Start.	m, m/sec, etc.	N	
RcvAPC	O		Receive Aperture Phase Center (APC). The size attribute represents the number of Receive APC (NumRcvAPCs) polynomials below. Receive APCs indexed x = 1, 2, … NumRcvAPCs.		N	size =”x”
RcvAPCPoly	R	XYZ_POLY	Receive Aperture Phase Center polynomial in ECF as a function of time t (variable 1). Time t = 0 at collection start. Index “x” indicates the APC.	m, m/sec, etc.	Y	index = “x”

Table 3-7 Radar Collection Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
RadarCollection	R		This block describes the radar collection information.		N	
TxFrequency	R		Transmitted frequency range of values.	-	N	
Min	R	DBL	Minimum transmitted RF frequency. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
Max	R	DBL	Maximum transmitted RF frequency. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
RefFreqIndex	O	INT	Indicates all RF frequency values are expressed as offsets from a reference frequency (Ref_Freq). If RefFreqIndex included ⇔ All RF frequency values are offsets from a reference frequency (Ref_Freq (Hz)). Ref_Freq value defined per Program Specific Implementation Document. See Section 1.4.	-	N	

Table 3-7 Radar Collection Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
Waveform	O		Transmit and receive demodulation waveform parameters. The size attribute represents the number of waveforms transmitted. (NumWaveforms).	-	N	size = “x”
WFParameters	R		Parameters for waveform x. Waveforms indexed x = 1, 2, … NumWaveforms.	-	Y	index = “x”
TxPulseLength	O	DBL	Transmit pulse length.	sec	N	
TxRFBandwidth	O	DBL	Transmit RF bandwidth of the transmit pulse.	Hz	N	
TxFreqStart	O	DBL	Transmit Start frequency for Linear FM waveform. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
TxFMRate	O	DBL	Transmit FM rate for Linear FM waveform.	Hz/sec	N	
RcvDemodType	O	ENU	Receive demodulation used when Linear FM waveform is used on transmit. “STRETCH” = De-ramp on Receive demodulation. “CHIRP” = No De-ramp On Receive demodulation.	-	N	Allowed values: “STRETCH”, “CHIRP”
RcvWindowLength	O	DBL	Receive window duration.	sec	N	
ADCSampleRate	O	DBL	Analog-to-Digital Converter sampling rate.	samples/ sec	N	
RcvIFBandwidth	O	DBL	Receive IF bandwidth.	Hz	N	

Table 3-7 Radar Collection Parameters									
Field Name					Req / Opt	Type	Description	Units	Rpt	Attributes
				RcvFreqStart	O	DBL	Receive demodulation start frequency. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
				RcvFMRate	O	DBL	Receive FM rate. Set to 0 for RcvDemodType = “CHIRP”.	Hz/sec	N	
		TxPolarization			R	ENU	Transmit polarization type.		N	Allowed values: “V”, “H”, “RHC”, “LHC”, “OTHER”, “UNKNOWN”, “SEQUENCE”
		TxSequence			O		Indicates the transmit signal steps through a repeating sequence of waveforms and/or polarizations. One step per Inter-Pulse Period. The size attribute represents the number of steps in the sequence (NumTxSteps). NumTxSteps $\geq$ 1	-	N	size =”x”
			TxStep		R		Transmit sequence step index. Transmit sequence indexed x = 1, 2, … NumTxSteps.	-	Y	index = “x”
				WFIndex	O	INT	Waveform number for this step. See Waveform parameters.		N	
				TxPolarization	O	ENU	Transmit signal polarization for this step.	-	N	Allowed values: “V”, “H”, “RHC”, “LHC”, “OTHER”

Table 3-7 Radar Collection Parameters										
Field Name					Req / Opt	Type	Description	Units	Rpt	Attributes
		RcvChannels			R		Receive data channel parameters. The size attribute represents the number of receive data channels (NumRcvChans).	-	N	size = “x”
			ChanParameters		R		Parameters for data channel x. Receive channel indexed x = 1, 2, … NumRcvChans.	-	Y	index = “x”
				TxRcvPolarization	R	ENU	Indicates the combined transmit and receive polarization (“TX:RCV”) for the channel.	-	N	Allowed values: “V:V”, “V:H”, “H:V”, “H:H”, “RHC:RHC”, “RHC:LHC”, “LHC:RHC”, “LHC:LHC”, “OTHER” “UNKNOWN”
				RcvAPCIndex	O	INT	Index of the Receive Aperture Phase Center (Rcv APC). Only include if Receive APC position polynomial(s) are included. See Table 3-5.	-	N	
		Area			O		Parameters describing the imaged area covered by the collection.	-	N	
			Corner		R		Set of 4 corner points in LLH.	-	N	
				ACP	R	LLH	Corner point parameters. Corners indexed x = 1, 2, 3, 4 clockwise. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd dd m	Y	index = “x”

Table 3-7 Radar Collection Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
Plane	O		Parameters describing a rectangular area in a geo-located display plane.	-	N	
RefPt	R		Start Line of the segment.	-	N	Optional: name = “xxx”
ECF	R	Start Sample of the segment.	Reference Point in ECF.	m	N	
Line	R	DBL	Reference Point line index.	-	N	
Sample	R	DBL	Reference Point sample index.	-	N	
XDir	R		X Direction parameters of the geo-located plane. X direction is the increasing line direction.	-	N	
UVectECF	R	XYZ	Unit vector in the X direction (ECF).	m	N	
LineSpacing	R	DBL	Line spacing in the X direction.	m	N	
NumLines	R	INT	Number of lines in the X direction.	-	N	
FirstLine	R	INT	First line index.	-	N	
YDir	R		Y Direction parameters of the geo-located plane. Y direction is the increasing sample direction.	-	N	
UVectECF	R	XYZ	Unit vector in the Y direction (ECF).	m	N	
SampleSpacing	R	DBL	Sample spacing in the Y direction.	m	N	

Table 3-7 Radar Collection Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
NumSamples	R	INT	Number of samples in the Y direction.	-	N	
FirstSample	R	INT	First sample index.	-	N	
SegmentList	O		Segments that correspond to the RadarCollection.Area.Plane defined above. (XDir/YDir)		N	size=”x”
Segment	R		Defines the data boundaries of the segment. Segments are indexed x = 1, 2, … number of segments in radar collection plane.		Y	index=”x”
StartLine	R	INT	Start Line of the segment.	-	N	
StartSample	R	INT	Start Sample of the segment.	-	N	
EndLine	R	INT	End Line of the segment.	-	N	
EndSample	R	INT	End Sample of the segment.	-	N	
Identifier	R	TXT	Identifier for the segment data boundary defined above	-	N	
Orientation	O	ENU	Describes the shadow intent of the display plane defined above.	-	N	Allowed values: “UP”, “DOWN” “LEFT”, “RIGHT” “ARBITRARY”
Parameter	O	TXT	Free format field that can be used to pass forward the radar collection information.	-	Y	name = "xxx" “xxx” is a descriptive identifier for this information

Table 3-8 Image Formation Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
ImageFormation	R		This block describes the image formation process.	-	N	
RcvChanProc	R		Parameters of the received processed channel	-	N	
NumChanProc	R	INT	Number of receive data channels processed to form the image.	-	N	
PRFScaleFactor	O	DBL	Factor indicating the ratio of the effective PRF to the actual PRF.	-	N	
ChanIndex	R	INT	Index of a data channel that was processed.	-	Y	
TxRcvPolarizationProc	R	ENU	Indicates the combined transmit and receive polarization (“TX:RCV”) processed to form the image.	-	N	Allowed values: “V:V”, “V:H”, “H:V”, “H:H”, “RHC:RHC”, “RHC:LHC”, “LHC:RHC”, “LHC:LHC”, “OTHER”, “UNKNOWN”
TStartProc	R	DBL	Earliest slow time value for data processed to form the image from CollectionStart	sec	N	
TEndProc	R	DBL	Latest slow time value for data processed to form the image from CollectionStart.	sec	N	
TxFrequencyProc	R		The range of transmit frequency processed to form the image.	-	N	

Table 3-8 Image Formation Parameters							
Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
MinProc	R	DBL	Minimum transmit frequency processed to form the image. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
MaxProc	R	DBL	Maximum transmit frequency processed to form the image. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
SegmentIdentifier	O	TXT	Identifier that describes the image that was processed. Must be included when SICD.RadarCollection.Area.Plane.SegmentList is included.	-	N	
ImageFormAlgo	R	ENU	Image formation algorithm used. PFA ⇔ Polar Fromat Algorithm. RMA ⇔ Range Migration (Omega-K, Chirp Scaling, Range-Doppler) RGAZCOMP ⇔ Simple range, Doppler compression.	-	N	Allowed values: “PFA”, “RMA”, “RGAZCOMP”, “OTHER”
STBeamComp	R	ENU	Parameter indicating if slow time beam shape compensation has been applied.	-	N	Allowed values: “NO” = No ST beam shape compensation. “GLOBAL” = Global ST beam shape compensation applied. “SV” = Spatially variant beam shape compensation applied.

Table 3-8 Image Formation Parameters								
Field Name				Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
		ImageBeamComp		R	ENU	Parameter indicating if image domain beam shape compensation has been applied.	-	N	Allowed values: “NO” = No image domain beam shape compensation. “SV” = Spatially variant image domain beam shape compensation applied.
		AzAutofocus		R	ENU	Parameter indicating if azimuth autofocus correction has been applied.	-	N	Allowed values: “NO” = No azimuth autofocus applied. “GLOBAL” = Global azimuth autofocus applied. “SV” = Spatially variant azimuth autofocus applied.
		RgAutofocus		R	ENU	Parameter indicating if range autofocus correction has been applied.	-	N	Allowed Values: “NO” = No range autofocus applied. “GLOBAL” = Global range autofocus applied. “SV” = Spatially variant range autofocus applied.
		Processing		O		Parameters to describe types of specific processing that may have been applied such as additional compensations.		Y	
			Type	R	TXT	Text identifier for the type of processing algorithm.”		N	
			Applied	R	BOOL	Parameter indicating if the processing has been applied.		N	Allowed values: “true” or “false”

Table 3-8 Image Formation Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
Parameter	O	TXT	Free format field that can be used to pass forward processing information.		Y	name = "xxxx", Name is a descriptive identifier for this information.
PolarizationCalibration	O		Polarization calibration parameter block.	-	N	
DistortCorrectionApplied	R	BOOL	Parameter indicating if polarization calibration parameters have been applied.	-	N	true ⇔ Polarization channel distortion correction processing applied. false ⇔ Not applied.
Distortion	R				N	
Polarization distortion model related the observed scattering matrix {**O**} to the true scattering matrix {**S**}. $\underbrace{\begin{bmatrix} O_{HH} & O_{VH} \\ O_{HV} & O_{VV} \end{bmatrix}}_{\text{Observed Scattering Matrix}} = A \bullet \underbrace{\begin{bmatrix} 1 & Q1 \\ Q2 & F1 \end{bmatrix}}_{\text{Receive Distortion Matrix}} \bullet \underbrace{\begin{bmatrix} S_{HH} & S_{VH} \\ S_{HV} & S_{VV} \end{bmatrix}}_{\text{True Scattering Matrix}} \bullet \underbrace{\begin{bmatrix} 1 & Q4 \\ Q3 & F2 \end{bmatrix}}_{\text{Transmit Distortion Matrix}}$						
CalibrationDate	O	XDT	Date of the calibration measurement.	-	N	
A	R	DBL	Absolute amplitude scale factor.	-	N	
F1	R	CMPLX	Receive distortion element (2,2).	-	N	
Q1	R	CMPLX	Receive distortion element (1,2).	-	N	
Q2	R	CMPLX	Receive distortion element (2,1).	-	N	
F2	R	CMPLX	Transmit distortion element (2,2).	-	N	

Table 3-8 Image Formation Parameters										
Field Name					Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
				Q3	R	CMPLX	Transmit distortion element (2,1).	-	N	
				Q4	R	CMPLX	Transmit distortion element (1,2).	-	N	
				GainErrorA	O	DBL	Gain estimation error standard deviation (in dB) for parameter A.	dB	N	
				GainErrorF1	O	DBL	Gain estimation error standard deviation (in dB) for parameter F1.	dB	N	
				GainErrorF2	O	DBL	Gain estimation error standard deviation (in dB) for parameter F2.	dB	N	
				PhaseErrorF1	O	DBL	Phase estimation error standard deviation (in radians) for parameter F1.	rad	N	
				PhaseErrorF2	O	DBL	Phase estimation error standard deviation (in radians) for parameter F2.	rad	N	

Table 3-9 SCP Center Of Aperture Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
SICD						
SCPCOA	R		Parameters describing the COA for the Scene Center Point.	-	N	
SCPTime	R	DBL	Center Of Aperture time for the SCP t_COA_SCP (from collection start).	sec	N	
Time dependent parameters computed at the SCP COA time (t_COA_SCP).						
ARPPos	R	XYZ	ARP position at t_COA_SCP in ECF.	m	N	
ARPVel	R	XYZ	ARP Velocity at t_COA_SCP in ECF.	m/s	N	
ARPAcc	R	XYZ	ARP Acceleration at t_COA_SCP in ECF.	m/s**2	N	
SideOfTrack	R	ENU	Side of track parameter. Allowed: L or R	-	N	Allowed: “L” or “R”
SlantRange	R	DBL	Slant range from the ARP to the SCP.	m	N	
GroundRange	R	DBL	Ground Range from the ARP nadir to the SCP. Distance measured along spherical earth model passing through the SCP.	m	N	
DopplerConeAng	R	DBL	The Doppler Cone Angle to SCP at t_COA_SCP.	deg	N	
Parameters computed relative to the Earth Tangent Plane (ETP) at the SCP.						
GrazeAng	R	DBL	Grazing Angle between the SCP Line of Sight (LOS) and Earth Tangent Plane (ETP)	deg	N	Range: [0:90]
IncidenceAng	R	DBL	Incidence Angle between the SCP LOS and ETP normal.	deg	N	Range: [0:90]
TwistAng	R	DBL	Angle between cross range in the ETP and cross range in the slant plane.	deg	N	Range: [-90:90]
SlopeAng	R	DBL	Slope Angle from the ETP to the slant plane at t_COA_SCP.	deg	N	Range: [0:90]

Table 3-9 SCP Center Of Aperture Parameters								
Field Name			Req / Opt	Type	Description	Units	Rpt	Attributes/Allowed Values
		AzimAng	R	DBL	Angle from north to the line from the SCP to the ARP Nadir at COA. Measured clockwise in the ETP. AzimuthAng = 45 ➔ ARP is northeast of the SCP at COA.	deg	N	Range: [0:360]
		LayoverAng	R	DBL	Angle from north to the layover direction in the ETP at COA. Measured clockwise in the ETP. LayoverAng = 45 ➔ A point above the ETP will layover along the line northeast of the SCP. Layover Distance = Height above ETP x tan(Slope Angle).	deg	N	Range: [0:360]

Table 3-10 Radiometric Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
Radiometric	O		Radiometric calibration parameters.	-	N	
Image Pixel Power: $Pwr_{II}(row,col) = Real(S_{II}(row,col))**2 + Imag(S_{II}(row,col))**2$.						
NoiseLevel	O		Noise Level Structure	-	N	
NoiseLevelType	R	ENU	Parameter to indicate that the noise power polynomial yields either absolute power level or power level relative to the SCP pixel location.	-	N	Allowed values: “ABSOLUTE” or “RELATIVE”
NoisePoly	R	2D_POLY	Polynomial coefficients that yield thermal noise power (in dB) in a pixel as a function of image row coordinate (variable 1) and column coordinate (variable 2).	dB, dB/m, etc.	N	order1 = “M” order2 = “N”
RCSSFPoly	O	2D_POLY	Polynomial coefficients that yield a scale factor to convert pixel power to RCS (sqm) as a function of image row coordinate (variable 1) and column coordinate (variable 2). Scale factor computed for a target at HAE = SCP_HAE.	m^2, m, 1, 1/m, etc.	N	order1 = “M” order2 = “N”
SigmaZeroSFPoly	O	2D_POLY	Polynomial coefficients that yield a scale factor to convert pixel power to clutter parameter Sigma-Zero (σ^0) as a function of image row coordinate (variable 1) and column coordinate (variable 2). Scale factor computed for a clutter cell at HAE = SCP_HAE.	1, 1/m, $1/m^2$ etc.	N	order1 = “M” order2 = “N”

Table 3-10 Radiometric Parameters

Field Name			Req / Opt	Type	Description	Units	Rpt	Attributes
		BetaZeroSFPoly	O	2D_POLY	Polynomial coefficients that yield a scale factor to convert pixel power to radar brightness or Beta-Zero (β_0) as a function of image row coordinate (variable 1) and column coordinate (variable 2). Scale factor computed for a clutter cell at HAE = SCP_HAE.	1, 1/m, $1/m^2$ etc.	N	order1 = “M” order2 = “N”
		GammaZeroSFPoly	O	2D_POLY	Polynomial coefficients that yield a scale factor to convert pixel power to clutter parameter Gamma-Zero (γ_0) as a function of image row coordinate (variable 1) and column coordinate (variable 2). Scale factor computed for a clutter cell at HAE = SCP_HAE.	1, 1/m, $1/m^2$ etc.	N	order1 = “M” order2 = “N”

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD					N	
Antenna	O		Parameters that describe the antenna illumination patterns during the collection.		N	
Parameters may be provided separately for the transmit (Tx) antenna and the receive (Rcv) antenna. For separate Tx and Rcv patterns, must also include separate Tx APC and Rcv APC position polynomials. See Table 3-5.						
Tx	O		Transmit Antenna Parameters		N	
XAxisPoly	R	XYZ_POLY	Antenna X-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	
YAxisPoly	R	XYZ_POLY	Antenna Y-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	
FreqZero	R	DBL	RF frequency (f0) used to specify the array pattern and EB steering direction cosines. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
EB	O		Electrical boresight (EB) steering directions for an electronically steered array.		N	
DCXPoly	R	POLY	Electrical boresight steering X-axis direction cosine (DCX) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”
DCYPoly	R	POLY	Electrical boresight steering Y-axis direction cosine (DCY) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”
Array	R		Array pattern polynomials that define the shape of the mainlobe.		N	

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
GainPoly	R	2D_POLY	One-way signal gain (in dB) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Gain relative to gain at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	One-way signal phase (in cycles) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Phase relative to phase at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”
Elem	O		Element array pattern polynomials for electronically steered arrays.		N	
GainPoly	R	2D_POLY	One-way signal gain (in dB) as a function of DCX (variable 1) and DCY (variable 2). Gain relative to gain at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	One-way signal phase (in cycles) as a function of DCX (variable 1) and DCY (variable 2). Phase relative to phase at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”
GainBSPoly	O	POLY	Gain polynomial (dB) vs. frequency for boresight (BS) at DCX = 0 and DCY = 0. Frequency ratio ((f-f0)/f0) input variable (variable 1). Constant coefficient = 0.0 always. GainBS(f) = c1*((f-f0)/f0) + c2*((f-f0)/f0)**2 + etc.	dB	N	order1 = “M”

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
EBFreqShift	O	BOOL	Parameter indicating the EB shifts with frequency for an electronically steered array. false ⇔ No shift with frequency. true ⇔ Shift with frequency per ideal array theory.		N	Allowed values: “false”, “true”
MLFreqDilation	O	BOOL	Parameter indicating the mainlobe (ML) width changes with frequency. false ⇔ No change with frequency. true ⇔ Change with frequency per ideal array theory.		N	Allowed values: “false”, “true”
Rcv	O		Receive Antenna Parameters		N	
XAxisPoly	R	XYZ_POLY	Antenna X-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	
YAxisPoly	R	XYZ_POLY	Antenna Y-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	
FreqZero	R	DBL	RF frequency (f0) used to specify the array pattern and EB steering direction cosines. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
EB	O		Electrical boresight (EB) steering directions for an electronically steered array.		N	
DCXPoly	R	POLY	Electrical boresight steering X-axis direction cosine (DCX) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
DCYPoly	R	POLY	Electrical boresight steering Y-axis direction cosine (DCY) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”
Array	R		Array pattern polynomials that define the shape of the mainlobe.		N	
GainPoly	R	2D_POLY	One-way signal gain (in dB) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Gain relative to gain at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	One-way signal phase (in cycles) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Phase relative to phase at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”
Elem	O		Element array pattern polynomials for electronically steered arrays.		N	
GainPoly	R	2D_POLY	One-way signal gain (in dB) as a function of DCX (variable 1) and DCY (variable 2). Gain relative to gain at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	One-way signal phase (in cycles) as a function of DCX (variable 1) and DCY (variable 2). Phase relative to phase at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”

Table 3-11 Antenna Parameters								
Field Name				**Req / Opt**	**Type**	**Description**	**Units**	**Rpt**	**Attributes**
			GainBSPoly	O	POLY	Gain polynomial (dB) vs. frequency for boresight (BS) at DCX = 0 and DCY = 0. Frequency ratio ((f-f0)/f0) input variable (variable 1). Constant coefficient = 0.0 always. GainBS(f) = c1*((f-f0)/f0) + c2*((f-f0)/f0)**2 + etc.	dB	N	order1 = “M”
			EBFreqShift	O	BOOL	Parameter indicating the EB shifts with frequency for an electronically steered array. false ⇔ No shift with frequency. true ⇔ Shift with frequency per ideal array theory.		N	Allowed values: “false”, “true”
			MLFreqDilation	O	BOOL	Parameter indicating the mainlobe (ML) width changes with frequency. false ⇔ No change with frequency. true ⇔ Change with frequency per ideal array theory.		N	Allowed values: “false”, “true”
For an equivalent Two-Way pattern, the ARP position versus time is the effective phase center.									
		TwoWay		O		Two-way Antenna Parameters		N	
			XAxisPoly	R	XYZ_POLY	Antenna X-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	
			YAxisPoly	R	XYZ_POLY	Antenna Y-Axis unit vector in ECF as a function of time (variable 1). Time t = 0 at collection start.	1, 1/s, etc.	N	

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
FreqZero	R	DBL	RF frequency (f0) used to specify the array pattern and EB steering direction cosines. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
EB	O		Electrical boresight (EB) steering directions for an electronically steered array.		N	
DCXPoly	R	POLY	Electrical boresight steering X-axis direction cosine (DCX) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”
DCYPoly	R	POLY	Electrical boresight steering Y-axis direction cosine (DCY) as a function of slow time (variable 1).	1, 1/s, etc.	N	order1 = “M”
Array	R		Array pattern polynomials that define the shape of the mainlobe.		N	
GainPoly	R	2D_POLY	Two-way signal gain (in dB) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Gain relative to gain at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	Two-way signal phase (in cycles) as a function of ΔDCX (variable 1) and ΔDCY (variable 2). Phase relative to phase at ΔDCX = 0 and ΔDCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”
Elem	O		Element array pattern polynomials for electronically steered arrays.		N	

Table 3-11 Antenna Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
GainPoly	R	2D_POLY	Two-way signal gain (in dB) as a function of DCX (variable 1) and DCY (variable 2). Gain relative to gain at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	dB	N	order1 = “M” order2 = “N”
PhasePoly	R	2D_POLY	Two-way signal phase (in cycles) as a function of DCX (variable 1) and DCY (variable 2). Phase relative to phase at DCX = 0 and DCY = 0. Constant coefficient = 0.0 always.	cycles	N	order1 = “M” order2 = “N”
GainBSPoly	O	POLY	Gain polynomial (dB) vs. frequency for boresight (BS) at DCX = 0 and DCY = 0. Frequency ratio ((f-f0)/f0) input variable (variable 1). Constant coefficient = 0.0 always. GainBS(f) = c1*((f-f0)/f0) + c2*((f-f0)/f0)**2 + etc.	dB	N	order1 = “M”
EBFreqShift	O	BOOL	Parameter indicating the EB shifts with frequency for an electronically steered array. false ⇔ No shift with frequency. true ⇔ Shift with frequency per ideal array theory.		N	Allowed values: “false”, “true”
MLFreqDilation	O	BOOL	Parameter indicating the mainlobe (ML) width changes with frequency. false ⇔ No change with frequency. true ⇔ Change with frequency per ideal array theory.		N	Allowed values: “false”, “true”

Table 3-12 Error Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
ErrorStatistics	O		Parameters used to compute error statistics within the SICD sensor model.		N	
CompositeSCP	O		Composite error statistics for the Scene Center Point. Slant plane range (Rg) and azimuth (Az) error statistics. Slant plane defined at SCP COA. See Section 4.9.		N	
Rg	R	DBL	Estimated range error standard deviation.	m	N	
Az	R	DBL	Estimated azimuth error standard deviation.	m	N	
RgAz	R	DBL	Estimated range and azimuth error correlation coefficient.		N	
Components	O		Error statistics by components.		N	
PosVelErr	R		Position and velocity error statistics for the radar platform.		N	
Frame	R	ENU	Coordinate frame used for expressing P,V errors statistics.		N	Allowed values: “ECF”, “RIC_ECF”, “RIC_ECI”. RIC = Radial, In-Track, Cross-Track. Radial – From earth center through the platform position.
P1	R	DBL	Position coordinate 1 standard deviation.	m	N	
P2	R	DBL	Position coordinate 2 standard deviation.	m	N	
P3	R	DBL	Position coordinate 3 standard deviation.	m	N	
V1	R	DBL	Velocity coordinate 1 standard deviation.	m/sec	N	
V2	R	DBL	Velocity coordinate 2 standard deviation.	m/sec	N	
V3	R	DBL	Velocity coordinate 3 standard deviation.	m/sec	N	
CorrCoefs	O		Correlation Coefficient parameters		N	
P1P2	R	DBL	P1, P2 correlation coefficient.	-	N	

Table 3-12 Error Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
P1P3	R	DBL	P1, P3 correlation coefficient.		N	
P1V1	R	DBL	P1, V1 correlation coefficient.		N	
P1V2	R	DBL	P1, V2 correlation coefficient.		N	
P1V3	R	DBL	P1, V3 correlation coefficient.		N	
P2P3	R	DBL	P2, P3 correlation coefficient.		N	
P2V1	R	DBL	P2, V1 correlation coefficient.		N	
P2V2	R	DBL	P2, V2 correlation coefficient.		N	
P2V3	R	DBL	P2, V3 correlation coefficient.		N	
P3V1	R	DBL	P3, V1 correlation coefficient.		N	
P3V2	R	DBL	P3, V2 correlation coefficient.		N	
P3V3	R	DBL	P3, V3 correlation coefficient.		N	
V1V2	R	DBL	V1, V2 correlation coefficient.		N	
V1V3	R	DBL	V1, V3 correlation coefficient.		N	
V2V3	R	DBL	V2, V3 correlation coefficient.		N	
PositionDecorr	O		Platform position error decorrelation function.		N	
CorrCoefZero	R	DBL	Error correlation coefficient for zero time difference (CC0).		N	
DecorrRate	R	DBL	Error decorrelation rate. Simple linear decorrelation rate (DCR). $\Delta t = \lvert t2 - t1 \rvert$ $CC(\Delta t) = Min(1.0,Max(0.0,CC0 - DCR*\Delta t))$	1/sec	N	
RadarSensor	R		Radar sensor error statistics.		N	
RangeBias	R	DBL	Range bias error standard deviation.	m	N	
ClockFreqSF	O	DBL	Payload clock frequency scale factor standard deviation. $SF = \Delta f/f0$.	-	N	

Table 3-12 Error Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
TransmitFreqSF	O	DBL	Transmit frequency scale factor standard deviation. SF = $\Delta f/f0$.	-	N	
RangeBiasDecorr	O		Range bias decorrelation rate.		N	
CorrCoefZero	R	DBL	Error correlation coefficient for zero time difference (CC0).	-	N	
DecorrRate	R	DBL	Error decorrelation rate. Simple linear decorrelation rate (DCR). $\Delta t = \|t2 - t1\|$ $CC(\Delta t) = Min(1.0,Max(0.0,CC0 - DCR*\Delta t))$	1/sec	N	
TropoError	O		Troposphere delay error statistics.		N	
TropoRangeVertical	O	DBL	Troposphere two-way delay error for normal incidence standard deviation. Expressed as a range error. $\Delta R = \Delta T \times c/2$.	m	N	
TropoRangeSlant	O	DBL	Troposphere two-way delay error for the SCP line of sight at COA standard deviation. Expressed as a range error. $\Delta R = \Delta T \times c/2$.	m	N	
TropoRangeDecorr	O				N	
CorrCoefZero	R	DBL	Error correlation coefficient for zero time difference (CC0).	-	N	
DecorrRate	R	DBL	Error decorrelation rate. Simple linear decorrelation rate (DCR). $\Delta t = \|t2 - t1\|$ $CC(\Delta t) = Min(1.0,Max(0.0,CC0 - DCR*\Delta t))$	1/sec	N	
IonoError	O		Ionosphere delay error statistics.		N	
IonoRangeVertical	O	DBL	Ionosphere two-way delay error for normal incidence standard deviation. Expressed as a range error. $\Delta R = \Delta T \times c/2$.	m	N	

Table 3-12 Error Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
IonoRangeRateVertical	O	DBL	Ionosphere two-way delay rate of change error for normal incidence standard deviation. Expressed as a range rate error. ΔRdot = ΔTdot x c/2.	m/sec	N	
IonoRgRgRateCC	R	DBL	Ionosphere range error and range rate error correlation coefficient.	-	N	
IonoRangeVertDecorr	O		Ionosphere range error decorrelation rate.		N	
CorrCoefZero	R	DBL	Error correlation coefficient for zero time difference (CC0).	-	N	
DecorrRate	R	DBL	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))	1/sec	N	
AdditionalParms	O		Additional user defined errors parameters.		N	
Parameter	R	TXT	Free format field that can be used to include additional parameters.	~	Y	name = "xxx", name is a descriptive identifier for this information

Table 3-13 Matched Collection Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
MatchInfo	O		Information about other collections that are matched to the current collection. The current collection is the collection from which this SICD product was generated.		N	
Note: The use of Matched Collection Parameters is per program specific implementation. Match Types, Type IDs, and match parameters are defined in the Program Specific Implementation Documentation.						
NumMatchTypes	R	INT	Number of types of matched collections. Match types are indexed mt = 1 to NumMatchTypes.		N	
MatchType	R		Block containing information about match type mt. Block repeated for mt = 1 to NumMatchTypes.		Y	index = “mt”
TypeID	R	TXT	Text string identifying the match type. Examples: “COHERENT” ,“STEREO”		N	
CurrentIndex	O	INT	Collection sequence index for the current collection.		N	
NumMatchCollections	R	INT	Number of matched collections for this match type. Matched collections indexed by mc = 1 to NumMatchCollections.		N	
MatchCollection	R		Block containing information about match collection mc. Block repeated for mc = 1 to NumMatchCollections.		Y	index = “mc”
CoreName	R	TXT	Text string that uniquely identifies the matching collection.		N	
MatchIndex	O	INT	Collection sequence index for the match collection.		N	
Parameter	O	TXT	Relevant match parameter. Attribute name identifies the parameter.		Y	name = “xxx”

Table 3-14 Range & Azimuth Compression Parameters							
Field Name			Req / Opt	Type	Description	Units	Rpt	Attributes
SICD								
	RgAzComp		C		Parameters included for a Range, Doppler image. Required parameters for **ImageFormAlgo = RGAZCOMP.**		N	
		AzSF	R	DBL	Scale factor that scales image coordinate az = ycol (meters) to a delta cosine of the Doppler Cone Angle at COA. $\Delta cosDCA_{COA}$ = AzSF x az	1/m	N	
		KazPoly	R	POLY	Polynomial function that yields azimuth spatial frequency (Kaz = Kcol) as a function of slow time (variable 1). Slow Time (sec) -> Azimuth spatial frequency (cycles/meter). Time relative to collection start.	cyc/m, cyc/m/s, cyc,/m/s^2, etc	N	order1 = “M”

Table 3-15 Polar Format Algorithm Parameters							
Field Name			Req / Opt	Type	Description	Units	Rpt	Attributes
SICD								
	PFA		C		Parameters included when the image is formed using the Polar Formation Algorithm. Required parameters for **ImageFormAlgo = PFA.**		N	
		FPN	R	XYZ	Focus Plane unit normal (ECF). Unit vector FPN points away from the center of the Earth.	-	N	
		IPN	R	XYZ	Image Formation Plane unit normal (ECF). Unit vector IPN points away from the center of the Earth.	-	N	
		PolarAngRefTime	R	DBL	Polar image formation reference time. Polar Angle = 0 at the reference time. Measured relative to collection start. Note: Reference time is typically set equal to the SCP COA time but may be different.	sec	N	
		PolarAngPoly	R	POLY	Polynomial function that yields Polar Angle (radians) as function of time (variable 1) relative to Collection Start. Time (sec) -> Polar Angle (radians).	rad rad/sec rad/sec**2 etc	N	order1 = “M”
		SpatialFreqSFPoly	R	POLY	Polynomial that yields the Spatial Frequency Scale Factor (KSF) as a function of Polar Angle (variable 1). Polar Angle(radians) -> KSF (dimensionless). Used to scale RF frequency (fx, Hz) to aperture spatial frequency (Kap, cycles/m). Kap = fx x (2/c) x KSF. Kap is the effective spatial frequency in the polar aperture.	1, 1/rad, 1/rad**2, Etc.	N	order1 = “M”

Table 3-15 Polar Format Algorithm Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
Krg1	R	DBL	Minimum range spatial frequency (Krg) output from the polar to rectangular resampling.	cyc/m	N	
Krg2	R	DBL	Maximum range spatial frequency (Krg) output from the polar to rectangular resampling.	cyc/m	N	
Kaz1	R	DBL	Minimum azimuth spatial frequency (Kaz) output from the polar to rectangular resampling.	cyc/m	N	
Kaz2	R	DBL	Maximum azimuth spatial frequency (Kaz) output from the polar to rectangular resampling.	cyc/m	N	
STDeskew	O		Parameters to describe image domain ST Deskew processing.		N	
Applied	R	BOOL	Parameter indicating if ST Deskew Phase function has been applied.		N	Allowed values: “true” or “false”
STDSPhasePoly	R	2D_POLY	Slow time deskew phase function to perform the ST / Kaz shift. Two-dimensional phase (cycles) polynomial function of image range coordinate (variable 1) and azimuth coordinate (variable 2).	cyc cyc/m cyc/m**2 etc	N	order1 = “M” order2 = “N”

Table 3-16 Range Migration Algorithm Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
SICD						
RMA	C		Parameters included when the image is formed using the Range Migration Algorithm. Required parameters for **ImageFormAlgo = RMA.**		N	
RMAlgoType	R	ENU	Identifies the type of migration algorithm used. OMEGA_K: Algorithms that employ Stolt interpolation of the Kxt dimension. $Kx = (Kf^2 - Ky^2)^{0.5}$ CSA: Wave number algorithm that process two-dimensional chirp signals. RG_DOP: Range-Doppler algorithms that employ RCMC in the compressed range domain.	-	N	Allowed values: “OMEGA_K”, “CSA”, or “RG_DOP”
ImageType	R	ENU	Identifies the specific RM image type / metadata type supplied. RMAT: Range Migration w/ Along Track motion compensation. RMCR: Range Migration w/ Cross Range motion compensation. INCA: Imaging Near Closest Approach. Special RM processing used for imaging near closest approach.	-	N	Allowed values: “RMAT”, “RMCR” or “INCA”

Table 3-16 Range Migration Algorithm Parameters

Field Name	Req / Opt	Type	Description	Units	Rpt	Attributes
Parameters for Range Migration with Along Track motion compensation. Included for RMA.ImageType = RMAT.						
RMAT	C		Parameters for RMA with Along Track (RMAT) motion compensation.		N	
PosRef	R	XYZ	Platform reference position (ECF) used to establish the reference slant plane.	m	N	
VelRef	R	XYZ	Platform reference velocity vector (ECF) used to establish the reference slant plane and the Along Track direction.	m/sec	N	
DopConeAngRef	R	DBL	Reference Doppler Cone Angle (degrees).	deg	N	
Parameters for RM with Cross Range motion compensation. Included for RMA.ImageType = RMCR.						
RMCR	C		Parameters for RMA with Cross Range (RMCR) motion compensation.		N	
PosRef	R	XYZ	Platform reference position (ECF) used to establish the reference slant plane and the range direction in the image.	m	N	
VelRef	R	XYZ	Platform reference velocity vector (ECF) used to establish the reference slant plane.	m/sec	N	
DopConeAngRef	R	DBL	Reference Doppler Cone Angle (degrees).	deg	N	

Table 3-16 Range Migration Algorithm Parameters									
Field Name				**Req / Opt**	**Type**	**Description**	**Units**	**Rpt**	**Attributes**
Parameters for Imaging Near Closest Approach. Included for RMA.ImageType = INCA.									
		INCA		C		Parameters for Imaging Near Closest Approach (INCA) image description.		N	
			TimeCAPoly	R	POLY	Polynomial function that yields Time of Closest Approach (sec) as function of image column (azimuth) coordinate (m). Time t = 0 at Collection Start.	sec, sec/m sec/m^2, etc	N	order1 = “M”
			R_CA_SCP	R	DBL	Range at Closest Approach (R_CA) for the SCP.	m	N	
			FreqZero	R	DBL	RF frequency (f_0) used for computing Doppler Centroid values. Typical f_0 set equal to center transmit frequency. **Note: Value may be relative to Ref_Freq. See Section 4.7.1.**	Hz	N	
			DRateSFPoly	R	2D_POLY	Polynomial function that yields Doppler Rate scale factor (DRSF) as a function of image location. Yields DRSF as a function of image range coordinate (variable 1) and azimuth coordinate (variable 2). Used to compute Doppler Rate at closest approach.	1, 1/m 1/m^2, etc	N	order1 = “M” order2 = “N”

Table 3-16 Range Migration Algorithm Parameters									
Field Name				Req / Opt	Type	Description	Units	Rpt	Attributes
			DopCentroidPoly	O	2D_POLY	Polynomial function that yields Doppler Centroid value as a function of image location (fdop_DC). The fdop_DC is the Doppler frequency at the peak signal response. The polynomial is a function of image range coordinate (variable 1) and azimuth coordinate (variable 2). Only used for Stripmap and Dynamic Stripmap collections.	Hz, Hz/m, Hz/m^2, etc	N	order1 = “M” order2 = “N”
			DopCentroidCOA	O	BOOL	Flag indicating that the COA is at the peak signal (fdop_COA = fdop_DC). DopCentroidCOA = “true” ⇔ Pixel COA at peak signal signal for all pixels. DopCentroidCOA = “false” ⇔ Pixel COA not at peak signal for some pixels. Only used for Stripmap and Dynamic Stripmap.	-	N	

4 XML Metadata Parameter Description

4.1 Collection & Image Creation Parameters

The Collection Information parameters identify the specific radar platform that collected the imaging data and the data set identifier. The Image Creation parameters identify the image formation application, the time and the location where the image formation processing occurred. Refer to Table 3-1.

The radar platform identifiers (parameters CollectorName and IlluminatorName) are defined per program specific convention. The specific collection identifier (parameter CoreName) is also defined per program specific convention. These identifiers may be composed of any number of concatenated fields as needed. Optional parameters IlluminatorName and CollectType are provided to clearly identify bistatic imaging collections.

The radar imaging mode is identified by the sensor independent parameter ModeType with allowed values SPOTLIGHT, STRIPMAP and DYNAMIC STRIPMAP. Optional parameter ModeID is used to include a program specific mode identifier. The inclusion of the parameter ModeID is recommended.

4.2 Image Data Parameters

The Image Data parameters describe the two dimensional pixels array. Refer to Table 3-2. The image pixel array is described by the pixel type and array size. Image pixels are indexed by global indices (row, col). See Section 1.2.1. The image array may be the original image produced by the image formation processor (referred as the full image) or a sub-image extracted from the original image. The first row of the full image is always row 0. The first column of the original image is always indexed column 0.

An important concept in the SICD metadata approach is that of a Scene Center Point (SCP) and a Scene Center Point pixel (SCP pixel). The SCP is a point located near the center of the scene covered by the full image. The image formation processing places the image of the Scene Center Point in the SCP pixel (parameter SCPPixel). The SCP pixel is located near the center of the Full Image. For error-free collection and processing, the image impulse response of a point scatterer located at the SCP is centered on the SCP pixel. An example full image pixel array is shown in Figure 4.2-1. The SCP position parameters are defined in Table 3-3. See parameters SCP.ECF and SCP.LLH.

The SCP position and the SCP Pixel indices are central to the proper interpretation and exploitation of a SICD image product. The SCP position and pixel are used as the reference for image pixel grid to geo-referenced mapping (e.g. image grid to ground plane resampling). The SCP pixel is also used as the reference for computing the image domain to spatial frequency domain transformations. See Section 4.4. The image formation algorithm may use the SCP explicitly in the image formation processing (such as in the Polar Format

Algorithm). For these images, the SCP position and pixel location are defined as part of the image formation process. For algorithms that do not use a SCP explicitly, an SCP position and pixel are computed for the SICD product. The process for defining the SCP pixel and position is to select a pixel close to the center of the image. The ground point in the scene that images to the center of the SCP pixel is then computed. The computation is based upon the precise Center of Aperture used for the selected pixel. The SCP point lies along the Center of Aperture iso-range and iso-range rate contour for the selected pixel. The ground height should correspond to the estimated ground height along the range, range rate contour.

A SICD product allows the pixel array elements to be stored using one of the three common complex image pixel formats. Parameter PixelType indicates the pixel type and binary format used. All pixels in a given product are stored with the same pixel type. Pixel formats of 2 bytes per pixel, 4 bytes per pixel and 8 bytes per pixel are supported. The three pixel types allow flexibility in balancing product file sizes and image dynamic range.

The complex image value of a given pixel is denoted S_{II}(row,col). For pixel types RE32F_IM32F and RE16I_IM16I, the real and imaginary components are stored in the file.

$$S_{II}(\text{row,col}) = \text{Real}\left(S_{II}(\text{row,col})\right) + j \bullet \text{Imag}\left(S_{II}(\text{row,col})\right)$$

For pixel type AMP8I_PHS8I, the amplitude and phase components are stored as unsigned 8-bit integers. For a given pixel, the amplitude component is denoted AMP(row,col) and the phase component is denoted PHS(row,col). Each component takes on values from 0 to 255. The amplitude component may be a direct representation of the pixel amplitude or may be used as an index into an amplitude look-up table (parameter AmpTable(0:255)). If no amplitude look-up table is provided, pixel component AMP(row,col) is the pixel amplitude. Pixel amplitude A_{II}(row,col) is determined as shown below. Pixel phase P_{II}(row,col) in cycles is computed from the pixel phase component as shown below. The complex image pixel S_{II}(row,col) is computed using the normal convention where pixel phase is the arctan(Imag(S_{II}(row,col)) / Real(S_{II}(row,col))).

$$A_{II}(\text{row,col}) = \begin{cases} \text{AmpTable}\left(\text{AMP(row,col)}\right), & \text{if AmpTable(0:255) is included} \\ \text{AMP(row,col)}, & \text{if AmpTable(0:255) is omitted} \end{cases}$$

$$P_{II}(\text{row,col}) = \frac{1}{256} \bullet \text{PHS(row,col)}$$

$$S_{II}(\text{row,col}) = A_{II}(\text{row,col}) \bullet \cos\left(2\pi \bullet P_{II}(\text{row,col})\right) + j \bullet A_{II}(\text{row,col}) \bullet \sin\left(2\pi \bullet P_{II}(\text{row,col})\right)$$

The impact of the binary pixel format on product utility is dependent on many variables including resolution, image signal to noise ratio and scene content. For most SAR systems

and scenes, complex image products using 4 bytes per pixel will have negligible loss in quality relative to products using 8 bytes per pixel. Products using 2 bytes per pixel will have a loss in quality that will impact the utility of derived products. The use of an amplitude look-up table can reduce the impact. In general, the 2 bytes per pixel format should only be used when minimizing product size is a high priority.

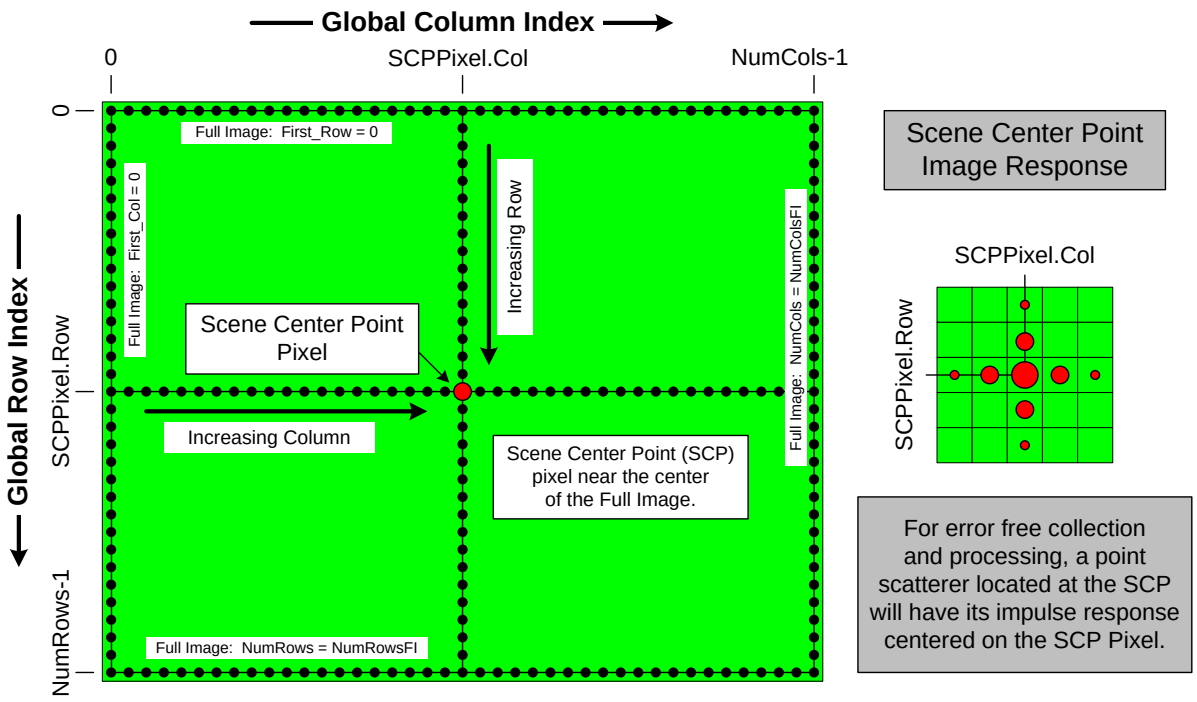


Figure 4.2-1 Full Image & SCP Pixel

Full Image pixel array and the SCP Pixel located near the center of the image.

