NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY

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NGA STANDARDIZATION DOCUMENT

COMPENSATED PHASE HISTORY DATA (CPHD)

Volume 1

Design & Implementation Description Document

Requirements and guidance for the design & implementation
of CPHD products for SAR imaging systems.

(2016-09-30)

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NATIONAL CENTER FOR GEOSPATIAL-INTELLIGENCE STANDARDS

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FOREWORD

This Compensated Phase History Data (CPHD) standardization document describes the design and implementation of CPHD data products for Synthetic Aperture Radar (SAR) systems. The CPHD standard defines a flexible data structure and file format for the storage and transmission of SAR Phase History Data (PHD). The CPHD structure provides a sensor independent format that is designed to accommodate the SAR signal data produced from conventional as well as advanced SAR sensors.

A CPHD product is an intermediate data product. The real utility is in the products and measurements that may be derived from it. The quality of the phase history signal arrays (bandwidth, dwell time, etc.), along with the set of metadata provided, are critical in generating the derived products. The “sensor independence” of the CPHD product refers to the ability of the allowed signal arrays and metadata options to describe accurately the signal data from many sensors and data processing systems. Sensor independence does not mean that all products have the same format for the signal data arrays or the same set of metadata parameters.

The CPHD Design & Implementation Description Document provides the description needed by producers of SAR PHD to design a product and select the set of metadata that describe it. It also provides the information needed by users of CPHD products to read the data and create SAR products. The CPHD data structure accommodates the PHD signal arrays from a variety of systems and collection methods. It provides support for collections with multiple data channels, collected simultaneously or sequentially, that are then processed separately or combined in the subsequent processing.

A companion suite of standardization documents, collectively known as Sensor Independent Complex Data (SICD) description documents, describe a standard product for SAR complex image products. The CPHD product is designed to complement the SICD product. The CPHD and SICD documentation and associated XML artifacts are available on the National System for Geospatial-Intelligence (NSG) Standards Registry.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 that is both the transmitter and the receiver of the echoes from the imaged scene (monostatic imaging). A relatively small number of systems use a pair of radar platforms operating as separate transmitter and passive receiver of the echoes from the imaged scene (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 synthesize a long 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 (fx_C) 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.

$$\Delta R = \frac{c}{2 \bullet BW} \qquad\qquad \Delta A = \frac{c}{2 \bullet fx\_C \bullet \Delta\theta}$$

The SAR signal data received and recorded during an imaging collection is commonly referred to as Phase History Data (PHD). The PHD signal array is typically a two-dimensional data array indexed by lines and samples. The lines of the signal array, also referred to as signal vectors, correspond to the received echoes of the transmitted pulses. Each signal vector is the received and recorded signal for the echoes from a single transmitted pulse. For each vector, the recorded data includes the amplitude, phase and precise time of arrival of the received echoes. Along with the PHD array, the SAR system records the metadata that will be needed to process the PHD to form the SAR image. The precise pulse transmit times and the receive sample times are recorded for each vector of the PHD signal array. Also recorded is the platform position versus time that is used to compute the SAR position at any time during the collection.

The initial PHD collected by a given SAR system is without exception sampled and formatted in a sensor specific format. The supporting metadata is also sensor specific with respect to both format and content. The sensor specific nature of the recorded PHD and the supporting metadata makes the initial steps of the data processing unique to the sensor. For most systems, the initial processing operates separately on each signal vector of the PHD signal array. The initial processing applies a set of amplitude and phase compensations that prepare the vector for the subsequent processing that will coherently combine the signal vectors. The compensations applied may also correct for the characteristics of the individual components of the radar system. The processing transforms the initial PHD signal array into what is referred to as the compensated PHD signal array.

While the initial PHD signal array and support data are unique to the SAR that collected them, the form of the compensated PHD signal array is not. For most SAR systems, the compensated PHD signal arrays may be formed in a common signal domain and format. Each compensated signal vector may be accurately characterized by a common set of parameters. The compensated PHD signal array may be formed such that there is no loss in signal content for the received echoes of the transmitted pulse. It is these properties that make the compensated PHD signal arrays well-suited for the development of a sensor independent data product.

The Compensated Phase History Data (CPHD) structure is designed for the storage and transmission of the compensated PHD signal array(s) and the metadata that describe them. The structure is designed to accommodate the SAR signal data produced from conventional as well as advanced SAR sensors. The data structure provides a sensor independent format for the signal arrays and supporting metadata. The structure is designed to enable the PHD from a robust set of SAR sensors to be processed by processing applications that are developed independent of the SAR sensor that performs the collection.

CPHD Design Documents

The CPHD product design is contained in this document and in the companion CPHD XML schema. The document number and XML schema are listed in Table 1-1. The Sensor Independent Complex Data (SICD) is a related standard for SAR complex image products. The SICD product design document is also listed in Table 1-1.

Table 1-1 Applicable Design Documents

Number	Title	Date
NGA.STND.0068-1	Compensated Phase History Data (CPHD), Volume 1, Design & Implementation Description Document	V1.0.0 30 Sept 2016
NGA.STND.0068	CPHD_schema_V1.0.0_2016_09_30.xsd The XML schema that defines the CPHD XML structure.	V1.0.0 30 Sept 2016
Related Design Documents		
NGA.STND.0024-1	Sensor Independent Complex Data (SICD), Volume 1, Design & Implementation Description Document	Version 1.1 30 Sept 2014

1.1 CPHD Product Summary

The CPHD product provides a sensor independent data structure and file format for SAR Phase History Data products. The CPHD data structure is designed to accommodate the PHD signal arrays from a wide variety of SAR sensors. For a given signal array, the compensations applied include the phase compensation that is commonly referred to as motion compensation. The compensation accounts for both the motion of the SAR platform as well as the precise timing of the transmitted pulses and received echoes from the imaged scene. Additional compensations may also be applied that correct for known distortions and/or gain variations in the radar system that collected the data. The attributes of the CPHD product are summarized below.

Imaging Collections

The CPHD product is designed for the SAR signal data from the following types of SAR imaging collections.

(1) The CPHD product is designed to accommodate signal data collected from a single radar platform during a single imaging collection.

(2) The data structure provides full support for monostatic SAR imaging collections. Monostatic imaging collections are collections for which transmit and receive antennas/apertures are located on the same platform. The transmit aperture and the receive aperture may be coincident or be separated on the platform.

(3) The data structure provides full support for both spotlight and stripmap imaging collections. The stripmap collection may be a side looking geometry or a stripmap with arbitrary geometry. The more general form of stripmap collection is referred to as a Dynamic Stripmap due to the dynamic imaging geometry. See NGA.STND.0024 SICD Volume 1. Shown in Figure 1-1 is an example of a conventional side looking stripmap collection.

(4) The data structure allows for multiple signal arrays that are collected during a single imaging collection. In a given product, each signal array is placed in a separate data channel. The data structure allows the signal data to be organized by how it is collected and/or how it is to be processed.

(5) The data structure provides full support for bistatic SAR imaging collections that utilize two platforms. For a Bistatic CPHD product, all PHD signal arrays are collected on the same receive-only platform. All radar pulses are transmitted from the same transmit platform. Shown in Figure 1-2 is an example of a bistatic spotlight imaging collection.

(6) For the example shown in Figure 1-2, the echoes of the transmitted pulses could be received and recorded by both radar platforms. The PHD collected on the transmit platform could be processed to form a Monostatic CPHD product. The PHD collected on the receive-only platform could be processed to form a Bistatic CPHD product. The result would be two CPHD products.

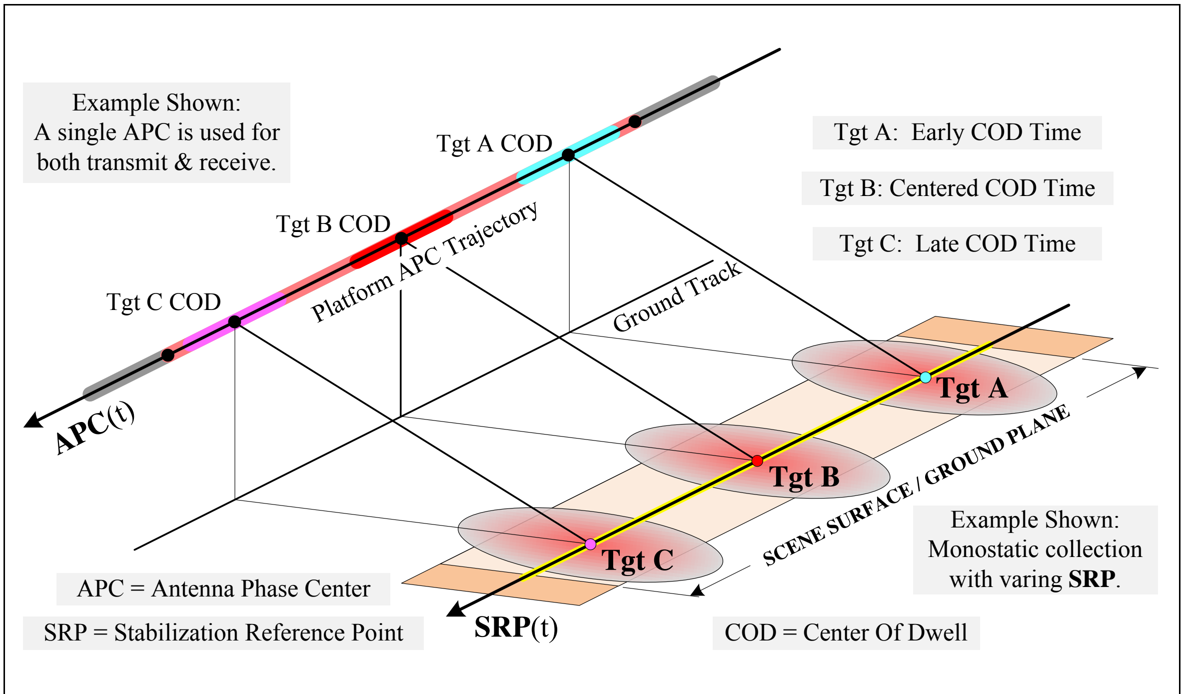


Figure 1-1 Side Looking Stripmap Collection
Monostatic SAR side-looking geometry for a stripmap mode collection.

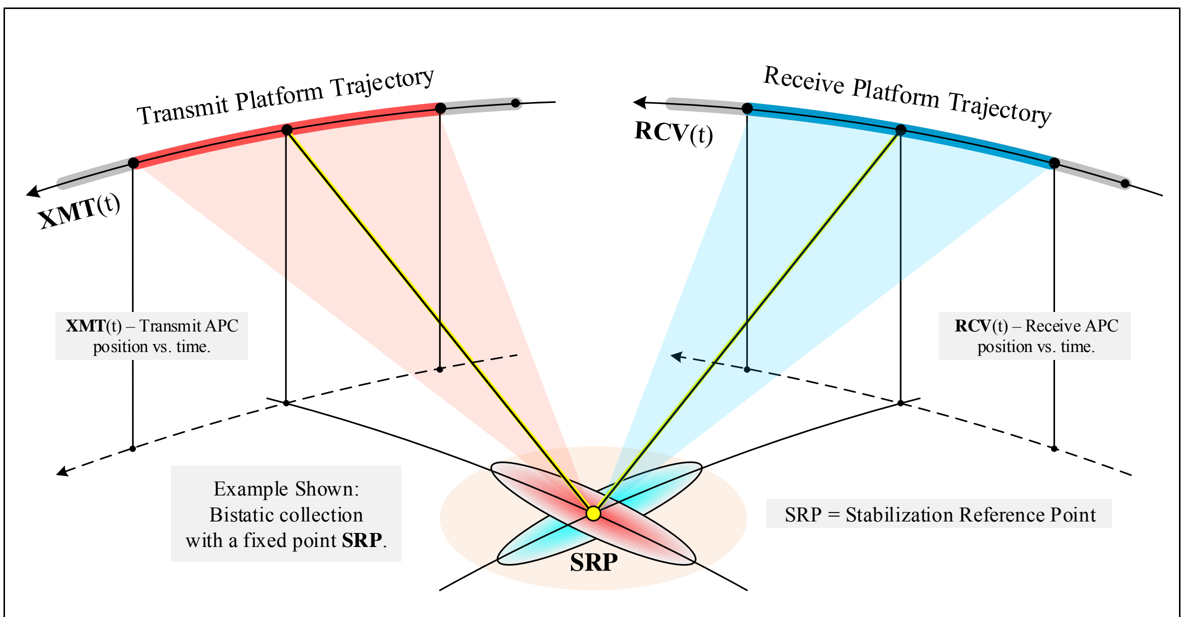


Figure 1-2 Bistatic Spotlight Collection
Bistatic SAR geometry for in a spotlight mode collection.

Data Structure

The data structure and file format have the following attributes. The data structure and file format are more fully described in Section 2.

(1) The data structure is composed of four data blocks. One block contains the signal data and the other three contain metadata that describe and support it. The Signal block, XML block and PVP (Per Vector Parameters) block are required and are included in all products. The Support block is optional.

(2) The XML block contains the text-based XML instance. The other three blocks contain binary-formatted data. The XML instance describes the collection parameters and the content of the other blocks in the given CPHD product.