4.3 Geographic Reference Parameters

The Image Geographic Reference Parameters describe mapping of image pixel locations to geo-located positions. Refer to Table 3-3. The Scene Center Point (SCP) position is specified as well as the approximate image corner points positions. Optional parameters allow for identifying and locating additional ground points that may be needed to support proper exploitation of the image product.

For SICD products, all geo-located positions are expressed using the World Geodetic System 1984 (WGS 84). Parameter GeoData.EarthModel = WGS_84 is included for clarity. All latitude values are Geodetic Latitude and all height values are relative to the WGS 84 reference ellipsoid (HAE = Height Above Ellipsoid). Values of latitude and longitude are specified in decimal degrees these within the following range of values.

$$-90.0 \leq \text{Latitude} \leq 90.0 \qquad -180.0 \leq \text{Longitude} \leq 180.0$$

The SCP position is the key reference point for relating image pixel grid location to geo-located positions. The SCP position is specified in Earth Centered Fixed (ECF) coordinates (parameter Geodata.SCP.ECF) and in WGS 84 Latitude, Longitude and HAE (parameter Geodata.SCP.LLH). These two positions are identical and redundant information but are provided to support both exploitation as well as search and discovery. A difference between the two positions (if any) is due to rounding of parameters expressed in ASCII format. For all precise computations, the parameter SCP.ECF is to be used.

4.4 Image Grid Parameters

The Image Grid parameters describe the spatial sampling represented by the rows and columns of the image array. Refer to Table 3-4. The parameters define the Image Plane that passes through the SCP position. The parameters describe sample spacing, impulse response width and the spatial frequency domain support for the row and column directions. For all images, the image orientation represents a view from above the earth. For most image grids, the increasing row direction is in an increasing range direction. For the common display convention (row 0 at the top of the display and pixel (0,0) at the upper left), most images will be displayed such that the radar illumination is from top of the display and the radar shadows are downward.

The SAR collection and image formation processing produces a two-dimensional image of the three-dimensional scene. The image may be described as a projection of the three-dimensional scene onto a two-dimensional Image Plane. The spatial sampling of the image grid may be described as a two-dimensional sampling in the Image Plane. Samples along a column of the image are treated as uniformly spaced positions in the plane in the "increasing row" direction. Samples along a row of the image are treated as uniformly spaced positions in the plane in the "increasing column" direction. The increasing row direction and increasing column direction are defined by two vectors that lie in the plane. While this is not precisely true for many SAR complex images, such a description provides a useful approximation for relating image pixels to geo-located positions.

4.4.1 Image Indices & Image Coordinates

The image array locations are specified using two sets of pixel based indices: (row,col) and (irow,icol). The image array locations are also specified using distance based coordinates (xrow,ycol). Indices (row,col) take on only integer values. Indices (irow,icol) and image coordinates (xrow,ycol) take on continuous values. See Figure 4.4-1.

(1) Global Row, Column Indices: (row,col)

The global row, column indices are used to index the pixels of the image array. The origin (0,0) is located at the first row (row = 0) and the first column of the first row (col = 0) of the Full Image array. In all descriptions that follow, the (row,col) indices are only used to index individuals elements of the pixel array. The global row, column indices take on INTEGER values only.

Global Row Index: row = 0, 1, 2, . . . , NumRowsFI -1

Global Column Index: col = 0, 1, 2, . . . , NumColsFI -1

(2) SCP Pixel-Centered Image Indices: (irow,icol)

The SCP pixel-centered image indices are continuous valued indices that are also used to index locations in the image pixel array. The origin (0,0) is located at the CENTER of the

SCP pixel. The image indices (irow,icol) are related to global row, column indices (row,col) as follows.

SCP Pixel-Centered Row Index: irow = row - SCPPixel.Row

SCP Pixel-Centered Column Index: icol = col - SCPPixel.Col

In the descriptions that follow, SCP pixel-centered indices (irow,icol) are used to address the image array as a continuous two-dimensional space. The image pixel values are considered to be the discrete samples of a continuous, two-dimensional image signal at the integer values of indices (irow,icol).

(3) SCP Centered Image Coordinates: (xrow,ycol)

The SCP centered image coordinates are continuous valued distances that treat the image array as equal spaced samples on an orthogonal grid. The origin (0,0) is located at the CENTER of the SCP pixel. Image coordinate xrow is equal to irow scaled by the row spacing (Row_SS). Image coordinate ycol is equal to icol scaled by the column spacing (Col_SS).

Row_SS = Grid.Row.SS Col_SS = Grid.Col.SS

xrow = Row_SS•irow ycol = Col_SS•icol

The most common practice in the SAR image formation processing and image exploitation is to use "pixel-centered" image indexing. For some common imagery formats, the specific image indices (row,col) or (r,c) when associated with the Common Coordinate System (CCS) are considered to have the origin at the upper left corner of the pixel (0,0). The image array sample, S_{II}(row,col), is considered to be the image sample at location (row + 0.5, col + 0.5). This potential source of confusion is avoided by the use of the precisely defined SCP pixel-centered indices (irow,icol).

(1) In all SICD descriptions, global indices (row,col) are only used to index the discrete elements of the pixel array. Indices (row,col) take on INTEGER values only.

(2) The SCP Pixel-Centered indices (irow,icol) are used to reference the pixel array as a continuous 2-dimensional space. An index value with zero fractional part references the center of the pixel.

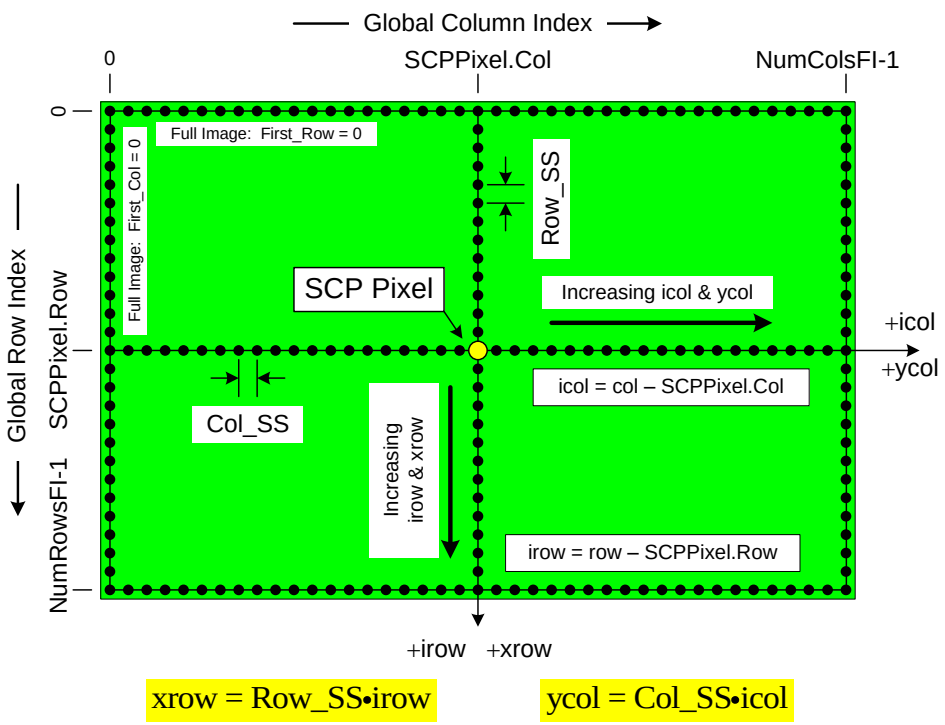


Figure 4.4-1 SCP Pixel-Centered Indices & Coordinates
SCP Pixel-Centered indices (irow,icol) and image coordinates (xrow,ycol).

4.4.2 Image Plane Parameters

The Image Plane in the SICD product contains the SCP and the image grid sample directions at the SCP pixel. For some SAR image formation algorithms, the Image Plane is explicitly defined as part of the processing. For others, the Image Plane unit vectors are computed based from the image formation processing parameters that were used. Algorithms that do not use an image formation plane explicitly typically produce slant plane images. A qualitative description of the Image Plane is provided as aid to users (parameter Grid.ImagePlane). Allowed values are SLANT, GROUND and OTHER.

The Image Plane is defined by the SCP and two unit vectors that lie in the plane. The unit vector in the row direction represents the change in Image Plane position moving from the SCP pixel in the increasing row direction. The unit vector in the column direction represents the change in Image Plane position moving from the SCP pixel in the increasing column direction. Unit vectors **uRow** and **uCol** are in ECF coordinates.

uRow = Grid.Row.UVectECF **uCol** = Grid.Col.UVectECF

The image sample spacings and half power impulse response widths are specified at the SCP pixel. The image grid sample spacings (Row_SS and Col_SS) represent the precise row and

column spacings at the SCP pixel and with respect to a displacement in the Image Plane. The row direction sample spacing (Row_SS) represents the displacement in the Image Plane along **uRow**. The column direction sample spacing (Col_SS) represents the displacement in the Image Plane along **uCol**. The image plane position, **IPP**(xrow,ycol), in ECF coordinates is computed as shown below. See Figure 4.4-2.

$$\mathbf{IPP}(\text{xrow,ycol}) = \mathbf{SCP} + \text{xrow}\bullet\mathbf{uRow} + \text{ycol}\bullet\mathbf{uCol}$$

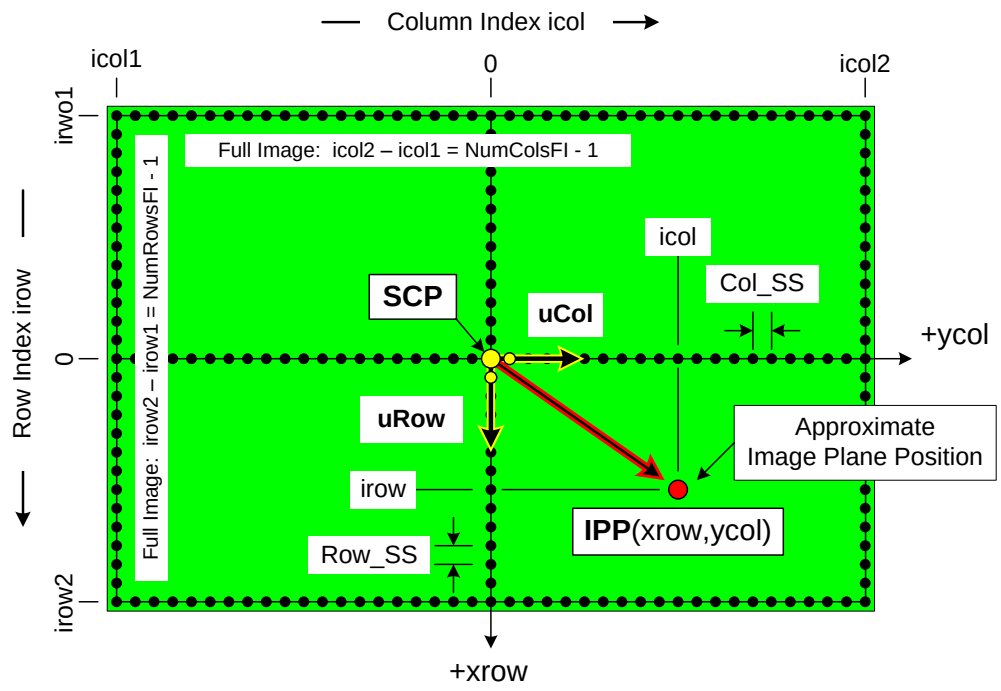


Figure 4.4-2 Image Plane Position (IPP)
Approximate image plane position based on constant row & column spacings.

4.4.3 Center Of Aperture Time

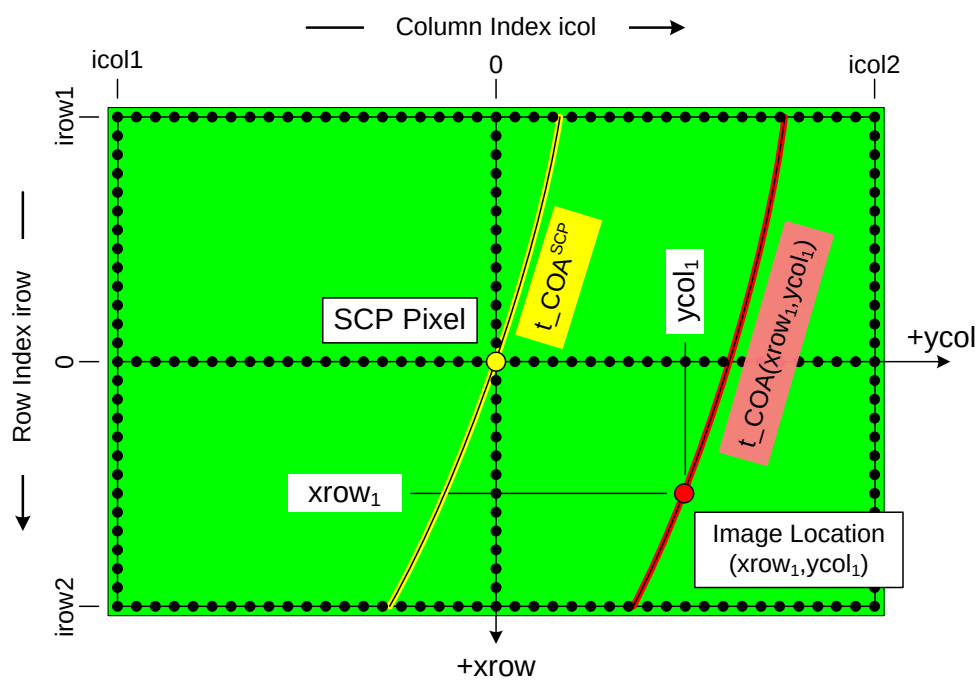
Accurate exploitation of the SAR image is dependent upon accurate knowledge of the Center Of Aperture (COA) time as a function of image location. The Center Of Aperture time (denoted t_COA) is used to determine many parameters including the precise range and range rate contour that projects a particular image location to a geo-located position. The t_COA is provided as a two-dimensional polynomial of image coordinates (xrow,ycol). The t_COA for image location (xrow,ycol) is computed as shown below.

$$\text{Grid.TimeCOAPoly}(m,n) = \text{cT_COA}(m,n), \quad m = 0 \text{ to } \text{M_TCOA}, \quad n = 0 \text{ to } \text{N_TCOA}$$

$$t_COA(xrow,ycol) = \sum_{m=0}^{M_TCOA} \sum_{n=0}^{N_TCOA} cT_COA(m,n) \bullet (xrow)^m \bullet (ycol)^n$$

Important to note is the t_COA computed above is the accurate value of t_COA for the image sample. Even though image coordinates (xrow,ycol) may be approximate displacements, the t_COA computed is the time to be used for accurate exploitation. The choice of the orders M_TCOA and N_TCOA are made such that the resulting t_COA values accurately match those achieved by the image formation processing. While the precise accuracy needed is dependent upon many factors, for most systems and derived products, computed t_COA values within 10 msec of the achieved value in the processing are acceptable.

For all images, coefficient cT_COA(0,0) is the t_COA for the SCP pixel. Images with constant t_COA (typically from spotlight collections) may be stored with only the cT_COA(0,0) coefficient and order parameters M_TCOA = N_TCOA = 0. An example image for which t_COA varies across the image is shown in Figure 4.4-3. Shown in the figure are two contours of constant t_COA. For most images, the contours will be approximately linear and equally spaced for even increments in t_COA.



$$t_COA(xrow_1, ycol_1) = \sum_{m=0}^{M_TCOA} \sum_{n=0}^{N_TCOA} cT_COA(m,n) \bullet (xrow_1)^m \bullet (ycol_1)^n$$

Figure 4.4-3 Precise Center Of Aperture Time

Example shows contour lines of constant t_COA for the SCP and an arbitrary pixel ($irow_1$, $icol_1$).

4.4.4 Image Grid Types

The type of image sample grid is a fundamental attribute of the complex image. The spatial sampling of the complex image is usually oriented along the natural radar coordinates range and cross range. The exact grid is a function of both the collection mode and the image formation algorithm. The image sample grid type is indicated by parameter Grid.Type. The allowed Grid Types listed below

(1) RGAZIM ⇔ Range & Azimuth
(2) RGZERO ⇔ Range & Zero Doppler
(3) XRGYCR ⇔ Cartesian Grid Oriented Range, Cross Range
(4) XCTYAT ⇔ Cartesian Grid Oriented Cross Track, Along Track
(5) PLANE ⇔ Arbitrary Image Plane w/ Axes U,V

Grid.Type = RGAZIM ⇔ Range & Azimuth

Image samples are oriented in range and azimuth with respect to the ARP position at an image formation reference time. The image formation reference time (t_{REF}) is often set to the SCP Center Of Aperture time. The image is oriented shadows downward and a view from above the earth. See Figures 4.4-4 and 4.4-5. Image rows are samples along constant (or nearly constant) range contours. Image row spacing is usually constant in range. Image columns are samples in azimuth. The column spacing is usually constant (or nearly constant) in some azimuth angle related quantity (e.g. cosine of the Doppler cone angle). The RGAZIM grid is the natural grid that results from simple Range and Azimuth Compression image formation algorithm (IFA). See Section 4.14. The Range & Azimuth grid is also the natural grid that results using the Polar Format IFA. See Section 4.15.

For the RGAZIM grid, the row coordinate is referred to as range and the column coordinate is referred to as azimuth. Pixel-centered indices (irg, iaz) are equal to general image indices (irow, icol) and image coordinates (rg, az) are equal to general image coordinates (xrow, ycol). Spatial frequency parameters (Krg, Kaz) are equal to general spatial frequency parameters (Krow, Kcol). Image coordinate values are in meters and spatial frequency values are in cycles/meter.

$$\begin{aligned} irg &= irow = row - SCPPixel.Row & iaz &= icol = col - SCPPixel.Col \\ rg &= xrow = Rg_SS \bullet irg & az &= ycol = Az_SS \bullet iaz \\ \mathbf{uRG} &= \mathbf{uRow} & \mathbf{uAZ} &= \mathbf{uCol} \\ Krg &= Krow & Kaz &= Kcol \end{aligned}$$

Grid.Type = RGZERO ⇔ Range & Zero Doppler

Image samples are oriented in range offset from the trajectory of the ARP and in azimuth parallel to the trajectory. The image is oriented shadows downward and a view from above the earth. See Figures 4.4-6 and 4.4-7. Image rows are samples along constant range contours relative to the ARP trajectory. Image row spacing is constant in range. The image columns are samples along a contour of closest approach (i.e. zero Doppler). The image column spacing may be uniform in distance in the scene or uniform in time of closest approach. The RGZERO grid is the natural grid that results for images formed using the Range Migration Algorithm IFA adapted to imaging near closest approach (INCA). See Section 4.16.2.

For the RGZERO grid, the row coordinate is referred to as range and the column coordinate is referred to as azimuth. Pixel-centered indices (irg, iaz) are equal to general image indices (irow, icol) and image coordinates (rg, az) are equal to general image coordinates (xrow, ycol). Spatial frequency parameters (Krg, Kaz) are equal to general spatial frequency parameters (Krow, Kcol). Image coordinate values are in meters and spatial frequency values are in cycles/meter.

$$\begin{aligned} irg &= irow = row - SCPPixel.Row & iaz &= icol = col - SCPPixel.Col \\ rg &= xrow = Rg_SS \bullet irg & az &= ycol = Az_SS \bullet iaz \\ \mathbf{uRG} &= \mathbf{uRow} & \mathbf{uAZ} &= \mathbf{uCol} \\ Krg &= Krow & Kaz &= Kcol \end{aligned}$$

Grid.Type = XRGYCR ⇔ Range & Cross Range

The XRGYCR grid is a slant plane grid that is oriented range and cross range. The slant plane is defined by the ARP position and velocity at a reference time ($\mathbf{POS}_{REF}$ and $\mathbf{VEL}_{REF}$) and the SCP. See Figure 4.4-8. The +XRG direction is oriented from the ARP to the SCP (in the increasing range direction). The +YCR direction is orthogonal to the +XRG direction (in the cross range direction). The rows of the image are along lines of constant XRG and evenly spaced. The columns of the image are along lines of constant YCR and evenly spaced.

For the XRGYCR grid, the row coordinate is referred to as range and the column coordinate is referred to as cross range. Pixel-centered indices (ixrg, iycr) are equal to general image indices (irow, icol) and image coordinates (xrg, ycr) are equal to general image coordinates (xrow, ycol). Spatial frequency parameters (Kxrg, Kycr) are equal to general spatial frequency parameters (Krow, Kcol). Image coordinate values are in meters and spatial frequency values are in cycles/meter.

$$\begin{aligned} ixrg &= irow = row - SCPPixel.Row & iycr &= icol = col - SCPPixel.Col \\ xrg &= xrow = Row_SS \bullet ixrg & ycr &= ycol = Col_SS \bullet iycr \end{aligned}$$

$$\mathbf{uXRG} = \mathbf{uRow} \qquad \mathbf{uYCR} = \mathbf{uCol}$$

$$Kxrg = Krow \qquad Kycr = Kcol$$

Grid.Type = XCTYAT ⇔ Cross Track & Along Track

The XCTYAT grid is a slant plane grid that is oriented cross track and along track. The slant plane is defined by the ARP position and velocity at a reference time ($\mathbf{POS}_{REF}$ and $\mathbf{VEL}_{REF}$) and the SCP. See Figure 4.4-8. The +XCT direction is orthogonal to the $\mathbf{VEL}_{REF}$ and in the increasing distance from the trajectory. The +YAT direction is orthogonal to the +XCT direction and parallel to the $\mathbf{VEL}_{REF}$. For right looking collections, the +YAT direction is in the same direction as $\mathbf{VEL}_{REF}$. For left looking collections, the +YAT is in the opposite direction as $\mathbf{VEL}_{REF}$. The rows of the image are along lines of constant XCT and evenly spaced. The columns of the image are along lines of constant YAT and evenly spaced. The grid is the natural output for image formation using the RMA.

For the XCTYAT grid, the row coordinate is referred to as cross track and the column coordinate is referred to as along track. Pixel-centered indices (ixct, iyat) are equal to general image indices (irow, icol) and image coordinates (xct, yat) are equal to general image coordinates (xrow, ycol). Spatial frequency parameters (Kxct, Kyat) are equal to general spatial frequency parameters (Krow, Kcol). Image coordinate values are in meters and spatial frequency values are in cycles/meter.

$$ixct = irow = row - SCPPixel.Row \qquad iyat = icol = col - SCPPixel.Col$$

$$xct = xrow = Row_SS \bullet ixct \qquad yat = ycol = Col_SS \bullet iyat$$

$$\mathbf{uXCT} = \mathbf{uRow} \qquad \mathbf{uYAT} = \mathbf{uCol}$$

$$Kxct = Krow \qquad Kyat = Kcol$$

Grid.Type = PLANE ⇔ Arbitrary Image Plane

The PLANE grid type is provided for images that do not meet the precise definition of the other grid types. The samples are uniformly spaced in a geolocated image plane that contains the SCP. The +U coordinate is equal to the row coordinate (xrow). The +V coordinate is equal to the column coordinate (ycol). The rows of the image are along lines of constant U coordinate and are evenly spaced. The columns of the image are along lines of constant V coordinate and are evenly spaced. For an arbitrary image grid, these may be an approximation to the true sampling of the rows and columns. The restrictions are that the image be a view from above the earth and that the shadows are most closely aligned with the +U direction.

For the PLANE grid, the row coordinate is referred to as +U and the column coordinate is referred to as +V. Pixel-centered indices (iu, iv) are equal to general image indices (irow, icol) and image coordinates (u, v) are equal to general image coordinates (xrow, ycol).

Spatial frequency parameters (Ku, Kv) are equal to general spatial frequency parameters (Krow, Kcol). Image coordinate values are in meters and spatial frequency values are in cycles/meter.

$$iu = irow = row - SCPPixel.Row \qquad iv = icol = col - SCPPixel.Col$$

$$u = xrow = Row_SS \bullet iu \qquad v = ycol = Col_SS \bullet iv$$

$$\mathbf{uU} = \mathbf{uRow} \qquad \mathbf{uV} = \mathbf{uCol}$$

$$Ku = Krow \qquad Kv = Kcol$$

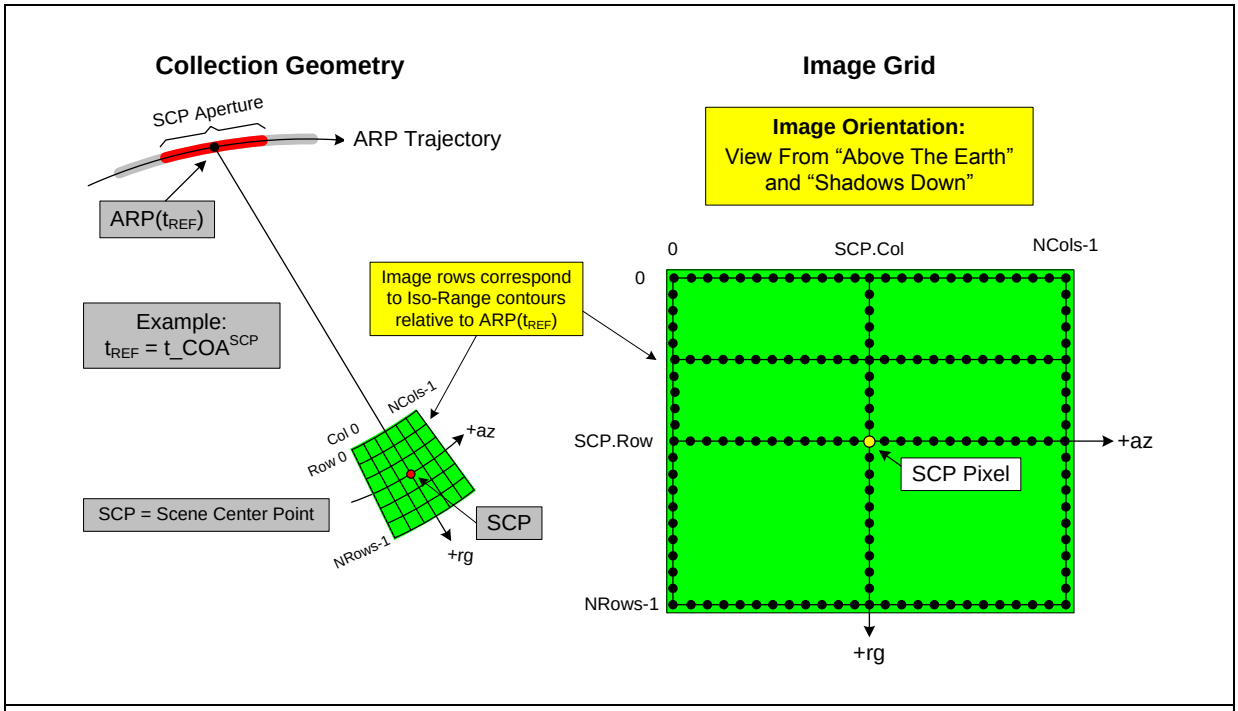


Figure 4.4-4 Range & Azimuth Image Grid
Rows oriented iso-range with respect to a fixed point.

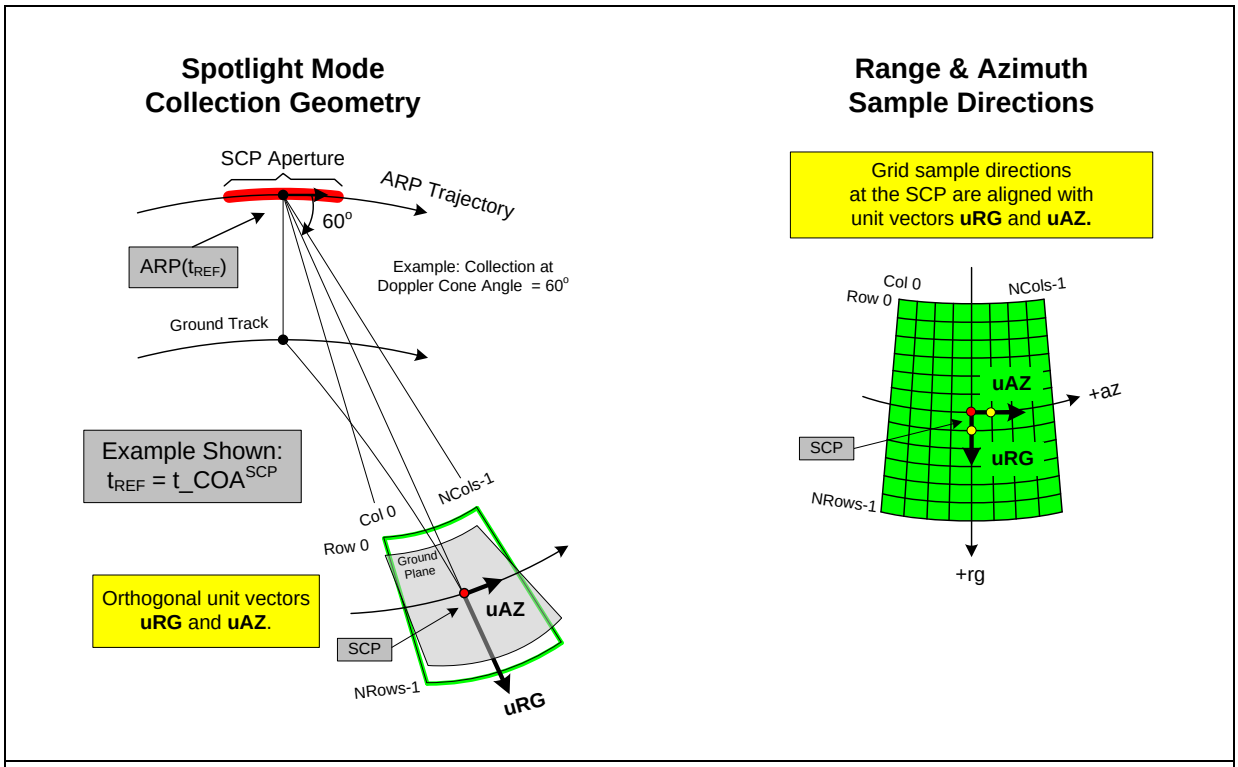


Figure 4.4-5 Range & Azimuth Unit Vectors

Example unit vectors uRG = uRow and uAZ = uCol for slant plane grid.

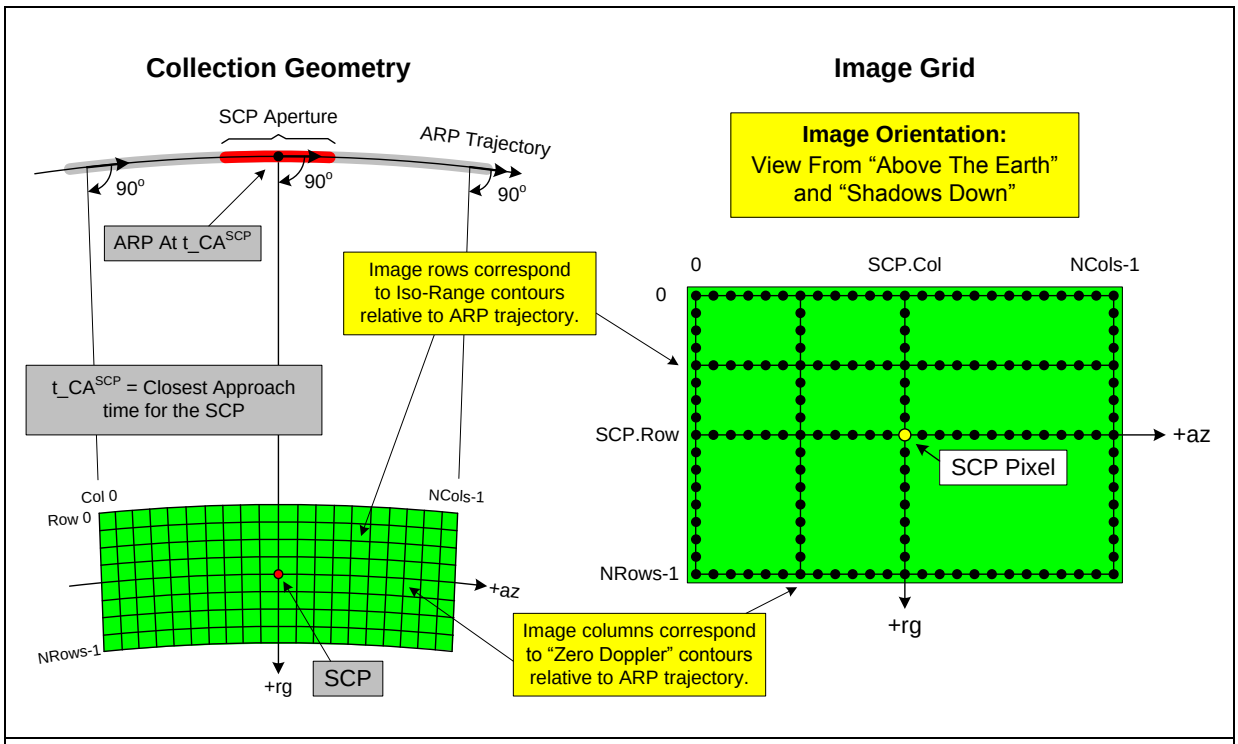


Figure 4.4-6 Range & Zero Doppler Image Grid

Rows oriented iso-range with respect to the ARP trajectory.

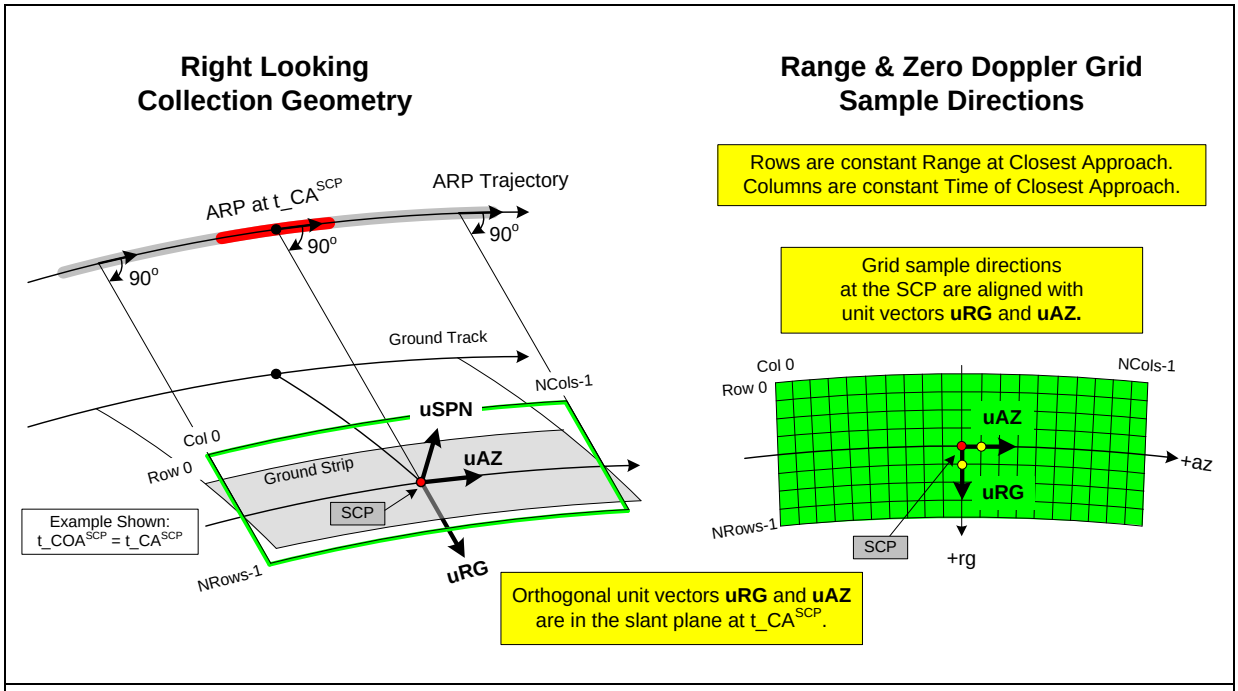


Figure 4.4-7 Range & Zero Doppler Image Grid

Unit vectors uRG = uRow and uAZ = uCol are in the slant plane at t_CA^{SCP}.

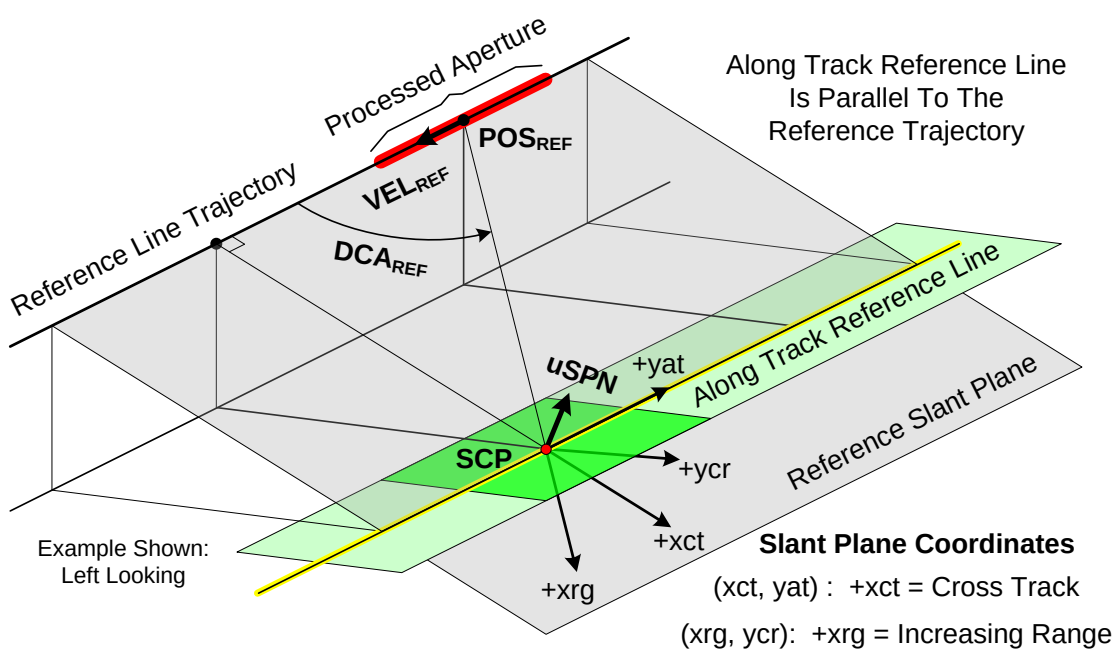


Figure 4.4-8 Slant Plane Image Coordinates

Slant plane coordinates (xrg, ycr) and (xct, yat) lie in the Reference Slant Plane.

4.4.5 Image Spatial Frequency Domain

The two-dimensional Fourier Transform (FT) of the complex image pixel array yields the spatial frequency domain. The characteristics of the spatial frequency domain are a fundamental attribute of the complex image. For all SAR complex images, the attributes of the spatial frequency domain were central to the image formation processing that produced the complex image.

The image domain is a two-dimensional space that is indexed by image pixel-centered indices (irow, icol) and image spatial coordinates (xrow,ycol). The samples of the complex image are considered to be samples of the continuous image signal at integer values of the image indices. For the NumRows x NumCols image grid, the image indices (irow, icol) span the following values. Image row coordinates of the first and last rows are xrow1 and xrow2. Image column coordinates of the first and last column are ycol1 and ycol2. See Figure 4.4-9.

$$\text{irow1} \le \text{irow} \le \text{irow2} \qquad \text{icol1} \le \text{icol} \le \text{icol2}$$

$$\text{irow1} = \text{FirstRow} - \text{SCPPixel.Row} \qquad \text{icol1} = \text{FirstCol} - \text{SCPPixel.Col}$$

$$\text{irow2} = \text{irow1} + \text{NumRows} - 1 \qquad \text{icol2} = \text{icol1} + \text{NumCols} - 1$$

$$\text{xrow1} = \text{Row_SS} \bullet \text{irow1} \qquad \text{ycol1} = \text{Col_SS} \bullet \text{ycol1}$$

$$\text{xrow2} = \text{Row_SS} \bullet \text{irow2} \qquad \text{ycol2} = \text{Col_SS} \bullet \text{ycol2}$$

The image domain impulse response widths (IRWs) are key attributes of the image. The half power impulse response widths are Row_IRW and Col_IRW. For most images, the impulse response is constant or varies only slightly within the image. The half power impulse response width is the “focused” response width at the SCP that is the goal of the processing. For images requiring post-image formation focusing (i.e. autofocus), the actual IRW may be degraded.

$$\text{Row_IRW} = \text{Row.ImpRespWid} \qquad \text{Col_IRW} = \text{Col.ImpRespWid}$$

The transform of the row coordinate is the row spatial frequency coordinate (xrow ⇔Krow). The transform of the column coordinate is the azimuth spatial frequency coordinate (ycol ⇔Kcol). The required spatial frequency parameters provided with all image products are as follows. All spatial frequency parameters are in cycles/meter.

$$\text{R2K} = \text{Row.Sgn} \qquad \text{C2K} = \text{Col.Sgn}$$

$$\text{Krow_IRBW} = \text{Row.ImpRespBW} \qquad \text{Kcol_IRBW} = \text{Col.ImpRespBW}$$

$$\text{Krow_Ctr} = \text{Row.KCtr} \qquad \text{Kcol_Ctr} = \text{Col.KCtr}$$

$$\Delta\text{Krow1} = \text{Row.DeltaK1} \qquad \Delta\text{Kcol1} = \text{Col.DeltaK1}$$

$\Delta Krow2 = Row.DeltaK2$ $\qquad$ $\Delta Krow2 = Col.DeltaK2$

The sampled image signal is $S_{II}(irow, icol)$. The sampled spatial frequency signal is $S_{KK}(nrow, ncol)$. For all SICD products, the sampled spatial frequency is computed as follows. The expression for $S_{KK}(nrow, ncol)$ is highlighted to as it is critical to both producers and users of SICD products.

$$\text{For } nrow = -\tfrac{1}{2}NFR, \ldots, 0, \ldots, \tfrac{1}{2}NFR:$$

$$\text{For } ncol = -\tfrac{1}{2}NFC, \ldots, 0, \ldots, \tfrac{1}{2}NFC:$$

$$S_{KK}(nrow, ncol) = \sum_{irow=irow1}^{irow2} \sum_{icol=icol1}^{icol2} S_{II}(irow, icol) \bullet \exp\left\{ j2\pi \bullet \left[R2K \bullet \frac{irow \bullet nrow}{NFR} + C2K \bullet \frac{icol \bullet ncol}{NFC} \right] \right\}$$

(1) Parameters R2K and C2K define the signs of the exponent in the Discrete Fourier Transform (DFT). For all images, the values R2K and C2K are equal (i.e. R2K = C2K = +1 or R2K = C2K = -1). The value of R2K (Row.Sgn) is the sign of exponent that transforms the increasing xrow dimension to yield increasing RF frequency.

(2) The "zero point" on the input signal is the SCP pixel ($S_{II}(0,0)$). Parameters NFR and NFC are the sizes of the transformed signal and are chosen by the image exploitation application.

For convenience, NFR and NFC are assumed to be even integers. Also for convenience, index nrow spans NFR + 1 values and index ncol spans NFC + 1 values.

The center of the spatial frequency is $S_{KK}(0,0)$. The spatial frequencies of the center point are (Krow_Ctr, Kcol_Ctr). See Figures 4.4-10 and 4.4-11. Spatial frequency Krow_Ctr is always positive and related to the center of the processed RF spectrum. For many images, spatial frequency parameter Kcol_Ctr is equal to 0. The spatial frequency coordinates (Krow, Kcol) are related to the spatial frequency indices (nrow, ncol) as follows. Offset frequencies $\Delta Krow$ and $\Delta Kcol$ are offsets relative to $S_{KK}(0,0)$.

$$Krow_SS = \frac{1}{Row_SS \bullet NFR} \qquad Kcol_SS = \frac{1}{Col_SS \bullet NFC}$$

$$\Delta Krow(nrow) = Krow_SS \bullet nrow \qquad \Delta Kcol(ncol) = Kcol_SS \bullet ncol$$

$$Krow(nrow) = Krg_Ctr + \Delta Krg(nrg) \qquad Kcol(ncol) = Kcol_Ctr + \Delta Kcol(ncol)$$

Offset frequencies $\Delta Krow$ and $\Delta Kcol$ span the following ranges of values.

$$-\frac{1}{2 \bullet Row_SS} \le \Delta Krow \le \frac{1}{2 \bullet Row_SS} \qquad -\frac{1}{2 \bullet Col_SS} \le \Delta Kcol \le \frac{1}{2 \bullet Col_SS}$$

The span of spatial frequencies containing valid data are indicated by parameters ΔKrow1, ΔKrow2, ΔKcol1 and ΔKol2. The parameters indicate the support in the spatial frequency domain for the entire image. Individual image pixels may be formed from a subset of the spatial frequency support for the image.

The spatial frequency support (often referred to as the spatial frequency aperture) for the SCP is described by bandwidth parameters Krow_IRBW and Kcol_IRBW. An example spatial frequency support is shown in Figure 4.4-12. The bandwidths are measured at the center of the support in the Krow and Kcol dimensions. For the example shown, the spatial frequency support is a rectangle and centered at $S_{KK}(0,0)$. For images with non-centered spatial frequency support, optional polynomial functions may be included to describe the variation in spatial frequency support as a function of position in the image. For images that have variable aperture centers in row spatial frequency, two-dimensional polynomial coefficients cΔKrowCOA(m,n) may be included (order M_KROW and order N_KROW). For images that have variable aperture centers in column spatial frequency, two-dimensional polynomial coefficients cΔKcolCOA(m,n) may be included (order M_KCOL and order N_KCOL).