(3) The Signal block contains one or more signal arrays. Each signal array is a two-dimensional array of phase history samples. The signal array data samples are complex-valued with real and imaginary components.

(4) The PVP block contains one or more Per Vector Parameters arrays. Each PVP array is a one-dimensional array of binary-formatted parameter sets. For each signal array, there is a PVP array that contains a parameter set for each vector of the signal array.

(5) The optional Support block contains one or more support arrays. Each Support Array (SA) is a two-dimensional grid of data elements. Each data element may contain one or more parameters. There are two defined support array types: the imaged scene surface height and the sampled antenna pattern(s).

(6) A CPHD product file is composed of a text-based File Header followed by the three or four blocks in the CPHD product. The File Header includes the sizes and offsets for the three or four blocks included in the product.

Data Channels

A CPHD product contains one or more data channels. Each data channel includes a signal array and a corresponding Per Vector Parameters (PVP) array. All data channels have the following attributes.

(1) The signal array is a two-dimensional array of signal vectors and samples. The vectors are ordered by increasing time of transmit and receive. The vector dimension is commonly referred to as “slow time” and is measured in seconds from the start of the collection.

(2) Each signal vector has been motion compensated to a fixed point in the imaged scene. For each signal vector, the selected scene point is the Stabilization Reference Point (SRP).

(3) The SRP position is provided for each signal vector in the PVP array. For a given signal array, the SRP position may be the same for all vectors or may vary from vector to vector.

(4) The signal vectors are formed in one of two allowed signal domains. The allowed signal domains are the FX domain and the TOA domain. All signal arrays in a given product are in the same domain. The signal domains are described Section 1.2.

(5) For the FX domain, the sample dimension is transmitted frequency and is measured in Hertz. The compensation processing transforms the "fast time" dimension of the initial PHD signal vectors to the "frequency" domain. The samples are ordered by increasing transmitted frequency values.

(6) For the TOA domain, the sample dimension is the time of arrival of the received echoes from the imaged scene. The compensation processing transforms the "fast time" dimension of the initial PHD signal vectors to the "compressed" time of arrival domain. For monostatic collections, the Time of Arrival domain is commonly referred to as the range compressed domain. The samples are ordered by increasing Time of Arrival of the received echoes.

(7) For a given data channel, the PVP array contains a set of metadata parameters for each signal vector. For each signal vector, the PVP metadata set includes the collection geometry & signal metadata parameters.

(8) For any signal array, the signal vectors may be transformed from one domain to the other domain via the Discrete Fourier Transform (DFT). Shown in Figure 1-3 is an example signal array and PVP array for a data channel. For all products, the PVP array describes the signal content in both the FX and the TOA domains.

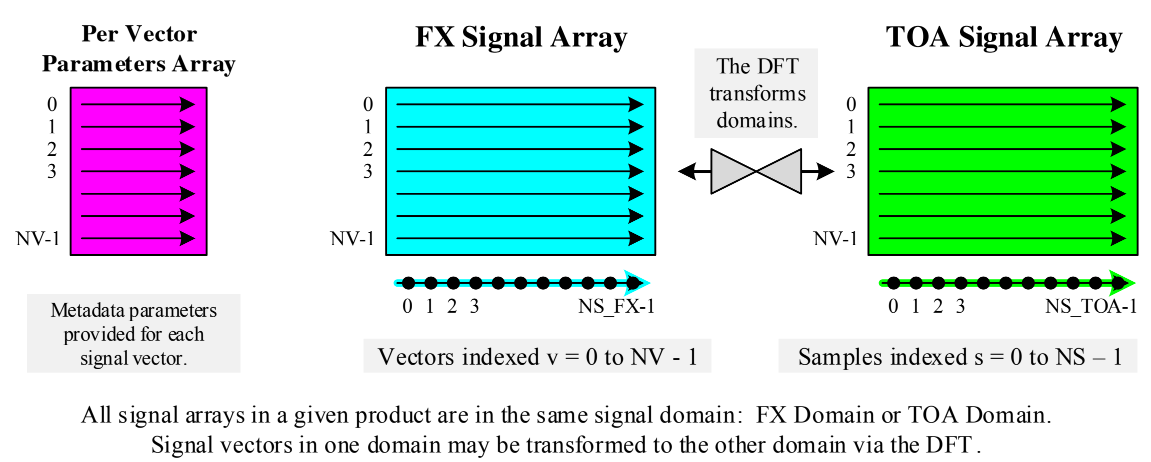


Figure 1-3 Signal & Per Vector Parameters Arrays
The Per Vector Parameters array describes the signal in both the FX or TOA domains.

1.2 Signal Array Formation

The signal array formation is a combination of the analog signal processing in the radar receiver and the digital signal processing that forms the compensated signal array. The digital compensation processing is selected based on the signal content of the transmitted radar pulses and the type of demodulation applied in the radar receiver. The resulting compensated PHD signal array may be in either of the two allowed signal domains. The allowed signal domains are the FX (transmit frequency) domain and the TOA (Time Of Arrival) domain. The signal content of the two domains are described in the following paragraphs. The basic elements of the compensation processing are also described.

The signal array is typically formed by processing each vector of the initial PHD signal array to form the vectors of the compensated signal array. For each signal vector, the compensation processing is matched to signal content and timing of the received echoes from a single transmitted pulse. Shown in Figure 1-4 is the collection geometry for a single transmitted pulse for a side-looking airborne SAR platform. Shown is the Stabilization Reference Point (SRP) that is the fixed scene point that will serve as the motion compensation point for the compensation processing. The collected range swath is shown along with fixed scene points TGT1 and TGT2 located at the near and far edges of the collected range swath.

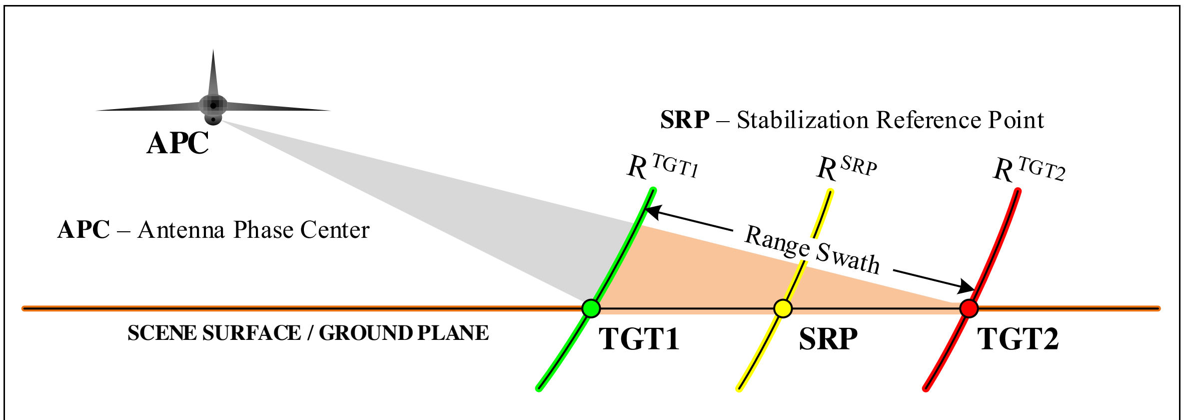


Figure 1-4 Single Pulse Geometry
Example instantaneous collection geometry for a single transmitted and received pulse.