For m = 0 to M_KROW & n = 0 to N_KROW:

cΔKrowCOA(m,n) = Row.DeltaKCOAPoly(m,n)

For m = 0 to M_ KCOL & n = 0 to N_ KCOL:

cΔKcolCOA(m,n) = Col.DeltaKCOAPoly(m,n)

For a given target at image coordinates ($xrow^{TGT}$, $ycol^{TGT}$), the center of support is assumed to be at ΔKrowCOA = 0 unless the ΔKrowCOA polynomial is included. The center of support is assumed to be at ΔKcolCOA = 0 unless the ΔKcolCOA polynomial is included. When the polynomial(s) are provided (either one or both), the center of support relative to $S_{KK}(0,0)$ is then computed as shown below.

$$\Delta KrowCOA^{TGT} = \sum_{m=0}^{M_KROW} \sum_{n=0}^{N_KROW} c\Delta KrowCOA(m,n) \bullet (xrow^{TGT})^m \bullet (ycol^{TGT})^n$$

$$\Delta KcolCOA^{TGT} = \sum_{m=0}^{M_KCOL} \sum_{n=0}^{N_KCOL} c\Delta KcolCOA(m,n) \bullet (xrow^{TGT})^m \bullet (ycol^{TGT})^n$$

A target with non-centered support is shown in Figure 4.4-13. Due to the circular nature of the sampled spectrum, values of ΔKrowCOA computed from the polynomial may need to be adjusted by an integer multiple of 1/Row_SS to yield the effective ΔKrowCOA. Similarly,

values of ΔKcolCOA computed from the polynomial may need to be adjusted by an integer multiple of 1/Col_SS to yield the effective ΔKcolCOA. Constant coefficients cΔKrowCOA(0,0) and cΔKrowCOA(0,0) are offset frequencies for SCP.

$$\Delta KrowCOA^{SCP} = c\Delta KrowCOA(0,0) \qquad \Delta KcolCOA^{SCP} = c\Delta KcolCOA(0,0)$$

Amplitude weighting applied in the spatial frequency domain to control the properties of the range and azimuth impulse responses may be described using the optional weighting parameters. Text fields may be included as well as a set of samples that define the shape of the window.

For m = 1 to NWROW:

$$Krow_Wgt(m) = Row.WgtFunct.Wgt(m)$$

For n = 1 to NWCOL:

$$Kcol_Wgt(n) = Col.WgtFunct.Wgt(n)$$

The parameters provided describe the weighting applied to SCP spatial frequency support. See Figure 4.4-12. The row weights represent uniformly spaced samples of the weighting function applied to the Krow_IRBW. Weight Krow_Wgt(m) is applied at:

$$\Delta Krow(m) = \Delta KrowCOA^{SCP} + \left(\frac{m-1}{NWROW-1} - \frac{1}{2}\right) \bullet Krow_IRBW$$

The column weights represent uniformly spaced samples of the weighting function applied to the Kcol_IRBW. Weight Kcol_Wgt(n) is applied at:

$$\Delta Kcol(n) = \Delta KcolCOA^{SCP} + \left(\frac{n-1}{NWCOL-1} - \frac{1}{2}\right) \bullet Kcol_IRBW$$

For all other points in the image, it assumed that same weighting function(s) are applied and centered on the center of support for each target. For the example target shown in Figure 4.4-13, the weighting function would be centered at $\Delta KrowCOA^{TGT}$ and $\Delta KcolCOA^{TGT}$.

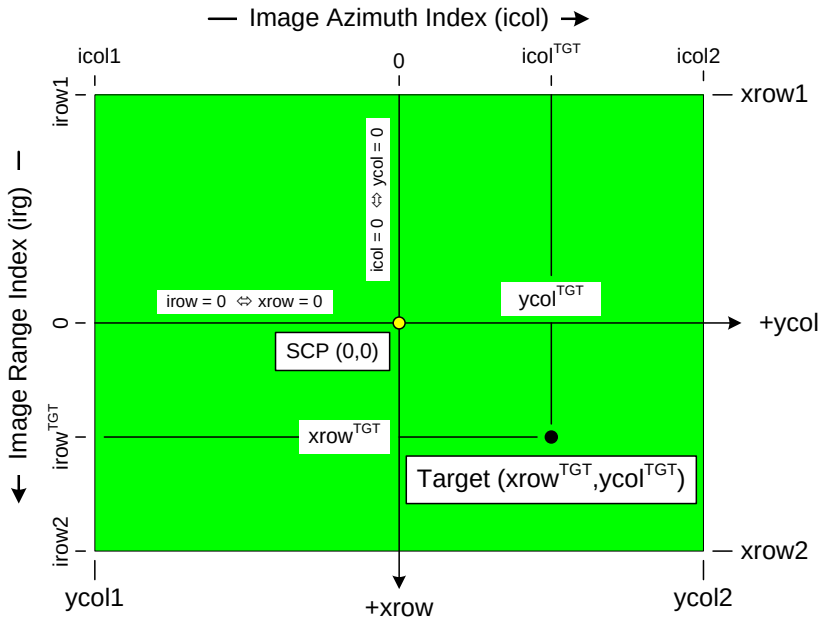


Figure 4.4-9 Image Domain Extent

Image domain extent of the NumRows x NumCols image pixel array.

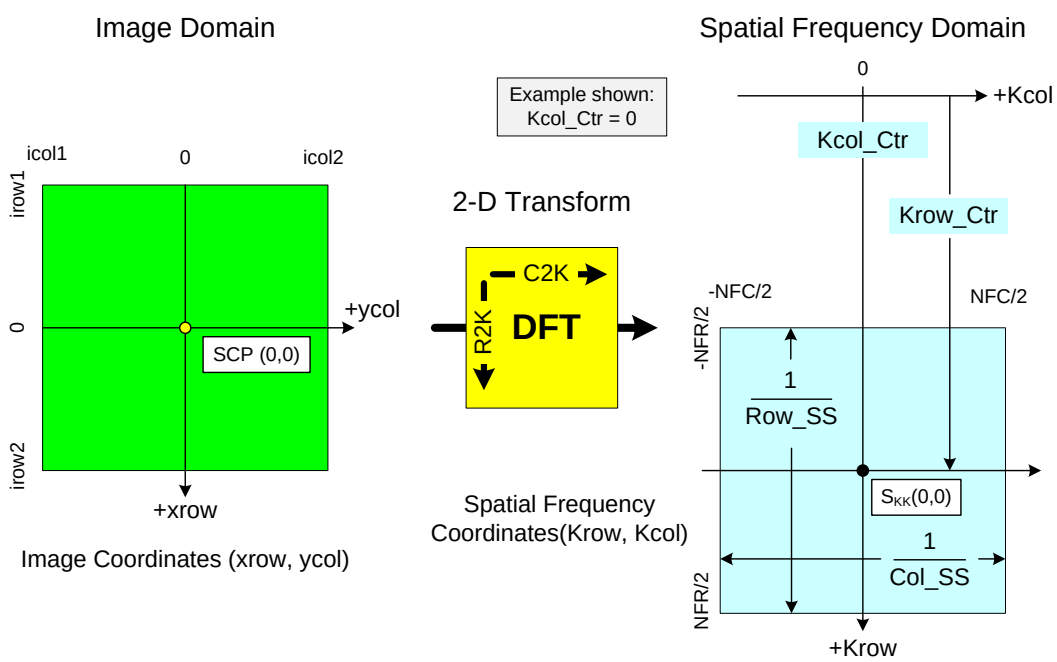


Figure 4.4-10 Image To Spatial Frequency Transform

Spatial frequency centered at Krow = Krow_Ctr and Kcol = Kcol_Ctr.

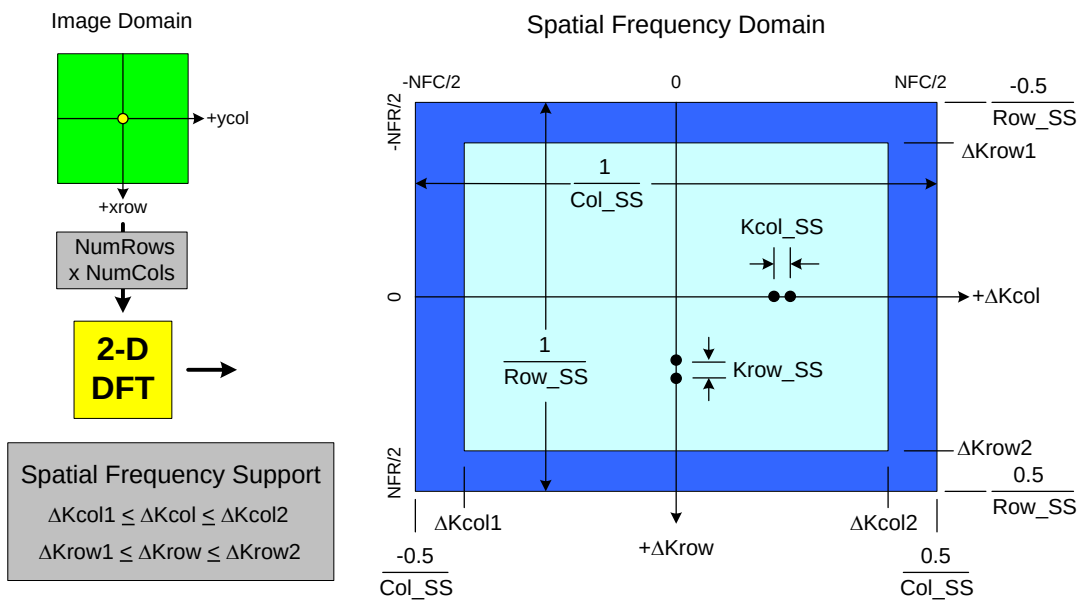


Figure 4.4-11 Row & Column Spatial Frequencies

Offset frequencies ΔKrow and ΔKcol measured relative to the center sample $S_{KK}(0,0)$.

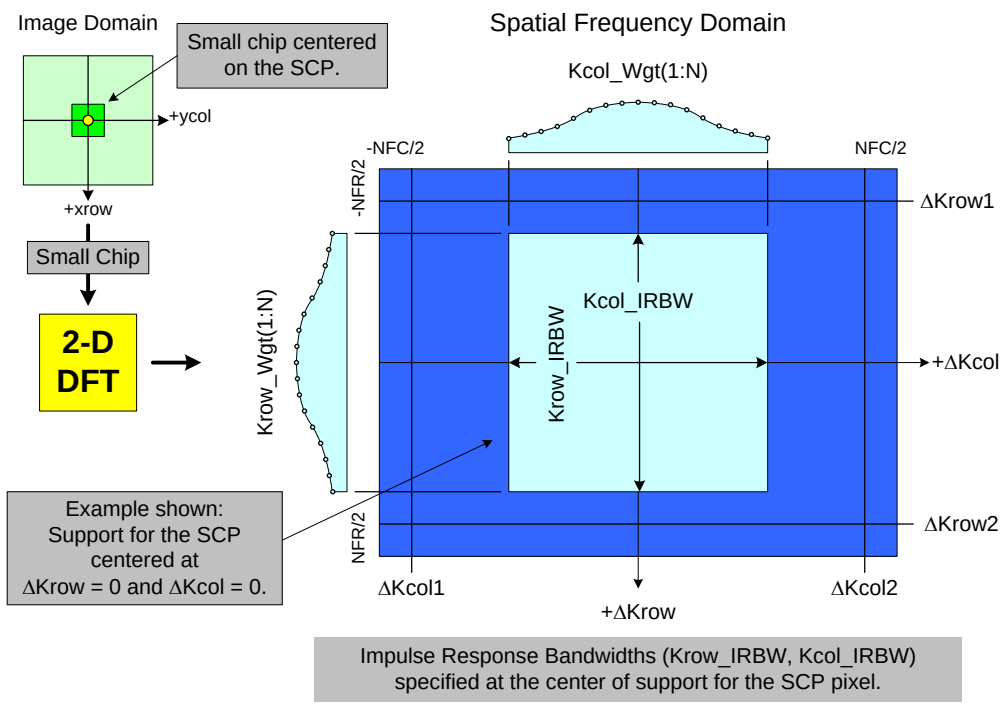


Figure 4.4-12 Spatial Frequency Support For The SCP

Bandwidths and optional weighting functions are centered on the SCP aperture.

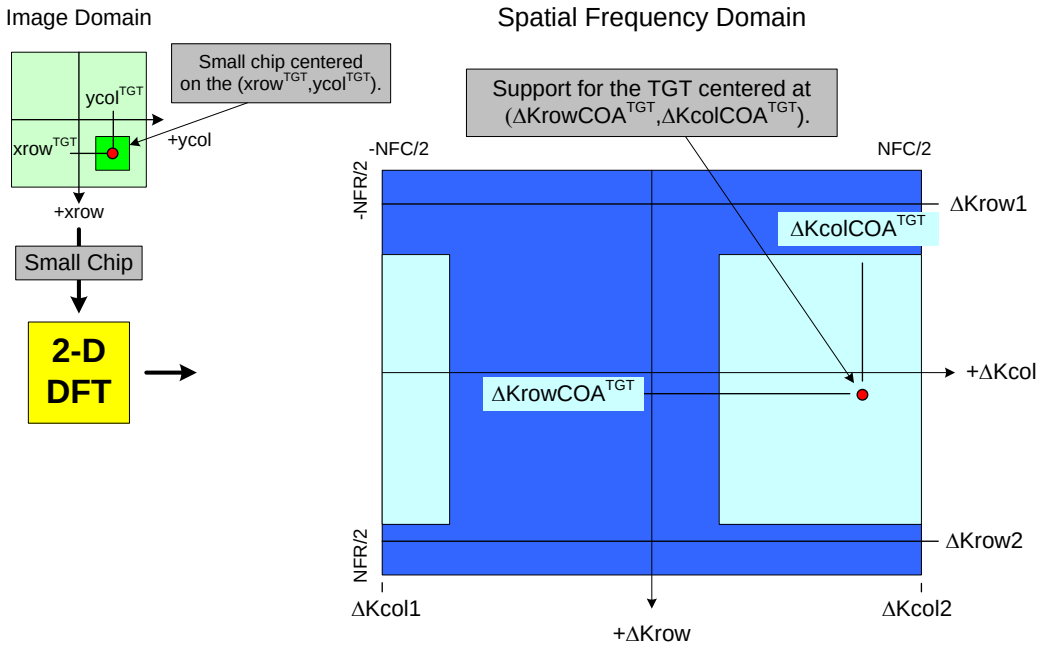


Figure 4.4-13 Spatial Frequency Support For Arbitrary Target

Offset frequencies ΔKrow and ΔKcol measured relative to the center sample $S_{KK}(0,0)$.

4.5 Collection Timeline Parameters

The parameters that describe the imaging collection timeline are summarized below. Refer to Table 3-5.

The SAR imaging collection timeline is specified by the Collection Start Time and the imaging collection duration. The Collection Start time, denoted CST, is specified in Coordinated Universal Time (UTC). The collection duration, denoted T_{COLL}, is specified in seconds. For a given collection, the CST and T_{COLL} are independent of the image products that are produced. An example collection timeline is shown in Figure 4.5-1. The CST is the reference for all time-based parameters. Parameters based on time in seconds relative to CST include the position versus time polynomials and COA time (t_{COA}) versus image grid location.

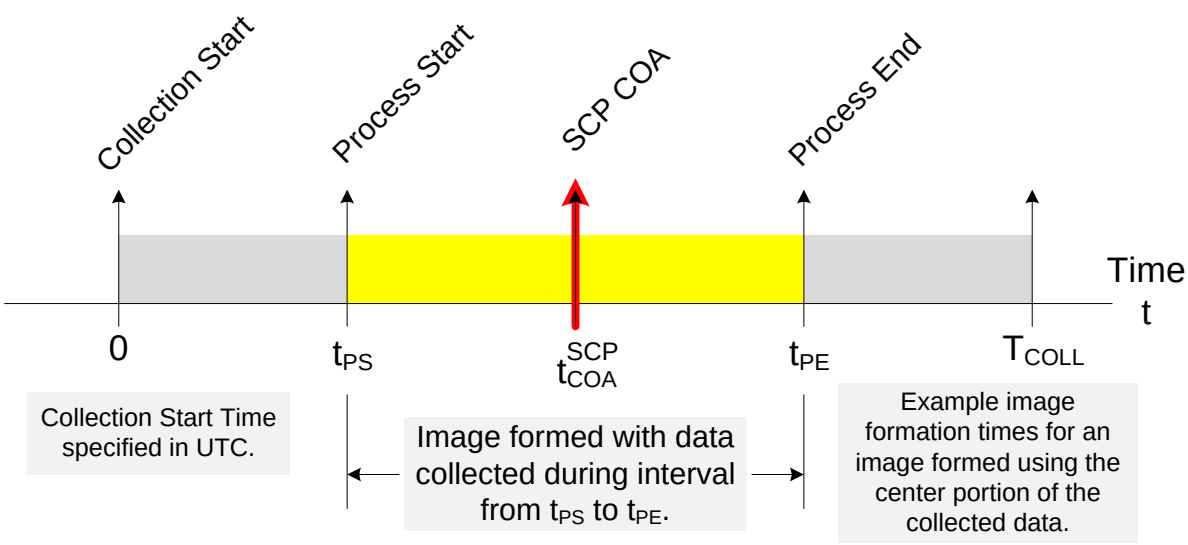


Figure 4.5-1 Collection Timeline
Collection timeline defined by Collection Start Time (CST) the duration (T_{COLL}).

The accurate exploitation of a given image product is not directly dependent upon the CST or the T_{COLL}. Exploitation processing makes use of time parameters expressed in seconds relative to CST. Shown in Figure 4.5-1 are times associated with an example image product. The image formation processing used data collected in the period from t_{PS} to t_{PE}. Times t_{PS} and t_{PE} are included in the Image Formation parameters (see Table 3-8). The image COA times are included in the Image Grid parameters (see Table 3-4).

XML: ImageFormation.TStartProc = t_{PS}
XML: ImageFormation.TEndProc = t_{PE}

The processing times, t_{PS} and t_{PE}, as well as the COA times are defined to be "reference times" in that they are used with the Aperture Reference Point (ARP) position versus time

polynomial. For a given vector of the collected Phase History Data (PHD), the reference time is computed as follows. For the pulse with transmit center time at t = txc and for which the center of the echo from the center collected range swath is received at time t = trc, the reference time is tref = (txc + trc)/2. The ARP position associated with the vector is approximately the mid-point between the transmit phase center at time txc and the receive phase center at time trc.

Parameters that describe the radar transmit and receive sequence may also be included. These optional parameters are recommended to be included in all products. The timeline is a sequence of Inter-Pulse Periods (IPPs). An IPP is often referred to as a Pulse Repetition Interval (PRI). The IPP includes one transmitted pulse and one listening window where the echoes are received and digitized to form a PHD vector. The IPP rate is referred to as the Pulse Repetition Frequency (PRF). While precise knowledge of the IPP sequence timing is needed for image formation processing, an approximate description will adequately support the analysis of the image products.

The IPP sequence that spans the collection is described by one or more sets of parameters. Each set of parameters spans a portion of the collection time. The sets of parameters are indexed by idx = 1 to NSets. The parameters included in each set are the following.

t_S(idx)	=	Start time of the interval (in sec).	XML: IPP.Set.TStart
t_E(idx)	=	End time of the interval (in sec).	XML: IPP.Set.TEnd
k_S(idx)	=	IPP index of the first IPP in interval.	XML: IPP.Set.IPPStart
k_E(idx)	=	IPP index of the last IPP in the interval.	XML: IPP.Set.IPPEnd
IPPPoly(idx)	=	IPP index polynomial, (cT2IPP(idx,m)).	XML: IPP.Set.IPPPoly

The IPPs that span the collection are indexed from k = k_S(1) to k_E(NSets). The IPP index polynomial converts time t in seconds relative to CST to IPP index value. For a given interval, time t_S(idx) is the start of IPP k_S(idx) and time t_E(idx) is the end of IPP k_E(idx). The IPP Index polynomial provides an estimate of the IPP index value for times from t_S(idx) to t_E(idx),

An example timeline spanned by three sets of IPP parameters is shown in Figure 4.5-2. At a given time t*, the corresponding IPP index k* is computed by selecting the polynomial that spans the time of interest. For time t* in the second interval, $t_S(2) \leq t^* < t_E(2)$, index k* is computed as follows. The instantaneous PRF at t* may also be computed.

$$k^* = \sum_{m=0}^{M_SET(2)} cT2IPP(2,m) \bullet (t^*)^m \qquad PRF(t^*) = \frac{d}{dt}\left(k(t^*)\right) = \sum_{m=1}^{M_SET(2)} m \bullet cT2IPP(2,m) \bullet (t^*)^{m-1}$$

The index k* takes on an integer value at the start of the IPP. For example, k* = 1000.0 indicates that t* is the start time of IPP 1000. For most SAR systems, the duration of any given IPP is actually an integer number of system clock cycles. For these systems, the polynomial fit can only approximate a varying IPP duration. For these systems, the

estimated IPP index and PRF are usually very accurate. The estimated PRF, for example, will usually accurately predict the location of ambiguities in range and azimuth.

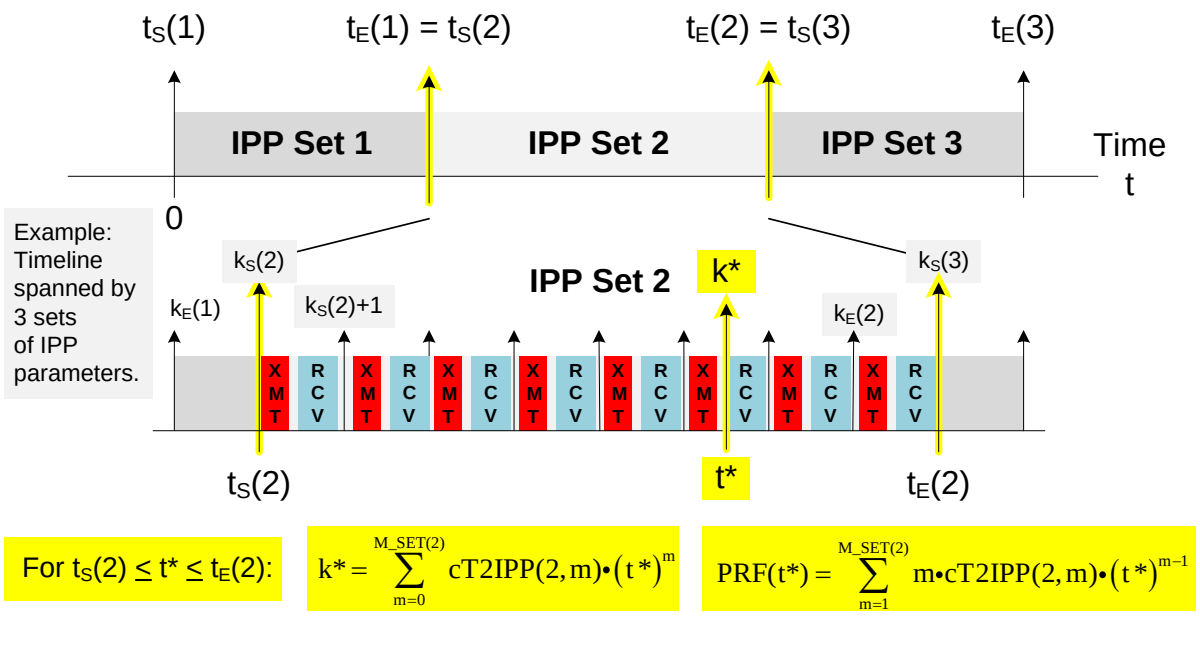


Figure 4.5-2 IPP Timing

Example timeline spanned by multiple IPP Index polynomials.

The IPP timing parameters are intended to reflect the true timing of the SAR system during a collection. For systems that used a short, repeating sequence on transmit, the IPP parameters will describe the individuals steps of the sequence. The repeating transmit sequence is described with Radar Collection structure TxSequence. See Table 3-7. Shown in Figure 4.5-3 is an example collection with alternating transmit polarizations (vertical polarization on one IPP and horizontal polarization on the next). Radar collection parameter Num_Tx_Steps = 2. For an image formed with data collected using only a single transmit polarization, the Image Formation parameter PRF_Scale_Factor = 1/2 indicating the Effective PRF is 1/2 of the actual PRF. See Table 3-8.

XML: RadarCollection.TxSequence size = 2 ⇔ NumTxSteps = 2
XML: ImageFormation.RcvChanProc.PRFScaleFactor = 1/2

Shown in Figure 4.5-4 is an example collection with a step-chirp set of waveforms. The transmitted pulse sequences through 3 distinct waveforms. Radar collection parameter Num_Tx_Steps = 3. For an image formed with the collected data, the Image Formation parameter PRF_Scale_Factor = 1/3 indicating the Effective PRF is 1/3 of the actual PRF.

XML: RadarCollection.TxSequence size = 3 ⇔ NumTxSteps = 3
XML: ImageFormation.RcvChanProc.PRFScaleFactor = 1/3

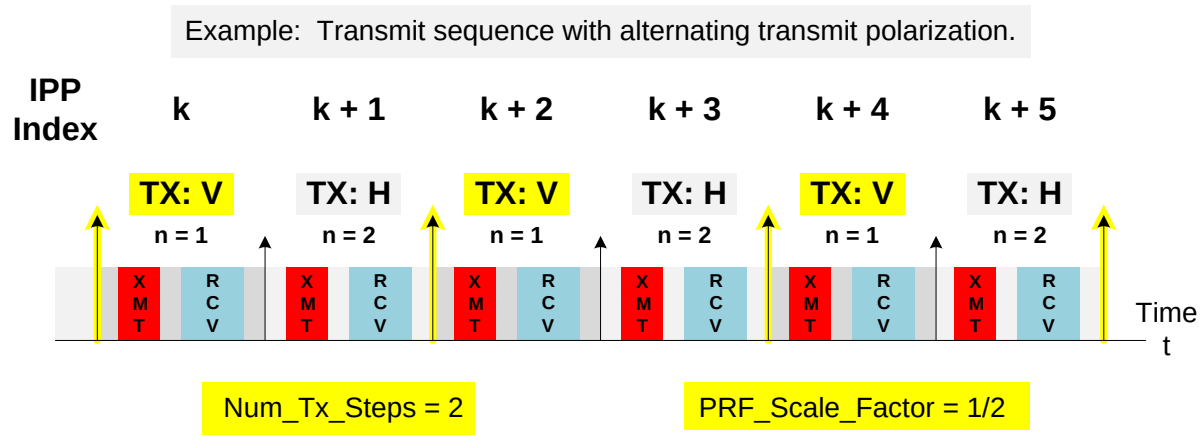


Figure 4.5-3 Transmit Sequence w/ Varying Polarization
IPP polynomial indicates the actual PRF. Effective PRF is 1/2 the actual PRF.

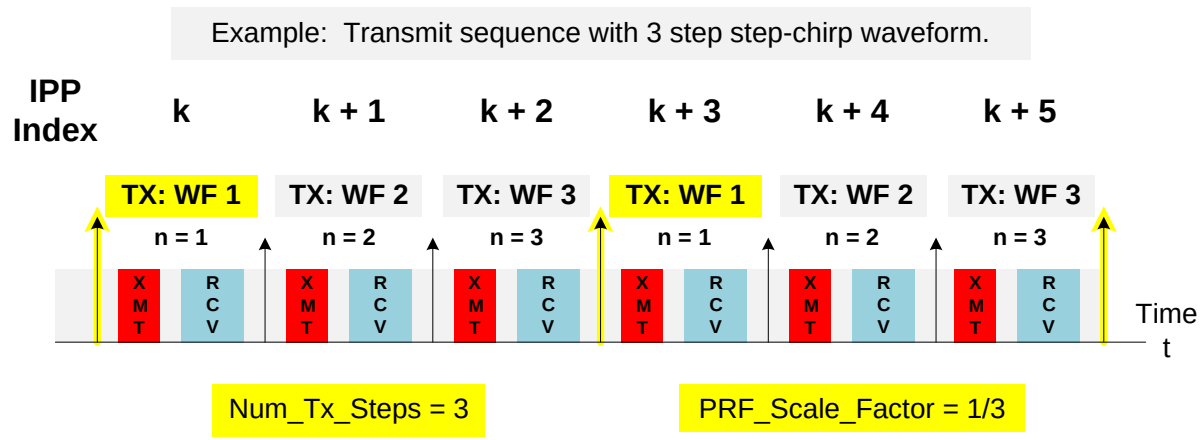


Figure 4.5-4 Transmit Sequence w/ Varying Waveform
IPP polynomial indicates the actual PRF. Effective PRF is 1/3 the actual PRF.

4.6 Reference Position Parameters

The parameters that describe the platform position(s) versus time during the imaging collection are summarized below. Refer to Table 3-6.

The SAR platform positions versus time are specified as vector polynomial functions of the collection time. For all images, the Aperture Reference Point (ARP) versus time is provided. The ARP is the platform position used for most image exploitation processing. The ARP position versus time is represented as a smooth polynomial function of time in seconds relative to Collection Start. For orbiting platforms, this will be a precise description of the position versus time. For airborne platforms, the ARP position versus time is an approximation to the true ARP position versus time trajectory. While the polynomial fit is typically inadequate for the initial motion compensation of the PHD, it is the correct position versus time for image exploitation processing. The ARP position versus time polynomial is recommended to be at least a second order fit.

Individual Aperture Phase Center (APC) positions versus time may be provided for platforms with separate transmit and receive aperture locations and/or antenna patterns. A single transmit APC, denoted TX, and one or more receive APCs, denoted RCV1, RCV2, etc. may be specified. An example SAR array with separate transmit and receive apertures is shown in Figure 4.6-1. Each APC position versus time is represented by a smooth polynomial function. The order of the APC polynomials should be the same as the order of the ARP polynomial.

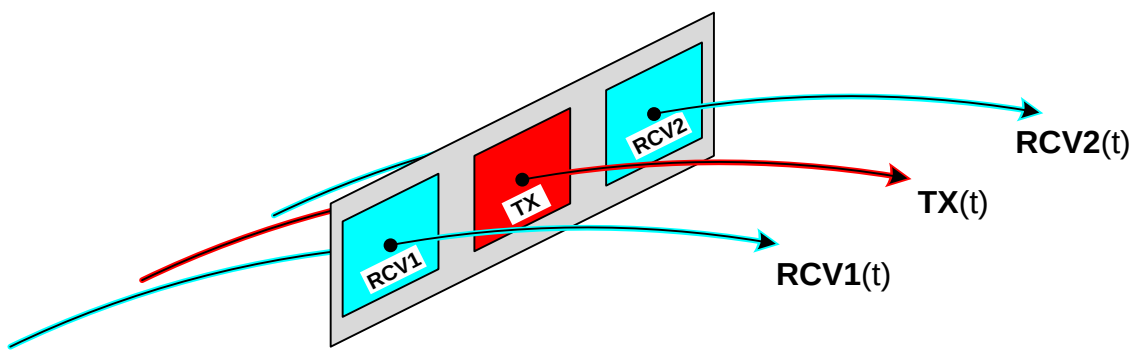


Figure 4.6-1 Platform With Multiple Apertures
Example platform w/ separate apertures for simultaneous collection of multiple polarizations.

The APC positions versus time are specified with parameter TxAPCPoly and the set of parameters RcvAPC. For the example shown in Figure 4.6-1, the size attribute of the parameter RcvAPC indicates the number of receive APCs used was 2. The index attribute of the RcvAPCPoly parameter identifies the receive APC number (RCV1 or RCV2).

XML: Position.RcvAPC	size = 2 ⇔ NumRcvAPCs = 2
XML: Position.RcvAPC.RcvAPCPoly	index = 1 ⇔ **RCV1**(t)

XML: Position.RcvAPC.RcvAPCPoly index = 2 ⇔ **RCV2**(t)

In addition to the platform positions versus time, a Ground Reference Point (GRP) position versus time may also be provided. The GRP position versus time is not needed for image exploitation. For systems that used a GRP in the planning and/or execution of the collections, it may be provided to give a more complete description of the collection.

4.7 Radar Collection Parameters

The parameters that describe the imaging collection are summarized below. Refer to Table 3-7. The Radar Collection parameters are independent of the particular image that has been produced. While many parameters are not needed for exploitation of the image contained in the product, they are available to provide context that may be useful.

4.7.1 Transmit Parameters

(1) Transmit Frequency

The minimum and maximum transmit frequency of the collection are provided (XML: TxFrequency.Min and TxFrequency.Max). For most SAR systems, a fixed band of frequencies is transmitted on all pulses. For systems that vary the bandwidth within the collection, the minimum frequency is the overall minimum frequency and the maximum is the overall maximum frequency.

An option is provided to express frequency values as offsets relative to a reference frequency, denoted Ref_Freq. Such a choice is defined as part of the product definition and is specified in the Program Specific Implementation Document. See Section 1.4. Products that have frequency values expressed as offsets are indicated by including the optional parameter Ref_Freq_Index (XML: RadarCollection.RefFreqIndex). The index value(s) and the corresponding reference frequency value(s) are selected as part of the product definition.

For a product that includes Ref_Freq_Index, the true frequency values are obtained by adding the value of the reference frequency to the parameter values contained in the product file.

$$\underbrace{\text{Tx.Frequency.Min(True)}}_{\text{True Value}} = \underbrace{\text{Tx.Frequency.Min(Product)}}_{\substack{\text{Value Included}\\ \text{In The Product}}} + \underbrace{\text{Ref_Freq}}_{\substack{\text{Defined In Program}\\ \text{Implmenation Document}}}$$

$$\underbrace{\text{Tx.Frequency.Max(True)}}_{\text{True Value}} = \underbrace{\text{Tx.Frequency.Max(Product)}}_{\substack{\text{Value Included}\\ \text{In The Product}}} + \underbrace{\text{Ref_Freq}}_{\substack{\text{Defined In Program}\\ \text{Implmenation Document}}}$$

Note: Frequency parameters whose values will be expressed as offsets when Ref_Freq_Index is included are identified in the tables that define them. See Tables 3-7, 3-8, 3-11 and 3-16.

(2) Waveform Parameters

The parameters that describe the transmitted waveform (i.e. pulse length, bandwidth, etc) and the receive demodulation may be included. A complete set of parameters may be included for systems that transmit a linear FM waveform. For most imaging collections, the same waveform is transmitted on every pulse. For such a system, the number of waveforms is set equal to one (size attribute NumWaveforms = 1). For systems that transmit a repeating sequence of waveforms, each waveform in the sequence can be described. The sequencing of the waveforms is specified with the transmit sequence parameters described below. For

example, a collection that employs a step-chirp waveform can be described with NumWaveforms set equal to the number of steps in the sequence. See Figure 4.5-4 for an example timeline.

An example of a system that uses a linear FM waveform with de-ramp on receive demodulation, often referred to as "stretch" demodulation, is shown in Figure 4.7-1. The parameters associated with the transmit waveform, the receive window and receive demodulation are shown.

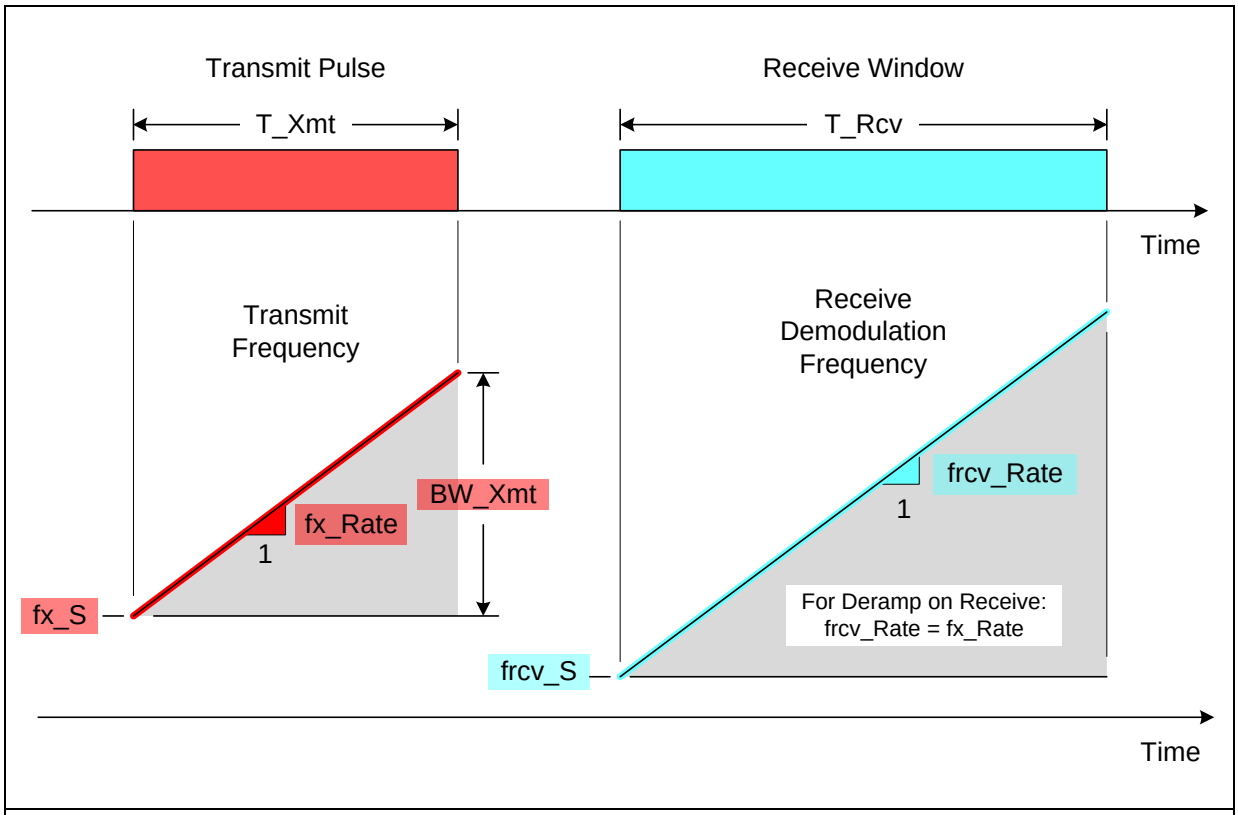


Figure 4.7-1 Linear FM Waveform Parameters
The linear FM waveform on transmit and the receive demodulation parameters.

(3) Transmit Polarization

The transmit polarization is included with all products. For most imaging collections, the same polarization is transmitted on every pulse. For such a collection, the transmit polarization is identified with a single parameter (XML: RadarCollection.TxPolarization). For collections that employ a repeating sequence of transmit polarizations, the value is set to "SEQUENCE". The most common transmit polarization sequence is alternating horizontal and vertical polarization on a per pulse basis. An example timeline for such a sequence is shown in Figure 4.5-3. The sequence of polarizations is then specified with the transmit sequence structure described below.

(4) Transmit Sequences

For an imaging collection that employed a repeating sequence of waveforms and/or transmit polarizations, the sequence may be described as shown in the example below. The number of steps in the sequence is NumTxSteps. The most commonly used transmit sequences vary either the waveform or the transmit polarization. Hence, the TxSequence structure only includes variation in these two parameters. The example below shows a sequence with 3 steps with the waveform the waveform varying.

XML: RadarCollection.TxSequence size = 3	⇔	NumTxSteps = 3
TxStep index = 1	⇔	TxStep 1
WFIndex = 1	⇔	WF 1 Transmitted
TxStep index = 2	⇔	TxStep 2
WFIndex = 2	⇔	WF 2 Transmitted
TxStep index = 3	⇔	TxStep 3
WFIndex = 3	⇔	WF 3 Transmitted

A sequence with NumTxSteps = 1 is allowed. This allows the products from SAR systems that use a sequence for some but not all collections to include the TxSequence structure in all image products.

4.7.2 Receive Data Channel Parameters

The receive data channels are described (XML: RcvChannels). The number of receive data channels is parameter NumRcvChans. The transmit/receive polarization for each channel is indicated. Also, for each data channel, the receive antenna phase center (APC) can also be identified. The receive APC index associates the receive data channel with a receive APC position included in the product. See Table 3-5. For many imaging collections, only one receive channel is collected with a single transmit/receive polarization. For these collections, the number of received data channels is set equal to 1 and the Tx:Rcv polarizations provided.

For imaging collections with multiple transmit/receive polarizations, the NumRcvChans indicates the number of unique transmit/receive polarization combinations collected. Two example collections demonstrate this. Consider an imaging collection with a fixed transmit polarization (e.g. TxPol = V) on all pulses and simultaneous collection of two receiver channels, one with RcvPol = V and one with RcvPol = H. The number of receive data channels is set equal to 2 and the Tx:Rcv polarizations are set to V:V and V:H. For this example the two data channels came from separate receive phase centers.

XML: RadarCollection.RcvChannels size = 2	⇔	NumRcvChans = 2
ChanParameters index = 1	⇔	Channel 1 Parameters
TxRcvPolarization = V:V		
RcvAPC = 1		

ChanParameters index = 2 ⇔ Channel 2 Parameters
TxRcvPolarization = V:H
RcvAPC = 2

Consider a second collection with alternating transmit polarization on a pulse-to-pulse basis (TxPol = V and TxPol = H) and simultaneous collection of two receiver channels (one with RcvPol = V and one with RcvPol = H). The data from each receiver channel is then separated to form two data channels available for image formation processing. For this collection, the number of receive data channels is set equal to 4 and the Tx:Rcv polarizations are set to V:V, V:H, H:V and H:H. For this example, receive data channels 1 and 2 were collected with receive APC 1 and receive data channels 3 and 4 were collected with receive APC 2.

XML: RadarCollection.RcvChannels size = 4 ⇔ NumRcvChans = 4
ChanParameters index = 1 ⇔ Channel 1 Parameters
TxRcvPolarization = V:V
RcvAPC = 1
ChanParameters index = 2 ⇔ Channel 2 Parameters
TxRcvPolarization = H:V
RcvAPC = 1
ChanParameters index = 3 ⇔ Channel 3 Parameters
TxRcvPolarization = V:H
RcvAPC = 2
ChanParameters index = 4 ⇔ Channel 4 Parameters
TxRcvPolarization = H:H
RcvAPC = 2

4.7.3 Area Imaged

The area imaged by the collection can be provided. This information is most useful when the area covered by the collection is larger than the area covered by the image contained in the product. This is most commonly the case for stripmap and dynamic stripmap mode collections. The imaged area is first identified by four area corner points, denoted APC(i) and indexed i = 1 to 4.

The imaged area also may be further specified by a rectangular region in a geo-located image display plane. The geo-located plane is specified by a reference point, denoted RPT, and two orthogonal unit vectors that lie in the plane, denoted **uX** and **uY**. An example is shown in Figure 4.7-2. The imaged area is a rectangle aligned with the X and Y unit vectors. The line index increases in the **uX** direction. The extent in the X direction is NL x ΔL and is located

by the values of L1 and the RPT line index. The sample index increases in the **uY** direction. The extent in the Y direction is NS x ΔS is located by the values of S1 and the RPT sample index.

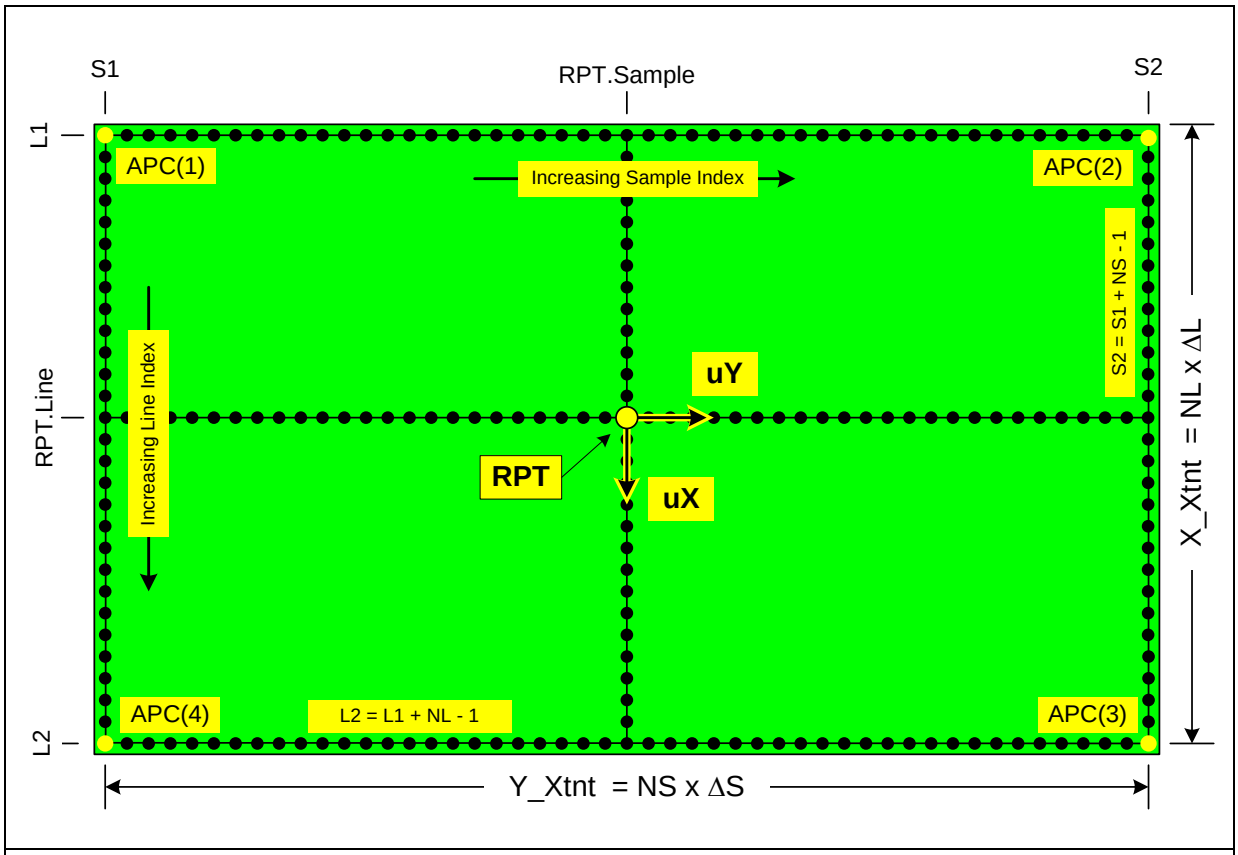


Figure 4.7-2 Rectangular Imaged Area
Area is a rectangle aligned with the X & Y direction in a geo-located plane.