The collection timing for the transmitted pulse and for the received echoes from the imaged scene are shown in Figure 1-5. The duration of the transmitted pulse is T_Xmt with the center of the pulse at the Antenna Phase Center (APC) at the time txc. The transmitted pulse has RF bandwidth BW_Xmt with center transmit frequency fx_C. The transmitted bandwidth is from frequency fx_1 to fx_2.

$$\text{fx\_1} = \text{fx\_C} - \frac{1}{2} \bullet \text{BW\_Xmt} \qquad\qquad \text{fx\_2} = \text{fx\_C} + \frac{1}{2} \bullet \text{BW\_Xmt}$$

The two-way propagation for the echo from a fixed point target at the SRP position is T_Prop^{SRP}. The Time of Arrival (TOA) of the center of the echo from the SRP at the APC is at trc^{SRP}. The receive window length is T_Rcv such that the full echo of the transmitted pulse is received for all points in the collected range swath. The TOA of the center of the echoes from fixed point targets at scene points TGT1 and TGT2 are at trc^{TGT1} and trc^{TGT2}. For the echoes from TGT1 and TGT2, the differences in Time of Arrival relative to the SRP echo are ΔTOA^{TGT1} and ΔTOA^{TGT2}. The relative amplitude of the received echoes is also shown with the SRP signal being the largest and the TGT2 signal being the smallest.

$$\Delta TOA^{TGT1} = trc^{TGT1} - trc^{SRP} \qquad \Delta TOA^{TGT2} = trc^{TGT2} - trc^{SRP}$$

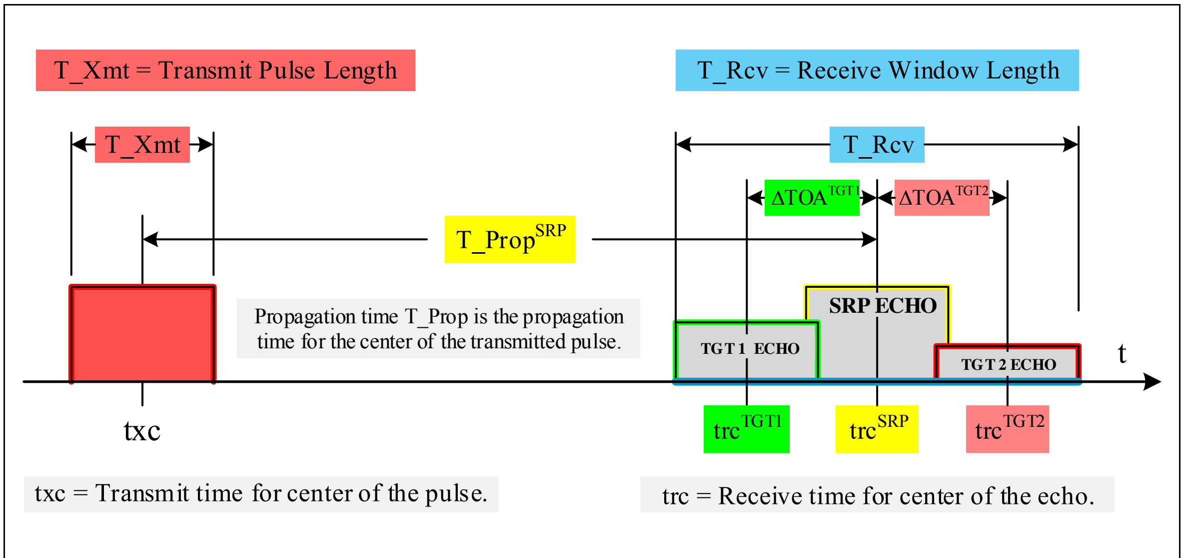


Figure 1-5 Transmit & Receive Timing
Example timing for a single transmitted and received pulse.

The formation of the compensated signal vector is a combination of the analog signal processing that occurs in the radar receiver and digital compensation processing that occurs in the data processor. For the received signal shown in Figure 1-5, the formation of the compensated signal vector is shown in Figure 1-6. The radar receiver is configured to receive and demodulate the echoes from the imaged scene. For most SAR systems, the transmitted waveform used is a Linear FM signal with constant FM rate. The receiver demodulation may be with a fixed frequency tuned to the center frequency fx_C or with a linear FM waveform that is matched in frequency and timing to the echo from the center of the collected range swath.

The initial PHD signal vector that is sampled in the radar receiver and input to the data processor is essentially a time-based signal. The sample dimension is commonly referred to as the Fast Time dimension due to the high sample rates of the Analog-to-Digital Converter (ADC) in the radar receiver. The compensation processing applied is a function of the transmitted waveform, the receiver demodulation and the precise ADC sample timing. The compensation processing applies a phase correction that sets the phase of the signal from the

SRP echo to zero. The phase applied is based on the precise TOA of the echo from the SRP and the precise timing of the receiver demodulation and ADC timing. The phase compensation applied is referred to as motion compensation since it also accounts for the motion of the radar platform relative to the imaged scene.

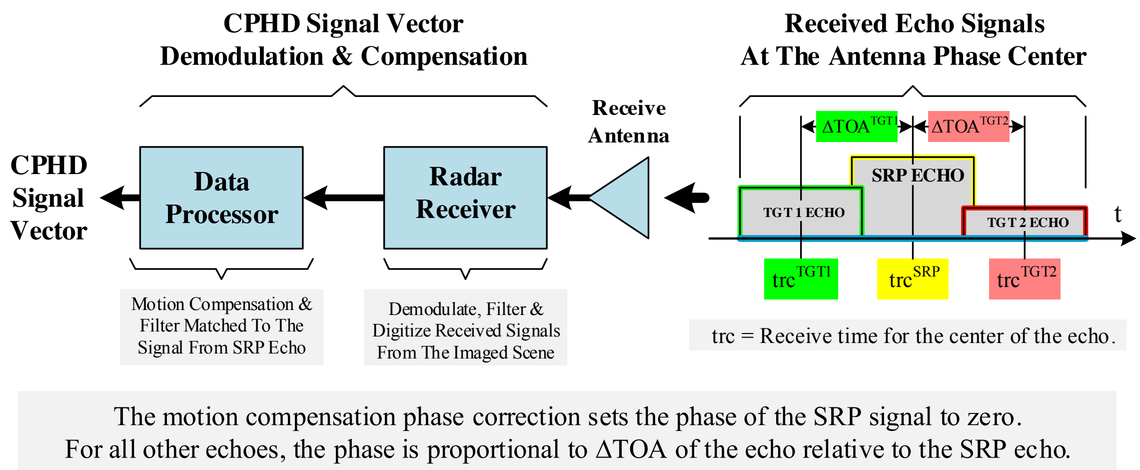


Figure 1-6 Receiver Demodulation & Compensation

The demodulation & compensation processing are matched to the signal from the SRP.