4.8 Image Formation Parameters

The parameters that describe the image formation processing are summarized below. Refer to Table 3-8. The image formation parameters describe the data processed and the image formation algorithms that were applied to form the image contained in the product file.

4.8.1 Processed Data Parameters

(1) Receive Data Channels Processed

The receive data channel(s) that were processed to form the image are listed. For most imaging collections, the image formation processing is performed on an individual data channel (parameter NumChanProc = 1). The channel index values are defined in the Radar Collection structure (XML: RadarCollection.ReceiveChannels). See Table 3-7. The combined transmit/receive polarization for the image contained in the product is also provided (XML: TxRcvPolarizationProc).

The optional PRF scale factor parameter (XML: RcvChanProc.PRFScaleFactor) is provided as appropriate to indicate the when the effective PRF for the image formed is different than the true PRF. The effective PRF is useful in determining the location of the ambiguous returns in range and/or azimuth that may appear in the image. As described in Section 4.5, the collection timeline parameters provide the true PRF of the collection, PRF(t). At time t*, the true PRF is PRF(t*). Effective PRF is computed by multiplying by the scale factor, PRF_SF.

$$\text{Effective_PRF}(t^*) = \text{PRF}(t^*) \bullet \text{PRF_Scale_Factor}$$

(2) Phase History Data Processed

The portion of the collected Phase History Data (PHD) processed is provided. The processed portion of slow time is denoted t_{PS} to t_{PE}. See Section 4.5 and Figure 4.5-1. The portion of the collected frequency band processed is also provided (XML: TxFrequencyProc).

4.8.2 Processing Algorithms Applied

(1) Image Formation Algorithm

The Image Formation Algorithm is identified for the most commonly used image formation algorithms (XML: ImageFormAlgo). Currently, three image formation algorithms may be identified.

(1) Range & Azimuth Compression (RGAZCOMP)
(2) Polar Format Algorithm (PFA)
(3) Range Migration Algorithm (RMA)

For an image formed with one of these three algorithms, additional parameters specific to the algorithm are also included. The Range & Azimuth Compression algorithm is the simplest approach and is described in detail in Section 4.14. For images formed with the Polar Format Algorithm, the parameters provided accommodate image formation for an arbitrary image formation plane and are described in Section 4.15. For images formed with the Range Migration Algorithm, the primary variations of the algorithm (Omega-K, Chirp Scaling and

Range-Doppler) are accommodated. The RMA specific parameters are described in Section 4.16.

(2) Slow Time Beam Compensation

The parameter is provided to indicate if the signal modulation in slow time due to the antenna beamshape has been compensated (XML: STBeamComp). The beamshape compensation is applied for most stripmap and dynamic stripmap collections in order to achieve the desired azimuth impulse response. The compensation applied may be the same for the entire image (a global compensation) or a compensation that varies across the scene may be applied (a spatially variant compensation).

(3) Image Domain Beam Compensation

The parameter is provided to indicate if the variation in signal intensity across the image due the antenna beamshape has been compensated (XML: ImageBeamComp). For complex images that have not been compensated for beamshape, the antenna beamshape parameters may be provided that allow the compensation to be computed and applied when creating derived products.

(4) Auto Focus Corrections

The two parameters are provided to indicate if image-derived focus corrections have been applied (XML: AzAutoFocus and RgAutoFocus). Azimuth auto focus corrections are required for many SAR systems in order to achieve a well focused image. Range auto focus corrections may also be required. These corrections may or may not have been applied to the complex image product. For both types of correction, the same correction may be applied to the entire image (a global correction) or a correction that varies across the scene may be applied (a spatially variant correction).

4.8.3 Polarization Parameters

For systems that simultaneously collect multiple polarizations, a complete set of polarization distortion parameters may be provided with the image product. The distortion parameters are usually computed from dedicated calibration collections. The date and time of the calibration collections and/or the effective date for the distortion parameters may be provided.

The parameters provided are the elements of the following model that relates the true scattering matrix {**S**} to the observed scattering matrix {**O**} for a fully polarimetric system. An example collection from such a system is shown in the second example of Section 4.7.2. The distortion parameters provided are the elements A, F1, F2 and Q1 through Q4 in the following matrix equation.

$$\underbrace{\begin{bmatrix} O_{HH} & O_{VH} \\ O_{HV} & O_{VV} \end{bmatrix}}_{\text{Observed Scattering Matrix}} = A \bullet \underbrace{\begin{bmatrix} 1 & Q1 \\ Q2 & F1 \end{bmatrix}}_{\text{Receive Distortion Matrix}} \bullet \underbrace{\begin{bmatrix} S_{HH} & S_{VH} \\ S_{HV} & S_{VV} \end{bmatrix}}_{\text{True Scattering Matrix}} \bullet \underbrace{\begin{bmatrix} 1 & Q4 \\ Q3 & F2 \end{bmatrix}}_{\text{Transmit Distortion Matrix}}$$

Additionally, the estimated error statistics may be provided for the parameters A, F1 and F2 that provide accuracy estimates of the co-pole distortion corrections.

4.9 SCP Center Of Aperture Parameters

The SCP Center Of Aperture (COA) parameters describe the instantaneous imaging geometry of the Aperture Reference Point (ARP) relative to the SCP at the SCP COA time. Refer to Table 3-9. The SCP COA parameters are provided to allow direct search and discovery on common SAR geometry parameters. All SCP COA parameters are computed from the ARP position versus time, the SCP position and the SCP COA time.

The SCP COA time (t_{COA}) is the precise COA time for the SCP pixel and is equal to the constant coefficient of the COA time polynomial (see Grid.TimeCOAPoly). The ARP position, velocity and acceleration are computed by evaluating the ARP position versus time polynomial and its derivatives. Time t_{COA} is in seconds from collection start time. An example SCP COA geometry is shown in Figure 4.9-1. Parameters in bold are vector parameters.

SCP = SCP position in ECF coordinates.

$\mathbf{ARP}_{COA}$ = ARP position in ECF coordinates at time t_{COA}.
$\mathbf{VARP}_{COA}$ = ARP velocity in ECF coordinates at time t_{COA}.
$\mathbf{AARP}_{COA}$ = ARP acceleration in ECF coordinates at time t_{COA}.

The SCP COA parameters slant range (R_{COA}) and ground range (Rg_{COA}) are provided for discovery. The ground range is a simple estimate measured along a spherical earth model passing through the SCP. Parameters ARP_DEC_{COA} and SCP_DEC are the distances from the ECF origin (EC). Compute parameters as follows.

$$R_{COA} = \left|\mathbf{SCP} - \mathbf{ARP}_{COA}\right|$$ XML: SlantRange = R_{COA}

$$ARP_DEC_{COA} = \left|\mathbf{ARP}_{COA}\right| \qquad \mathbf{uARP}_{COA} = \frac{1}{ARP_DEC_{COA}} \bullet \mathbf{ARP}_{COA}$$

$$SCP_DEC = \left|\mathbf{SCP}\right| \qquad \mathbf{uSCP} = \frac{1}{SCP_DEC} \bullet \mathbf{SCP}$$

$$EA_{COA} = \cos^{-1}\left(\mathbf{uARP}_{COA} \bullet \mathbf{uSCP}\right)$$

$$Rg_{COA} = SRP_DEC \bullet EA_{COA}$$ XML: GroundRange = Rg_{COA}

The Side Of Track and the Doppler Cone Angle at COA (DCA_{COA}) are provided for discovery. The Side Of Track is set to “L” or “R”. The DCA is always a positive angle independent of the side of track. Unit vector $\mathbf{uLOS}_{COA}$ is from the ARP position at COA to the SCP. Parameter LOOK is set to +1 or -1 as shown below. Compute parameters as follows. The DCA_{COA} is in decimal degrees.

$$\mathrm{VM}_{\mathrm{COA}} = \left|\mathbf{VARP}_{\mathrm{COA}}\right| \qquad \mathbf{uVARP}_{\mathrm{COA}} = \frac{1}{\mathrm{VM}_{\mathrm{COA}}} \bullet \mathbf{VARP}_{\mathrm{COA}}$$

$$\mathbf{uLOS}_{\mathrm{COA}} = \frac{1}{\mathrm{R}_{\mathrm{COA}}} \bullet \left(\mathbf{SCP} - \mathbf{ARP}_{\mathrm{COA}}\right) \qquad \mathbf{LEFT}_{\mathrm{COA}} = \mathbf{uARP}_{\mathrm{COA}} \times \mathbf{uVARP}_{\mathrm{COA}}$$

$$\mathrm{DCA}_{\mathrm{COA}} = \underbrace{\cos^{-1}\left(\mathbf{uVARP}_{\mathrm{COA}} \bullet \mathbf{uLOS}_{\mathrm{COA}}\right)}_{\substack{\text{Angle on the interval} \\ \text{0 to 180 degrees.}}} \qquad \text{XML: DopplerConeAng} = \mathrm{DCA}_{\mathrm{COA}}$$

$$\mathrm{SideOfTrack} = \begin{cases} \mathrm{L}, & \mathbf{LEFT}_{\mathrm{COA}} \bullet \mathbf{uLOS}_{\mathrm{COA}} > 0 \\ \mathrm{R}, & \text{otherwise} \end{cases} \qquad \text{XML: SideOfTrack}$$

$$\mathrm{LOOK} = \begin{cases} +1, & \mathbf{LEFT}_{\mathrm{COA}} \bullet \mathbf{uLOS}_{\mathrm{COA}} > 0 \\ -1, & \text{otherwise} \end{cases}$$

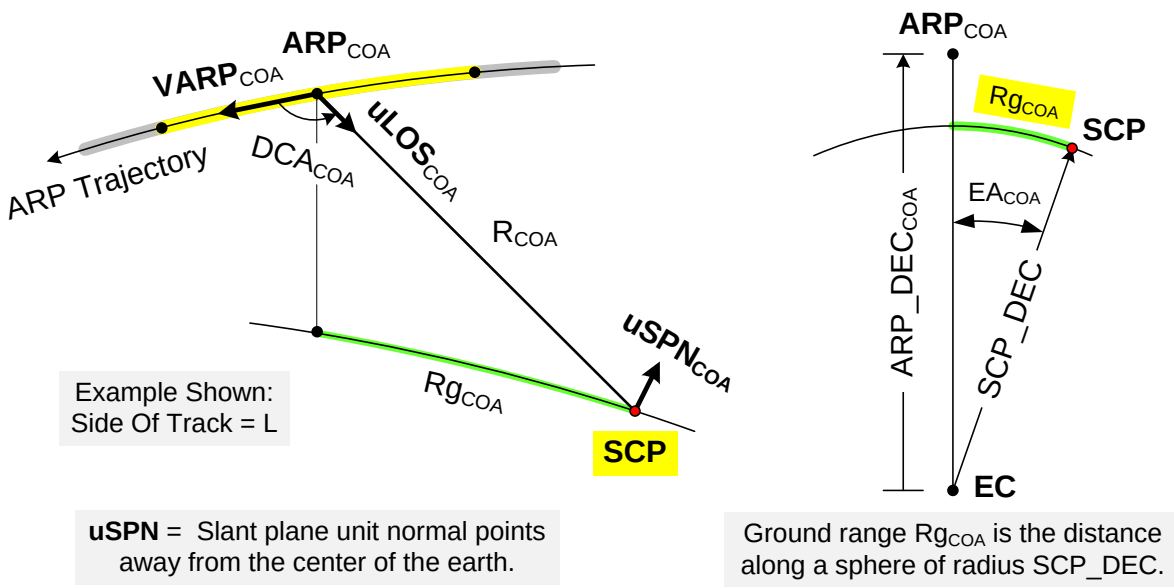


Figure 4.9-1 Geometry At SCP COA
The ARP position and velocity are shown at the SCP COA time.

The Earth Tangent Plane (ETP) at the SCP is the plane tangent to the surface of constant height above the WGS 84 ellipsoid (HAE) that contains the SCP. See Figure 4.9-2. The ETP is an approximation to the ground plane at the SCP. Define ground plane coordinates (GPX, GPY, GPZ) with origin at the SCP. The +GPZ axis is normal to the plane and in the direction of increasing HAE. The GPX and GPY axes line in the plane. The +GPX axis is defined by the ARP ETP nadir at COA ($\mathbf{AETP}_{\mathrm{COA}}$). The ground plane coordinates (GPC)

are a right-handed system. The GPC unit vectors in ECF coordinates (**uGPX**, **uGPY**, **uGPZ**) are computed as follows. Parameters SCP_Lat and SCP_Lon are the SCP WGS 84 geodetic latitude and longitude.

$$\mathbf{uGPZ} = \begin{bmatrix} \cos(\text{SCP_Lon})\bullet\cos(\text{SCP_Lat}) \\ \sin(\text{SCP_Lon})\bullet\cos(\text{SCP_Lat}) \\ \sin(\text{SCP_Lat}) \end{bmatrix}$$ ETP Unit Normal

$$\text{ARP_GPZ}_{\text{COA}} = \left(\mathbf{ARP}_{\text{COA}} - \mathbf{SCP}\right)\bullet\mathbf{uGPZ}$$ ARP GPZ coordinate at COA

$$\mathbf{AETP}_{\text{COA}} = \mathbf{ARP}_{\text{COA}} - \mathbf{uGPZ}\bullet\text{ARP_GPZ}_{\text{COA}}$$

$$\text{ARP_GPX}_{\text{COA}} = \left|\mathbf{AETP}_{\text{COA}} - \mathbf{SCP}\right|$$ ARP GPX coordinate at COA

$$\mathbf{uGPX} = \frac{1}{\text{ARP_GPX}_{\text{COA}}}\bullet\left(\mathbf{AETP}_{\text{COA}} - \mathbf{SCP}\right) \qquad \mathbf{uGPY} = \mathbf{uGPZ}\times\mathbf{uGPX}$$

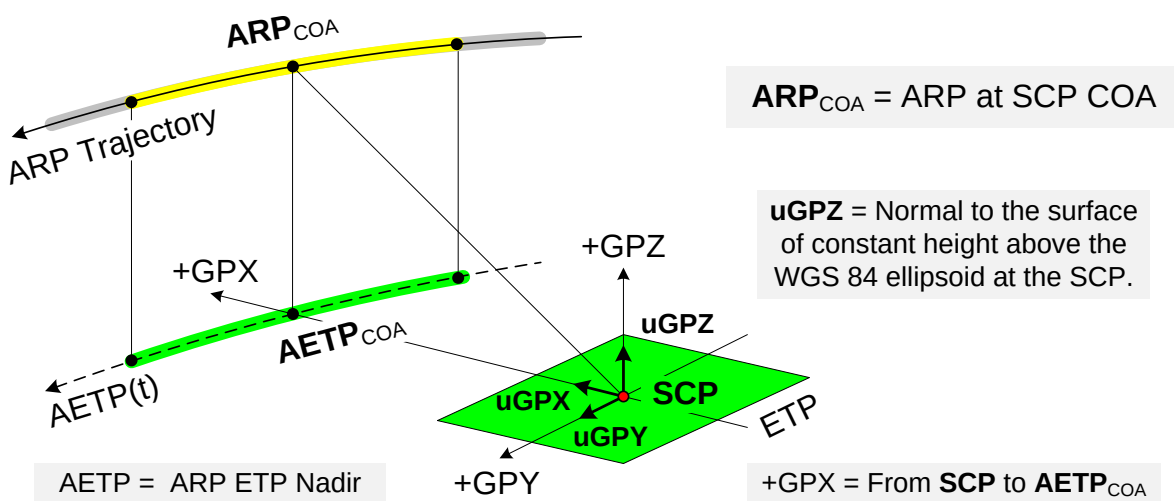


Figure 4.9-2 SCP Earth Tangent Plane
Ground Plane coordinate axes GPX and GPY lie in the ETP.

The ARP grazing angle (GRAZ) and incidence angle (INCD) are provided for discovery. See Figure 4.9-3. The cosine and sine of the grazing angle (cosGRAZ and sinGRAZ) are computed from the ARP GP coordinates at COA. Angles are in decimal degrees.

$$\text{cosGRAZ} = \frac{\text{ARP_GPX}_{\text{COA}}}{\text{R}_{\text{COA}}} \qquad \text{sinGRAZ} = \frac{\text{ARP_GPZ}_{\text{COA}}}{\text{R}_{\text{COA}}}$$

$$\mathrm{GRAZ} = \underbrace{\cos^{-1}\left(\cos\mathrm{GRAZ}\right)}_{\substack{\text{Angle on the interval}\\ \text{0 to 90 degrees.}}}$$ XML: GrazeAng = GRAZ

$$\mathrm{INCD} = 90.0 - \mathrm{GRAZ}$$ XML: IncidenceAng = INCD

The SAR slant plane (SP) is a plane defined at an instant in time and with respect to a point in the scene being imaged. The SCP slant plane at COA is the plane that contains the ARP position and velocity at COA and the SCP. Define slant plane coordinates (SPX, SPY, SPZ) with origin at the SCP. The +SPZ axis is normal to the plane and in the direction of increasing HAE. The SPX and SPY axes line in the plane. The +SPX axis is the along the line from the SCP to ARP at COA. The slant plane coordinates (SPC) are a right-handed system. The SPC unit vectors in ECF coordinates (**uSPX**, **uSPY**, **uSPZ**) are computed as follows.

$$\mathbf{SPZ} = \mathrm{LOOK}\bullet\left(\mathbf{uVARP}_{\mathrm{COA}} \times \mathbf{uLOS}_{\mathrm{COA}}\right) \qquad \mathbf{uSPZ} = \frac{1}{\left|\mathbf{SPZ}\right|}\bullet\mathbf{SPZ}$$

$$\mathbf{uSPX} = -\mathbf{uLOS}_{\mathrm{COA}} \qquad \mathbf{uSPY} = \mathbf{uSPZ} \times \mathbf{uSPX}$$

The slant plane coordinates are defined such that the ARP position and velocity at COA are as shown below. The ARP velocity at COA lies in the plane. For a left looking geometry, $\mathrm{VARP_SPY}_{\mathrm{COA}} > 0$. For a right looking geometry, $\mathrm{VARP_SPY}_{\mathrm{COA}} < 0$.

$$\mathbf{ARP}_{\mathrm{COA}} = \underbrace{\begin{bmatrix} \mathrm{R}_{\mathrm{COA}} \\ 0 \\ 0 \end{bmatrix}}_{\substack{\text{Slant Plane}\\ \text{Coordinates}}} \qquad \mathbf{VARP}_{\mathrm{COA}} = \underbrace{\begin{bmatrix} \mathrm{VARP_SPX}_{\mathrm{COA}} \\ \mathrm{VARP_SPY}_{\mathrm{COA}} \\ 0 \end{bmatrix}}_{\substack{\text{Slant Plane}\\ \text{Coordinates}}}$$

The SCP slant plane slope angle (SLOPE) is provided for discovery. The slope angle is the angle between the ETP normal and the SCP SP normal. The slope angle is expressed as a positive value. The slope angle is computed as follows.

$$\mathrm{SLOPE} = \underbrace{\cos^{-1}\left(\mathbf{uGPZ}\bullet\mathbf{uSPZ}\right)}_{\substack{\text{Angle on the interval}\\ \text{0 and 90 degrees.}}}$$ XML: SlopeAng = SLOPE

The imaging direction and the layover direction are useful discovery parameters when selecting images of a given scene. The imaging direction is given by the Azimuth Angle (AZIM) and the layover direction is given by the Layover Angle (LAYOVER). See Figure 4.9-3. Both angles are measured in the ETP. Both angles are measured clockwise from north at the SCP. The azimuth angle indicates the direction of the incident illumination at COA. The layover angle indicates the direction a point above the SCP will layover at COA. The unit vectors that lie in the ETP in the north and east directions, **uNORTH** and **uEAST**, are computed as follows. Unit vectors **uNORTH** and **uEAST** are in ECF coordinates.

$$\mathbf{uEAST} = \begin{bmatrix} -\sin(\text{SCP_Lon}) \\ \cos(\text{SCP_Lon}) \\ 0 \end{bmatrix} \qquad \mathbf{uNORTH} = \mathbf{uGPZ} \times \mathbf{uEAST}$$

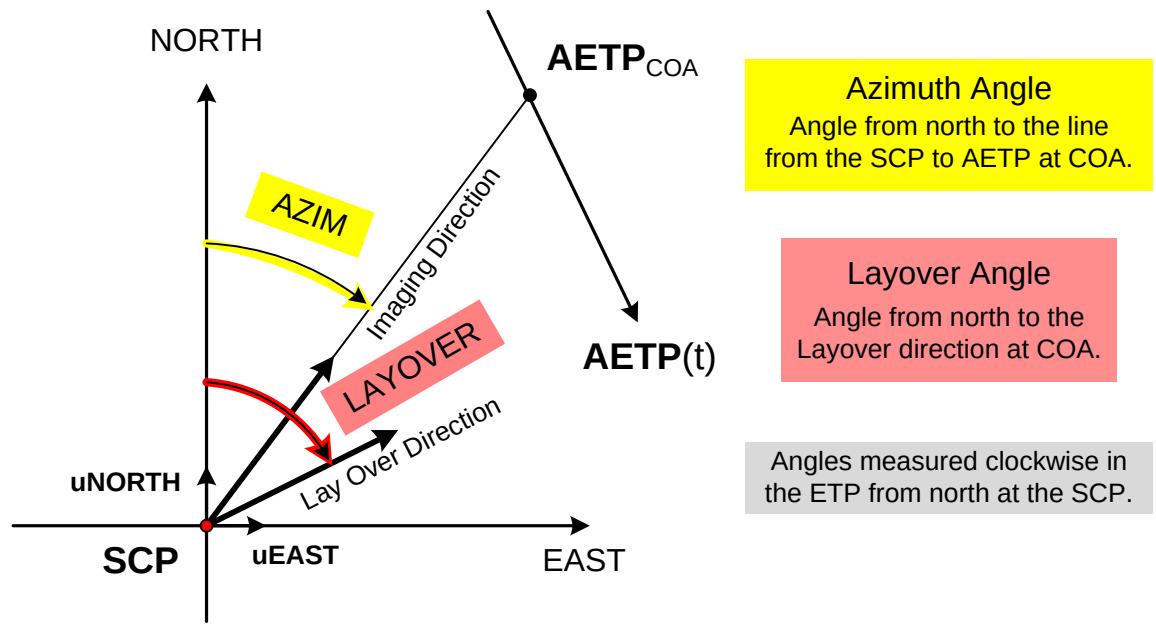


Figure 4.9-3 Azimuth & Layover Directions
Azimuth Angle & Layover Angle are measured in the ETP at COA.

The azimuth angle is computed by using the unit vector in the +GPX direction (**uGPX**).

$$\text{AZ_NORTH} = \text{u}\mathbf{NORTH} \bullet \mathbf{uGPX} \qquad \text{AZ_EAST} = \mathbf{uEAST} \bullet \mathbf{uGPX}$$

$$\text{AZIM} = \underbrace{\tan^{-1}\left(\text{AZ_EAST} \big/ \text{AZ_NORTH} \right)}_{\substack{\text{Four quadrant ArcTan Function.} \\ \text{Angle on the interval 0 to 360 degrees.}}} \qquad \text{XML: AzimAng = AZIM}$$

The layover direction vector in the ETP at COA, denoted $\mathbf{LODIR}_{COA}$, is computed by projecting the ETP unit normal (**uGPZ**) into the ETP along the slant plane unit normal (**uSPZ**). The projection distance is 1/cos(SLOPE). The layover angle is computed from the layover direction vector.

$$\mathbf{LODIR}_{COA} = \mathbf{uGPZ} - \frac{1}{\cos\text{SLOPE}} \bullet \mathbf{uSPZ}$$

$$\text{LO_NORTH} = \text{u}\mathbf{NORTH} \bullet \mathbf{LODIR}_{COA} \qquad \text{LO_EAST} = \mathbf{uEAST} \bullet \mathbf{LODIR}_{COA}$$

$$\text{LAYOVER} = \underbrace{\tan^{-1}\left(\text{LO_EAST} \big/ \text{LO_NORTH}\right)}_{\substack{\text{Four quadrant ArcTan Function.} \\ \text{Angle on the interval 0 to 360 degrees.}}} \qquad \text{XML: LayoverAng = LAYOVER}$$

The Grazing Plane and the Plane of Incidence are two additional planes also defined at an instant in time and with respect to a point in the scene being imaged. The SCP Grazing Plane (GZP) at COA is the plane that contains the ARP position at COA, the SCP and the GPY axis. The SCP Plane of Incidence (POI) at COA is the plane that contains the SCP, the GPY axis and the Grazing Plane normal. See Figure 4.9-4. The GZP is used as the image formation plane for some processing systems. The POI is useful when describing the polarization of the transmitted waveform. The Grazing Plane unit normal vector is denoted **uZI**. Vector **uZI** in ECF coordinates is computed as follows.

$$\mathbf{uZI} = \mathbf{uGPZ} \bullet \cos\text{GRAZ} - \mathbf{uGPX} \bullet \sin\text{GRAZ}$$

The twist angle (TWST) is provided for discovery. The twist angle, sometimes referred to as the tilt angle, is the angle in the POI from the +GPY axis and to the +SPY axis. See Figure 4.9-3. The twist angle is computed as follows.

$$\text{TWST} = \underbrace{-\sin^{-1}\left(\mathbf{uGPY} \bullet \mathbf{uSPZ}\right)}_{\substack{\text{Angle on the interval} \\ \text{-90 to 90 degrees.}}} \qquad \text{XML: TwistAng = TWST}$$

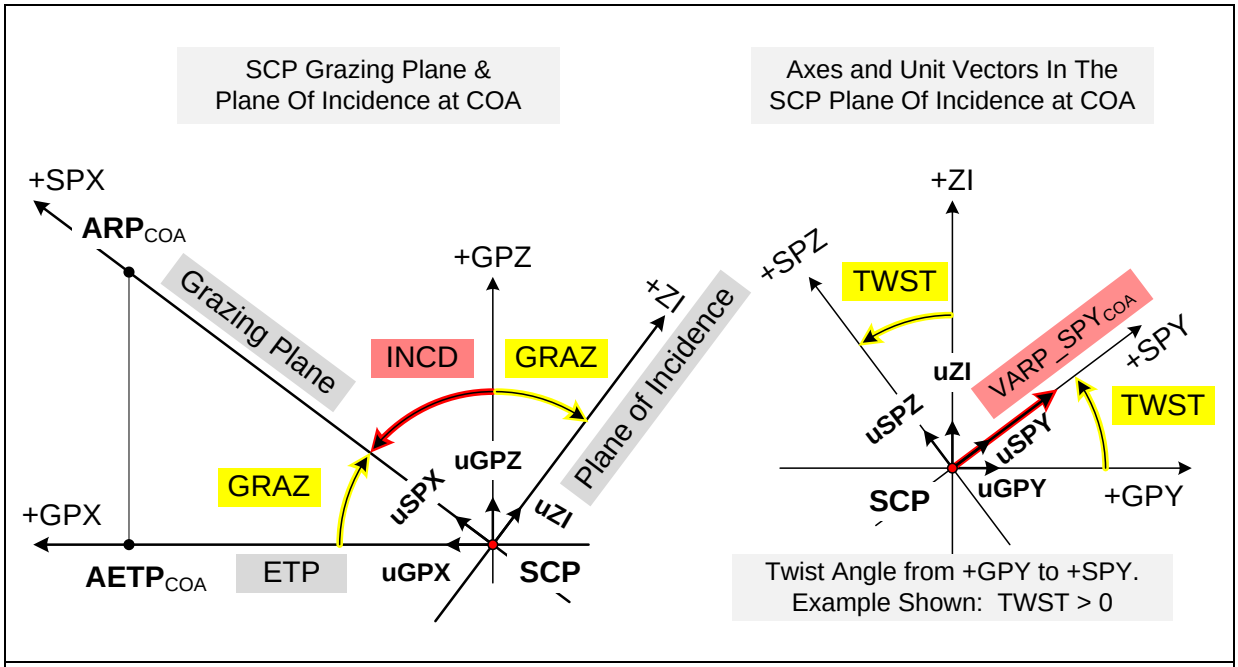


Figure 4.9-4 SCP Grazing Plane & Plane Of Incidence
The grazing (GRAZ), incidence (INCD) and twist (TWST) angles are shown.

Note: The twist or tilt angle in other descriptions may use a different convention for determining positive and negative angles. For the convention defined above, the twist angle will tend to be positive for left looking and closing geometries or right looking and opening geometries. The twist angle will go to zero near broadside for both left and right looking collections.

The Direction Cosine Matrix that relates positions expressed in the Ground Plane coordinates to positions expressed in Slant Plane coordinates is shown below. The coordinates systems are related by two Euler rotations, R_2(-GRAZ) and R_1(TWST). The first rotation, R_2(-GRAZ), is a negative rotation about the +GPY axis. The second rotation, R_1(TWST), is a positive rotation about the +SPX axis.

$$\mathbf{P}_{\mathrm{SPC}} = \mathrm{DCM}_{\mathrm{GPC}}^{\mathrm{SPC}} \bullet \mathbf{P}_{\mathrm{GPC}} \qquad \mathrm{DCM}_{\mathrm{GPC}}^{\mathrm{SPC}} = \mathrm{R}_1(\mathrm{TWST}) \bullet \mathrm{R}_2(-\mathrm{GRAZ})$$

$$\underbrace{\begin{bmatrix} \mathrm{P_SPX} \\ \mathrm{P_SPY} \\ \mathrm{P_SPZ} \end{bmatrix}}_{\substack{\text{Position in} \\ \text{SP Coordinates}}} = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{cosTWST} & \mathrm{sinTWST} \\ 0 & -\mathrm{sinTWST} & \mathrm{cosTWST} \end{bmatrix}}_{\mathrm{R}_1(\mathrm{TWST})} \bullet \underbrace{\begin{bmatrix} \mathrm{cosGRAZ} & 0 & \mathrm{sinGRAZ} \\ 0 & 1 & 0 \\ -\mathrm{sinGRAZ} & 0 & \mathrm{cosGRAZ} \end{bmatrix}}_{\mathrm{R}_2(\text{-}\mathrm{GRAZ})} \bullet \underbrace{\begin{bmatrix} \mathrm{P_GPX} \\ \mathrm{P_GPY} \\ \mathrm{P_GPZ} \end{bmatrix}}_{\substack{\text{Position in} \\ \text{GP Coordinates}}}$$

4.10 Radiometric Parameters

The radiometric parameters that may be included in an image product are summarized below. Refer to Table 3-10. The parameters available provide an estimate of the noise level in the image and a set of scale factors that convert pixel power level to radar cross section.

The complex image signal array is denoted S_{II}(row,col) where each pixel has a real and imaginary component. The pixel power value, sometimes referred to as the pixel intensity, is P_{II}(row,col), where P_{II}(row,col) is the sum of the squares of the real and imaginary components. A power level may also be expressed in decibels, P_dB_{II}(row,col), relative to power level 1.0.

$$S_{II}(\text{row,col}) = \text{Real}\left(S_{II}(\text{row,col})\right) + j \bullet \text{Imag}\left(S_{II}(\text{row,col})\right)$$

$$P_{II}(\text{row,col}) = \text{Real}\left(S_{II}(\text{row,col})\right)^2 + \text{Imag}\left(S_{II}(\text{row,col})\right)^2$$

$$P_dB_{II}(\text{row,col}) = 10 \bullet \log_{10}\left(P_{II}(\text{row,col})\right)$$

In the descriptions that follow, SCP pixel-centered indices (irow,icol) and image coordinates (xrow,ycol) are used to address the image signal array as a continuous two-dimensional space. The image pixel values {S_{II}(row,col)} are considered to be the discrete samples of a continuous, two-dimensional image signal at the integer values of indices (irow,icol). See Section 4.4.1.

For the parameters related to image signal power for inherently random signals, the term power refers to the expected value of the signal power. For a noise power value, the value is the expected value of the noise power at a given image location. For the clutter reflectivity scale factors, the scale factors relate the expected value of the clutter power to the clutter-based reflectivity.

4.10.1 Noise Power Level

The noise power level as a function of image location can be included in the image product. The noise power level is expressed as a two-dimensional polynomial of the image coordinates. At image grid location (xrow,ycol), the noise power level estimate PN_dB(xrow,ycol) is computed as follows.

$$\text{NoisePoly}(m,n) = \text{cNDB}(m,n), \quad m = 0 \text{ to M_NDB}, \quad n = 0 \text{ to N_NDB}$$

$$\text{PN_dB}(\text{xrow,ycol}) = \sum_{m=0}^{\text{M_NDB}} \sum_{n=0}^{\text{N_NDB}} \text{cNDB}(m,n) \bullet (\text{xrow})^m \bullet (\text{ycol})^n$$

The noise level estimate may be one of two types – absolute or relative – as indicated by parameter NoiseLevelType. For an absolute noise level, a power estimate of PN_dB(xrow,ycol) = 20.0 dB indicates the expected noise power is PN(xrow,ycol) = 100.0. For a relative noise level, a noise power estimate PN_dB(xrow,ycol) = 3.01 dB indicates the

noise power is 3.01 dB higher than the noise level at the SCP pixel and the ratio PN(xrow,ycol) / PN(0,0) = 2.0.

4.10.2 Target RCS Scale Factor

The relationship between target radar cross section (RCS) and image signal power can be included in the image product. The relationship between point target RCS and image signal power is expressed as a two-dimensional polynomial of the image coordinates. At image grid location (xrow,ycol), the RCS scale factor RCS_SF(xrow,ycol), is computed as follows.

$$\text{RCSSFPoly}(m,n) = \text{cRCS}(m,n), \quad m = 0 \text{ to } M_RCS, \quad n = 0 \text{ to } N_RCS$$

$$\text{RCS_SF}(\text{xrow},\text{ycol}) = \sum_{m=0}^{M_RCS} \sum_{n=0}^{N_RCS} \text{cRCS}(m,n) \bullet (\text{xrow})^m \bullet (\text{ycol})^n$$

The RCS scale factor relates image signal power for an ideal point scatterer to RCS in square meters. For a point target with impulse response centered at (xrow,ycol) and peak image power P_TGT_{II}(xrow,ycol), the RCS is computed by scaling the peak image power value.

$$\text{Target RCS}(m^2) = \text{RCS_SF}(\text{xrow},\text{ycol}) \bullet P_TGT_{II}(\text{xrow},\text{ycol})$$

The scale factor RCS_SF(xrow,ycol) is computed for a target located at the same Height Above the Ellipsoid (HAE) as the SCP. It is also computed for P_TGT_{II}(xrow,ycol) being the peak signal response for the focused target with impulse response.

4.10.3 Clutter Reflectivity Scale Factors

The relationship between image signal power and clutter reflectivity can be included in the image product. Image power to clutter reflectivity scale factors may be included for clutter reflectivity parameters Sigma-Zero (σ^0), Beta-Zero (β_0) and/or Gamma-Zero (γ_0). For a given clutter reflectivity parameter, the image power to clutter reflectivity scale factor is a function of the image location. For example, at image location (xrow,ycol), the value of clutter reflectivity Sigma-Zero that produces image power P_{II}(xrow,ycol) is as follows.

$$\text{Sigma-Zero} = \text{SigmaZero_SF}(\text{xrow},\text{ycol}) \bullet P_{II}(\text{xrow},\text{ycol})$$

(1) Sigma-Zero Scale Factor

The Sigma-Zero scale factor is expressed as a two-dimensional polynomial of the image coordinates. At image grid location (xrow,ycol), the scale factor SigmaZero_SF(xrow,ycol) is computed as follows.

$$\text{SigmaZeroPoly}(m,n) = \text{cSIG}(m,n), \quad m = 0 \text{ to } M_SIG, \quad n = 0 \text{ to } N_SIG$$

$$\text{SigmaZero_SF}(\text{xrow},\text{ycol}) = \sum_{m=0}^{M_SIG} \sum_{n=0}^{N_SIG} \text{cSIG}(m,n) \bullet (\text{xrow})^m \bullet (\text{ycol})^n$$

The value of clutter reflectivity Sigma-Zero that produces a given image power is the image power P_{II}(xrow,ycol) multiplied by the scale factor.

$$\text{Sigma-Zero} = \text{SigmaZero_SF}(\text{xrow},\text{ycol}) \bullet P_{II}(\text{xrow},\text{ycol})$$

(2) Beta-Zero Scale Factor

The Beta-Zero scale factor is expressed as a two-dimensional polynomial of the image coordinates. At image grid location (xrow,ycol), the scale factor BetaZero_SF(xrow,ycol) is computed as follows.

$$\text{BetaZeroPoly}(m,n) = \text{cBETA}(m,n), \quad m = 0 \text{ to M_BETA}, \quad n = 0 \text{ to N_ BETA}$$

$$\text{BetaZero_SF}(\text{xrow},\text{ycol}) = \sum_{m=0}^{\text{M_BETA}} \sum_{n=0}^{\text{N_BETA}} \text{cBETA}(m,n) \bullet (\text{xrow})^m \bullet (\text{ycol})^n$$

The value of clutter reflectivity Beta-Zero that produces a given image power is the image power P_{II}(xrow,ycol) multiplied by the scale factor.

$$\text{Beta-Zero} = \text{BetaZero_SF}(\text{xrow},\text{ycol}) \bullet P_{II}(\text{xrow},\text{ycol})$$

(3) Gamma-Zero Scale Factor

The Gamma-Zero scale factor is expressed as a two-dimensional polynomial of the image coordinates. At image grid location (xrow,ycol), the scale factor GammaZero_SF(xrow,ycol) is computed as follows.

$$\text{GammaZeroPoly}(m,n) = \text{cGMMA}(m,n), \quad m = 0 \text{ to M_GMMA}, \quad n = 0 \text{ to N_ GMMA}$$

$$\text{GammaZero_SF}(\text{xrow},\text{ycol}) = \sum_{m=0}^{\text{M_GMMA}} \sum_{n=0}^{\text{N_GMMA}} \text{cGMMA}(m,n) \bullet (\text{xrow})^m \bullet (\text{ycol})^n$$

The value of clutter reflectivity Gamma-Zero that produces a given image power is the image power P_{II}(xrow,ycol) multiplied by the scale factor.

$$\text{Gamma-Zero} = \text{GammaZero_SF}(\text{xrow},\text{ycol}) \bullet P_{II}(\text{xrow},\text{ycol})$$

4.10.4 Clutter Reflectivity Details

For a given terrain, the clutter reflectivity parameters σ^0, β_0 and γ_0 are dimensionless ratios that relate the area of an image resolution cell to the equivalent RCS of the cell containing ground clutter. The RCS of the ground clutter in the cell is equal to the area of the resolution cell times the clutter reflectivity. For a given reflectivity parameter, the area of the clutter cell is expressed after projection to a given plane. The plane of the projection is unique to each parameter.

Sigma-Zero(σ^0):	Ratio between RCS and the area of the resolution cell projected to the ground plane.
Beta-Zero(β_0):	Ratio of the RCS to the area of the resolution cell projected into the slant plane.
Gamma-Zero(γ_0):	Ratio between RCS and the area of the clutter cell projected into plane of incidence which is normal to the line of sight.

For a given resolution cell in the image, the parameters have the following relationship. The grazing angle and the slope angle are dependent upon the ground plane selected for computing the area of the resolution cell. See Section 4.9.

$$\text{Sigma-Zero} = \text{Beta-Zero} \bullet \cos(\text{SLOPE}) = \text{Gamma-Zero} \bullet \sin(\text{GRAZ})$$

The Sigma-Zero scale factor provided in an image product is computed based upon the projection of the image points onto the surface of constant Height Above Ellipsoid (HAE) passing through the SCP. Each image point is projected at the COA for the point. For each image point, the ground plane is the Earth Tangent Plane (ETP) that is tangent to the surface of constant HAE. The area of the resolution cell in the ETP is the ground plane area. The slope and grazing angles will vary slightly as the ETP geometry varies from image point to image point.

An example resolution cell projected to the ground plane is shown in the left half of Figure 4.10-1. The area in ground plane, $AREA_{GP}$, is computed from the resolution cell dimensions in the ground plane, ΔR_{GP} and ΔA_{GP}. The RCS for the ground clutter in the cell, RCS_{CLTR}, is the $AREA_{GP}$ scaled by Sigma-Zero.

$$AREA_{GP} = \Delta R_{GP} \bullet \Delta A_{GP} \qquad RCS_{CLTR} = \text{Sigma-Zero} \bullet AREA_{GP}$$

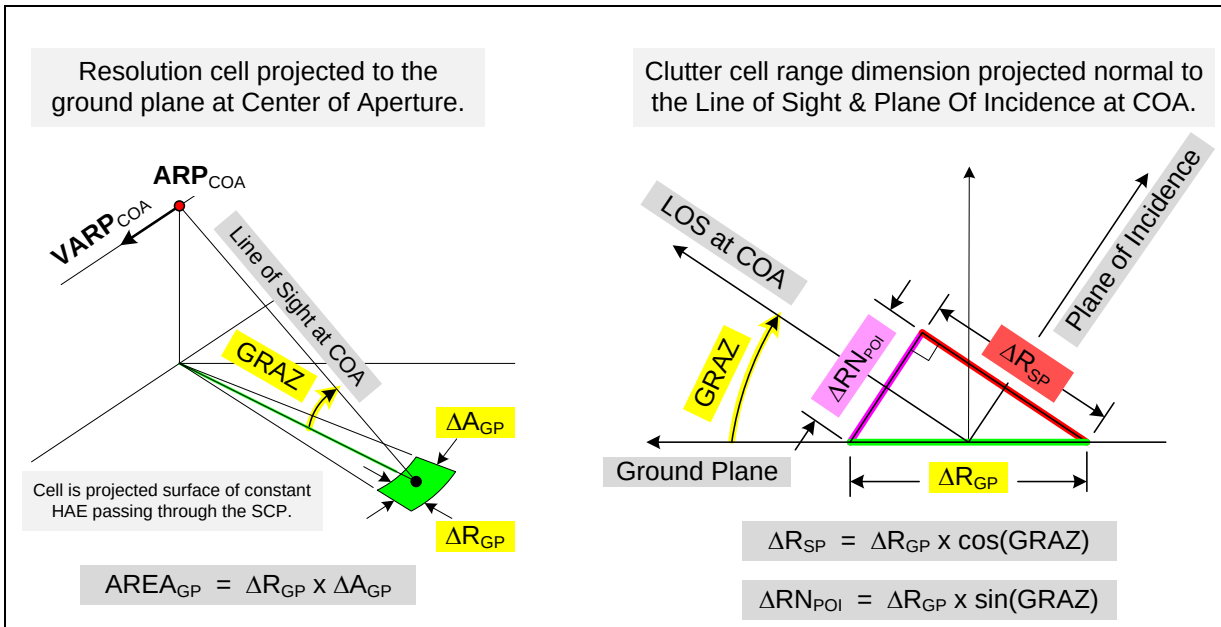


Figure 4.10-1 Resolution Cell In The Ground Plane

Clutter cell dimensions in the ground plane (left) and projected range cell dimensions (right).

The projection to the slant plane and to the plane of incidence is shown in the right half of Figure 4.10-1. The resolution cell area projected into the slant plane, $AREA_{SP}$, is the ground plane area projected normal to the COA slant plane. The RCS for the ground clutter in the

cell is $AREA_{SP}$ scaled by Beta-Zero. The cosine of the SLOPE angle may be written as the product of the cosine of the grazing angle times the cosine of the twist angle.

$$AREA_{SP} = AREA_{GP} \bullet \cos(SLOPE) = AREA_{GP} \bullet \underbrace{\cos(GRAZ) \bullet \cos(TWST)}_{\cos(SLOPE)}$$

$$AREA_{SP} = \Delta R_{SP} \bullet \Delta A_{SP} = \underbrace{\Delta R_{GP} \bullet \cos(GRAZ)}_{\Delta R_{SP}} \bullet \underbrace{\Delta R_{GP} \bullet \cos(TWST)}_{\Delta A_{SP}}$$

$$RCS_{CLTR} = BetaZero \bullet AREA_{SP}$$

The resolution cell area projected normal to the line of sight, $AREA_{POI}$, is the ground plane are projected normal the Plane of Incidence (POI). The RCS for the ground clutter in the cell is $AREA_{POI}$ scaled by Gamma-Zero.

$$AREA_{POI} = AREA_{GP} \bullet \sin(GRAZ)$$

$$AREA_{POI} = \Delta RN_{POI} \bullet \Delta A_{GP} = \underbrace{\Delta R_{GP} \bullet \sin(GRAZ)}_{\Delta RN_{POI}} \bullet \Delta A_{GP}$$

$$RCS_{CLTR} = Gamma\text{-}Zero \bullet AREA_{POI}$$

4.11 Transmit & Receive Antenna Parameters

The parameters that describe the transmit and receive antenna patterns are summarized below. Refer to Table 3-11. The antenna parameters describe the mainlobe illumination patterns of the transmit and receive antennas of the SAR platform. The illumination patterns are functions of the time of the illumination and the pointing direction relative to the antenna orientation.

The antenna parameters allow the variation in received signal level due to the variation in illumination patterns to be computed for all points in the imaged scene. For a given point in the scene, the variation in received signal power and signal phase may be computed as a function of time and frequency. The variation in signal versus time may be used to compute compensation for undesired broadening of the azimuth impulse response. The variation in integrated signal level over time versus position in the image may be used to compute compensation for variation in overall image intensity.

For all SAR collections, the received signal level from a point in the scene is a function of the transmit antenna pattern at the time of transmit and the receive antenna pattern at the time of reception. Separate sets of antenna parameters may be provided for the transmit and receive antenna. For most collections, the combined effect of the two patterns may be accurately described by a single two-way antenna pattern. For these collections, a single set of antenna parameters may be provided that describes the two-way illumination pattern.