The compensated signal vector is the output of a matched-filter type of processing of the received echoes of the transmitted pulse. The compensation processing transforms the signal vector from a time-based signal to an echo-based signal. The signal content for the received echoes is now described in terms of the frequency content of the transmitted waveform and the TOA of the echoes relative to the SRP echo. The details of the transmitted waveform and the radar receiver timing are no longer needed. Shown in Figure 1-7 is the amplitude of the compensated signal vector in the two allowed domains. For the FX domain signal vector, the signals from the received echoes are aligned and separated by the frequency content of the transmitted pulse. For the TOA domain signal vector, the signals are separated by the difference in TOA of the echoes relative to the echo from the SRP.

The phase of the compensated signal vector is shown in Figure 1-8. For the FX domain signal vector, the phase of the SRP signal is set equal to zero by the compensation processing. For the signals from other points in the imaged scene, the phase versus frequency is proportional to the ΔTOA of the echo relative to the SRP echo. For the TOA domain signal vector, the phase of the mainlobe of the compressed SRP signal is set equal to zero. For the signals from other points in the imaged scene, the phase of the mainlobe is proportional to fx_C times the ΔTOA of the echo relative to the SRP echo. All phase values are in cycles.

$$\text{FX Domain:}\quad \Phi(fx)^{TGT} = fx \bullet \Delta TOA^{TGT} \qquad \text{TOA Domain:}\quad \Phi_{ML}^{TGT} = fx\_C \bullet \Delta TOA^{TGT}$$

Note: For error free collection and processing, the FX domain phase of the SRP echo is set to a constant value that may or may not be precisely zero. The SRP phase is set to the same constant value for all vectors of the compensated PHD signal array. For a TOA domain signal array, the phase of the SRP mainlobe is set to the same constant value for all vectors.

The signal arrays are designed to provide a complete description of the signals from the received echoes of the transmitted pulses. The FX and TOA domains and the signal model parameters are described in detail in Section 4. The signal model provides a precise model for computing the ΔTOA for all echoes in the imaged scene. The signal model also provides a precise model for computing the phase of the received echoes.

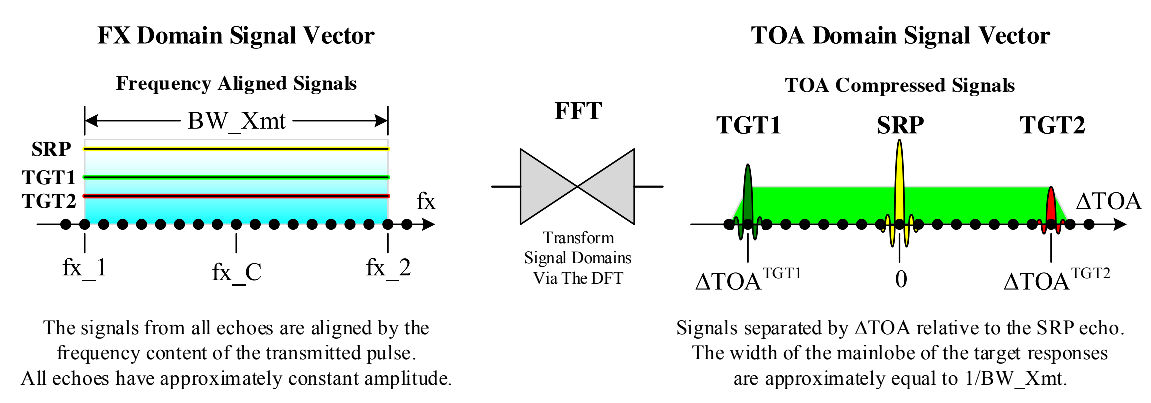


Figure 1-7 FX & TOA Domain Signal Amplitudes
Signal amplitudes are aligned in the FX domain and separated in the TOA domain.

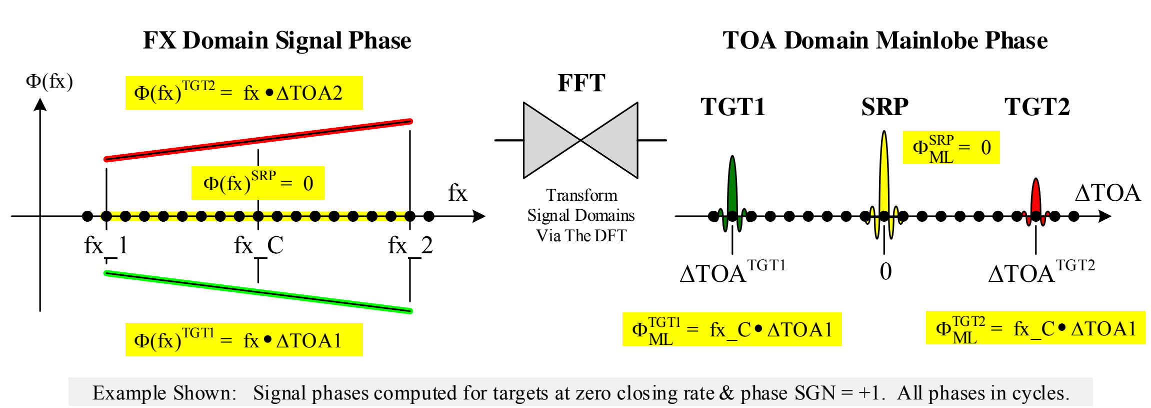


Figure 1-8 FX & TOA Domain Signal Phases
Signal phases in the FX and TOA domains are proportional to ΔTOA of the echo.

2 Data Structure & File Format

The data structure is composed of four data blocks. A CPHD product file is formed by combining a File Header and the blocks of the data structure. The File Header and the data blocks are combined in a simple "flat file" format to form the product file. A given product file is composed from the following components.

(1) File Header
(2) XML Block
(3) Support Block - Optional
(4) Per Vector Parameters (PVP) Block
(5) Signal Block

The File Header contains UTF-8 text and is included in all CPHD product files. The XML block also contains UTF-8 text and is included in all CPHD products. The Support block, PVP block and Signal block contain binary-formatted data. The Support block is an optional block that may or may not be included in a given product. The PVP block and the Signal block are included in all products.

The file components are ordered as listed above and as shown in Figure 2-1. The File Header is located at the start of the file with no offset allowed. The first byte of the product file contains the first byte of the File Header. If the Support block is included, it follows the XML block and precedes the PVP block. Optional fill bytes may be included prior to any data block following the File Header.

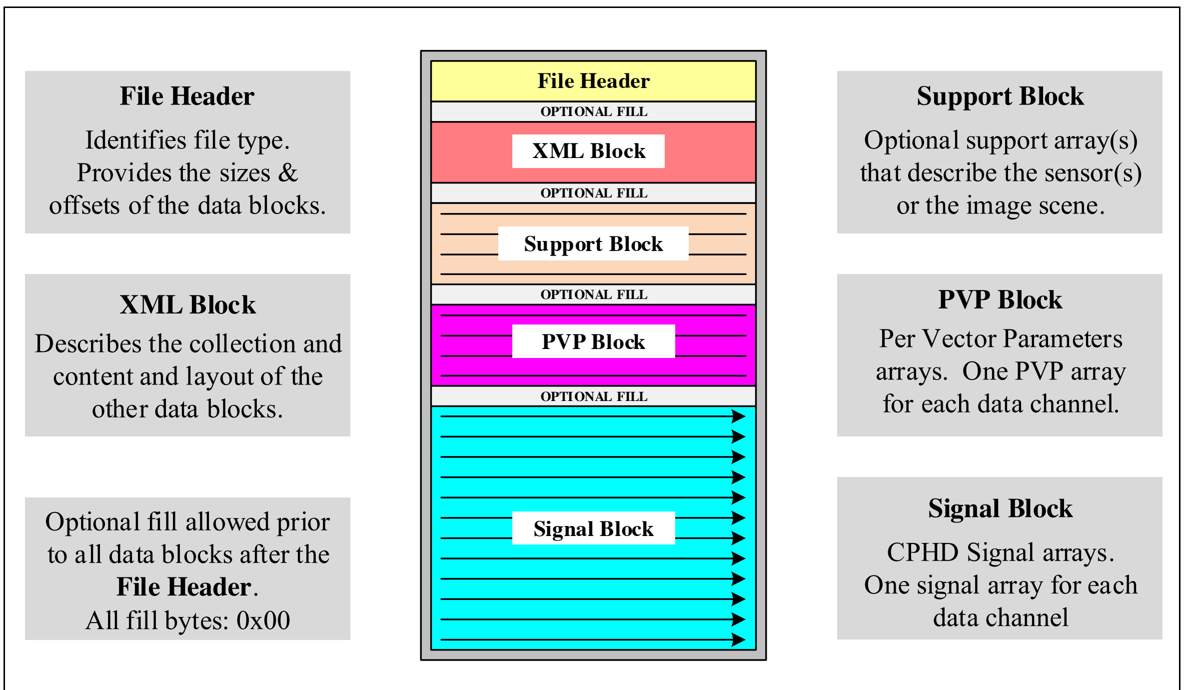


Figure 2-1 CPHD Product File Format
The product file is composed of the File Header and the data blocks.

Shown in Figure 2-2 is an example file that only includes the three required data blocks. For a product that does not contain a Support block, the PVP block follows the XML block.

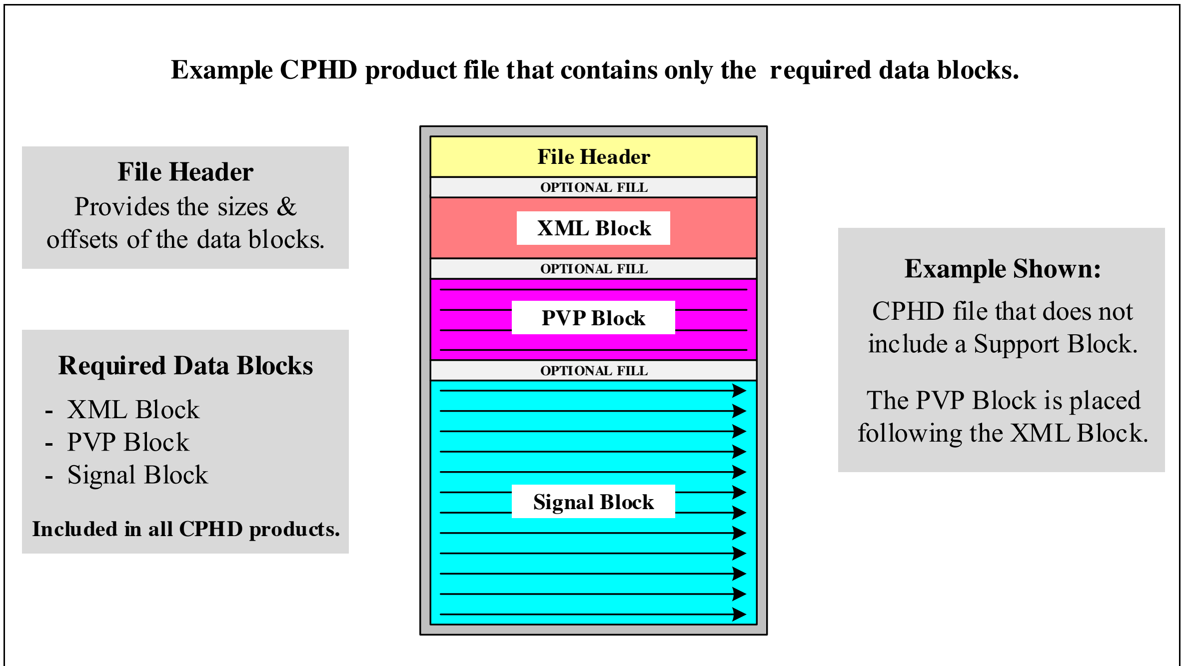


Figure 2-2 CPHD Example File

Example file that contains only the File Header and the three required data blocks.

The logical hierarchy of the format of a CPHD product file is described below. A given product file is formed by concatenating the file components with optional fill bytes. The File Header includes parameters that describe the size and location of the other blocks in the product file.

<fill>	::=	<"\0">+
<cphd file>	::=	<file header>
		[<fill>]
		<XML block>
		[<fill>]
		[<support block>]
		[<fill>]
		<pvp block>
		[<fill>]
		<signal block>

Note: All binary parameters are formatted with the Most Significant Byte (MSB) stored first (i.e. binary data in Big Endian format).

Optional fill bytes may be included between any pair of components independent of the inclusion of fill bytes between other components. All fill bytes shall be restricted to 0x00 (null characters).