A set of antenna parameters describes the antenna's mechanical orientation versus time, the relative gain pattern versus pointing direction and the relative phase pattern versus pointing direction. The gain pattern is expressed in dB relative to the gain at boresight. The phase pattern is expressed in cycles relative to the phase at boresight. Variation in boresight gain versus frequency may also be provided. For electronically scanned antennas, the electronic steering of the mainlobe versus time is provided.

For a fixed point target in the imaged scene, denoted TGT, the relative gain and phase due to the antenna illumination patterns is $G(t, f)^{TGT}$ and $\Phi(t, f)^{TGT}$. Time t is the time the transmitted signal is incident at the scene being imaged. For an image product with only a two-way antenna pattern provided, the gain and phase are computed from the two-way pattern evaluated at the time of incidence.

$$G(t,f)^{TGT} = G_{2WAY}\left(t,f\right)^{TGT} \qquad \Phi(t,f)^{TGT} = \Phi_{2WAY}\left(t,f\right)^{TGT}$$

For an image product with separate transmit and receive antenna patterns, the gain is the sum of the gains and the phase is the sum of the phases for the two patterns. For time of incidence t, the time of transmit tx(t) and the time of reception is trcv(t) may be accurately computed using the ranges from the TGT to aperture phase centers, $R_TX(t)^{TGT}$ and $R_RCV(t)^{TGT}$.

$$tx(t) = t - \frac{1}{c} \bullet R_TX(t)^{TGT} \qquad trcv(t) = t + \frac{1}{c} \bullet R_RCV(t)^{TGT}$$

$$G(t,f)^{TGT} = G_{TX}\left(tx(t),f\right)^{TGT} + G_{RCV}(trcv(t),f)^{TGT}$$

$$\Phi(t,f)^{TGT} = \Phi_{TX}\left(tx(t),f\right)^{TGT} + \Phi_{RCV}\left(trcv(t),f\right)^{TGT}$$

For most imaging collections, the transmit and receive gains to a given point vary slowly with time. Computing the transmit and receive patterns at the time of incidence will be sufficiently accurate.

$$G(t,f)^{TGT} = G_{TX}\left(t,f\right)^{TGT} + G_{RCV}(t,f)^{TGT} \qquad \Phi(t,f)^{TGT} = \Phi_{TX}\left(t,f\right)^{TGT} + \Phi_{RCV}\left(t,f\right)^{TGT}$$

Consider a collection from a platform with separate transmit and receive antennas. The transmit antenna phase center (APC) position versus time is **TX**(t). The receive antenna phase center position versus time is **RCV1**(t). A single receive data channel is collected and processed to form the image. The Aperture Reference Position versus time is **ARP**(t). Shown in Figure 4.11-1 is a portion the ARP and APC trajectories. For the signal incident at the scene at time t*, the transmit time is tx(t*) and the receive time is trcv(t*). Shown is the ARP at time t* and the APC positions at the three times. The transmit and receive antennas are shown at the three times. Also shown is an equivalent antenna located at the **ARP**(t*) that can be used to compute the two-way illumination pattern. The mechanical orientation of each antenna is defined by a pair of orthogonal unit vectors, **uX** and **uY**. The mechanical boresight is defined by unit vector **uZ = uX x uY**. For a mechanically steered antenna, the mainlobe boresight is in the +**uZ** direction. For an electronically steered antenna, the mainlobe boresight is electronically steered within the hemisphere that is centered on +**uZ**.

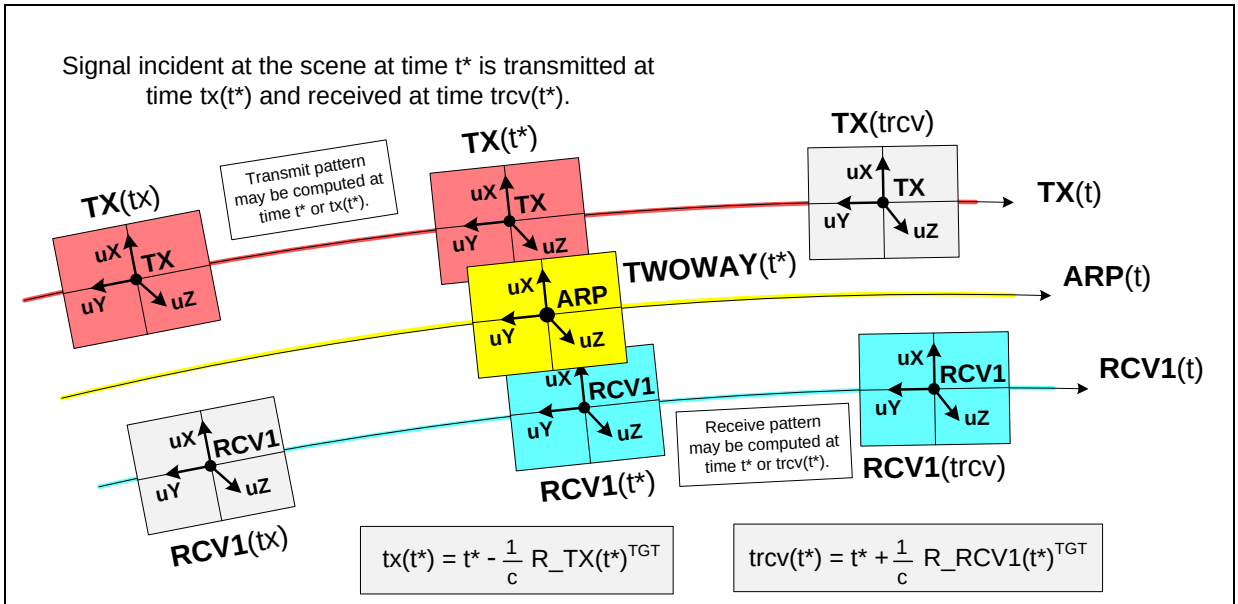


Figure 4.11-1 Antenna Positions & Orientations
Separate TX and RCV antennas and an equivalent two-way antenna are shown.

Pointing directions in the antenna reference frame are expressed as unit vectors. Shown in Figure 4.11-2 is an example antenna reference frame. A unit pointing vector, **uPT**, is defined by the direction cosines relative to the X and Y axes, DCX and DCY. The ordered pair (DCX, DCY) is referred to as the direction cosine pair for unit pointing vector **uPT**.

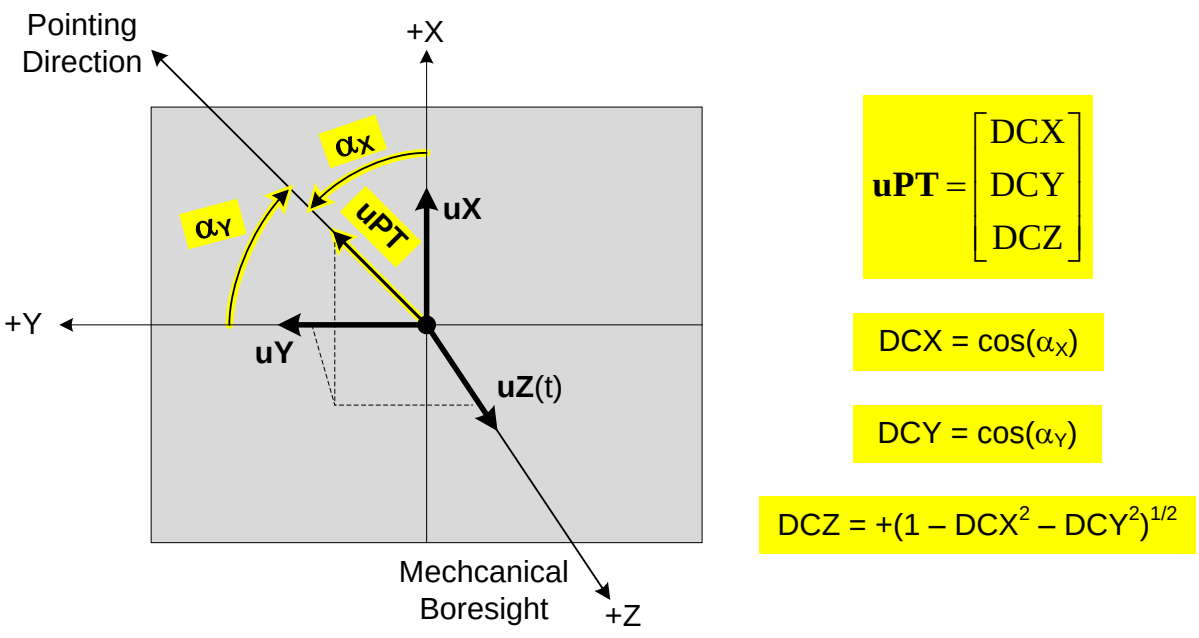


Figure 4.11-2 Antenna Reference Frame
Pointing vectors are expressed as unit vectors in the XYZ frame.

The following sections describe the antenna parameters that may be provided with an image product. The example collection shown in Figure 4.11-1 is used as a reference. For a target TGT illuminated time t*, the relative gain and phase due to the antenna illumination patterns, $G(t^*,f)^{TGT}$ and $\Phi(t^*,f)^{TGT}$, are computed. The computation using an equivalent two-way antenna pattern is described in Section 4.11.1. The computation using separate transmit and receive antenna patterns is described in Section 4.11.2.

All antenna phase center positions and orientations are provided as functions of time t. All positions are in ECF coordinates. The aperture orientations are computed relative to the ECF coordinate frame as described below. For all computations, time t is in seconds relative to Collection Start.

4.11.1 Two-Way Antenna Pattern

The gain and phase for target TGT are computed using a set of Two-Way antenna pattern parameters as described in following section. Gain $G(t^*,f)^{TGT}$ is in dB and phase $\Phi(t^*,f)^{TGT}$ is in cycles.

$$G(t,f)^{TGT} = G_{2WAY}\left(t,f\right)^{TGT} \qquad \Phi(t,f)^{TGT} = \Phi_{2WAY}\left(t,f\right)^{TGT}$$

(1) Frequency Dependent Parameters

The base set of parameters are for frequency f_0. The parameters that vary with frequency are indicated by the inclusion of optional parameters.

f_0 = Base Frequency XML: Antenna.TwoWay.FreqZero

Boresight gain as a function of frequency is specified by including the gain versus frequency polynomial. Gain term $GF_{2WAY}(f)$ is computed by evaluating the polynomial at $(f - f_0)/ f_0$. Gain $GF_{2WAY}(f)$ is in dB. If polynomial is not included, set $GF_{2WAY}(f) = 0$.

$GF_{2WAY}(f) = GainBSPoly((f- f_0)/ f_0)$ XML: Antenna.TwoWay.GainBSPoly

Mainlobe dilation versus frequency is indicated by optional parameter MLFreqDilation set equal to TRUE. The modeled mainlobe dilation has the width vary inversely with frequency. If the parameter is not included or is set to FALSE, the mainlobe pattern does not vary with frequency. Set parameter MLD(f) as follows.

$$MLD(f) = \begin{cases} \dfrac{f}{f_0}, & \text{If MLDilation = TRUE} \\ 1.0 & \text{Otherwise} \end{cases}$$

XML: Antenna.TwoWay.MLFreqDilation

For an electronically steered antenna, the mainlobe boresight shift versus frequency is indicated by optional parameter EBFreqShift set equal to TRUE. The modeled boresight shift has the mainlobe boresight shift toward the mechanical boresight. If the parameter is not included or is set to FALSE, the mainlobe boresight does not shift with frequency. Set parameter EBS(f) as follows.

$$EBS(f) = \begin{cases} \dfrac{f_0}{f}, & \text{If EBFreqShift = TRUE} \\ 1.0 & \text{Otherwise} \end{cases}$$

XML: Antenna.TwoWay.EBFreqShift

(2) Two-Way Antenna Phase Center & Orientation

For the equivalent Two-Way antenna pattern, the antenna phase center at time t* is the **ARP**(t*). The antenna orientation is also computed at time t*. The antenna orientation vectors **XVP**(t*) and **YVP**(t*) are computed by evaluating the vector-time polynomials.

XVP(t*) = XAxisPoly(t*) XML: Antenna.TwoWay.XAxisPoly

YVP(t*) = YAxisPoly(t*) XML: Antenna.TwoWay.YAxisPoly

Vectors **XVP**(t*) and **YVP**(t*) may not be unit length or precisely orthogonal due to slight errors in the polynomial fit. Vector **uZ**(t*) is normal plane formed by vectors **XVP**(t*) and **YVP**(t*). Adjusted unit vectors **uX**(t*) and **uY**(t*) form an orthogonal basis. All vectors are in ECF coordinates. The antenna reference frame is shown in Figure 4.11-2.

$$\mathbf{uXVP}(t^*) = \frac{1}{|\mathbf{XVP}(t^*)|} \bullet \mathbf{XVP}(t^*) \qquad \mathbf{uYVP}(t^*) = \frac{1}{|\mathbf{YVP}(t^*)|} \bullet \mathbf{YVP}(t^*)$$

$$\mathbf{Z}(t^*) = \mathbf{uXVP}(t^*) \times \mathbf{uYVP}(t^*) \qquad \mathbf{uZ}(t^*) = \frac{1}{|\mathbf{Z}(t^*)|} \bullet \mathbf{Z}(t^*)$$

$$\alpha(t^*) = \sin^{-1}\left(\mathbf{uXVP}(t^*) \bullet \mathbf{uYVP}(t^*)\right) \qquad \mathbf{uN}(t^*) = \mathbf{uZ}(t^*) \times \mathbf{uXVP}(t^*)$$

$$\mathbf{uX}(t^*) = \cos\left(\tfrac{1}{2} \bullet \alpha(t^*)\right) \bullet \mathbf{uXVP}(t^*) - \sin\left(\tfrac{1}{2} \bullet \alpha(t^*)\right) \bullet \mathbf{uN}(t^*)$$

$$\mathbf{uY}(t^*) = \sin\left(\tfrac{1}{2} \bullet \alpha(t^*)\right) \bullet \mathbf{uXVP}(t^*) + \cos\left(\tfrac{1}{2} \bullet \alpha(t^*)\right) \bullet \mathbf{uN}(t^*)$$

(3) Mainlobe Boresight Pointing Vector

For an electronically steered antenna, the boresight pointing vector versus time is included with the optional boresight steering polynomials. The steering polynomials provide the boresight direction cosines at time t and frequency f_0. The values are then scaled by parameter EBS(f) to account for boresight shift versus frequency. For a mechanically steered antenna, the boresight is along +**uZ**(t*) direction (DCX = DCY = 0). The direction cosine pair (DCX_EB(t*,f), DCY_EB(t*,f)) is computed as follows.

For an electronically steered antenna:

$DCX_EB_0(t^*)$ = DCX_EBPoly(t*) XML: Antenna.TwoWay.EB.DCXPoly

$DCY_EB_0(t^*)$ = DCY_EBPoly(t*) XML: Antenna.TwoWay.EB.DCYPoly

$$DCX_EB(t^*,f) = EBS(f) \bullet DCX_EB_0(t^*) \qquad DCY_EB(t^*,f) = EBS(f) \bullet DCY_EB_0(t^*)$$

For a mechanically steered antenna: DCX_EB(t*,f) = 0 and DCY_EB(t*,f) = 0

(4) Target Pointing Vector

The unit pointing vector from the antenna phase center to the target TGT, **uTGT**(t*), is computed in ECF coordinates. The direction cosine pair ($DCX(t^*)^{TGT}$ and $DCY(t^*)^{TGT}$) is then computed as follows.

$$\mathbf{uTGT}(t^*) = \frac{1}{\left|\mathbf{TGT} - \mathbf{ARP}(t^*)\right|} \bullet \left(\mathbf{TGT} - \mathbf{ARP}(t^*)\right)$$

$$DCX(t^*)^{TGT} = \mathbf{uTGT}(t^*) \bullet \mathbf{uX}(t^*) \qquad DCY(t^*)^{TGT} = \mathbf{uTGT}(t^*) \bullet \mathbf{uY}(t^*)$$

The difference in direction cosines for the target relative to the mainlobe boresight is also computed.

$$\Delta DCX(t^*,f)^{TGT} = DCX(t^*)^{TGT} - DCX_EB(t^*,f)$$
$$\Delta DCX(t^*,f)^{TGT} = DCX(t^*)^{TGT} - DCX_EB(t^*,f)$$

(5) Array Pattern Gain & Phase

The shape of the mainlobe of the illumination pattern is defined by the array pattern. The array pattern is specified by a gain polynomial and a phase polynomial. The gain polynomial, G_ARR_Poly, specifies the gain in dB relative to the gain at mainlobe boresight. The phase polynomial, Φ_ARR_Poly, specifies the phase in cycles relative to the phase at mainlobe boresight.

G_ARR_Poly(ΔDCX, ΔDCY)	XML: Antenna.TwoWay.Array.GainPoly
Φ_ARR_Poly (ΔDCX, ΔDCY)	XML: Antenna.TwoWay.Array.PhasePoly

For target TGT, the two-way array pattern gain and phase, $G_ARR_{2WAY}(t^*,f)^{TGT}$ and $\Phi_ARR_{2WAY}(t^*,f)^{TGT}$, are computed as follows. The array polynomials are for frequency f_0 and scale factor MLD(f) accounts for mainlobe dilation versus frequency (if any).

$$G_ARR_{2WAY}(t^*,f)^{TGT} = G_ARR_Poly\left(MLD(f) \bullet \Delta DCX(t^*,f)^{TGT}, MLD(f) \bullet \Delta DCY(t^*,f)^{TGT}\right)$$
$$\Phi_ARR_{2WAY}(t^*,f)^{TGT} = \Phi_ARR_Poly\left(MLD(f) \bullet \Delta DCX(t^*,f)^{TGT}, MLD(f) \bullet \Delta DCY(t^*,f)^{TGT}\right)$$

For most mechanically scanned antennas, the phase within the mainlobe is constant and the phase polynomial is set to 0. For many antennas, the mainlobe gain is accurately described by a two-dimensional quadratic function based on the beamwidths.

(6) Element Pattern Gain & Phase

For an electronically steered antenna, the gain is reduced as the mainlobe is steered off mechanical boresight. The variation in gain as a function of steering is included with the optional element pattern gain polynomial, G_ELEM_Poly. An element pattern phase polynomial is also included, Φ_ELEM_Poly. For most antennas, the element pattern phase is constant and Φ_ELEM_Poly is set to zero. For a mechanically steered antenna, the element pattern polynomials are not included.

G_ELEM_Poly(DCX, DCY)	XML: Antenna.TwoWay.Elem.GainPoly
Φ_ELEM_Poly(DCX, DCY)	XML: Antenna.TwoWay.Elem.PhasePoly

For target TGT, the two-way element pattern gain and phase, $G_ELEM_{2WAY}(t^*)^{TGT}$ and $\Phi_ELEM_{2WAY}(t^*)^{TGT}$, are computed as follows.

For an electronically steered antenna:

$$G_ELEM_{2WAY}(t^*)^{TGT} = G_ELEM_Poly\left(DCX(t^*)^{TGT}, DCY(t^*)^{TGT}\right)$$

$$\Phi_ELEM_{2WAY}(t^*)^{TGT} = \Phi_ELEM_Poly\left(DCX(t^*)^{TGT}, DCY(t^*)^{TGT}\right)$$

For a mechanically steered antenna:

$$G_ELEM_{2WAY}(t^*)^{TGT} = 0 \qquad \Phi_ELEM_{2WAY}(t^*)^{TGT} = 0$$

(7) Two-Way Gain & Phase

For target TGT, the two-way gain and phase at time t* and frequency f is the sum of the gains and the sum of the phases computed above.

$$G_{2WAY}(t^*,f)^{TGT} = GF_{2WAY}(f) + G_ARR_{2WAY}(t^*,f)^{TGT} + G_ELEM_{2WAY}(t^*)^{TGT}$$

$$\Phi_{2WAY}(t^*,f)^{TGT} = \Phi_ARR_{2WAY}(t^*,f)^{TGT} + \Phi_ELEM_{2WAY}(t^*)^{TGT}$$

4.11.2 One-Way Antenna Patterns

The gain and phase for target TGT are computed using a pair of one-way antenna pattern parameter sets as summarized in following section. Gain $G(t^*,f)^{TGT}$ is in dB and phase $\Phi(t^*,f)^{TGT}$ is in cycles.

$$G(t^*,f)^{TGT} = G_{TX}\left(tx(t^*),f\right)^{TGT} + G_{RCV}(trcv(t^*),f)^{TGT}$$

$$\Phi(t^*,f)^{TGT} = \Phi_{TX}\left(tx(t^*),f\right)^{TGT} + \Phi_{RCV}\left(trcv(t^*),f\right)^{TGT}$$

The computations for the one-way patterns are nearly identical as those shown for the two-way pattern in Section 4.11.1. For the transmit pattern, the gain is computed as the sum of three gains and the phase the sum of two phases.

$$G_{TX}(t^*,f)^{TGT} = GF_{TX}(f) + G_ARR_{TX}(t^*,f)^{TGT} + G_ELEM_{TX}(t^*,f)^{TGT}$$

$$\Phi_{TX}(t^*,f)^{TGT} = \Phi_ARR_{2WAY}(t^*,f)^{TGT} + \Phi_ELEM_{2WAY}(t^*)^{TGT}$$

For the receive pattern, the gain is computed as the sum of three gains and the phase the sum of two phases.

$$G_{RCV}(t^*,f)^{TGT} = GF_{RCV}(f) + G_ARR_{RCV}(t^*,f)^{TGT} + G_ELEM_{RCV}(t^*)^{TGT}$$

$$\Phi_{TX}(t^*,f)^{TGT} = \Phi_ARR_{2WAY}(t^*,f)^{TGT} + \Phi_ELEM_{2WAY}(t^*)^{TGT}$$

The only differences are the computation of the transmit APC position and the receive APC position. These differences are described below.

(1) Transmit APC & Orientation

The transmit APC position at time t* is computed as shown below.

TX(t*) = Tx_APC_Poly(t*) XML: Position.TxAPCPoly

The transmit antenna orientation is computed at t* as shown below.

XVP(t*) = XAxisPoly(t*) XML: Antenna.Tx.XAxisPoly
YVP(t*) = YAxisPoly(t*) XML: Antenna.Tx.YAxisPoly

Unit vectors **uX**(t*), **uY**(t*) and **uZ**(t*) are generated using the same normalization steps as shown above for the equivalent two-way antenna.

(2) Receive APC & Orientation

The receive APC position versus time polynomial is selected for the receive data channel processed. The Image Formation parameter block specifies which receive data channel is processed . The Radar Collection parameter block indicates which Receive APC is associated with the receive data channel. See Tables 3-6, 3-7 and 3-8.

The receive antenna APC and orientation are computed at t* as shown below. Index idx is the receive APC index value for the processed receive data channel.

RCV(t*) = Rcv_APC_Poly(idx, t*)	XML: Position.RcvAPC.RcvAPCPoly
XVP(t*) = XAxisPoly(t*)	XML: Antenna.Rcv.XAxisPoly
YVP(t*) = YAxisPoly(t*)	XML: Antenna.Rcv.YAxisPoly

Unit vectors **uX**(t*), **uY**(t*) and **uZ**(t*) are generated using the same normalization steps as shown above for the equivalent two-way antenna.

4.12 Error Parameters

The parameters provided to determine error statistics for geo-location estimates computed from an image product are summarized below. Refer to Table 3-12. The error statistics are optional parameters. For an image product that includes them, the provided parameters are used with the SICD sensor model to compute error statistics for the parameters estimated in the model.

The SAR sensor model mapping of image pixel grid locations to geolocated points in the imaged scene involves two fundamental projection computations. See Figure 4.12-1.

(1) Image To Scene: The projection from image pixel grid location to a geolocated point in the scene that was imaged.

(2) Scene To Image: The projection from geolocated point in the scene to the image pixel grid location.

The error statistics included with an image product may be used to compute error statistics for both fundamental projections. For the image to scene projection, the errors statistics for the geo-located scene point estimate may be computed. For the scene to image projection, the error statistics for the computed image location may also be computed.

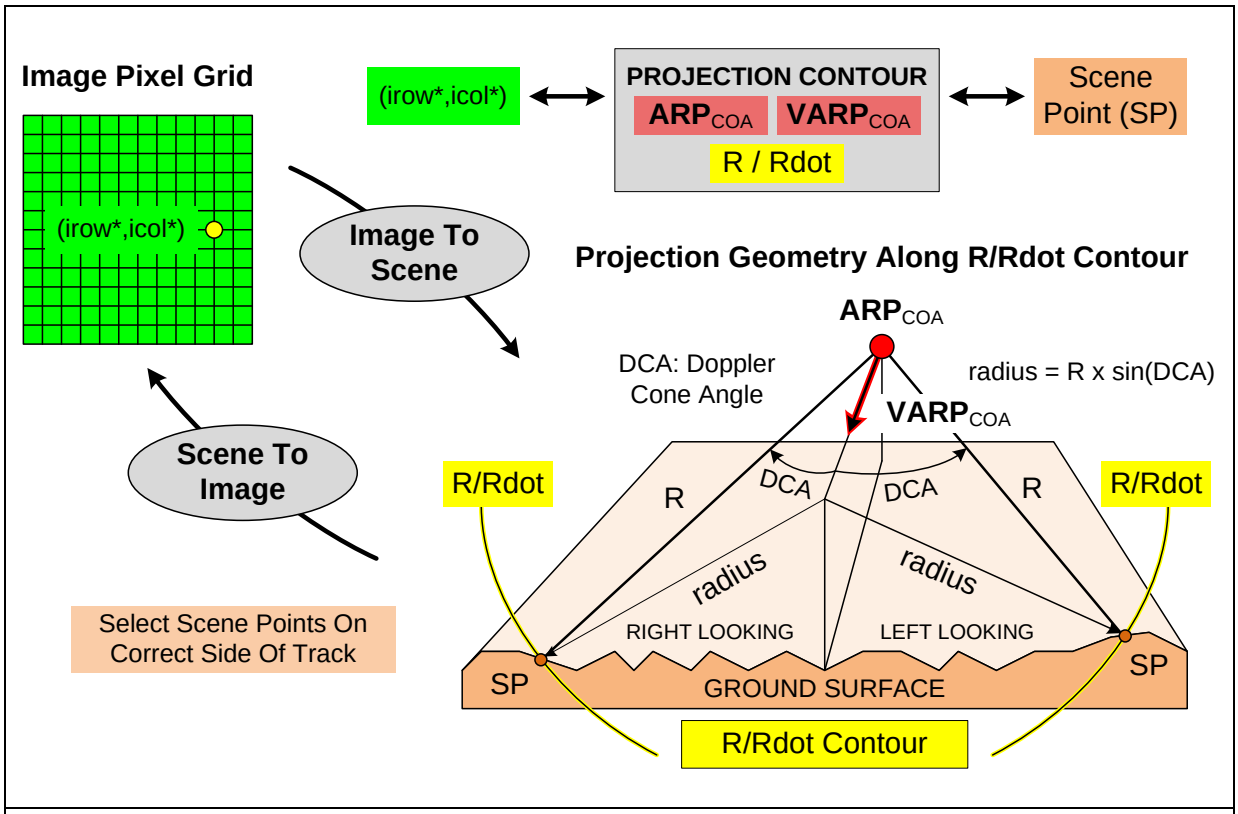


Figure 4.12-1 SAR Geo-location Computations

Image grid location (irow*,icol*) projects to the ground surface along a R/Rdot contour.

The error statistics included with an image product are of two types: (1) composite error statistics or (2) component error statistics. The composite error statistics are the elements of a simple range and azimuth covariance matrix. The component error statistics are divided into the components that contribute to errors in sensor model estimates.

4.12.1 Composite Error Statistics

The error sources that impact the accuracy of geo-location estimates from a SAR image are characterized by their contributions to the error in measured range and range rate. An error in range rate translates to an error in azimuth in the slant plane at COA. For a given image, the composite effect of all error sources may be expressed as a range and azimuth covariance matrix. The composite error parameters contain the composite covariance elements.

4.12.2 Component Error Statistics

The error statistics provided in an image product may be specified for the individual components that contribute to errors in geo-location estimates from a SAR image.

(1) Position & Velocity Covariance Matrix

The elements of the position and velocity covariance matrix are included. The diagonal terms are always specified. The correlation coefficients may also be included. The decorrelation versus time for position estimates may also be specified with a simple linear model.

(2) Radar Sensor Errors

The primary error sources associated with the radar sensor are a range bias and a transmitted frequency error. The parameters of a range bias decorrelation model may also be included.

(3) Propagation Model Errors

The error statistics associated with the predicted propagation delays due to the troposphere and the ionosphere may be included. Error decorrelation model parameters may also be included.

4.13 Matched Collection Parameters

The parameters that identify other imaging collections that are matched to the current collection are summarized below. The current imaging collection is the imaging collection from which the image contained in the product file was produced. Refer to Table 3-13. The use of these parameters is per program specific implementation and product design.

A pair of imaging collections may be considered to be "matched" based on many criteria. The criteria by which collections are matched is referred to as the Match Type. For example, a set of collections may be matched in that they are a time sequence collected from the same imaging geometry over a number of days or weeks in order to detect changes in the scene. A second set of collections may be matched in that they cover a set of adjacent scenes for which a large area composite image product may be produced.

The matched collection information provided is separated by Match Type. For each Match Type, a list of matched collections is provided. The number of match types and the match type identifiers are defined as part of the product design. The match type identifier, TypeID, is a text based parameter. For tasking and/or collection systems that assign each collection in the set an integer sequence index, the sequence index may be also be provided. For the current collection, the sequence index is referred to as the Current Index. For a matched collection, the sequence index is referred to as the Match Index.

Additional parameters may be included with each matched collection that are relevant to the match criteria. For example, collections that are matched by collection geometry may include the parameters and their values that indicate the quality of the match. For collections matched for coherent image processing, the parameters included may be the differences in grazing angle and azimuth angle of the matched collection relative to the current collection. The choice of additional parameters is defined as part of the product design.

4.13.1 Matched Collection Example Structure

An example matched collection information structure is shown below. In the example shown, match collection lists are provided for two Match Types. For the first match type, TypeID = TIME_SEQUENCE, three match collections are listed for which the current collection is collection 2 of 4. Note that the number of matched collections does not include the current collection. For the second match type, TypeID = IMAGE_ANGLE, one matched collection is listed. For the matched collection, an additional parameter is provided with the name = “ANGLE” and value 10.0.

```
XML:  MatchInfo
          NumMatchTypes = 2
              MatchType     index = 1                      ⇔  Match Type 1
                  TypeID = “TIME_SEQUENCE”                 ⇔  TypeID 1
                  CurrentIndex = 2                         ⇔  Current Collection Index
                  NumMatchCollections = 3
                  MatchCollection     index = 1            ⇔  Match 1
                      CoreName = “xxx”                     ⇔  Collection ID
                      MatchIndex = 1                       ⇔  Match Collection Index
                  MatchCollection     index = 2            ⇔  Match 2
                      CoreName = “xxx”                     ⇔  Collection ID
                      MatchIndex = 3                       ⇔  Match Collection Index
                  MatchCollection     index = 3            ⇔  Match 3
                      CoreName = “xxx”                     ⇔  Collection ID
                      MatchIndex = 4                       ⇔  Match Collection Index
              MatchType     index = 2                      ⇔  Match Type 2
                  TypeID = “IMAGE_ANGLE”                   ⇔  TypeID 2
                  NumMatchCollections = 1
                  MatchCollection     index = 1            ⇔  Match 1
                      CoreName = “xxx”                     ⇔  Collection ID
                      Parameter  name = “ANGLE”   10.0     ⇔  Parameter ANGLE = 10.0
```

4.14 Range & Azimuth Compression Parameters

The parameters that describe the image formation processing for images formed with simple range and azimuth compression are described below. Refer to Table 3-14. The SICD.RgAzComp parameters are always included when the image formation algorithm is identified as RGAZCOMP. See Table 3-8.

The range and azimuth compression algorithm is the simplest approach to transform SAR Phase History Data (PHD) into a complex image. The processing consists of two 1-dimensional Discrete Fourier Transforms (DFTs). See Figure 4.14-1. The resulting image is commonly referred to as a Range, Doppler image. This approach is only useful for coarse resolution and/or small image sizes. Simple compression is rarely (if ever) considered as a unique SAR image formation algorithm. Its limitations are what motivated the development of the other image formation algorithms. While simple compression is of limited practical utility, it is easily described in precise detail. The handful of parameters that are unique to the simple approach are provided for completeness.

The discussion below covers two groups of parameters: SICD.RgAzComp parameters and a subset of the SICD.Grid parameters. The RgAzComp parameters relate image azimuth location to range rate at COA and slow time to the azimuth spatial frequency domain. The Grid parameters, provided for all images, are also described. For those less familiar with SAR image formation processing, this discussion may be helpful in understanding their use with the other image formation algorithms.

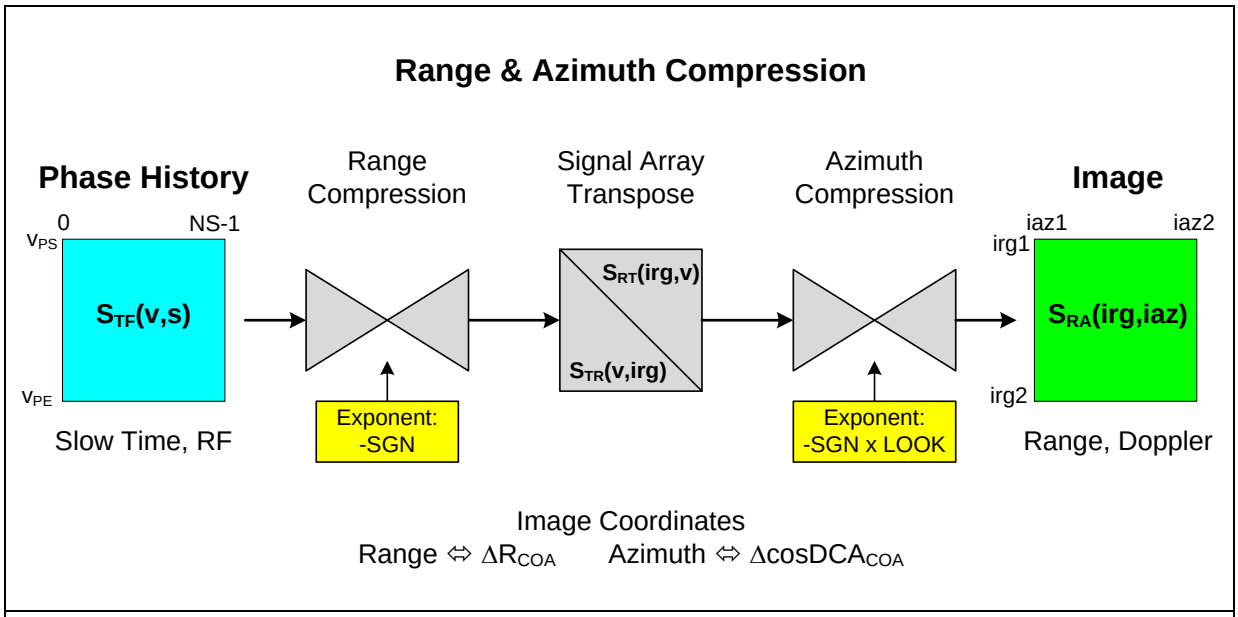


Figure 4.14-1 Range & Azimuth Compression
The image is a Range, Doppler projection at Center of Aperture (COA).

4.14.1 Input Phase History Data Array

An example input PHD array is shown in Figure 4.14-2. The PHD array, $S_{TF}(v,s)$, is composed of slow time vectors by frequency samples. A portion of the input vectors from v = v_{PS} to v_{PE} are processed to form the image. Increasing vector index v corresponds to increasing slow time t. The set of RF samples from s = 0 to NS – 1 are processed to form the image. Increasing sample index s corresponds to increasing frequency value. For a given vector, the samples are the frequency aligned signals that represent the echoes from the scene that was imaged at reference time t.

Also shown in Figure 4.14-2 is the collection geometry at the time t* associated with a single vector of the PHD array, v*. The Aperture Reference Position (ARP) at time t* is ARP(t*). The Scene Center Point (SCP) is a fixed ground point at the center of the imaged scene. The PHD has been motion compensated to the SCP. Also shown is an arbitrary fixed target (TGT) located in the imaged scene. Vector v* is signal resulting from the received echoes of a single transmitted pulse. Time t* is approximately the time the center of the transmitted pulse is reflected from the SCP.

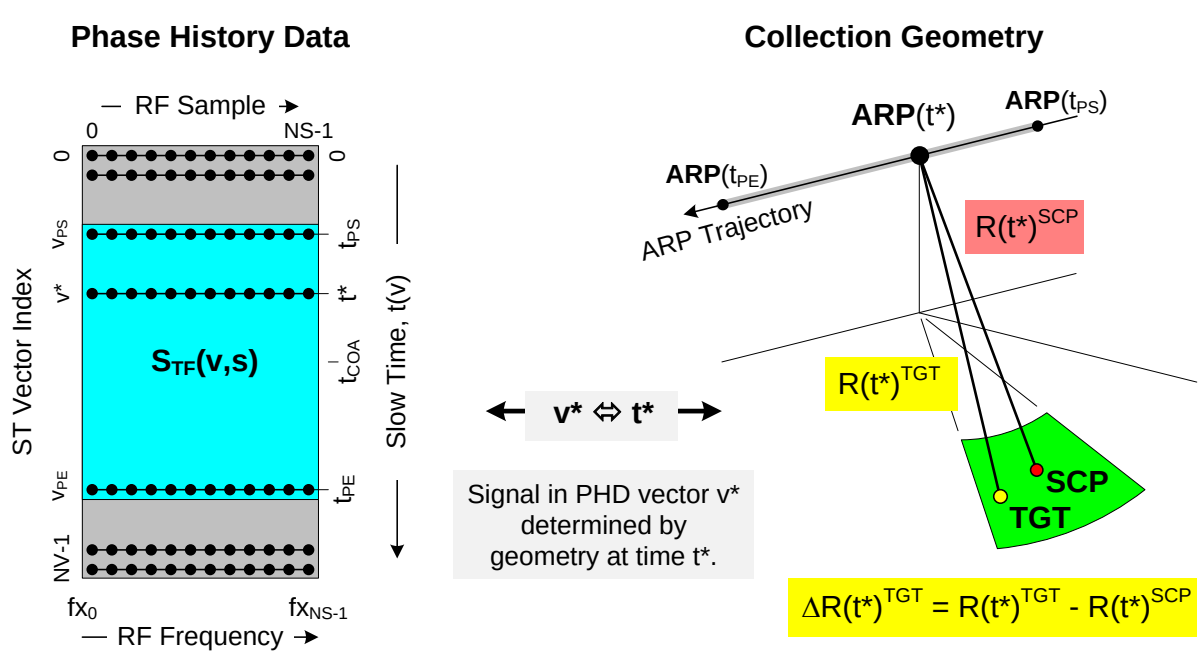


Figure 4.14-2 PHD Array & Collection Geometry

The signal for PHD vector v* is based on the ARP to SCP geometry at time t*.

The vector index v and slow time t, are assumed to be accurately related by a low order polynomial function. The mapping from vector index v to reference time t is given by the polynomial with coefficients denoted cV2T(m) for m = 0 to M_V2T. The polynomial may be an exact representation or the result of a fit to a set times that may include some slight jitter. Time t is in seconds relative to Collection Start time.

$$t(v) = \sum_{m=0}^{M_V2T} cV2T(m) \bullet v^m$$

For the set of vectors used to form the image, v_{PS} to v_{PE}, the Center of Aperture vector index, v_{COA}, is precisely in the center. For an even number of processed vectors, the value of v_{COA} will include a fractional portion of 0.5. The Center of Aperture time, t_{COA}, is the time computed for vector index $v = v_{COA}$. Times t_{PS} and t_{PE} are computed as well.

$$v_{COA} = \frac{1}{2} \bullet \left(v_{PS} + v_{PE} \right) \qquad t_{COA} = \sum_{m=0}^{M_V2T} cV2T(m) \bullet \left(v_{COA} \right)^m$$

$$t_{PS} = \sum_{m=0}^{M_V2T} cV2T(m) \bullet \left(v_{PS} \right)^m \qquad t_{PE} = \sum_{m=0}^{M_V2T} cV2T(m) \bullet \left(v_{PE} \right)^m$$

The vector index v is computed from slow time t using the polynomial shown below. The coefficients of the polynomial, denoted cT2V(m) for m = 1 to M_T2V, are a series expansion about time t_{COA}. Parameter $ST_RATE_{COA} = cT2V(1)$ is the slow time sampling rate of the PHD in Hertz at time t_{COA}.

$$v(t) = v_{COA} + \sum_{m=1}^{M_T2V} cT2V(m) \bullet \left(t - t_{COA} \right)^m \qquad ST_RATE_{COA} = cT2V(1)$$

The samples of the PHD array are equally spaced samples of transmitted frequency, fx(s). The frequency parameters associated with the PHD array are computed as shown below. Frequency parameters fx_0 and fx_SS are constant across vectors. The center index value, s_{COA}, and the center frequency value, fx_{COA}, are used to compute Center of Aperture parameters associated with the image. All frequency parameters are in Hertz.

$$fx(s) = fx_0 + fx_SS \bullet s \qquad fx_BW = NS \bullet fx_SS$$

$$s_{COA} = \frac{1}{2} \bullet \left(NS - 1 \right) \qquad fx_{COA} = fx_0 + fx_SS \bullet s_{COA}$$

The samples of the PHD array have been motion compensated to the SCP. The result of the motion compensation is to set the phase of the signal from the SCP to 0 for all samples of all vectors. For vector v*, the phase of the signal for target TGT is a function of the geometry at time t*. Ranges $R(t^*)^{TGT}$ and $R(t^*)^{SCP}$ are computed relative to the ARP at time t*. Phase $\Phi(v^*,s)^{TGT}$ is in cycles.

$$\Phi(v^*, s) = SGN \bullet fx(s) \bullet \frac{2}{c} \bullet \Delta R(t^*)^{TGT} \qquad \Delta R(t^*)^{TGT} = R(t^*)^{TGT} - R(t^*)^{SCP}$$

The phase sign parameter SGN = +1 or -1 is constant for all samples of the PHD array.

4.14.2 PHD Array To Image Array

The processing steps to compress the PHD signal array, $S_{TF}(v,s)$, to the image signal array, $S_{RA}(irg,iaz)$, are as follows. The size of the range compression DFT is NFRC. The sign of the exponent of the range compression DFT is set such that increasing index irg corresponds to increasing range. The size of the azimuth compression DFT is NFAC. The sign of the azimuth compression DFT is set to produce an image that is a view from above the earth. Optional amplitude weighting functions $w_{RG}(s)$ and $w_{AZ}(v)$ may be used to control image domain sidelobes. The DFT sizes are selected such that the image domain oversample ratios, Rg_OSR and Az_OSR, are between 1.0 and 2.0.

Range Compression For irg = irg1, . . ., 0, . . . , irg2:

$$S_{TR}(v,irg) = \sum_{s=0}^{NS-1} w_{RG}(s) \bullet S_{TF}(v,s) \bullet \exp\underbrace{\left\{-SGN \bullet j2\pi \bullet \frac{(s-s_0)\bullet irg}{NFRC}\right\}}_{\text{Exponent: } -SGN}$$

$$Rg_OSR = \frac{NFRC}{NS} \qquad 1.0 < Rg_OSR < 2.0$$

Signal Array Transpose

$$S_{RT}(irg,v) = S_{TR}(v,irg)$$

Azimuth Compression For iaz = iaz1, . . ., 0, . . . , iaz2:

$$S_{RA}(irg,iaz) = \sum_{v=v_{PS}}^{v_{PE}} w_{AZ}(v) \bullet S_{RT}(irg,v) \bullet \exp\underbrace{\left\{-SGN \bullet LOOK \bullet j2\pi \bullet \frac{(v-v_0)\bullet iaz}{NFAC}\right\}}_{\text{Exponent: } -SGN \text{ x } LOOK}$$

$$Az_OSR = \frac{NFAC}{v_{PE} - v_{PS} + 1} \qquad 1.0 < Az_OSR < 2.0$$

The resulting image signal array size is NumRows x NumCols.

$$NumRows = irg2 - irg1 + 1 \qquad NumCols = iaz2 - iaz1 + 1$$

4.14.3 Center of Aperture Parameters

The imaging geometry parameters computed at time t_{COA} are used in the description below. The parameters to be computed are as follows. See Section 4.9 for precise equations.

SCP = SCP position in ECF coordinates.

$\mathbf{ARP}_{COA}$ = ARP position at time t_{COA} in ECF coordinates.

$\mathbf{VARP}_{COA}$ = ARP velocity at time t_{COA} in ECF coordinates.

VM_{COA} = Magnitude of the ARP velocity at time t_{COA}.

R_{COA}^{SCP} = Range to SCP at t_{COA}.

$\cos DCA_{COA}^{SCP}$ = Cosine of the Doppler Cone Angle (DCA) to the SCP at t_{COA}.

$\sin DCA_{COA}^{SCP}$ = Sine of the Doppler Cone Angle (DCA) to the SCP at t_{COA}.

LOOK = +1 or -1 where +1 ⇔ Left Looking and -1 ⇔ Right Looking

$\mathbf{uLOS}_{COA}^{SCP}$ = Line of sight unit vector from the $\mathbf{ARP}_{COA}$ to the **SCP**.

$\mathbf{uSPN}_{COA}^{SCP}$ = Unit vector normal to the SCP slant plane at t_{COA}.