2.1 File Header

The File Header contains UTF-8 text that identifies the file type and CPHD Version number. The File Header also contains a set of parameters expressed as Key-Value Pairs (KVPs) that provide the sizes and byte offsets of the data blocks contained in the given product.

The File Header consists of the concatenation of three blocks of text characters: (1) File Type Header, (2) Key-Value Pair List and (3) Section Terminator. The structure of the File Header block is shown below.

<file header>	::=	<file type header> <key-value pair list> <section terminator>
<file type header>	::=	<"CPHD"> <"/"> <version> <"\n">
<key-value pair list>	::=	<key-value pair>+
<key-value pair>	::=	<kvp key> < " := "> <kvp value><"\n">
<section terminator>	::=	<"\f\n">

The File Type Header identifies the file type as CPHD and identifies the version number. The File Type Header is a variable length field of the form:

<"CPHD"> < "/"> <version> <"\n">

The slash "/" (0x2F) separates the version field and the newline "\n" (0x0A) terminates the File Type Header. The version number is the version number of the CPHD Design & Implementation Description Document (i.e. this document) for which the data structure and content are defined.

The Key-Value Pair List is a variable length block that is formed by concatenating the selected Key-Value Pairs. A set of KVP keys is defined in Table 2-1. The set of keys includes all required keys and several optional keys. Additional optional KVP keys may be defined per a program specific Product Design Document. Each KVP is a variable length field of the form:

<kvp key> < " := "> <kvp value> <"\n">

The KVPs are formatted per the following rules and restrictions. The key and value are separated by the 4 character sequence " := " (0x20, 0x3A, 0x3D, 0x20) and terminated by a newline "\n" (0x0A). All product files will include the required KVPs. A given KVP key will occur only once in a given product. The KVPs may occur in any order. A given product may include any number of optional KVPs. All KVPs will have text-based keys and values and may not use the "\n", "\f", or the four character " := " in the text string that is the key or the value.

The two byte section terminator "\f\n" (0x0C, 0x0A) marks the end of the File Header. The section terminator enables a reader application to identify the end of the File Header block and enables viewing of the file header using standard functions on some systems (e.g. the "more" command on a UNIX system).

Table 2-1 File Header Key-Value Pair Keys

Key Name	REQ/OPT	Description
XML_BLOCK_SIZE	REQ	Size of the XML instance that describes the product (in bytes, decimal integer format). Size does NOT include the 2 bytes of the section terminator. Section terminator = ASCII "\f\n"
XML_BLOCK_BYTE_OFFSET	REQ	Offset to the first byte of the XML block (in bytes, decimal integer format).
SUPPORT_BLOCK_SIZE	OPT	Size of the Support block (in bytes, decimal integer format). Note: If the Support block is omitted, this KVP is not included.
SUPPORT_BLOCK_BYTE_OFFSET	OPT	Offset to the first byte of the Support block (in bytes, decimal integer format). Note: If the Support block is omitted, this KVP is not included.
PVP_BLOCK_SIZE	REQ	Size of the PVP block (in bytes, decimal integer format).
PVP_BLOCK_BYTE_OFFSET	REQ	Offset to the first byte of the PVP block (in bytes, decimal integer format).
SIGNAL_BLOCK_SIZE	REQ	Size of the Signal block (in bytes, decimal integer format).
SIGNAL_BLOCK_BYTE_OFFSET	REQ	Offset to the first byte of the Signal block (in bytes, decimal integer format).
CLASSIFICATION	REQ	Product classification information (text-based field) that is human-readable. Allowed values to be defined per program specific Product Design Document. Default value: "UNCLASSIFIED"
RELEASE_INFO	REQ	Product release information (text-based field) that is human-readable. Allowed values to be defined per program specific Product Design Document. Default value: "UNRESTRICTED"
Note: For CLASSIFICIATION and RELEASE_INFO, values must match the corresponding values in the XML instance. See Table 11.1, Classification and ReleaseInfo nodes.		

2.2 XML Block

The XML block is the concatenation of the XML instance and the section terminator. The form of the XML block is shown below.

<XML block> ::= <XML instance>
<section terminator>

<section terminator> ::= <"\f\n">

The XML instance describes the imaging collection as well as the sizes and content of the other data blocks. The XML data is formatted per eXtensible Markup Language, Version 1.0. The CPHD XML structure is described in Section 10 and Section 11 and defined per the schema. The section terminator is the same as the File Header block section terminator.

2.3 Support Block

The Support block is a set of one or more support arrays that may be included to describe the imaging collection. The Support block is formed by the concatenation of the support arrays in the given product.

<support block> ::= <support array>+

Each support array is a two-dimensional array of binary-formatted data elements. Each data element contains one or more parameters. The defined support arrays describe the imaged scene (e.g. a two-dimensional array of scene surface heights) or an attribute of the radar sensor. The data structure also allows for one or more support arrays to be included that are defined per a Product Design Document (i.e. user-defined or added support arrays). All support arrays are optional. For a product that does not include any support arrays, the Support block is omitted.

Shown in Figure 2-3 is an example Support block that includes 2 support arrays. The number of support arrays, NumSupportArrays, is specified in the Data node of the XML structure. For each array, the size of the array (i.e. number of rows and number of columns) and the size of the data elements are specified in the Data node of the XML structure. See Table 11-4. The support arrays have the following attributes.

(1) The support arrays are referenced by their unique string identifiers (SA_IDs). For a product with multiple support arrays, the arrays are stored consecutively and in the order specified by their ArrayByteOffsets. Fill bytes between arrays are not allowed.

(2) A support array is indexed by (row, column). The rows of the array are indexed by m = 0, 1, 2, . . ., NumRowsSA(SA_ID) - 1. The columns of the array are indexed by n = 0, 1, 2, . . ., NumColsSA(SA_ID) - 1. The number of rows and columns may be unique for each array.

(3) For each support array, the data element format may be unique. Each data element may contain one or more parameters. For each support array, the

format of the data elements is specified in the SupportArray node of the XML structure. See Table 11-7.

(4) The format of the data elements specifies the number of parameters and the binary format of each parameter of the element. The parameters of a given element are stored in adjacent bytes. The method for specifying the binary data elements is defined in Table 10-2.

(5) The data elements of a given row are stored in adjacent bytes (i.e. the column index n is the "fast" index of the array).

(6) The last element of a given row and the first element of the next row are stored in adjacent bytes.