The slant plane geometry at COA for two example collections, one left looking and one right looking, are shown in Figure 4.14-3. For the examples shown, the ARP trajectory is a straight line. Distance s is measured along the circle of constant range R_{COA}^{SCP}. Distance s = 0 at the SCP . The scale factor AzSF is the rate of change of the cosine of the DCA ($\cos DCA_{COA}$) with respect to distance s at the SCP. The units of AzSF are meters^{-1}.

$$AzSF = \frac{\partial}{\partial(s)}\left(\cos\left(DCA(s)_{COA}\right)\right)\Big|_{s=0} \qquad AzSF = -LOOK \bullet \frac{\sin\left(DCA_{COA}^{SCP}\right)}{R_{COA}^{SCP}}$$

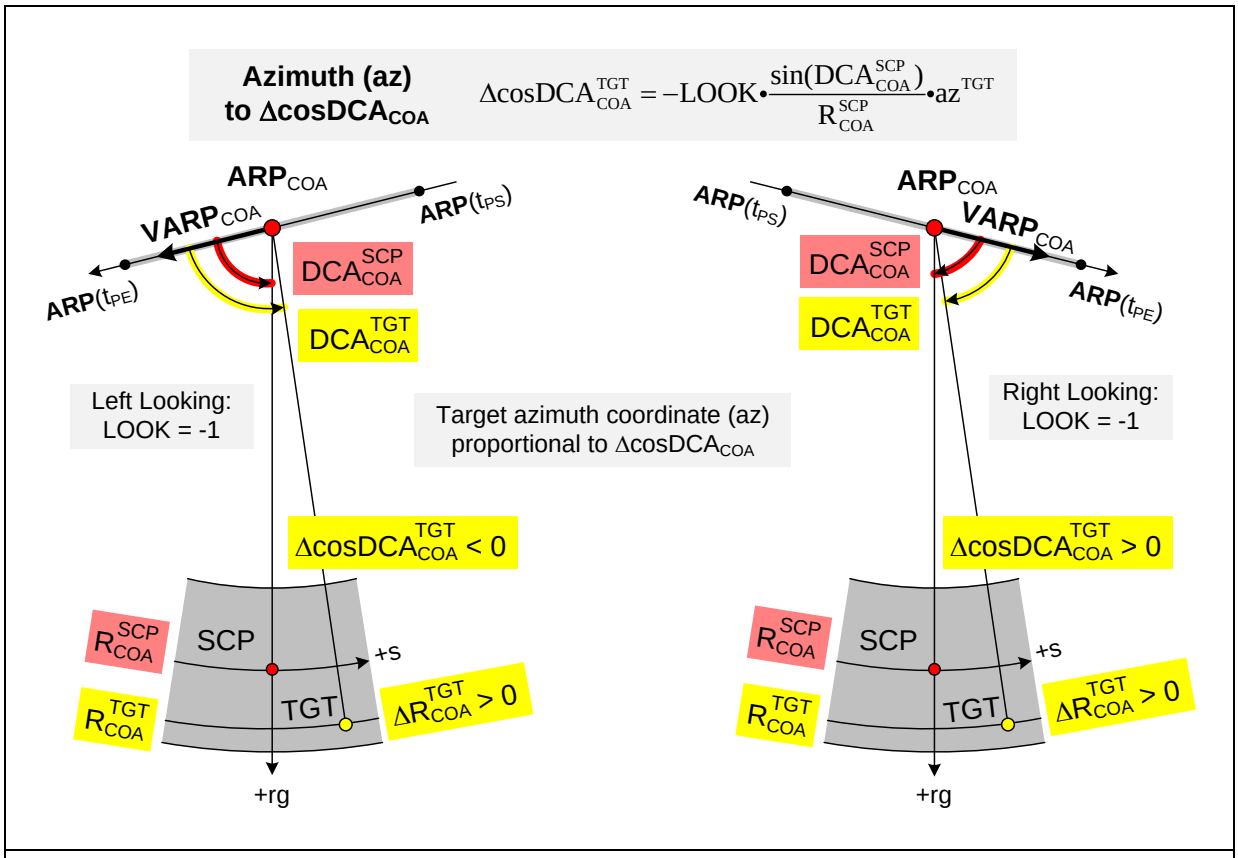


Figure 4.14-3 Center Of Aperture Slant Plane

Example slant planes at COA are shown for left looking and right looking collections.

4.14.4 Range, Doppler Image

An example Range, Doppler image array is shown in Figure 4.14-4. The rows of the image are along contours of constant range relative to the ARP at COA. The rows are evenly spaced increments in range at COA. The columns of the image are along lines of constant ΔcosDCA at COA. The columns are evenly spaced increments of ΔcosDCA at COA which correspond to evenly spaced increments in Doppler frequency.

The image coordinates are range and azimuth (rg, az). The row coordinate is the range coordinate (xrow = rg) and the column coordinate is the azimuth coordinate (ycol = az). The range coordinate is range relative to the SCP at COA. The azimuth coordinate, expressed as a distance, is the difference in cos(DCA) at COA relative to the SCP scaled by 1/AzSF. For target TGT shown in Figure 4.14-3, the impulse response will be centered at image coordinates (rg^{TGT}, az^{TGT}). Image coordinates are computed as follows. For both example collections shown, the azimuth coordinate $az^{TGT} > 0$.

$$rg^{TGT} = \Delta R_{COA}^{TGT} \qquad az^{TGT} = \frac{1}{AzSF} \bullet \Delta cosDCA_{COA}^{TGT}$$

$$\Delta R_{COA}^{TGT} = R_{COA}^{TGT} - R_{COA}^{SCP} \qquad \Delta cosDCA_{COA}^{TGT} = cosDCA_{COA}^{TGT} - cosDCA_{COA}^{SCP}$$

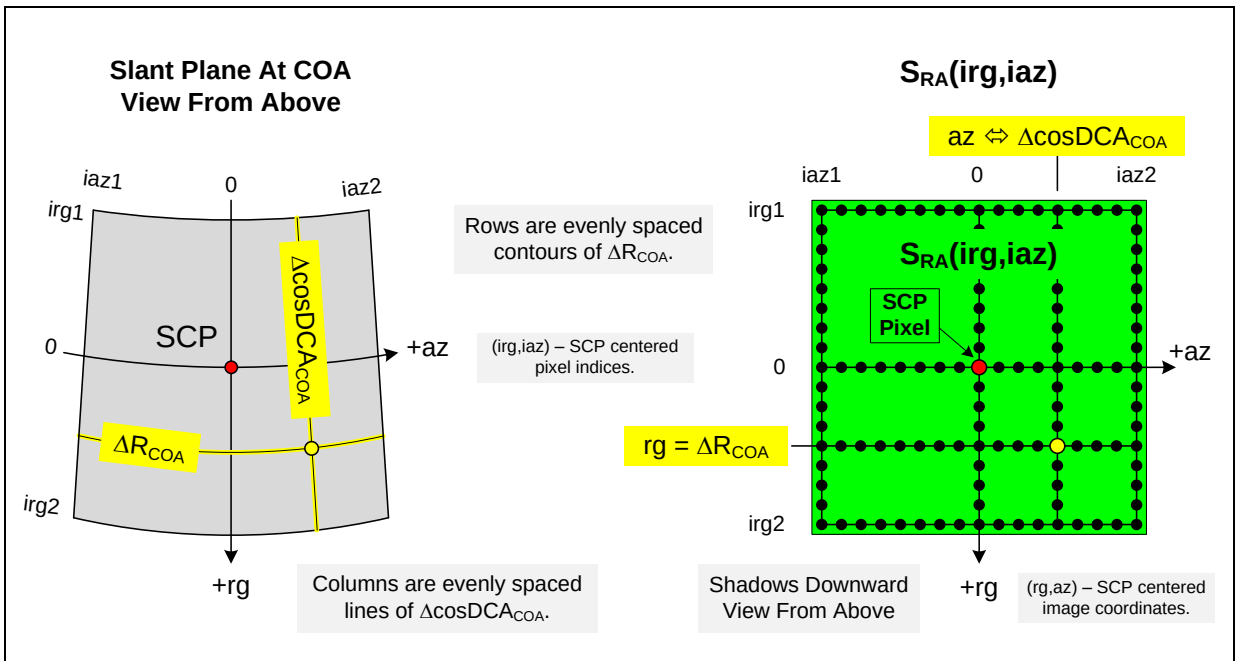


Figure 4.14-4 Range, Doppler Image Array
Image array locations in the slant plane at COA.

4.14.5 RgAzComp Parameters

The parameters unique to simple range and azimuth compression are as follows. Scale factor AzSF (computed above) is the scale factor that scales the azimuth coordinate (in meters) to an increment in ΔcosDCA at COA.

XML: RgAzComp.AzSF = AzSF

Scale factor ΔKaz/Δv is the increment in azimuth spatial frequency (Kaz) per slow time vector. For left looking collections: ΔKaz/Δv > 0. For right looking collections: ΔKaz/Δv < 0.

$$\frac{\Delta Kaz}{\Delta v} = LOOK \bullet \frac{2 \bullet fx_{COA}}{c} \bullet \left(\frac{VM_{COA} \bullet \sin(DCA_{COA}^{SCP})}{R_{COA}^{SCP}} \right) \bullet \frac{1}{ST_RATE_{COA}}$$

For slow time vector v, the azimuth spatial frequency is: $Kaz(v) = \frac{\Delta Kaz}{\Delta v} \bullet \left(v - v_{COA} \right)$.

The azimuth spatial frequency is computed from slow time t using the polynomial Kaz(t) with coefficients denoted cT2Kaz(m) for m = 0 to M_T2KAZ. The coefficients are computed by combining the polynomial for index v as a function t (coefficients cT2V(m) and order M_T2V above) and the linear relationship for Kaz as a function of index v. Order M_T2KAZ = M_T2V. For all images: $t_{COA} \Leftrightarrow v_{COA} \Leftrightarrow Kaz_{COA} = 0$.

$$Kaz(t) = \sum_{m=0}^{M_T2KAZ} cT2Kaz(m) \bullet t^m$$

XML: RgAzComp.KazPoly

4.14.6 Image Grid Parameters

The image grid parameters for the image formed with simple range and azimuth compression are set as follows. Set Table 3-4. Parameter formulas are provided with minimal description as they are common SAR processing parameters. The parameters are expressed in terms of the DFT expressions shown in Section 4.14.2 above.

The image formed is a slant plane image. The grid type is RGAZIM. The COA time for all pixels is t_{COA}. The COA time polynomial has only a constant coefficient.

XML: ImagePlane = SLANT

XML: Type = RGAZIM

XML: Grid.TimeCOAPoly - Constant coefficient set to t_{COA}. Order1 = Order2 = 0.

The image plane unit vectors **uRG** and **uAZ** lie in the SCP slant plane at COA.

$$\mathbf{uRG} = \mathbf{uLOS}_{\mathrm{COA}}^{\mathrm{SCP}}$$ XML: Row.UVectECF

$$\mathbf{uAZ} = \mathbf{uSPN}_{\mathrm{COA}}^{\mathrm{SCP}} \times \mathbf{uLOS}_{\mathrm{COA}}^{\mathrm{SCP}}$$ XML: Col.UVectECF

The phase sign parameters for row and column directions are set equal to the phase sign of the PHD array (i.e. parameter SGN in the equation below).

$$\Phi(v^*, s) = \mathrm{SGN} \bullet \mathrm{fx}(s) \bullet \frac{2}{c} \bullet \Delta R(t^*)^{\mathrm{TGT}}$$ XML: Row.Sgn & Col.Sgn

The parameters associated with the range coordinate (rg) and range spatial frequency (Krg) are computed from the parameters associated with the Range Compression DFT (NS, NFRC and s_0). Spatial frequency parameters (Krg_SS, Krg_COA, etc.) are in cycles/meter. Sample s_0 is the "zero" input sample index of the range compression DFT and will correspond to the center of the spatial frequency domain, Krg_Ctr. For parameter $s_0 = s_{COA}$, Krg_Ctr = Krg_COA and ΔKrg_COA = 0. Optional polynomial parameter Row.DeltaKCOAPoly is omitted. For $s_0 \neq s_{COA}$, the optional polynomial is included with the constant coefficient equal to ΔKrg_COA and Order1 = Order2 = 0.

$$\mathrm{Krg_COA} = \frac{2}{c} \bullet \mathrm{fx}_{\mathrm{COA}} \qquad \mathrm{Krg_SS} = \frac{2}{c} \bullet \mathrm{fx_SS}$$

$$\mathrm{Krg_IRBW} = \mathrm{NS} \bullet \mathrm{Krg_SS}$$ XML: Row.ImpRespBW

$$\mathrm{Krg_Ctr} = \frac{2}{c} \bullet \left(\mathrm{fx}_0 + \mathrm{fx_SS} \bullet s_0\right)$$ XML: Row.KCtr

$$\Delta\mathrm{Krg_COA} = \mathrm{Krg_COA} - \mathrm{Krg_Ctr}$$ XML: Row.DeltaKCOAPoly

Range spacing Rg_SS and impulse response width Rg_IRW are in meters. Impulse response broadening factor k_{RG} is associated with weighting function $w_{RG}(s)$. For uniform weighting, k_{RG} = 0.886.

$$\mathrm{Rg_SS} = \frac{1}{\mathrm{NFRC} \bullet \mathrm{Krg_SS}}$$ XML: Row.SS

$$\mathrm{Rg_IRW} = \frac{k_{RG}}{\mathrm{Krg_IRBW}}$$ XML: Row.ImpRespWid

Parameters ΔKrg1 and ΔKrg2 define support relative to Krg_Ctr of the range spatial frequency support of the image. Compute initial values of ΔKrg1 and ΔKrg2 as follows.

$$\Delta\mathrm{Krg1_Init} = \Delta\mathrm{Krg_COA} - 0.5 \bullet \mathrm{Krg_IRBW}$$

$$\Delta\mathrm{Krg2_Init} = \Delta\mathrm{Krg_COA} + 0.5 \bullet \mathrm{Krg_IRBW}$$

The initial values are compared to the limits of -0.5/Rg_SS and +0.5/Rg_SS to detect a wrapped spectrum.

$$\text{IF} \quad \Delta\text{Krg1_Init} < -\frac{0.5}{\text{Rg_SS}} \quad \text{OR} \quad \Delta\text{Krg2_Init} > +\frac{0.5}{\text{Rg_SS}}, \rightarrow \text{Krg Spectrum Wrapped.}$$

Set final values of ΔKrg1 and ΔKrg2 as follows.

$$\Delta\text{Krg1} = \begin{cases} \Delta\text{Krg1_Init}, & \text{Krg Spectrum Not Wrapped} \\ -\dfrac{0.5}{\text{Rg_SS}}, & \text{Krg Spectrum Wrapped} \end{cases} \qquad \text{XML: Row.DeltaK1}$$

$$\Delta\text{Krg2} = \begin{cases} \Delta\text{Krg2_Init}, & \text{Krg Spectrum Not Wrapped} \\ +\dfrac{0.5}{\text{Rg_SS}}, & \text{Krg Spectrum Wrapped} \end{cases} \qquad \text{XML: Row.DeltaK2}$$

The parameters associated with the azimuth coordinate (az) and azimuth spatial frequency (Kaz) are computed from the parameters associated with the Azimuth Compression DFT (v_{PS}, v_{PE}, NFAC and v_0). Spatial frequency parameters (Kaz_SS, Kaz_COA, etc.) are in cycles/meter. For all images, Kaz_COA = 0. Vector v_0 is the "zero" input vector index of the azimuth compression DFT and will correspond to the center of the spatial frequency domain, Kaz_Ctr. For parameter $v_0 = v_{COA}$, Kaz_Ctr = Kaz_COA = 0 and ΔKaz_COA = 0. Optional polynomial parameter Col.DeltaKCOAPoly is omitted. For $v_0 \neq v_{COA}$, the optional polynomial is included with the constant coefficient equal to ΔKaz_COA and Order1 = Order2 = 0.

$$\text{Kaz_SS} = \text{LOOK} \bullet \left(\frac{\Delta\text{Kaz}}{\Delta\text{v}} \right)$$

$$\text{Kaz_IRBW} = \left(\text{v}_{\text{PE}} - \text{v}_{\text{PS}} + 1 \right) \bullet \text{Kaz_SS} \qquad \text{XML: Col.ImpRespBW}$$

$$\text{Kaz_Ctr} = \frac{\Delta\text{Kaz}}{\Delta\text{v}} \bullet \left(\text{v}_0 - \text{v}_{\text{COA}} \right) \qquad \text{XML: Col.KCtr}$$

$$\Delta\text{Kaz_COA} = -\text{Kaz_Ctr} \qquad \text{XML: Col.DeltaKCOAPoly}$$

Azimuth spacing Az_SS and impulse response width Az_IRW are in meters. Impulse response broadening factor k_{AZ} is associated with weighting function $w_{AZ}(s)$. For uniform weighting, $k_{AZ} = 0.886$.

$$\text{Az_SS} = \frac{1}{\text{NFAC} \bullet \text{Kaz_SS}} \qquad \text{XML: Col.SS}$$

$$\text{Az_IRW} = \frac{k_{RG}}{\text{Kaz_IRBW}}$$ XML: Col.ImpRespWid

Parameters ΔKaz1 and ΔKaz2 define support relative to Kaz_Ctr of the azimuth spatial frequency support of the image. Compute initial values of ΔKaz1 and ΔKaz2 as follows.

$$\Delta\text{Kaz1_Init} = \Delta\text{Kaz_COA} - 0.5 \bullet \text{Kaz_IRBW}$$

$$\Delta\text{Kaz2_Init} = \Delta\text{Kaz_COA} + 0.5 \bullet \text{Kaz_IRBW}$$

The initial values are compared to the limits of -0.5/Az_SS and +0.5/Az_SS to detect a wrapped spectrum.

$$\text{IF} \quad \Delta\text{Kaz1_Init} < -\frac{0.5}{\text{Az_SS}} \quad \text{OR} \quad \Delta\text{Kaz2_Init} > +\frac{0.5}{\text{Az_SS}}, \rightarrow \text{Kaz Spectrum Wrapped.}$$

Set final values of ΔKaz1 and ΔKaz2 as follows.

$$\Delta\text{Kaz1} = \begin{cases} \Delta\text{Kaz1_Init}, & \text{Kaz Spectrum Not Wrapped} \\ -\dfrac{0.5}{\text{Az_SS}}, & \text{Kaz Spectrum Wrapped} \end{cases}$$ XML: Col.DeltaK1

$$\Delta\text{Kaz2} = \begin{cases} \Delta\text{Kaz2_Init}, & \text{Kaz Spectrum Not Wrapped} \\ +\dfrac{0.5}{\text{Az_SS}}, & \text{Kaz Spectrum Wrapped} \end{cases}$$ XML: Col.DeltaK2

4.15 Polar Format Algorithm Parameters

The parameters that describe the image formation processing for images formed with the Polar Format Algorithm (PFA) are described below. Refer to Table 3-15. The SICD.PFA parameters are always included when the image formation algorithm is identified as PFA (See Table 3-8, parameter ImageFormAlgo = PFA).

The Polar Format Algorithm (PFA) is applicable to any SAR imaging collection. The algorithm was initially developed for fine resolution spotlight imaging but has been extended to handle all collections. The basic algorithm is well suited to imaging away from broadside and has been extended to handle accelerating platforms. The algorithm processes the motion compensated Phase History Data (PHD) as if the samples are located relative to a set of polar coordinates in the image spatial frequency domain. The key step in the PFA processing is a two-dimensional resampling of the PHD from polar coordinates to rectangular coordinates. A two-dimensional Discrete Fourier Transform then yields the complex image.

For an image formed with the PFA algorithm, the parameters that describe the image include both PFA specific parameters as well as general image grid parameters used to describe all images. The discussion below addresses both sets of parameters. The PFA specific parameters include the mapping of the PHD samples to polar aperture in the spatial frequency domain. Many of the image grid parameters, e.g. the image plane and sample grid orientation, are also determined as part of the PHD to spatial frequency mapping.

4.15.1 PFA Geometry Parameters

The PFA is based upon forming an image of the points that lie in a single geometric plane that contains the Scene Center Point (SCP). The geometric plane containing the points being imaged is referred to as the Focus Plane (FP). The typical choice for the Focus Plane is the best estimate of the ground plane for the scene being imaged. An example collection geometry is shown in Figure 4.15-1. Shown in the left portion of the figure is the ARP trajectory and the Focus Plane containing the SCP. The Focus Plane orientation is specified by the Focus Plane unit normal vector, denoted **uFPN**. The **uFPN** always points away from the center of earth. The projection of the ARP position onto the FP is the ARP Focus Plane Nadir, denoted AFPN. The projection is normal to the FP. Shown in the right portion of Figure 4.15-1 is the two-dimensional Phase History Data array. The dimensions of the PHD are slow time vectors by RF samples with all vectors motion compensated to the SCP. The PHD is as described in Section 4.14-1. The portion of the PHD processed to form the image is from v_{PS} to v_{PE} corresponding to slow times t_{PS} and t_{PE}.

An image formation reference time, denoted t_{REF}, is used to establish the coordinate systems used in the PFA processing. The reference time is the time the polar angle is equal to zero and also establishes the range direction in the image. The reference time is often set equal to the SCP COA time but may be different. The AFPN at the reference time is used to establish the Focus Plane coordinate system (FPX, FPY, FPZ). The +FPZ direction is normal to the

FP (**uFPZ** = **uFPN**). The +FPX direction is from the SCP to the AFPN at t_{REF}. The +FPY direction forms a right handed coordinate system ($\mathbf{uFPY} = \mathbf{uFPZ} \times \mathbf{uFPX}$).

uFPN = Focus Plane Unit Normal XML: PFA.FPN

t_{REF} = PFA Reference Time XML: PFA.PolarAngRefTime

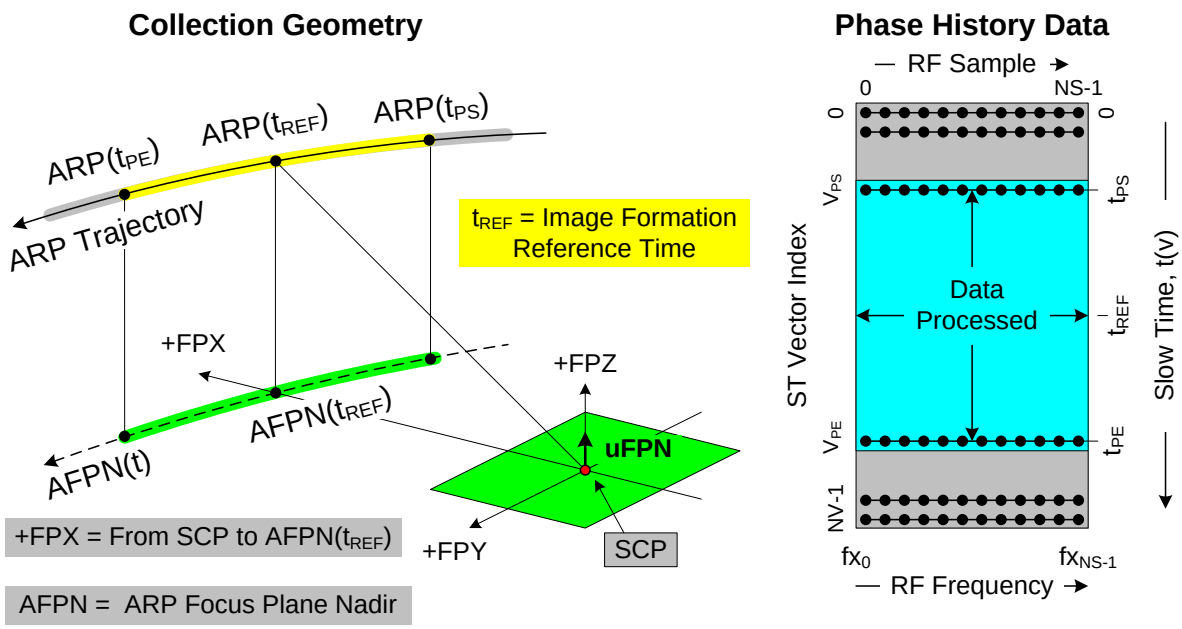


Figure 4.15-1 Collection Geometry & Phase History Data
Focus Plane defined by the SCP and the Focus Plane unit normal (uFPN).

The PFA setup includes the selection of an Image Formation Plane or Image Plane (IP). The selection is independent of the selected Focus Plane. An arbitrary Image Formation Plane is shown in the Figure 4.15-2. The IP contains the SCP and is specified by the Image Plane unit normal, denoted **uIPN**. The **uIPN** always points away from center of the earth. The projection of the ARP position onto the IP is the ARP Image Plane Projection, denoted AIPP. The projection is normal to the FP. The AIPP at the reference time is used to establish the Image Plane coordinate system (IPX, IPY, IPZ). The +IPZ direction is normal to the IP (**uIPZ** = **uIPN**). The +IPX direction is from the SCP to the AIPP at t_{REF}. The +IPY direction forms a right handed coordinate system ($\mathbf{uIPY} = \mathbf{uIPZ} \times \mathbf{uIPX}$). The SICD PFA parameters allow for the Image Formation Plane to be at any orientation (including the ground plane or the focus plane). A common choice for the IP is the instantaneous SAR slant plane containing the SCP at time t_{REF}. See Figure 4.15-3.

uIPN = Image Formation Plane Unit Normal XML: PFA.IPN

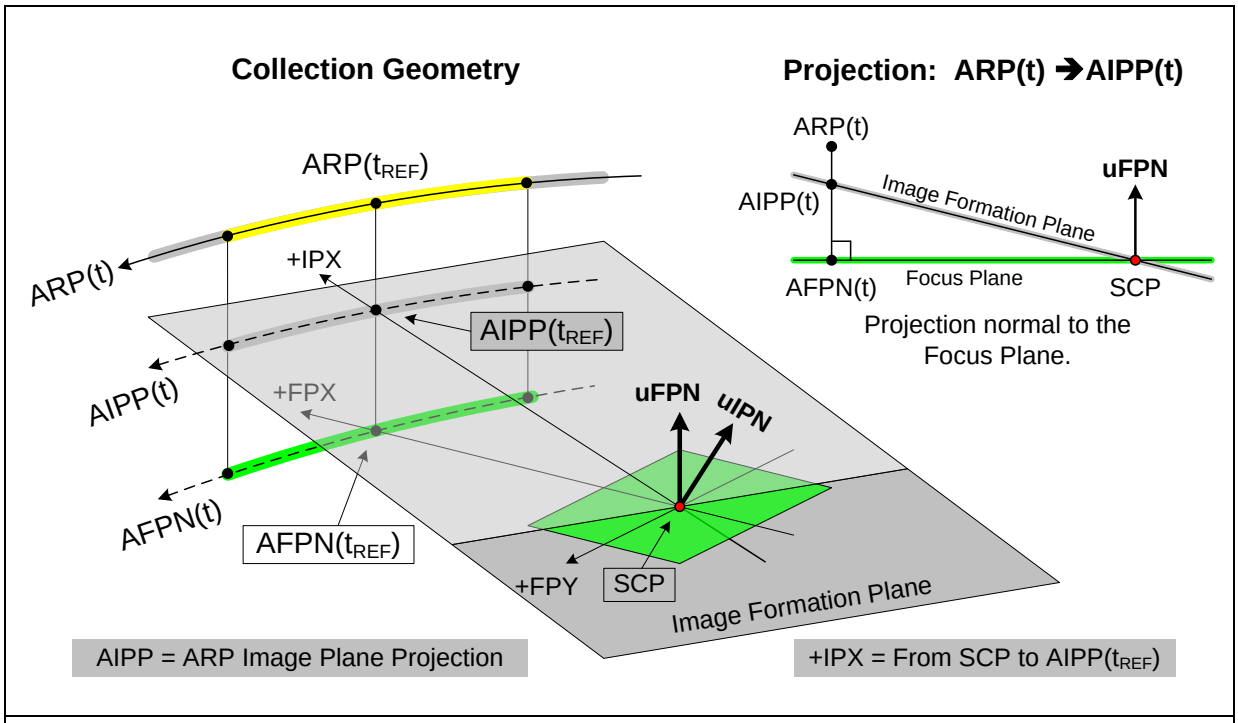


Figure 4.15-2 Image Formation Plane

An arbitrary Image Formation Plane and the ARP IP Projection position (AIPP).

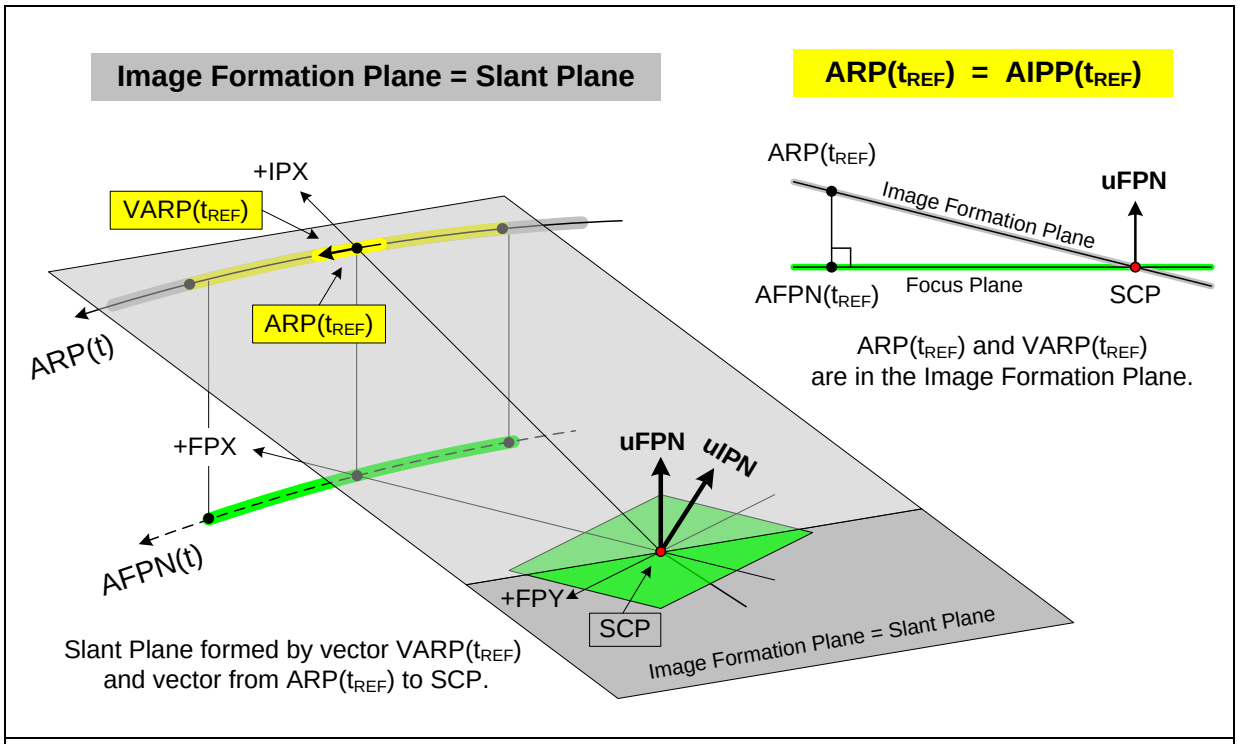


Figure 4.15-3 Slant Plane Image Formation Plane

A common choice for the IP is the SAR slant plane at t_{REF} that contains the SCP.

The resulting PFA image is Grid Type = RGAZIM. See Section 4.4.4. The rows and columns of the image nominally form a rectangular grid in the Image Plane aligned with the IPX and IPY axes. Two example image grids are shown in Figure 4.15-4. The left half of the figure shows the true image plane orientation of the rows and columns of image grid. The rows are arcs nominally oriented along constant IPX and the columns nominally along constant IPY. The SCP row and column are precisely aligned at the SCP pixel. The right half of the figure shows an idealized projection that results as the range to scene goes to infinity and the radar wave fronts becomes planar. The rows and columns become an orthogonal grid. The image grid unit vectors, denoted **uRG** and **uAZ**, are set as follows.

uRG = -uIPX	XML: Grid.Row.UVectECF
uAZ = -uIPY	XML: Grid.Col.UVectECF

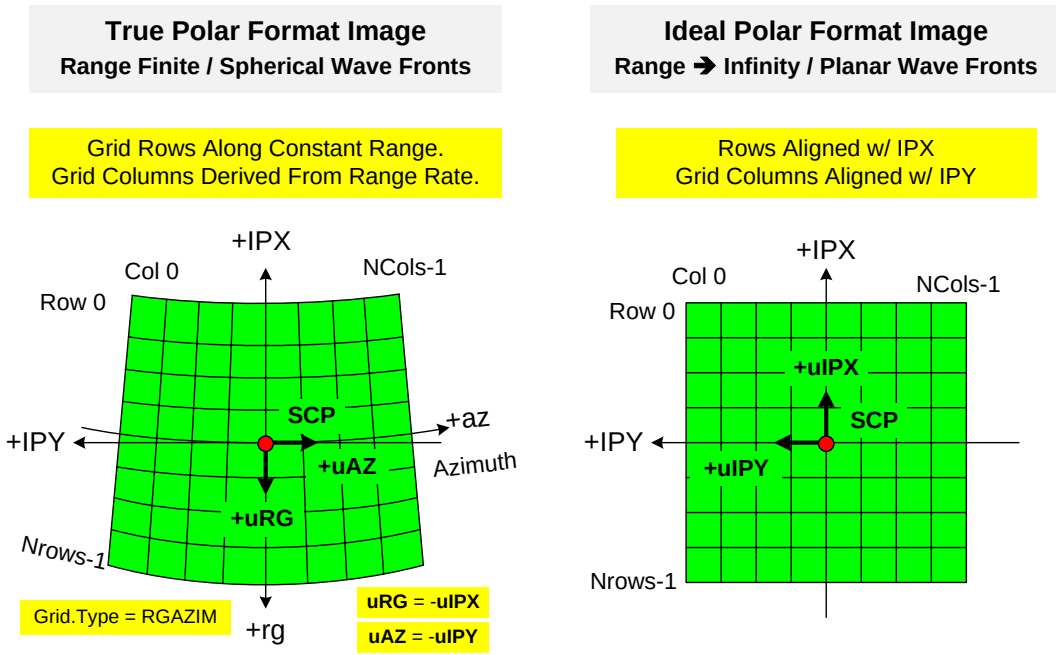


Figure 4.15-4 PFA Image Grid
The actual range, azimuth image grid and the ideal PFA sample grid.

4.15.2 PHD Mapping To Spatial Frequency Coordinates

The mapping of the Phase History Data coordinates to spatial frequency coordinates is what gives the polar format algorithm its name. The input PHD coordinates slow time and RF frequency, denoted (t, fx), are first mapped to polar coordinates Kap(t, fx) and $\theta_{PLR}(t)$. Polar coordinates (Kap, θ_{PLR}) are mapped to rectangular coordinates (Krg, Kaz) via the standard polar to rectangular conversion. The rectangular coordinates (Krg, Kaz) are the spatial frequency coordinates of the image. The ARP position at time t determines the angle $\theta_{PLR}(t)$ and scale factor $KSF(\theta_{PLR}(t))$.

$t \rightarrow$ **ARP**$(t) \rightarrow$ **AIPP**$(t) \rightarrow \theta_{PLR}(t)$ & $KSF(\theta_{PLR}(t))$

$$Kap(t,fx) = fx \bullet \frac{2}{c} \bullet KSF\left(\theta_{PLR}(t)\right)$$

$$Krg(t,fx) = Kap(t,fx) \bullet \cos\left(\theta_{PLR}(t)\right) \qquad Kaz(t,fx) = Kap(t,fx) \bullet \sin\left(\theta_{PLR}(t)\right)$$

The mapping is shown graphically in Figure 4.15-5. For a given PHD data vector v* collected with associated slow time t*, the mapping of PHD coordinates (t*,fx*) to spatial frequency coordinates (Krg*, Kaz*) is shown.

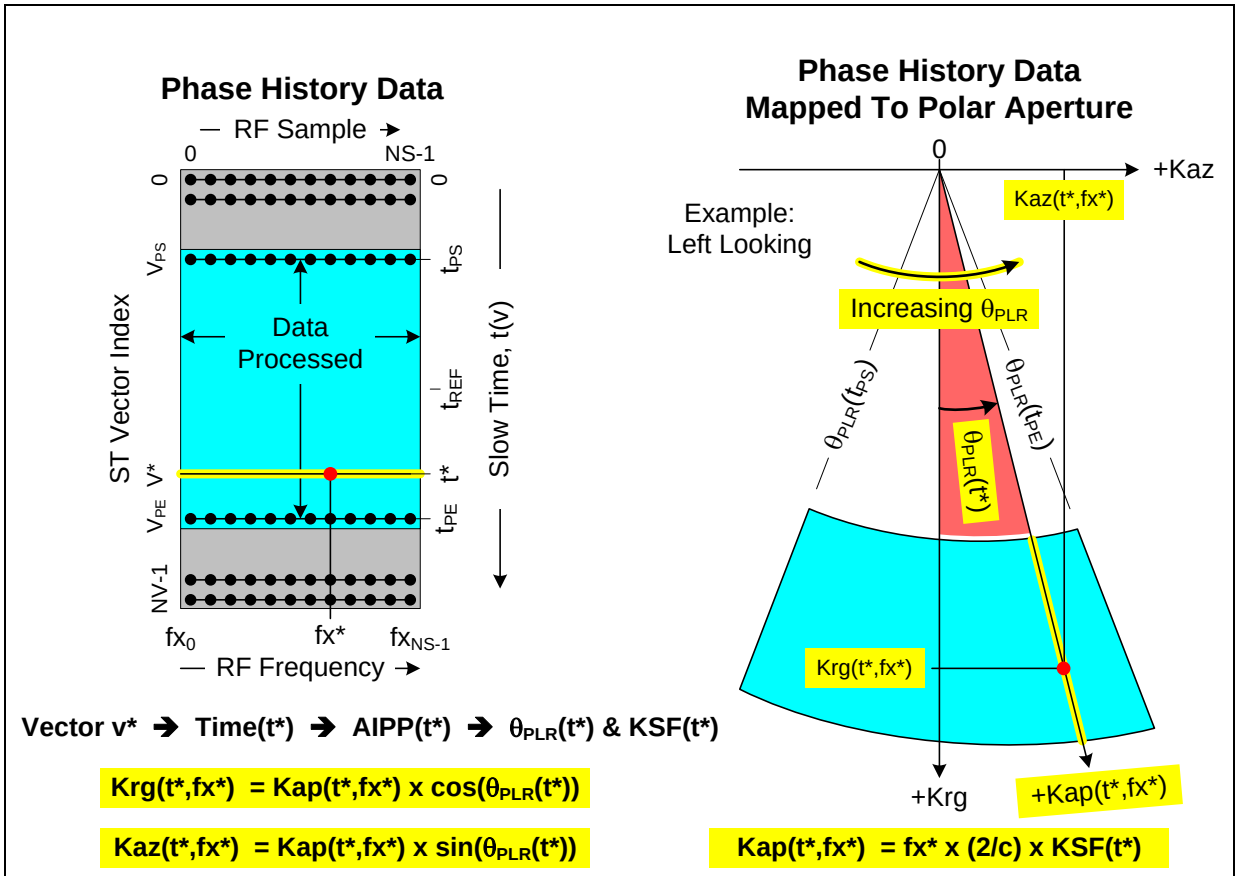


Figure 4.15-5 Phase History Mapping To Spatial Frequency
Phase history sample at (t, fx) mapped to aperture coordinates (Krg, Kaz).

The polar angle $\theta_{PLR}(t)$ is computed from the AIPP position at time t expressed in IP coordinates. The definition of the polar angle is shown below and graphically in Figure 4.15-6. By definition, $\theta_{PLR}(t_{REF}) = 0$. Figure 4.15-7 compares the polar angle versus time for left-looking and right-looking collection geometries.

$$\mathbf{AIPP}(t^*)_{IPC} = \begin{bmatrix} AIPP_IPX(t^*) \\ AIPP_IPY(t^*) \\ 0 \end{bmatrix} \qquad \theta_{PLR}(t^*) = \operatorname{atan}\left(\frac{AIPP_IPY(t^*)}{AIPP_IPX(t^*)}\right)$$

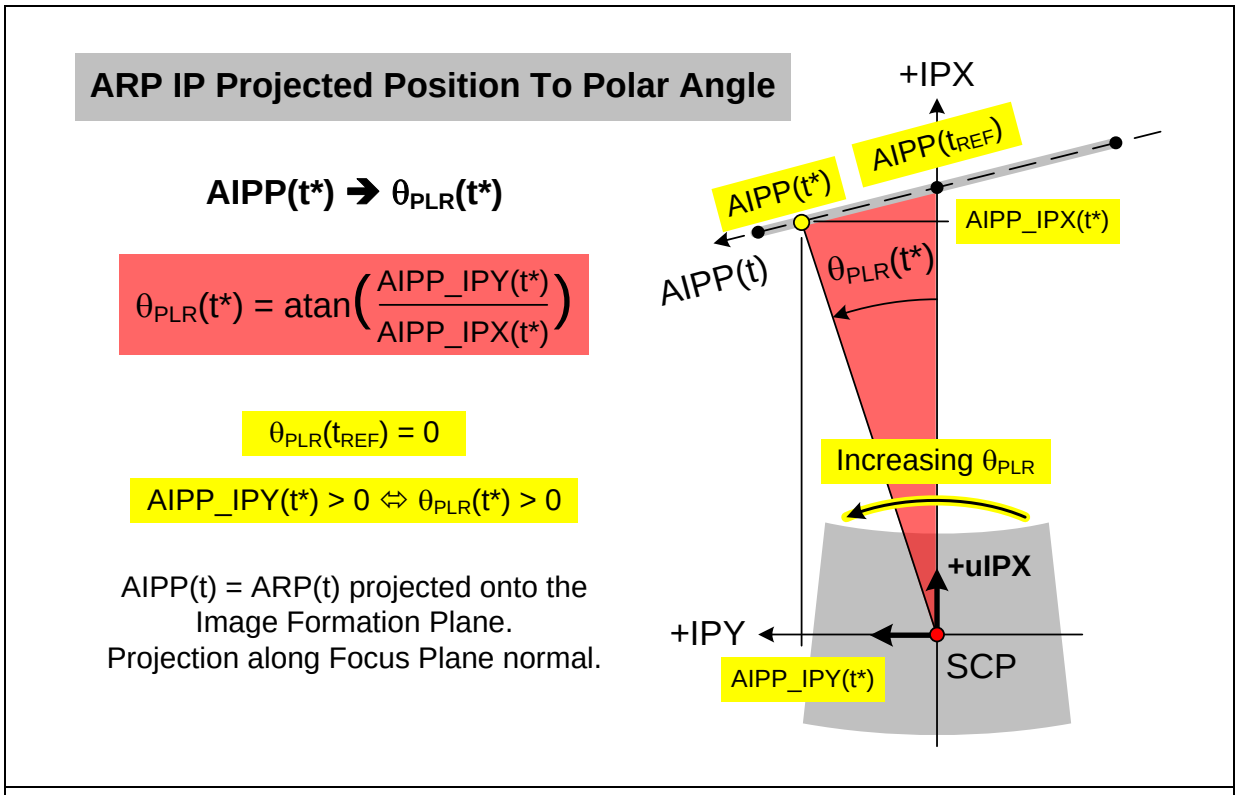


Figure 4.15-6 Polar Angle From AIPP
Polar angle measured Counter Clockwise from +IPX for all collections.

Useful for image exploitation is having the polar angle expressed as a function of time. The polar angle polynomial, coefficients denoted cPA(m), provides a convenient way for computing polar angle and polar angle rate. The scale factor KSF used to scale frequency value (fx in Hz) to radial spatial frequency value (Kap in cycles/meter), is also used in image exploitation. The common method for computing the scale factor at a given time or polar angle is shown in Figure 4.15-8. In general, the scale factor varies as a function of polar angle. A convenient form is to have the scale factor as a function of polar angle, $KSF(\theta_{PLR})$. The spatial frequency scale factor polynomial, coefficients denoted cKSF(m), provides KSF as function of polar angle. The value of the scale factor, $KSF(\theta_{PLR})$, is computed from the polynomial.

XML: PFA.PolarAngPoly(m) = cPA(m) m = 0 to M_PA

XML: PFA.SpatialFreqSFPoly(m) = cKSF(m) m = 0 to M_KSF

$$\theta_{PLR}(t) = \sum_{m=0}^{M_PA} cPA(m)\bullet t^{m} \qquad d\theta_{PLR}(t)/dt = \sum_{m=1}^{M_PA} m\bullet cPA(m)\bullet t^{m-1}$$

$$KSF(\theta_{PLR}) = \sum_{m=0}^{M_KSF} cKSF(m)\bullet(\theta_{PLR})^{m} \qquad \frac{d}{d\theta}KSF(\theta_{PLR}) = \sum_{m=1}^{M_KSF} m\bullet cKSF(m)\bullet(\theta_{PLR})^{m-1}$$

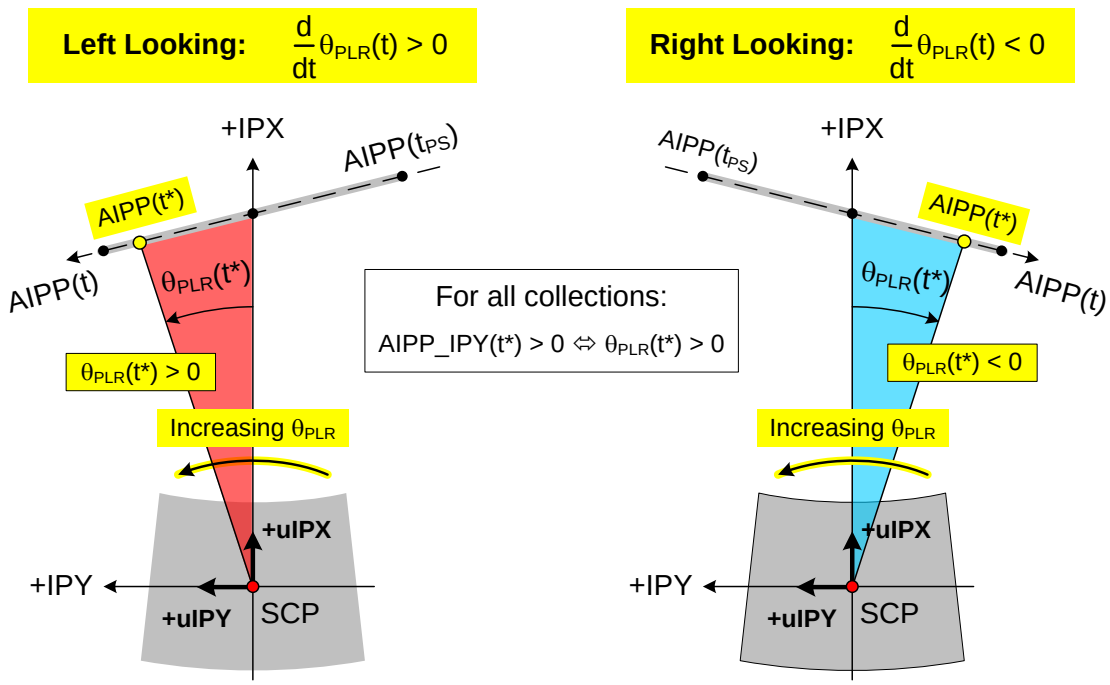


Figure 4.15-7 Polar Angle Measured CCW For All Collections
Polar Angle Rate positive for LEFT looking and negative for RIGHT looking.

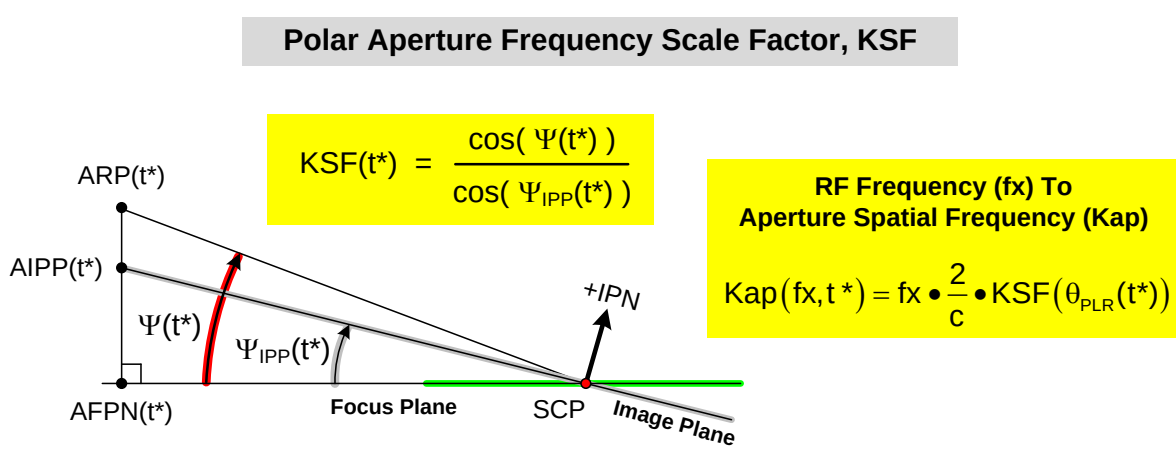


Figure 4.15-8 Polar Aperture Frequency Scale Factor
Commonly used scale factor KSF that scales RF frequency fx to Kap.

4.15.3 Image Spatial Frequency Parameters

The polar to rectangular resampling yields a rectangular aperture in the image spatial frequency domain. The rectangular aperture is aligned with the Krg and Kaz axes. The size of the rectangular aperture is a choice made in the image formation processing. The extent of the rectangular aperture used to form the image is given by range spatial frequency parameters Krg1 and Krg2 and azimuth spatial frequency parameters Kaz1 and Kaz2. These are the limits of the input PHD that contribute to the image. They do not include any additional zero-fill that may be needed for the two-dimensional DFT used to form the image.

XML: PFA.Krg1	XML: PFA.Kaz1
XML: PFA.Krg2	XML: PFA.Kaz2

Figure 4.15-9 shows an example input PHD where the rectangular aperture is inscribed within the polar aperture of the input PHD. A portion of the collected PHD is discarded due to the choice of the inscribed aperture. Figure 4.15-10 shows the same input PHD where the rectangular aperture is circumscribed around the polar aperture of the input PHD. Portions of the circumscribed rectangular aperture are zero-filled as shown. For each aperture, the limits Krg1, Krg2, Kaz1 and Kaz2 are as shown.

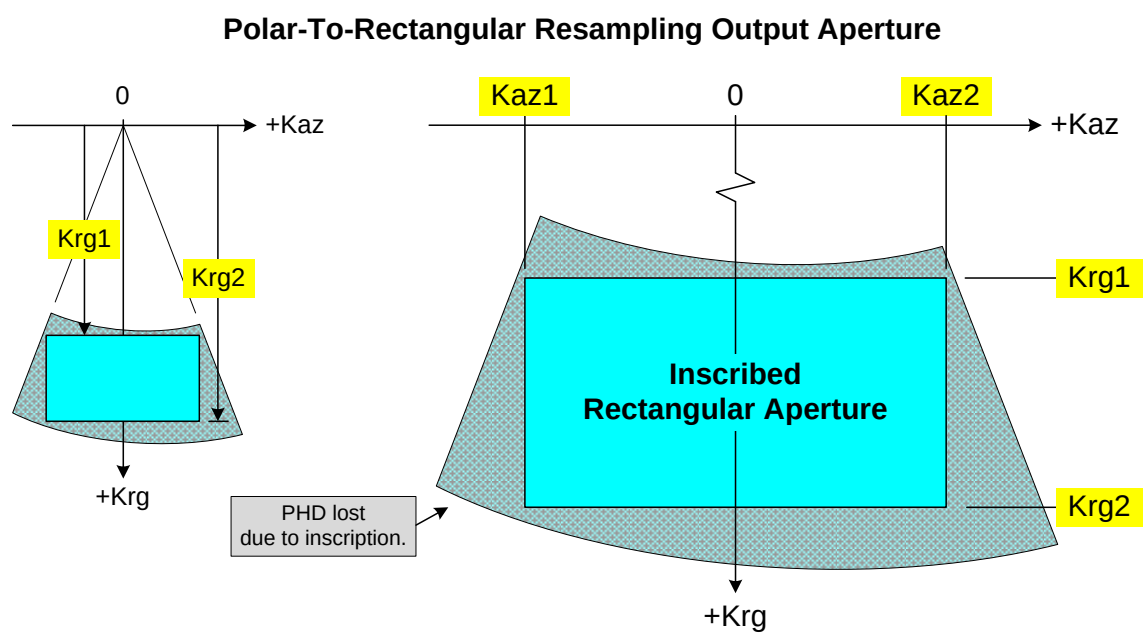


Figure 4.15-9 Inscribed Rectangular Aperture
Example rectangular aperture inscribed within the polar aperture of the input PHD.

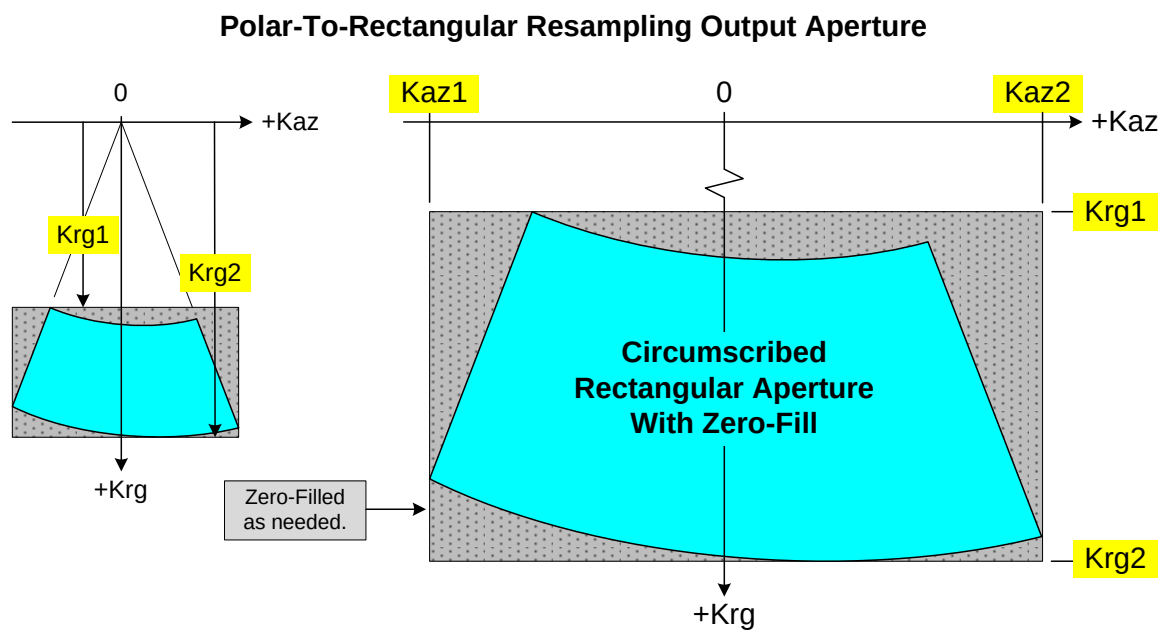


Figure 4.15-10 Circumscribed Rectangular Aperture

Example rectangular aperture circumscribed around the polar aperture of the input PHD.

The sampled image spatial frequency grid following the polar to rectangular resampling is denoted S_{KK}(nrg, naz). The rows, indexed by nrg, are evenly spaced samples in the Krg dimension. The columns, indexed by naz, are evenly spaced samples in Kaz. An example grid is shown in Figure 4.15-11. Also shown is the expression for the image compression two-dimensional DFT. Spatial frequency point (KrgCtr, KazCtr) corresponds to the center point of the DFT. The resulting image domain signal is S_{II}(irg, iaz). The phase sign parameter SGN is associated with the motion compensated PHD (where SGN = +1 or -1). See Section 4.14-1. The sign of the image compression DFT is set as shown in the figure. Row and column phase sign parameters are set equal to the phase sign associated with PHD.

XML: Grid.Row.Sgn = SGN XML: Grid.Col.Sgn = SGN

Spatial frequency KrgCtr corresponding to index value nrgc is typically set equal (or nearly equal) to (Krg1 + Krg2)/2. Spatial frequency KazCtr corresponding to index value nazc is typically set either to 0 or to (Kaz1 + Kaz2)/2. Row parameter KCtr is set equal to KrgCtr and column parameters KCtr is set equal to KazCtr.

XML: Grid.Row.KCtr = KrgCtr XML: Grid.Col.KCtr = KazCtr

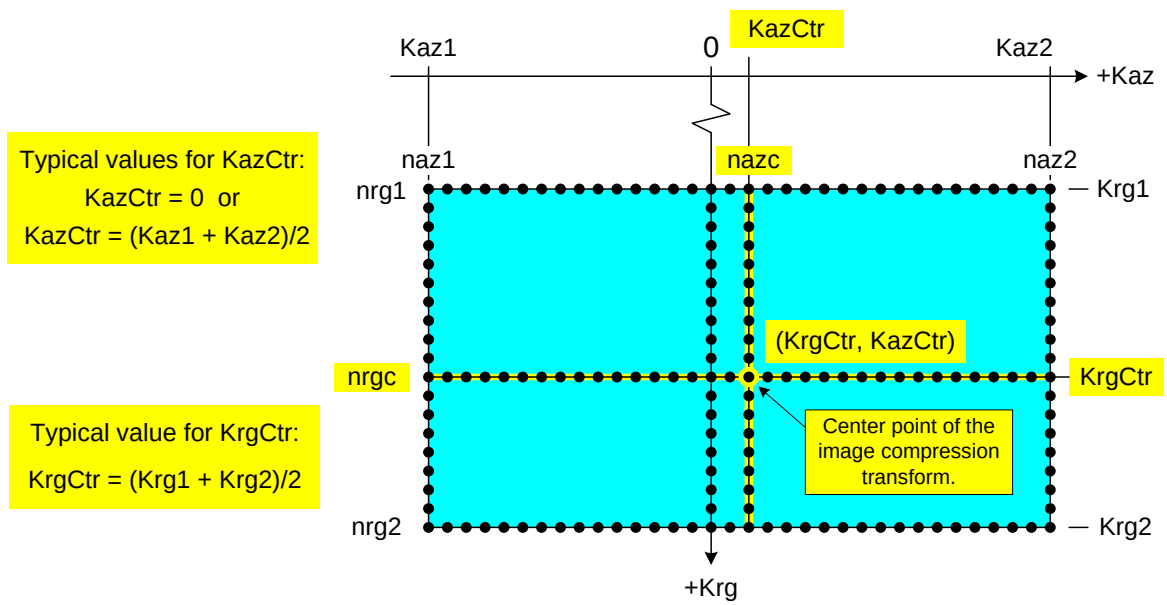


Image Compression 2-D DFT

$$\underbrace{S_{II}(irg,iaz)}_{\text{Image Signal}} = \sum_{nrg=nrg1}^{nrg2}\sum_{naz=naz1}^{naz2}\underbrace{S_{KK}(nrg,naz)}_{\text{Spatial Frequency Domain Signal}}\bullet\exp\left\{-j2\pi\bullet SGN\bullet\left[\frac{irg\bullet(nrg-nrgc)}{NFR}+\frac{iaz\bullet(naz-nazc)}{NFC}\right]\right\}$$

Figure 4.15-11 Spatial Frequency Signal

Example rectangular aperture that is the output of the polar to rectangular resampling.

4.15.4 Slow Time Deskew

The slow time deskew phase function is a phase function that is applied to the image domain signal for to form an image with varying Center of Aperture times. Such images are typically formed from dynamic stripmap mode collections. The deskew function is used to align the center of aperture in azimuth spatial frequency for all points in the image. The slow time deskew function, denoted $\theta_{DS}(rg,az)$, is a two-dimensional polynomial function of image coordinates (rg,az). Also provided is the logical parameter, denoted APPLIED, to indicate if the deskew function has been applied to the image.

XML: PFA.STDeskew.Applied = APPLIED

APPLIED = TRUE ⇔ ST Deskew polynomial has been applied.

APPLIED = FALSE ⇔ ST Deskew polynomial has NOT been applied.

XML: PFA.STDeskew.STDSPhasePoly(m,n) = cSTDS(m,n) m = 0 to M_DS, n = 0 to N_DS

$$\theta_{DS}(rg,az) = \sum_{m=0}^{M_DS}\sum_{n=0}^{N_DS} cSTDS(m,n)\bullet(rg)^m\bullet(az)^n$$

Consider the image signal array, $S1_{II}(irg,iaz)$, that is the output of the image compression 2-D DFT and prior to applying the deskew function. An example image from a dynamic stripmap collection is shown in Figure 4.15-12. The image range index spans irg = irg1 to irg2. The image azimuth index spans iaz = iaz1 to iaz2. The image includes zero filled regions that correspond to area outside the imaged strip. The range sample spacing is Rg_SS and azimuth sample spacing is Az_SS. Also shown is the image response from targets A, B and C. Target B is located at the SCP and has its impulse response centered on the SCP pixel, $S_{II}(0,0)$. The deskew phase function is then applied to signal $S1_{II}(irg,iaz)$, as shown below. The resulting image signal array with deskew applied is $S2_{II}(irg,iaz)$.

$$\underbrace{S2_{II}(irg,iaz)}_{\substack{\text{Image Signal}\\ \text{With Deskew Applied}}} = \underbrace{S1_{II}(irg,iaz)}_{\substack{\text{Image Signal}\\ \text{Prior To Deskew}}} \bullet \exp\left\{ j \bullet 2\pi \bullet \left(\sum_{m=0}^{M_DS} \sum_{n=0}^{N_DS} cSTDS(m,n) \bullet (Rg_SS \bullet irg)^m \bullet (Az_SS \bullet iaz)^m \right) \right\}$$

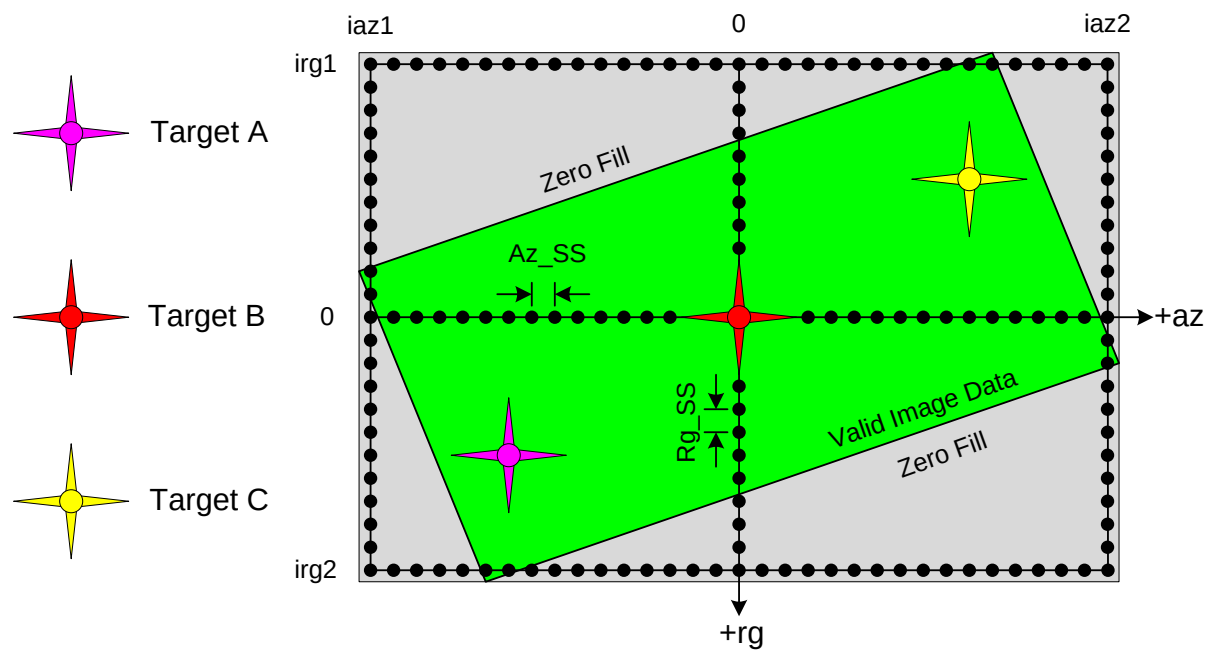


Figure 4.15-12 Image Array w/ Targets A, B & C
Example image for a Dynamic Stripmap image which includes non-valid zero fill.

The spatial frequency domain for image signal $S1_{II}(irg,iaz)$ is shown in Figure 4.15-13. The center point of spatial frequency domain at $\Delta Krg = 0$ and $\Delta Kaz = 0$ corresponds to center point (KrgCtr, KazCtr) in the resampled rectangular aperture. For the example shown, an inscribed rectangular aperture was used. Targets A, B and C were illuminated at different times as the antenna beam was scanned along the imaged strip. The spatial frequency domain for image signal $S2_{II}(irg,iaz)$ is shown in Figure 4.15-14. The effect of the deskew phase function is to shift the center of apertures to $\Delta Kaz = 0$ for all targets. Also shown is a

secondary effect which is to introduce a "skew" in the range spatial frequency dimension. This secondary effect, usually considered undesirable although unavoidable, is highly variable with imaging geometry and image size. For a given target located at image location (rg^{TGT}, az^{TGT}), the range frequency shift due to the deskew, ΔKrg^{TGT}, is given by the following expression.

$$\Delta Krg^{TGT} = -SGN \bullet \left.\frac{\partial \theta_{DS}(rg,az)}{\partial (rg)}\right|_{TGT} = -SGN \bullet \sum_{m=1}^{M_DS} \sum_{n=0}^{N_DS} m \bullet cSTDS(m,n) \bullet (rg^{TGT})^{m-1} \bullet (az^{TGT})^{m}$$

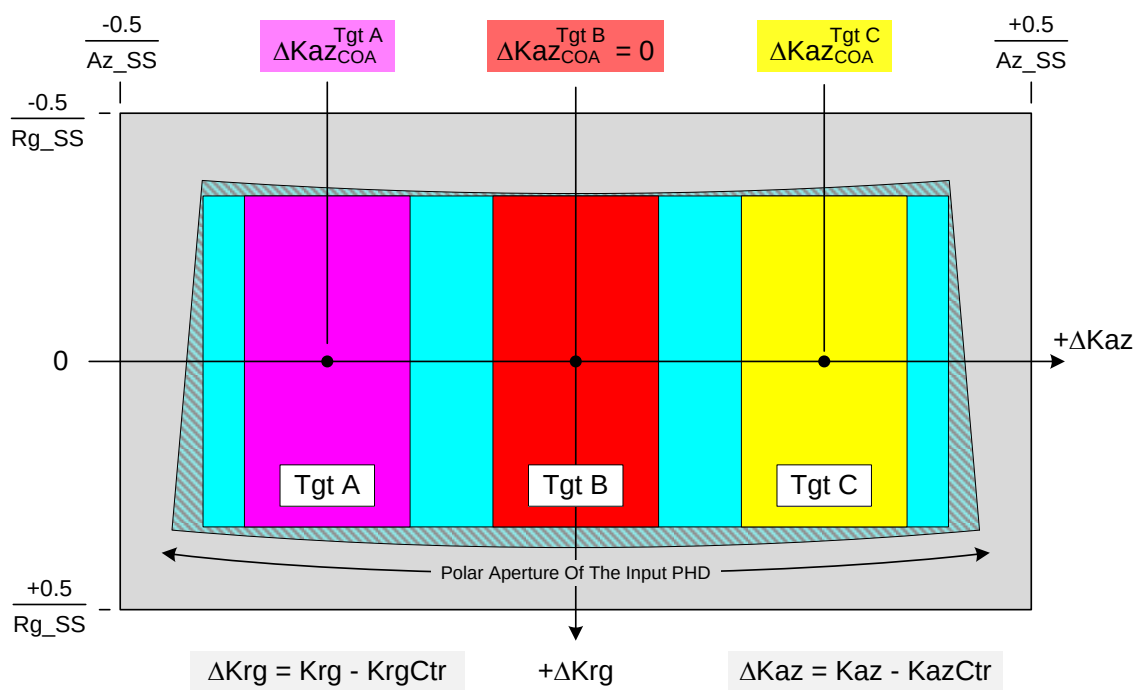


Figure 4.15-13 Spatial Frequency Prior To ST Deskew

Spatial frequency support for $S1_{II}$(irg,iaz) varies with image location.

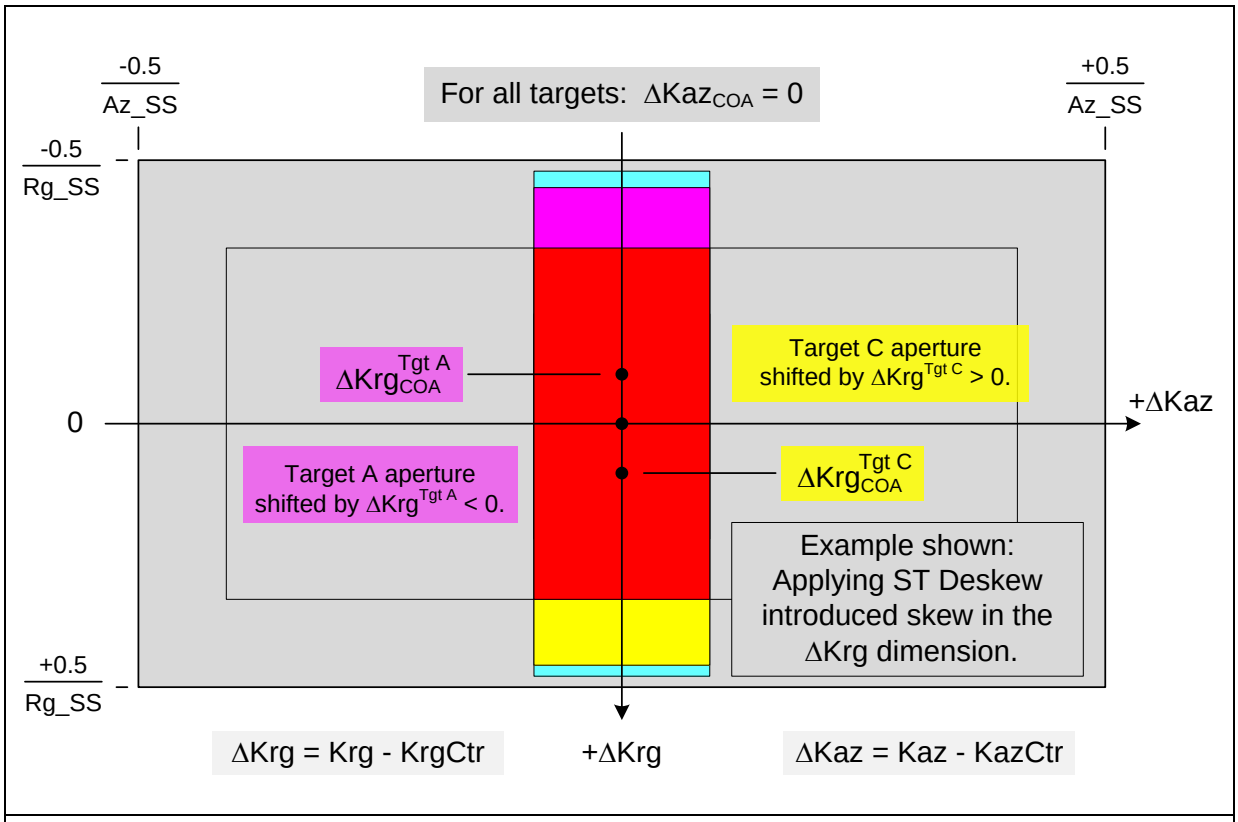


Figure 4.15-14 Spatial Frequency Post ST Deskew

Azimuth spatial frequency support for $S2_{II}$(irg,iaz) is centered at ΔKaz = 0 for all targets.

4.16 Range Migration Algorithm Parameters

The parameters that describe the image formation processing for images formed with any one of several Range Migration Algorithms (RMAs) are described below. Refer to Table 3-16. The SICD.RMA parameter block is always included when the image formation algorithm is identified as an RMA based algorithm (See Table 3-8, ImageFormAlgo = RMA).

The Range Migration Algorithm is based on the principle that for straight line flight of the radar platform, the range of a fixed point as a function of platform displacement is hyperbolic. For a given fixed ground point, the shape of the hyperbola is defined by the range at closest approach (denoted R_CA). If the radar platform flies with constant speed, the range versus time is also described by a hyperbola. The development of the RM approach has resulted in several variations of the algorithm referred to here as RMA types. All RMA types (described below), are based on the hyperbolic shape of the range histories. The particular RMA type used is dependent upon the imaging geometry, the transmitted frequency band and the resolutions in range and azimuth of image. Also considered is the scene size to be processed in a single image formation operation and the extent to which the platform trajectory deviates from a precisely straight line.

The RMA is most commonly used for stripmap collections with imaging of the ground points as they pass through closest approach (i.e. broadside stripmap imaging). The RMA may also be used for imaging collections away from broadside (i.e. squinted imaging) by applying motion compensation to a moving point in the early stages of the processing. Use of RMA for squinted imaging is primarily used for spotlight collections.

The RMA approach is based upon the radar platform flying a straight line trajectory and collecting data at uniformly spaced positions along the flight path. A platform travelling with constant speed and operating with a fixed Pulse Repetition Frequency (PRF) will achieve this condition. For a typical airborne platform, the trajectory only approximates a straight line due to limitations in aircraft control (e.g. due to variable winds). Variation in platform displacement between radar pulses is also common when variations in platform speed are not compensated with variations in PRF. The early stages of the data processing will include motion compensation that corrects for deviation from straight line flight as well as vibration of the radar antenna. Compensation for deviations from uniform spacing in platform position may also be applied. The compensations for non-straight line flight will be precise at the center of the scene or strip being imaged. The compensated data is then processed as if were from a straight line trajectory.

In adapting the RM algorithm to process collections away from broadside, motion compensation is applied to account for the range rates that yield true Doppler frequencies that are many multiples of the operating PRF. Two approaches have been developed. The first approach applies motion compensation to a moving point in the along track direction. This results in an image that is still in the natural along track, cross track orientation. See Grid.Type = XCTYAT. A second approach applies motion compensation to a moving point

in the cross range direction. This results in an image that is oriented range, cross range. See Grid.Type = XRGYCR. For collections at broadside, the two approaches become identical.

For platforms that only image near closest approach (within a few degrees of broadside), the RMA is easily adapted to accommodate non-straight line flight. For any platform trajectory, the range versus time for a point near closest approach is accurately approximated by a hyperbolic fit. For an orbital trajectory, the curve of the orbit is accounted for in the hyperbolic approximation. This allows the RMA to be readily extended to satellite platforms imaging near broadside.

(1) RMA Types

The RMA approach includes a transform from slow time to Doppler frequency or, more accurately, from platform displacement to along track spatial frequency. The processing of the data both before and after the transform differentiates the various RMA types. The choice of algorithm type depends upon the resolution to be achieved and the size of the scene to processed in a single image formation operation. The three RMA types are summarized as follows. See parameter RMAlgoType.

Range-Doppler: RMAlgoType = RG_DOP. Prior to the slow time to Doppler transform, each fast time vector is range compressed. The output of the slow time to Doppler transform is the Range-Doppler domain. Following the slow time to Doppler transform, a correction for migration through range cells is performed. Following range cell migration correction, a one-dimensional transform yields the compressed image. The Range-Doppler algorithm is most commonly used for imaging near closest approach.

Omega-K: RMAlgoType = OMEGA_K. Prior to the slow time to Doppler transform, each fast time vector is range dispersed. The fast time dimension of the collection has been processed to align all echoes by radio frequency (RF). The RF dimension is often expressed in rad/sec and is the “Omega” dimension. The Doppler dimension is more accurately the along track spatial frequency dimension and is the “K” dimension (labeled the Kyt dimension below). A two-dimensional phase correction for the Scene Center Point is then applied (the first step in a matched filter). Following the phase correction, the RF/Omega dimension is resampled to yield cross track spatial frequency (labeled the Kxt dimension below). The resampling is commonly referred to as Stolt Interpolation. Following the resampling, a two-dimensional transform yields the compressed image.

Chirp-Scaling: RMAlgoType = CSA. Prior to the slow time to Doppler transform, each fast time vector is range dispersed and retains the differential in time of arrival associated with differences in range. This is the natural fast time signal for systems that use a linear FM waveform and do not employ de-ramp on receive. The response for any given target is a “chirp” in the fast time dimension. Following the slow time to Doppler transform, the signal history of any given point is a two-dimension chirp. The processing of the two-dimensional chirp signals uses a sequence of one-dimensional transforms and matched filters that yields the compressed image.

While the type of RMA algorithm is an important consideration for forming the image, the RMA type is not critical in describing or exploiting the resulting image. For finer image resolution, the image formation algorithm will require more accurate focusing of individual

points. For larger scene sizes, the image formation algorithm will need to correct larger amounts of differential range curvature. For straight line flight, the resulting image for all RMA types is an orthogonal grid of points in the slant plane.

(2) Image Types

The images formed with the RMA are considered to be of three types. Image types RMAT and RMCR are formed for collections with nearly straight line trajectories and accommodate squinted collection. Image Type INCA are formed only for collections Near Closest Approach but accommodates non-straight line trajectories. See parameter ImageType.

RMAT: ImageType = RMAT. The image plane is a slant and is referred to as the reference slant plane. See Figure 4.16-1. Along track motion compensation may be applied for large range rates in squinted collections. The image grid is a rectangular grid oriented cross track, along track. See Section 4.16.1 below.

RMCR: ImageType = RMCR. The image plane is the reference slant plane. Cross range motion compensation may be applied for large range rates in squinted collections. The image grid is a rectangular grid oriented range, cross range. See Section 4.16.2 below.

INCA: ImageType = INCA. Used only for collections where all points in the scene are imaged near closest approach. The image grid is always range and zero Doppler (grid type RGZERO). The condition "near closest approach" is described below. The restriction for near straight line trajectory does not apply. See Section 4.16.3 below.

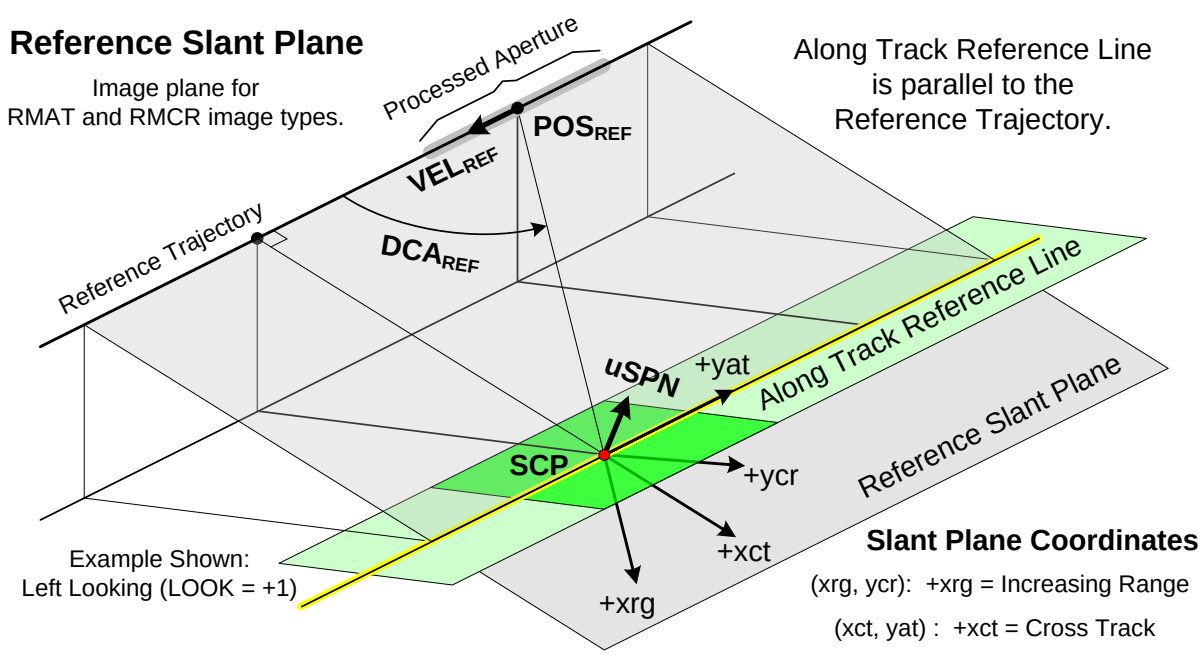


Figure 4.16-1 Reference Slant Plane

Slant plane coordinates (xct, yat) and (xrg, ycr) lie in the Reference Slant Plane.

4.16.1 RMAT Images

The parameters associated with an image formed with the RMA and oriented cross track, along track are summarized below. For collections away from broadside, motion compensation to a reference point moving along track is applied. The collection geometry is defined by a straight line trajectory that approximates the actual trajectory of the platform. The straight line trajectory is referred to as the reference line trajectory. The reference line trajectory is defined by the reference position ($\mathbf{POS}_{REF}$) and the reference velocity vector ($\mathbf{VEL}_{REF}$). The reference line trajectory may be computed as the best fit straight line trajectory to the true ARP trajectory. The reference line trajectory may also be an extrapolated position and velocity determined during the collection setup computations.

$\mathbf{POS}_{REF}$ = Reference Position XML: RMAT.PosRef

$\mathbf{VEL}_{REF}$ = Reference Velocity XML: RMAT.VelRef

The image formation plane is the Reference Slant Plane (RSP). The RSP is the plane that contains the reference position and velocity vector and the Scene Center Point (**SCP**). Example RMAT reference slant planes are shown in Figure 4.16.1-1. The reference Doppler Cone Angle, DCA_{REF}, is the DCA to the SCP relative to the reference position and velocity. The line passing through the SCP and parallel to the reference line trajectory is the Along Track reference line.

DCA_{REF} = Reference Doppler Cone Angle XML: RMAT.DCARef

The image formed is a rectangular grid oriented as shown in Figure 4.16.1.1. For all cases, the image is a view from above the earth. The image plane basis vectors, **uXCT** and **uYAT**, are shown in the figure. The row coordinate (xct) is increasing away from the reference line trajectory. For the left looking geometry, the image column coordinate (yat) is decreasing in the direction of $\mathbf{VEL}_{REF}$. For the right looking geometry, the image column coordinate is increasing in the direction of $\mathbf{VEL}_{REF}$. The side of track parameter LOOK = +1 for left looking collections and LOOK = -1 for right looking collections (see section 4.9 above).

uXCT = Cross Track Unit Vector XML: Grid.Row.UVectECF

$\mathbf{uYAT} = -\text{LOOK} \bullet \frac{\mathbf{VEL}_{REF}}{\left|\mathbf{VEL}_{REF}\right|}$ XML: Grid.Col.UVectECF

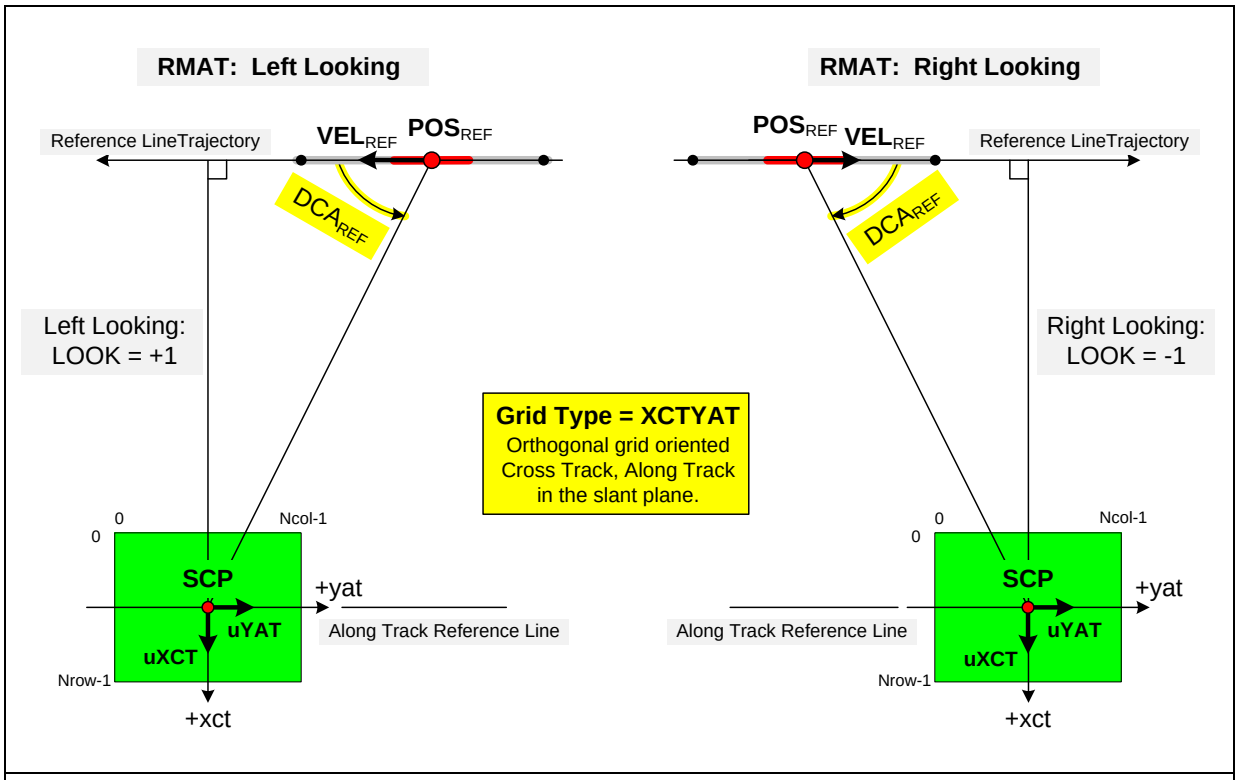


Figure 4.16.1-1 RMAT Image Coordinates

Slant plane coordinates (xct, yat) lie in the Reference Slant Plane.

For a point target in the imaged scene, the mapping from Phase History Data (PHD) coordinates (t, fx) to the image spatial frequency coordinates is a function of the Doppler Cone Angle (DCA) to the point. For the grid type XCTYAT, the spatial frequency coordinates are (Kxct, Kyat). At a time t, a target in the imaged scene, TGT, is at $DCA(t)^{TGT}$. Frequency f (in Hz) maps to aperture radial frequency Kf (in cycles/meter) by the normal 2/c scaling. For target TGT, spatial frequency Kf is mapped to spatial frequency along angle $KA(t)^{TGT}$ where $KA(t)^{TGT}$ is related to the $DCA(t)^{TGT}$ as follows.

$$Kf = f \bullet \frac{2}{c} \qquad KA(t)^{TGT} = \begin{cases} \pi - DCA(t)^{TGT}, & \text{if } LOOK = +1 \\ DCA(t)^{TGT}, & \text{if } LOOK = -1 \end{cases}$$

The cosine and sine of the angle $KA(t)^{TGT}$, $\cos(KA(t)^{TGT})$ and $\sin(KA(t)^{TGT})$, are computed as follows.

$$\cos\left(KA(t)^{TGT}\right) = -LOOK \bullet \cos\left(DCA(t)^{TGT}\right) \qquad \sin\left(KA(t)^{TGT}\right) = +\sqrt{1-\cos^2\left(KA(t)^{TGT}\right)}$$

$$Kxct(t,f)^{TGT} = Kf \bullet \sin\left(KA(t)^{TGT}\right) \qquad Kyat(t,f)^{TGT} = Kf \bullet \cos\left(KA(t)^{TGT}\right)$$

An example spotlight mode collection is shown in Figure 4.16.1.2. The platform collected a fixed transmit bandwidth, BW (Hz), centered at frequency fx_C (Hz). The reference slant plane and image area are shown in the left portion of the figure. Shown are three reference slant plane locations, A, B and C, and the corresponding slant plane integration angles spanned by the collection. The spatial frequency domain following the equivalent of the Stolt interpolation of the Omega-K algorithm is shown in the right portion of the figure. The spatial frequency apertures are shown for targets located at points A, B and C. The variation in aperture size and location corresponds to the different DCA intervals spanned for each of the targets.

The center of the saved resampled aperture is located at spatial frequency location (KxctCtr, KyatCtr). The center of the spatial frequency domain is specified in the generic row and column center frequency parameters. For the example shown in Figure 4.16.1-2, the center of the saved spatial frequency corresponds to center frequency fx_C mapped along the radial corresponding to the $KA_{REF} = DCA_{REF}$.

$$KxctCtr = Kap_C \bullet \sin\left(KA_{REF}\right) \qquad \text{XML: Grid.Row.KCtr = KxctCtr}$$

$$KyatCtr = Kap_C \bullet \cos\left(KA_{REF}\right) \qquad \text{XML: Grid.Col.KCtr = KyatCtr}$$

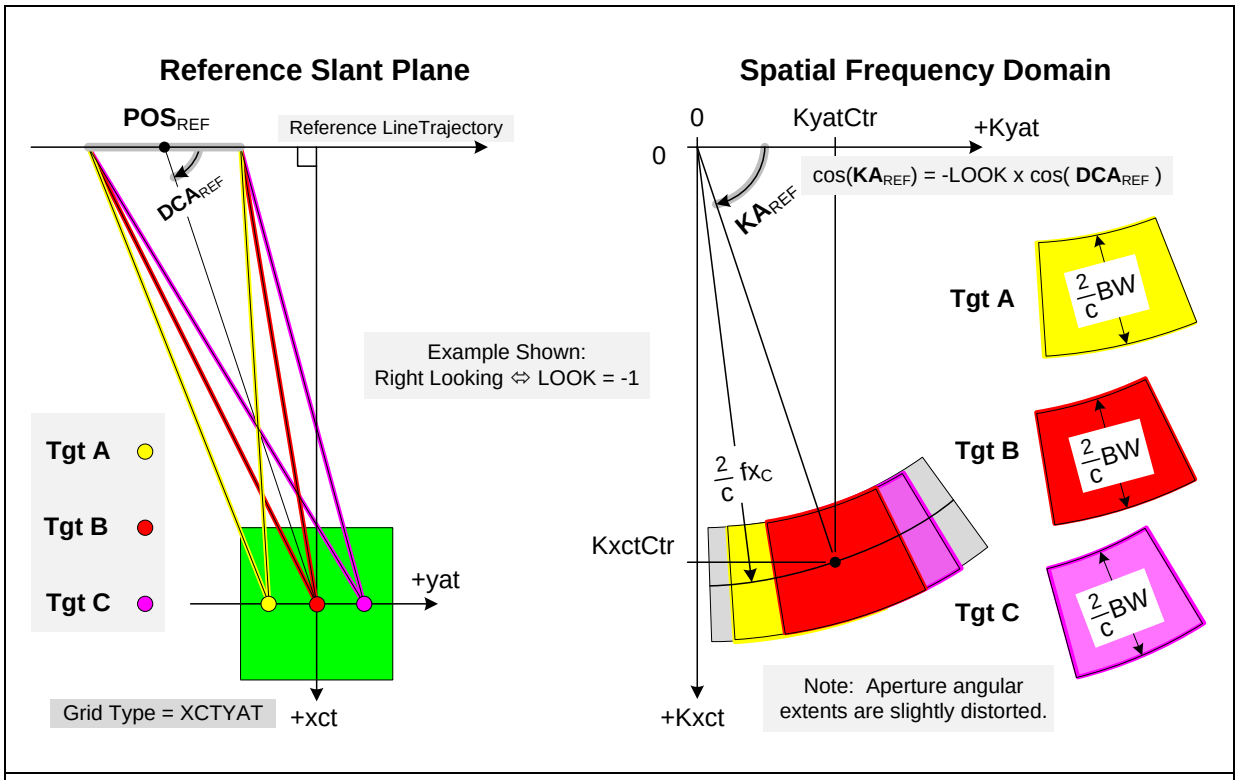


Figure 4.16.1-2 RMAT Spatial Frequency Domain

Example RMAT image spatial frequency domain for a Spotlight mode collection.

4.16.2 RMCR Images

The parameters associated with an image formed with the RMA and oriented range, cross range are summarized below. For collections away from broadside, motion compensation to a reference point moving cross range is applied. The collection geometry parameters for RMCR images are identical to those used for the RMAT images. The collection geometry is defined by a reference line trajectory that approximates the actual trajectory of the platform. The reference line trajectory is defined by the reference position ($\mathbf{POS}_{REF}$) and the reference velocity vector ($\mathbf{VEL}_{REF}$).

$\mathbf{POS}_{REF}$ = Reference Position XML: RMCR.PosRef

$\mathbf{VEL}_{REF}$ = Reference Velocity XML: RMCR.VelRef

The image formation plane is the Reference Slant Plane (RSP). The RSP is the plane that contains the reference position and velocity vector and the Scene Center Point (**SCP**). Example RMCR reference slant planes are shown in Figure 4.16.2-1. The reference Doppler Cone Angle, DCA_{REF}, is the DCA to the SCP relative to the reference position and velocity.

DCA_{REF} = Reference Doppler Cone Angle XML: RMCR.DCARef

The image formed is a rectangular grid oriented as shown in Figure 4.16.2.1. For all cases, the image is a view from above the earth. The image plane basis vectors, **uXRG** and **uYCR**, are as shown in the figure. The row coordinate (xrg) is increasing in the increasing range direction. The column coordinate (ycr) is increasing as shown independent of the side of track.

$$\mathbf{uXRG} = \frac{1}{\left|\mathbf{SCP}-\mathbf{POS}_{REF}\right|}\bullet\left(\mathbf{SCP}-\mathbf{POS}_{REF}\right)$$ XML: Grid.Row.UVectECF

uYCR = Cross Range Unit Vector XML: Grid.Col.UVectECF

During the initial steps of the processing, the PHD is motion compensated (also known as phase stabilized) to a point that moves in the cross range direction along the ycr axis. The stabilization point is referred to as the Stabilization Reference Point, denoted SRP(t). An example right looking collection geometry is shown Figure 4.16.2-2. In the left portion of the figure, the ARP trajectory and the SRP track are shown. At all times, the SRP position is the projection of the ARP position onto the ycr axis. The portion the PHD processed is from slow time t_{PS} to t_{PE}. Shown in the figure are the ARP and SRP positions at time t_{PS} and t_{PE} and two additional times t_1 and t_2, where $t_{PS} < t_1 < t_2 < t_{PE}$.

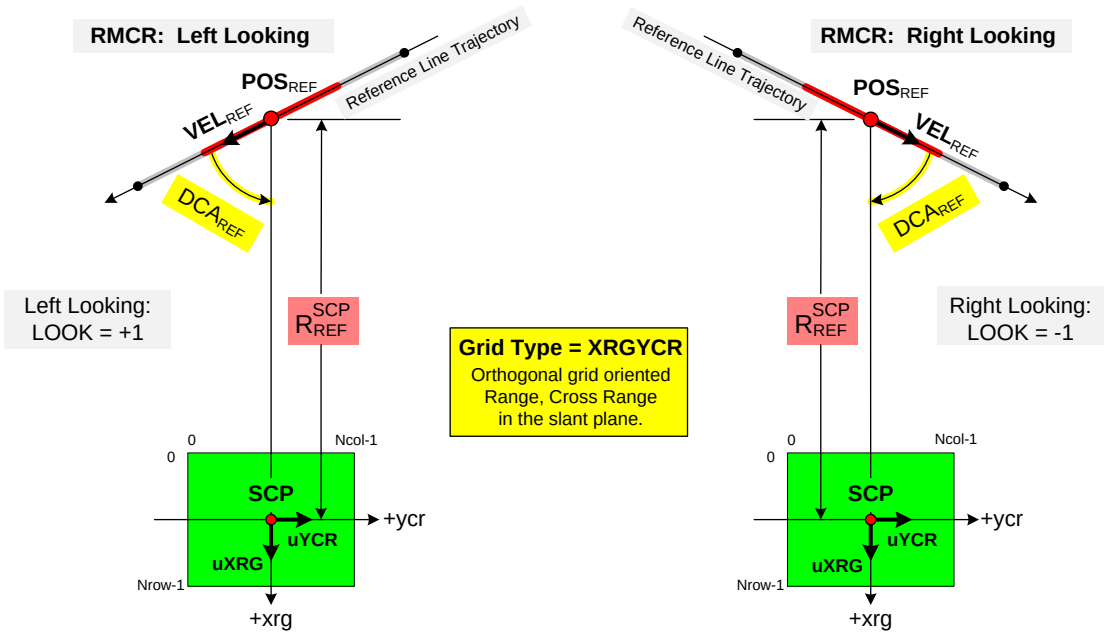


Figure 4.16.2-1 RMCR Image Coordinates

Slant plane coordinates (xrg, ycr) lie in the Reference Slant Plane.

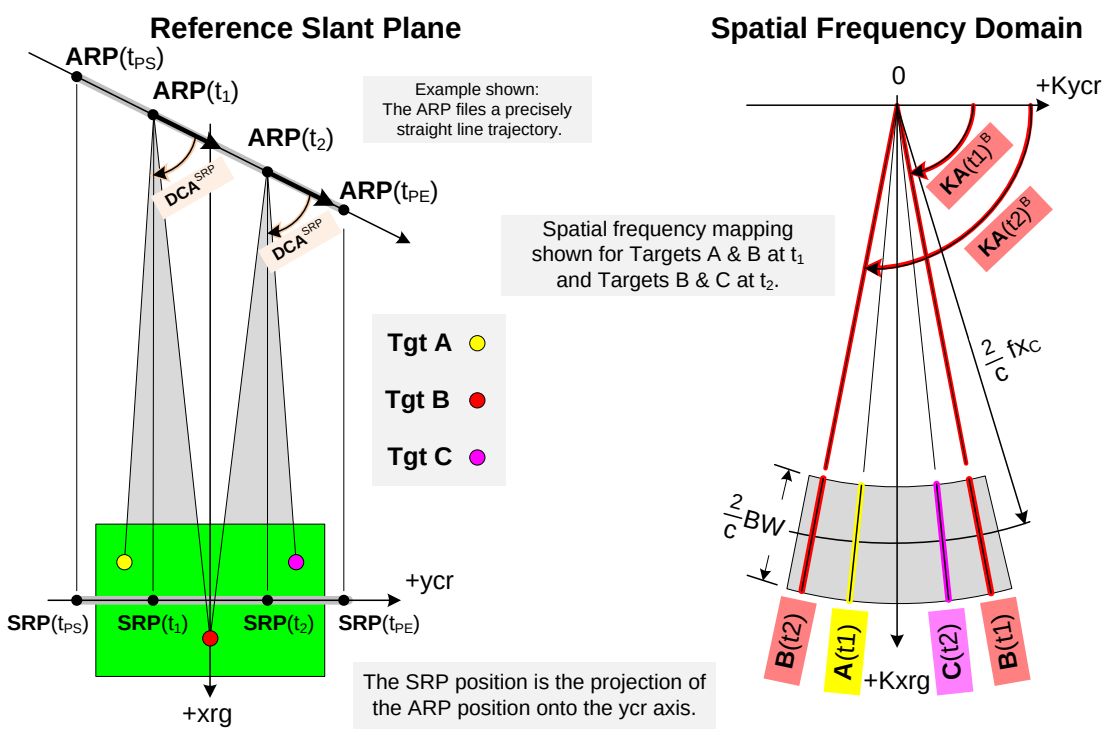


Figure 4.16.2-2 Target Position & PHD Mapping

At time t, the target DCA relative the SRP DCA determines mapping to PHD space.

For a point target in the imaged scene (TGT), the mapping from PHD coordinates (t, fx) to image spatial frequency coordinates is a function of the DCA to the SRP and the DCA to the target. At a time t, the DCA to the SRP is $DCA(t)^{SRP}$ and DCA to the target is $DCA(t)^{TGT}$. Frequency f (in Hz) maps to aperture radial frequency Kf (in cycles/meter) by the normal 2/c scaling. For target TGT, spatial frequency Kf is mapped along spatial frequency angle $KA(t)^{TGT}$. The cosine and sine of $KA(t)^{TGT}$ are related to $DCA(t)^{SRP}$ and $DCA(t)^{TGT}$ as follows.

$$\cos\left(KA(t)^{TGT}\right) = \frac{-LOOK}{\sin\left(DCA(t)^{SRP}\right)} \bullet \left(\cos\left(DCA(t)^{TGT}\right) - \cos\left(DCA(t)^{SRP}\right)\right)$$

$$\sin\left(KA(t)^{TGT}\right) = +\sqrt{1-\cos^2\left(KA(t)^{TGT}\right)} \qquad Kf = f \bullet \frac{2}{c}$$

For an RMCR image and grid type XRGYCR, the spatial frequency coordinates are (Kxrg, Kycr). The mapping to spatial frequency coordinates (Kxrg, Kycr) is as follows.

$$Kxrg(t,f)^{TGT} = Kf \bullet \sin\left(KA(t)^{TGT}\right) \qquad Kycr(t,f)^{TGT} = Kf \bullet \cos\left(KA(t)^{TGT}\right)$$

For small integration angles and/or imaging collections near closest approach, the expression for the $\cos(KA(t)^{TGT})$ is accurately approximated by the expression below.

$$\cos\left(KA(t)^{TGT}\right) \approx LOOK \bullet \left(DCA(t)^{TGT} - DCA(t)^{SRP}\right)$$

For the example imaging collection shown in Figure 4.16.2-2, three slant plane target locations A, B and C are shown. The image spatial frequency domain is shown in the right half of the figure. The platform collected a fixed transmit bandwidth, BW (Hz), centered at frequency fx_C (Hz). For PHD collected at time t_1, the mapping to (Kxrg, Kycr) is shown for targets located at points A and B. For PHD collected at time t_2, the mapping to (Kxrg, Kycr) is shown for targets located at point B and C.

An example dynamic stripmap collection is shown in Figure 4.16.2-3 where the antenna footprint is scanned in the cross range direction. The beam center moves along the ycr axis at the same rate that the ARP moves in the cross range direction. The platform collected a fixed transmit bandwidth, BW (Hz), centered at frequency fx_C (Hz). The SRP tracks the beam center along the ycr axis. The image is formed such that the COA time for a point at (xrg^{TGT}, ycr^{TGT}) is when the beam center and the SRP are at (0, ycr^{TGT}). Shown are three target positions A, B and C located on the ycr axis. For each target, the integration angle and the ARP at COA are shown. For the points A, B and C, the apertures in slow time are non-overlapping. The apertures in the spatial frequency domain are shown in rigth portion of the

figure. For points A, B and C, the apertures in the spatial frequency domain are precisely overlapped and centered at Kycr = 0. A typical RMCR image will have a spatial frequency domain aperture trim applied such that all points in the scene have the same aperture. Such a trimming is easily implemented as part of the Stolt interpolation processing.

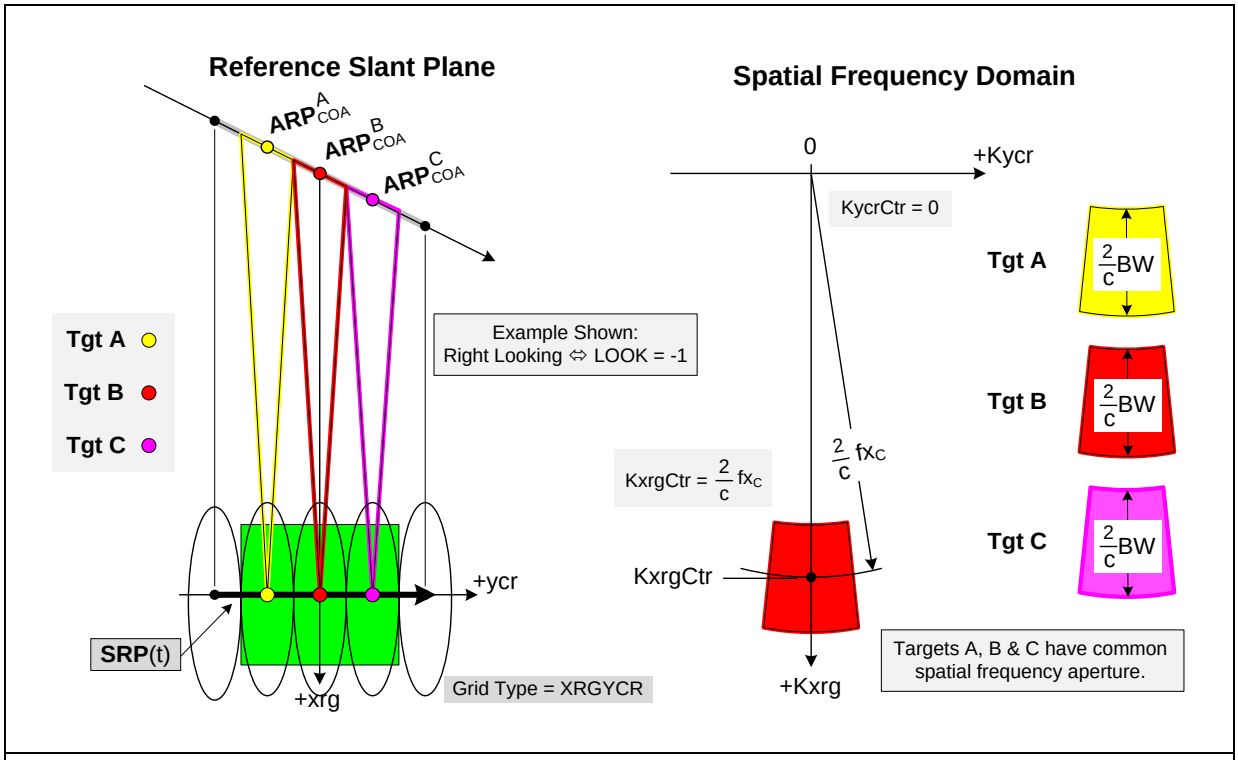


Figure 4.16.2-3 RMCR For Dynamic Stripmap

The beam center and the SRP track cross range along the ycr axis.

4.16.3 INCA Images

For the special case of imaging near closest approach, the RMA can be used to form the pixels of the image based on range at closest approach and time of closest approach. The image formed is of grid type RGZERO. The pixels of a given row are formed for points that have a common range at closest approach (R_CA). The columns of the image are formed for points that have a common time of closest approach (t_CA). See Figures 4.16.3-1 and 4.16.3-2. For straight flight trajectory, the image is a slant plane projection of the imaged scene with rows and columns forming an orthogonal grid (similar to grid type XCTYAT). For non-straight line trajectories (such as for an orbiting platform), the rows will be formed for points along curved contours of constant range from the trajectory. For all cases, the image is considered to be a slant plane image.

Grid.Type = RGZERO Gird.ImagePlane = SLANT

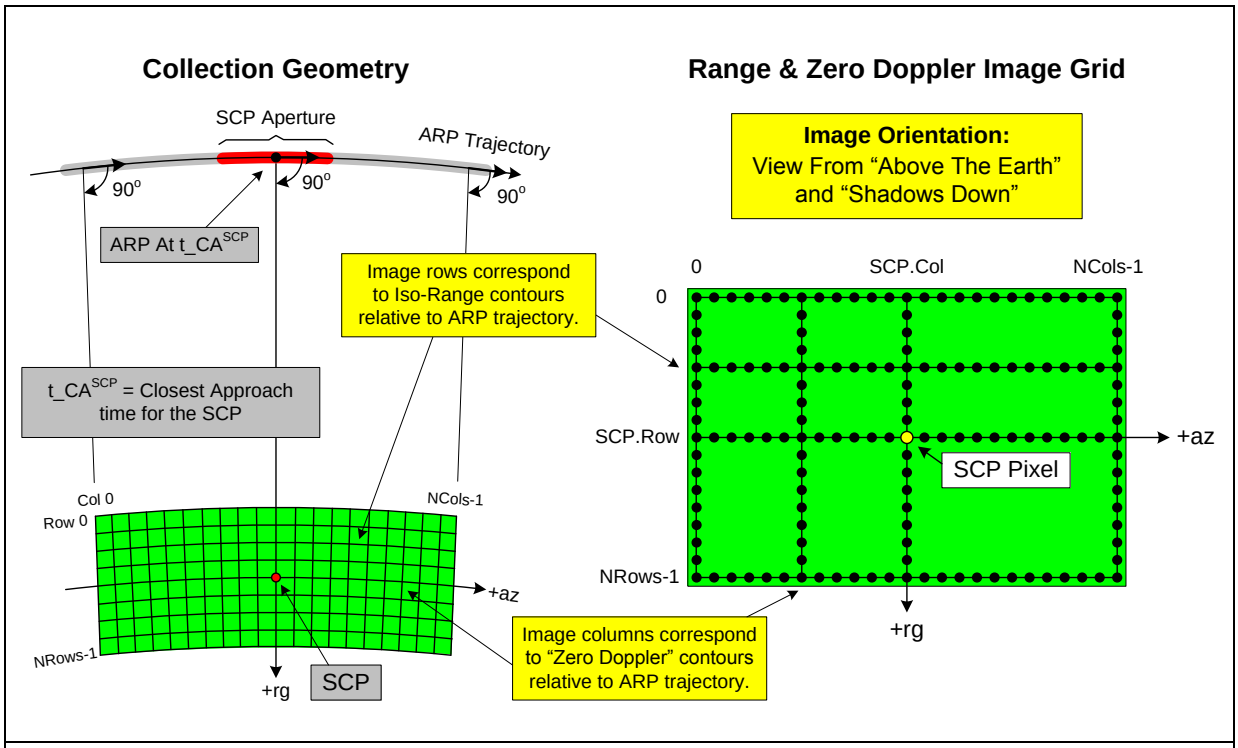


Figure 4.16.3-1 Range & Zero Doppler Image Grid
Rows oriented along contours of constant range from to the ARP trajectory.

The images formed with rows of constant R_CA and columns of constant t_CA are accurately described by the INCA parameters under the following conditions. For a given point in the imaged scene, the range as a function of time (R(t)) during the integration period for the point is accurately described by parameters computed at time of closest approach. For a ground point in the scene, the range as a function of time is approximated using the following parameters.

t_CA	Time of closest approach.
R_CA	Range at Closest Approach from the ARP trajectory.
VM_CA	Magnitude of the ARP velocity at t_CA.
DRSF	Doppler Rate Scale Factor used to compute the d^2R/dt^2 at t_CA.

The range versus time is approximated by the hyperbolic function RA(t) shown below. The Doppler Rate Scale Factor (DRSF) is computed such that the second derivative of RA(t) at closest approach is equal to the true second derivative (i.e. at t = t_CA, $d^2(RA)/dt^2 = d^2R/dt^2$).

$$RA(t) = \left[R_CA^2 + DRSF \bullet VM_CA^2 \bullet (t - t_CA)^2 \right]^{1/2}$$

$$DRSF = \left.\frac{d^2R(t)}{dt^2}\right|_{CA} \bullet \frac{R_CA}{VM_CA^2} \quad \Leftrightarrow \quad \left.\frac{d^2RA(t)}{dt^2}\right|_{CA} = \frac{DRSF}{R_CA} \bullet VM_CA^2 = \left.\frac{d^2R(t)}{dt^2}\right|_{CA}$$

For a platform that flies a straight line at constant speed, the expression is exact for all time and parameter DRSF = 1.0 for all values of R_CA. An example trajectory and range versus time functions are shown in Figure 4.16.3-2. For ground point PT, the period "Near Closest Approach" is when the difference between RA(t) and R(t) is small. For accurate exploitation using INCA parameters, the error in RA(t) should be less than the smaller of 0.10 m or 0.25 of the range impulse response width (Rg_IRW). For an orbiting platform and Rg_IRW = 1.0 m, the period of closest approach for ground points spans approximately 6 degrees of Doppler Cone Angle (DCA) centered on closest approach (DCA = 90 deg).

$$\text{Near Closest Approach} \Leftrightarrow \left| R(t) - RA(t) \right| < \text{Min}(0.25 \bullet Rg_IRW, 0.10 \text{ m})$$

(1) SCP Position & SCP Pixel

The RMA may not explicitly define a ground point in the scene for image formation processing. For the INCA images, the SCP pixel and position are set by first selecting a pixel close to the center of the image. See Figure 4.16.3-3. The ground point in the scene that images to the SCP pixel is then computed. The computation is based upon the precise Center of Aperture used for the selected pixel. The SCP position lies along the Center of Aperture iso-range and iso-range rate contour for the selected pixel. The ground height should correspond to the estimated ground height used in the processing.

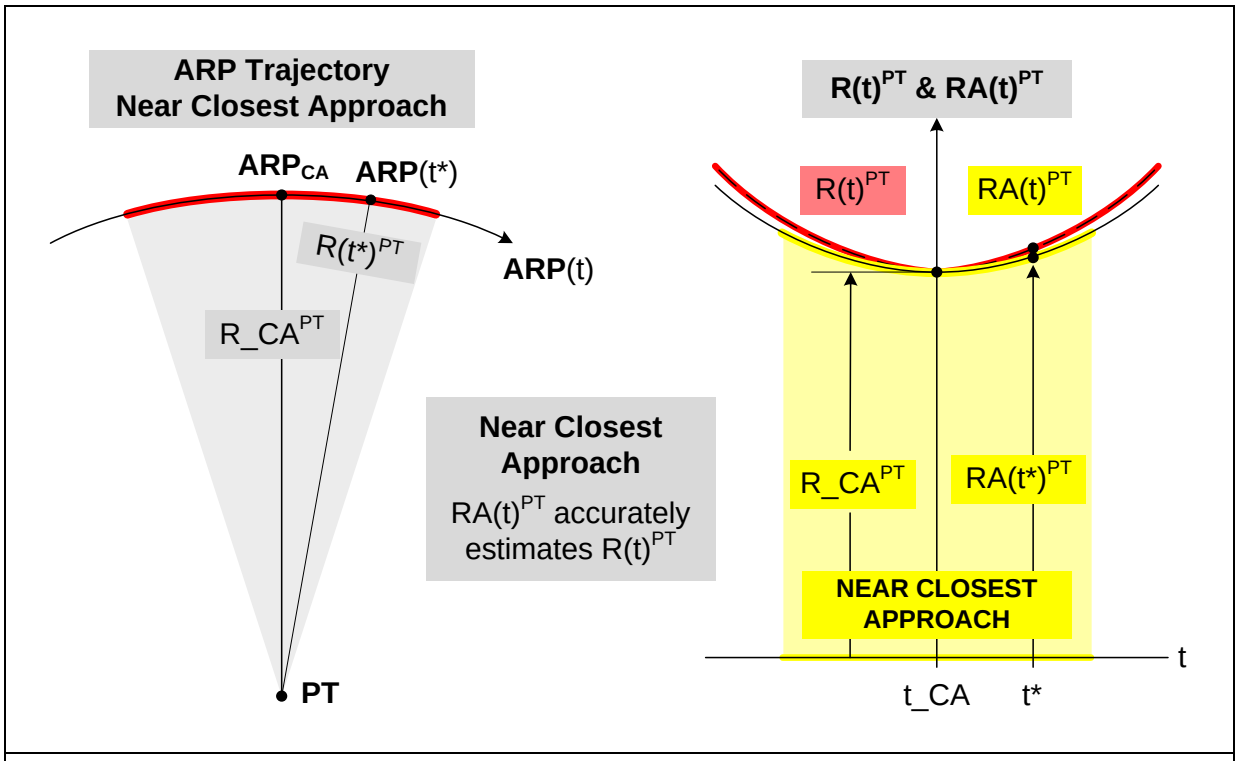


Figure 4.16.3-2 Period Near Closest Approach
Closest approach to point PT where $R(t)^{PT}$ is accurately estimated by $RA(t)^{PT}$.

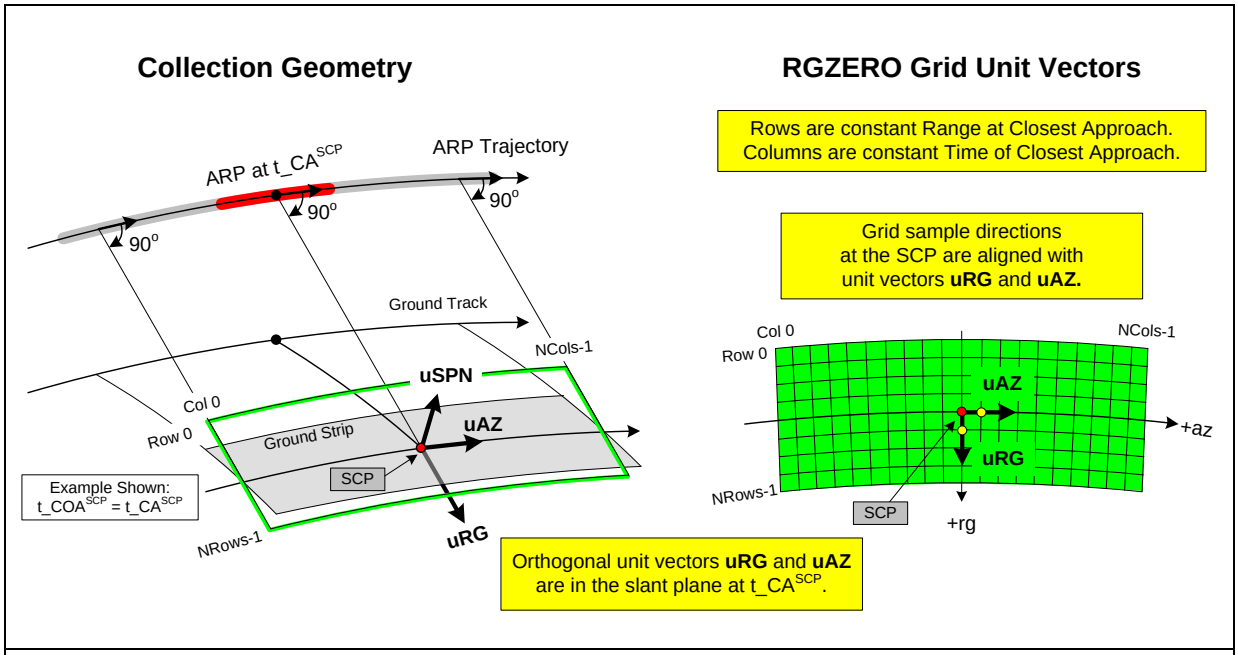


Figure 4.16.3-3 Range & Zero Doppler Image Grid
Image plane unit vectors lie in the slant plane at t_CA^{SCP}.

(2) Image Plane Parameters

The RGZERO image grid is oriented "shadows down" and "a view from above the earth". Image plane unit vectors are computed based on the slant plane that contains the SCP and the ARP position and velocity at SCP closest approach (t_CA^{SCP}). See Figure 4.16.3-3. The row coordinate is referred to as the range coordinate (rg). The column coordinate is referred to as the azimuth coordinate (az). The unit row vector points from the ARP to the SCP and is in the increasing range direction (**uRG**). The unit column vector points in the azimuth direction (**uAZ**). The slant plane normal vector (**uSPN**) points away from the center of the earth. Vectors **uRG**, **uAZ** and **uSPN** always form a right-handed coordinate system.

INCA.R_CA_SCP = R_CA^{SCP} = Range to the SCP at closest approach.

Grid.Row.UVectECF = **uRG** $\qquad$ $\mathbf{uRG} \times \mathbf{uAZ} = \mathbf{uSPN}$

Grid.Col.UVectECF = **uAZ**

Image row spacing (Rg_SS) is the spacing in range at closest approach. The rows of the RGZERO grid are equally spaced in R_CA. For image pixel (row,col), the SCP pixel centered row index (irg), the row coordinate (rg) and the range at closest approach are computed as follows.

Grid.Row.SS = Rg_SS

irg = row – SCPPixel.Row $\qquad$ rg = Rg_SS•irg

R_CA = R_CA^{SCP} + rg

Image column spacing (Az_SS) is set equal to the spacing in azimuth measured at the SCP. For the RGZERO grid, the precise spacing between columns may varies slightly from column to column and along a column from near to far range. For image pixel (row,col), the SCP centered column index (iaz) and the column coordinate (az) are computed as follows.

Grid.Col.SS = Az_SS = Column spacing at the SCP pixel.

iaz = col – SCPPixel.Col $\qquad$ az = Az_SS•iaz

The time of closest approach is given by a polynomial function of the azimuth coordinate. The t_CA polynomial (coefficients denoted cT_CA(n), order N_TCA) gives the precise time of closest approach for all columns.

INCA.TimeCAPoly(n) = cT_CA(n) $\quad$ n = 0 to N_TCA

$$t_CA(az) = \sum_{n=0}^{N_TCA} cT_CA(n) \bullet (az)^n$$

For platforms that fly at constant speed, the processing will form columns with constant spacing in t_CA and the image will have fixed azimuth spacing along a row. For platforms that fly with varying speed, the processing may still form columns with fixed spacing in t_CA or may form columns with varying spacing in t_CA to achieve fixed azimuth spacing along a row. For all images, the precise t_CA(az) is used for exploitation.

(3) Image Impulse Response Widths

The impulse response widths in the range and azimuth dimensions are set as follows. Parameters Rg_IRW and Az_IRW are the slant plane half-power impulse response widths (IRWs) in range and azimuth measured at the SCP. For an INCA image, the range IRW is usually constant across the image. The azimuth IRW may vary slightly across the image.

Grid.Row.ImpRespWid	=	Rg_IRW	Slant plane, half-power IRWs
Grid.Col.ImpRespWid	=	Az_IRW	at the SCP / SCP Pixel.

(4) DFT Sign Parameters & Doppler Frequency Convention

The DFT exponents for transforming from the image domain to the spatial frequency domain are set as follows. The parameter Row.Sgn is the sign of the DFT exponent (+1 or -1) that transforms the image row dimension (increasing range) to the increasing range spatial frequency (increasing Krg also corresponds to increasing RF). For a RGZERO grid, the same sign is used to transform the column dimension (increasing azimuth) to the increasing azimuth spatial frequency (increasing Kaz).

Grid.Row.Sgn	=	SGN	where SGN = +1 or -1
Grid.Col.Sgn	=	SGN	

The value of the SGN matches the sign of the phase versus range in the image formation processor. The SGN is initially set by the radar analog processing prior to analog-to-digital conversion but is ultimately set by the image formation processing. The phase versus range ($\Phi(f_0,R(t))$) and the Doppler frequency ($fdop(f_0,R(t))$) versus range rate are as follows.

$$\Phi(f_0,R(t)) = SGN \bullet f_0 \bullet \frac{2}{c} \bullet R(t) \qquad fdop(f_0,R(t)) = SGN \bullet f_0 \bullet \frac{2}{c} \bullet \left(\frac{d}{dt} R(t) \right)$$

Frequency f_0 is the RF value considered, phase $\Phi(f_0,R(t))$ is in cycles and frequency $fdop(f_0,R(t))$ is in Hz. The same value of SGN is used for relating closing/opening targets with positive/negative Doppler frequency values.

For SGN = -1:	Closing targets,	$d(R(t))/dt < 0 \Leftrightarrow fdop > 0$
	Opening targets,	$d(R(t))/dt > 0 \Leftrightarrow fdop < 0$
For SGN = +1:	Closing targets,	$d(R(t))/dt < 0 \Leftrightarrow fdop < 0$
	Opening targets,	$d(R(t))/dt > 0 \Leftrightarrow fdop > 0$

For the Doppler frequency computations that follow, the frequency used (f_0) is the value that specifies the center of the range spatial frequency domain (KrgCTR). The center of the azimuth spatial frequency domain (KazCTR) is always 0.

$$\text{INCA.FreqZero} = f_0 = \text{Frequency for computing all Doppler frequency values.}$$

$$\text{Grid.Row.KCtr} = \text{KrgCTR} = f_0 \bullet \frac{2}{c}$$

$$\text{Grid.Col.KCtr} = \text{KazCTR} = 0$$

(5) Doppler Rate Scale Factor

The DRSF parameter sets the second derivative of the RA(t) function at closest approach ($d^2(RA)/dt^2$) to that used in the image formation. This also sets the first derivative of the Doppler frequency (i.e. Doppler Rate) at closest approach. The correct value of Doppler Rate is important to achieving correct azimuth focusing. The processing may vary the DRSF used across the image. It is provided as a function of image coordinates (rg,az). The DRSF polynomial (coefficients denoted cDRSF(m,n), orders M_DRSF and N_DRSF) gives the DRSF used for range function RA(t). For image location (rg,az), DRSF used to from the image is computed as follows.

$$\text{INCA.DRateSFPoly(m,n)} = \text{cDRSF(m,n)}, \quad m = 0 \text{ to M_DRSF}, \quad n = 0 \text{ to N_DRRF}$$

$$\text{DRSF(rg,az)} = \sum_{m=0}^{\text{M_DRSF}} \sum_{n=0}^{\text{N_DRSF}} \text{cDRSF}(m,n) \bullet (\text{rg})^m \bullet (\text{az})^n$$

For image location (rg,az), the Doppler Rate at Closest Approach (DR_CA, in Hz/sec) is computed as follows.

$$\text{DR_CA(rg,az)} = \text{SGN} \bullet f_0 \bullet \frac{2}{c} \bullet \left(\frac{d^2}{dt^2} \text{RA(t)} \bigg|_{\text{CA}} \right)$$

$$\text{DR_CA(rg,az)} = \text{SGN} \bullet f_0 \bullet \frac{2}{c} \bullet \left(\frac{\text{DRSF(rg,az)}}{\text{R_CA(rg)}} \bullet \text{VM_CA(az)}^2 \right)$$

For all points in scene, the Doppler Rate is nearly constant for period near closest approach. The Doppler frequency versus time may be accurately computed using the Doppler Rate at closest approach. For image location (rg,az), the Doppler frequency versus time is accurately approximated as a linear function.

$$\text{fdop(t; rg,az)} = \text{DR_CA(rg,az)} \bullet (t - \text{t_CA(az)})$$

(6) Center Of Aperture Time

The Center Of Aperture time (t_COA) is a key parameter needed for proper image exploitation. The time of Center of Aperture is provided as a function of image coordinates (rg,az). The t_COA polynomial (coefficients denoted cT_COA(m,n), orders M_TCOA and N_TCOA) is specified as follows.

$$\text{Grid.TimeCOAPoly}(m,n) = \text{cT_COA}(m,n), \quad m = 0 \text{ to M_TCOA}, \quad n = 0 \text{ to N_TCOA}$$

$$\text{t_COA}(rg,az) = \sum_{m=0}^{\text{M_TCOA}} \sum_{n=0}^{\text{N_TCOA}} \text{cT_COA}(m,n) \bullet (rg)^m \bullet (az)^n$$

For a given image location, the difference between the COA time and the closest approach time (Δt_COA(rg,az)) is used for several computations.

$$\Delta\text{t_COA}(rg,az) = \text{t_COA}(rg,az) - \text{t_CA}(az)$$

For image location (rg,az), the range and range rate at COA (R_COA and Rdot_COA) used for the projection from image location (rg,az) to a geo-located surface are computed as follows using the RA(t) function at t_COA and its second derivative at closest approach ($d^2(RA)/dt^2$ at t = t_CA).

$$\text{R_COA}(rg,az) = \left[\text{R_CA}(rg)^2 + \text{DRSF}(rg,az) \bullet (\Delta\text{t_COA}(rg,az))^2 \bullet \text{VM_CA}(az)^2\right]^{1/2}$$

$$\text{Rdot_COA}(rg,az) = \underbrace{\frac{\text{DRSF}(rg,az)}{\text{R_CA}(rg)} \bullet (\text{VM_CA}(az))^2}_{d^2(RA(t))/dt^2 \text{ at t_CA}} \bullet \Delta\text{t_COA}(rg,az)$$

An example INCA image is shown in Figure 4.16.3-5. The example shown is for a right looking collection and the phase SGN = -1. Two targets in the scene (Target A and Target B) are shown that have the same range at closest approach. The range function RA(t) and the Doppler frequency function fdop(t) are also shown for two targets. The periods near closest approach do not overlap. Target A has its t_COA prior to t_CA ($\Delta t_COA^A < 0$). Target B has its t_COA after t_CA ($\Delta t_COA^B > 0$).

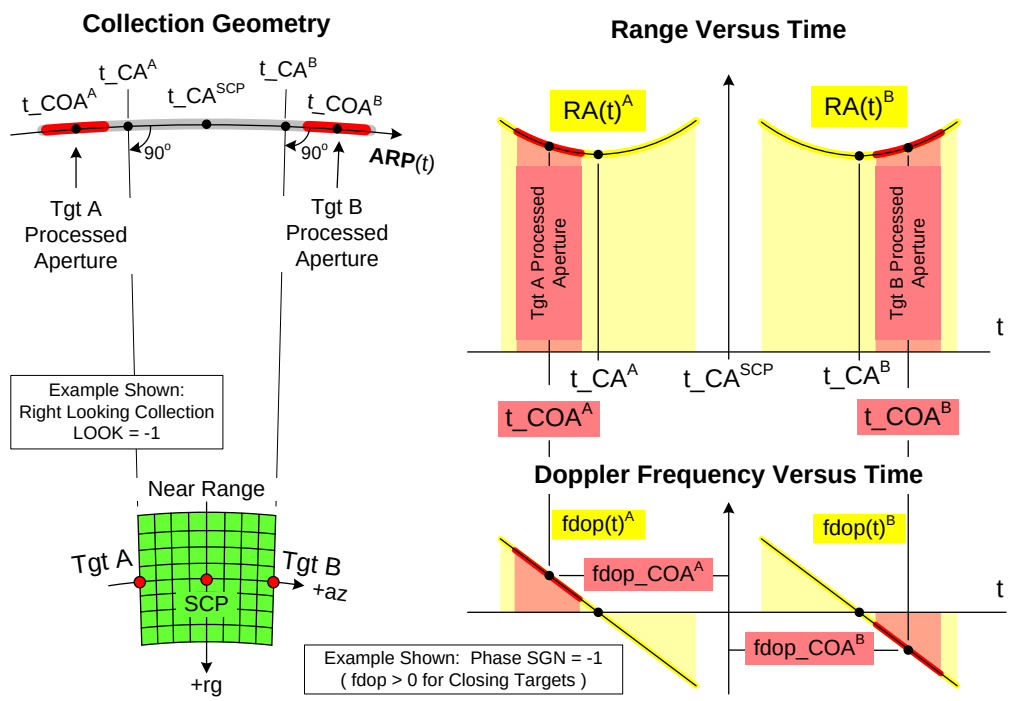


Figure 4.16.3-4 Example INCA Image, Range & Doppler vs. Time
Target A imaged prior to t_CA^A. Target B imaged after t_CA^B.

(7) Doppler Centroid

For stripmap and dynamic stripmap collections, the radar antenna is scanned across the scene that is imaged. For a given point in the scene, the received signal rises and then falls as the mainlobe of the radar antenna passes over the point. The Doppler frequency at the peak of the response is referred to as the Doppler Centroid (fdop_DC). The Doppler Centroid is provided as a function of image coordinates (rg,az). The Doppler Centroid polynomial (coefficients denoted cDOPC (m,n), order M_DOPC and order N_DOPC) gives Doppler frequency at the peak signal.

$$\text{INCA.DopCentroidPoly(m,n)} = \text{cDOPC(m,n)}, \quad m = 0 \text{ to M_DOPC}, \quad n = 0 \text{ to N_DOPC}$$

$$\text{fdop_DC(rg,az)} = \sum_{m=0}^{\text{M_DOPC}} \sum_{n=0}^{\text{N_DOPC}} \text{cDOPC}(m,n) \bullet (\text{rg})^m \bullet (\text{az})^n$$

The time the peak signal occurs, t_DC(rg,az), is computed by as follows.

$$\text{t_DC(rg,az)} = \text{t_CA(az)} + \frac{1}{\text{DR_CA(rg,az)}} \bullet \text{fdop_DC(rg,az)}$$

For the example INCA image shown in Figure 4.16.3-5, example signal versus time functions are shown in Figure 4.16.3-5. Target A has peak signal occur before closest approach ($t_DC^A < t_CA^A$). Target B has peak signal occur after closest approach ($t_DC^B > t_CA^B$). Also in this example, the SCP target has its peak signal occur at closest approach ($t_DC^{SCP} = t_CA^{SCP}$). For Targets A and B, the COA times shown in Figure 4.16.3-4 (t_COA^A and t_COA^B) are equal to the peak signal times shown in Figure 4.16.3-5.

For a given imaging collection, the peak signal times are determined by the achieved platform attitude and radar antenna pointing. The COA times are chosen by the image formation processing. For many systems, the peak signal times are calculated in the early stages of the processing (referred to as Doppler Centroid estimation). Setting the COA times equal to the peak signal times maximizes image signal-to-noise ratio while also minimizing ambiguity levels. For most stripmap and dynamic stripmap images, the COA times are set equal to the peak signal times for all pixels. Optional parameter DopCentroidCOA can be used to indicate that the COA times are equal to the peak signal times for all pixels (the usual condition).

INCA.DopCentroidCOA = TRUE ⇔ Indicates all COA times track peak signal times.
INCA.DopCentroidCOA = FALSE ⇔ Indicates COA times do not track peak signal times.

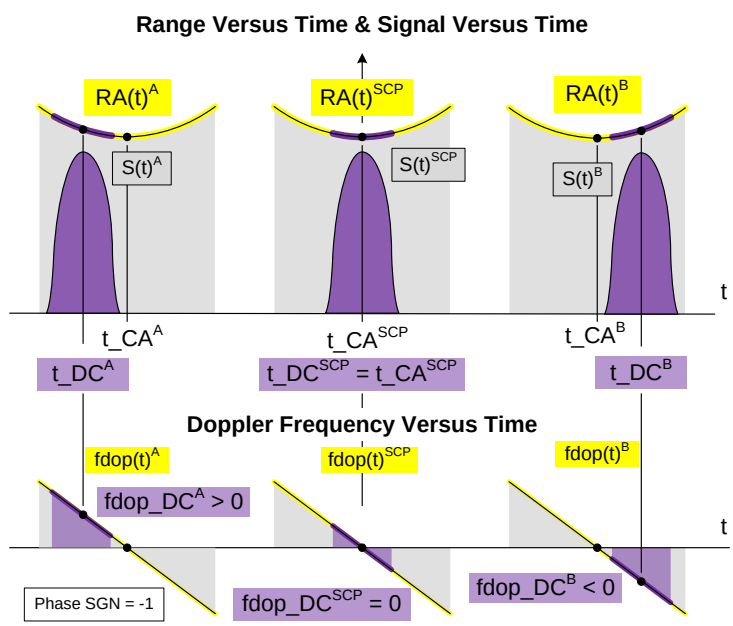


Figure 4.16.3-5 Example Doppler Centroid Values
Peak signal occurs at t_DC and Doppler frequency value fdop_DC.

(8) Spatial Frequency Domain Center Of Aperture

For all INCA images, the spatial frequency domain support as a function of image location is as follows. The range spatial frequency (Krg) support is centered at Krg = KrgCTR for image pixels (for all pixels, ΔKrgCOA = 0). In general, the azimuth spatial frequency (Kaz) support varies as a function of image location. For image location (rg,az), the center of the azimuth spatial frequency support is as follows.

$$\text{KazCOA(rg,az)} = \underbrace{\text{KazCTR}}_{\substack{\text{Equal to 0 for all} \\ \text{RGZERO images.}}} + \Delta\text{KazCOA(rg,az)}$$

The ΔKazCOA polynomial (coefficients denoted cKAZCOA(m,n), orders M_KAZ and N_KAZ) is specified as follows.

$$\text{Grid.Col.DeltaKCOAPoly(m,n)} = \text{c}\Delta\text{KazCOA(m,n)}, \quad \text{m} = 0 \text{ to M_KAZ}, \quad \text{n} = 0 \text{ to N_KAZ}$$

$$\Delta\text{KazCOA(rg,az)} = \sum_{m=0}^{\text{M_KAZ}} \sum_{n=0}^{\text{N_KAZ}} \text{cKAZCOA}(m,n) \bullet (\text{rg})^m \bullet (\text{az})^n$$

An example spatial frequency domain plot is shown in Figure 4.16.3-6. The span of the spatial frequency domain is 1/Az_SS. The Doppler frequency span corresponding to spatial frequency span 1/Az_SS is follows.

$$\Delta\text{Kaz} = \frac{1}{\text{Az_SS}} \quad \Leftrightarrow \quad \Delta\text{fdop} = \frac{1}{|\text{cT_CA}(1)| \bullet \text{Az_SS}}$$

Where $|\text{cT_CA}(1)| \bullet \text{Az_SS} = \Delta\text{t_CA}^{\text{SCP}}$ = spacing in t_CA at the SCP pixel.

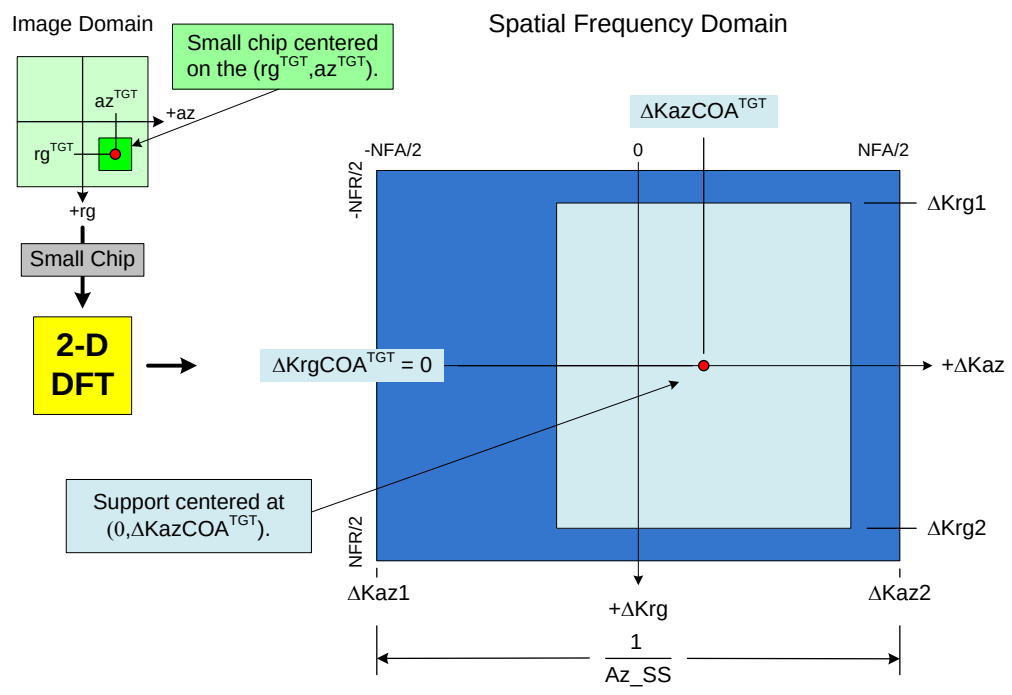


Figure 4.16.3-6 Example Target Spatial Frequency Domain

Target support centered at ΔKrg = 0 and ΔKazCOA.