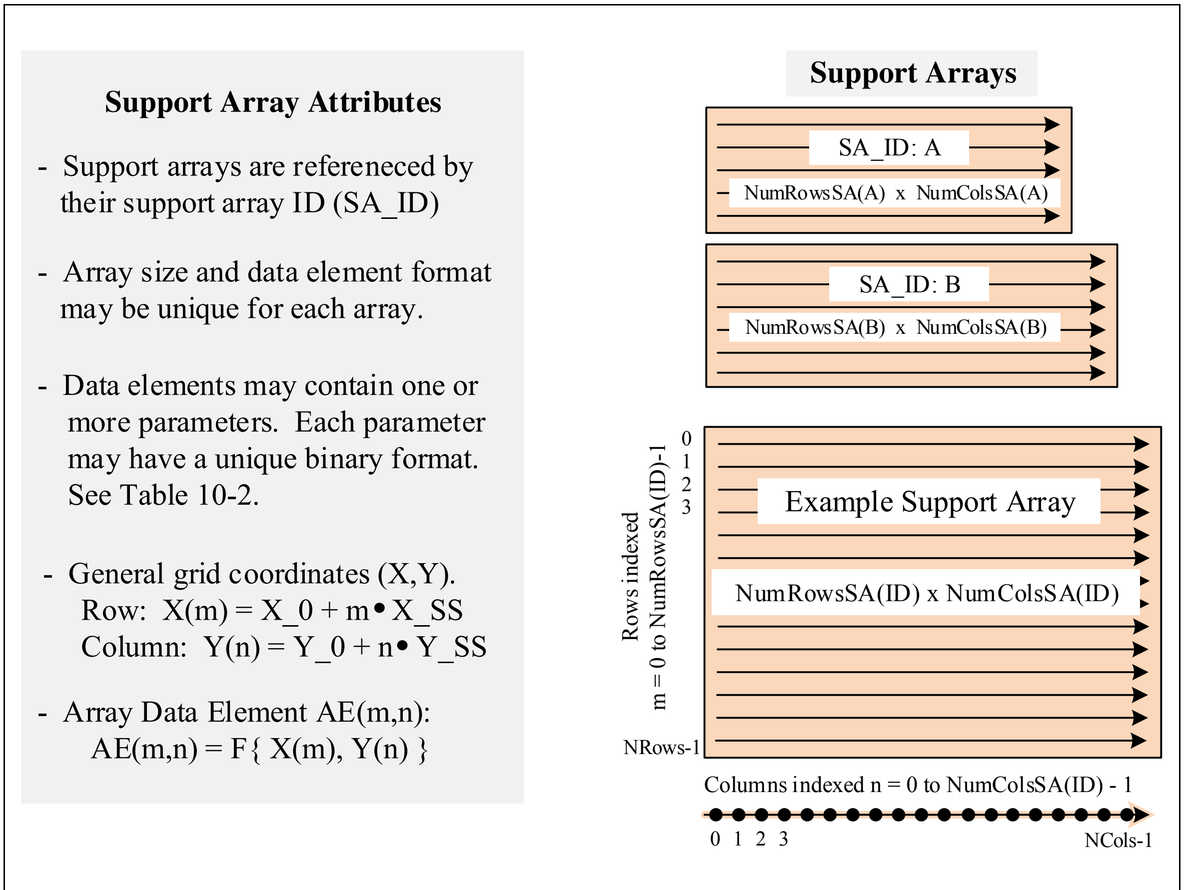


Figure 2-3 Support Block
Example Support block that contains two support arrays.

A given support array is a 2-dimensional grid of sampled data elements that are a function of two variables. Each data element is referred to as the array element and the two independent variables are referred to as the grid coordinates. The array element is generically denoted AE(m,n). The grid coordinates are generically referred to as (X, Y). The X coordinate is the row coordinate and the Y coordinate is the column coordinate. The array element is a function of the two grid coordinates, AE(m,n) = F{X(m),Y(n)}. For data elements with multiple parameters, each parameter is a function of the grid coordinates. For each defined support array, the array data element and grid coordinates are defined. In a given product, the size of the array and the range of values spanned by the grid coordinates are specified in the product. The following example is provided for clarification.

2.3.1 Defined Support Arrays

The imaged scene is a region on a geolocated reference surface. See Section 6 and Table 11-3. A point on the surface is specified by image area coordinates (IAX, IAY). Image area coordinate IAZ is the distance above or below the reference surface. An array of scene surface heights may be included via the IAZ support array. See Table 11-7. The IAZ array data element is a single parameter that is the surface height in meters. The grid coordinates are image area coordinates (IAX, IAY) and are specified in meters.

$$\mathrm{IAX}(m) = \mathrm{X}(m) = \mathrm{X\_0} + m \bullet \mathrm{X\_SS} \qquad \mathrm{IAY}(n) = \mathrm{Y}(n) = \mathrm{Y\_0} + n \bullet \mathrm{Y\_SS}$$

Array value IAZ(m,n) is an estimate of the true surface height at the surface location (IAX(m), IAY(n)). The array size parameters are specified in the Data node of the XML structure. See Table 11.4. The size parameters are linked to the support array parameters via the support array identifier. An IAZ array grid of 201 x 401 heights that spans an area of size 2.0 km x 4.0 km is specified as shown below. Each IAZ array data element is a single parameter stored in F4 format. The IAZ array total data size is 201 x 401 x 4 = 322,404 bytes.

Data / SupportArray	SupportArray / IAZArray
Identifier = “LiDARHeight”	Identifier = “LiDARHeight”
NumRows = 201	ElementFormat = “IAZ=F4;”
NumCols = 401	X_0 = -1000.0
BytesPerElement = 4	Y_0 = -2000.0
ArrayByteOffset = 0	X_SS = 10.0
	Y_SS = 10.0

2.4 PVP Block & Signal Block

A CPHD product contains one or more data channels. Each channel includes a signal array and a corresponding PVP array. The PVP block is formed by the concatenation of the PVP arrays. The Signal block is formed by the concatenation of the Signal arrays. The XML structure specifies the number of channels in the product and the size of each signal array. Each signal array may have a unique size. The XML instance also specifies the set of Per Vector Parameters provided for each signal vector.

The channels in a product are referenced by channel identifiers (Ch_IDs). For each channel, the Ch_ID is a unique character string that identifies the channel within the product. The choice of Ch_ID values is specified by Product Design Document and is based upon the characteristics of the channels being formed (e.g. polarization on transmit and/or receive of the collected data that was processed to form the signal array). Shown in Figure 2-4 are the PVP block and the Signal block for an example CPHD product that contains 3 channels. For the example shown, the channel identifiers are A, B, and C.

For each data channel, the locations of the PVP arrays in the PVP block and the locations of the signal arrays in the Signal block are specified in the Data branch of the XML instance. For a given product, the PVP arrays may be in any order when forming the PVP block. The PVP arrays are located consecutively in the block and fill bytes between arrays are not permitted. The signal arrays may be in any order when forming the Signal block. The signal arrays are located consecutively in the block and fill bytes between arrays are not permitted.

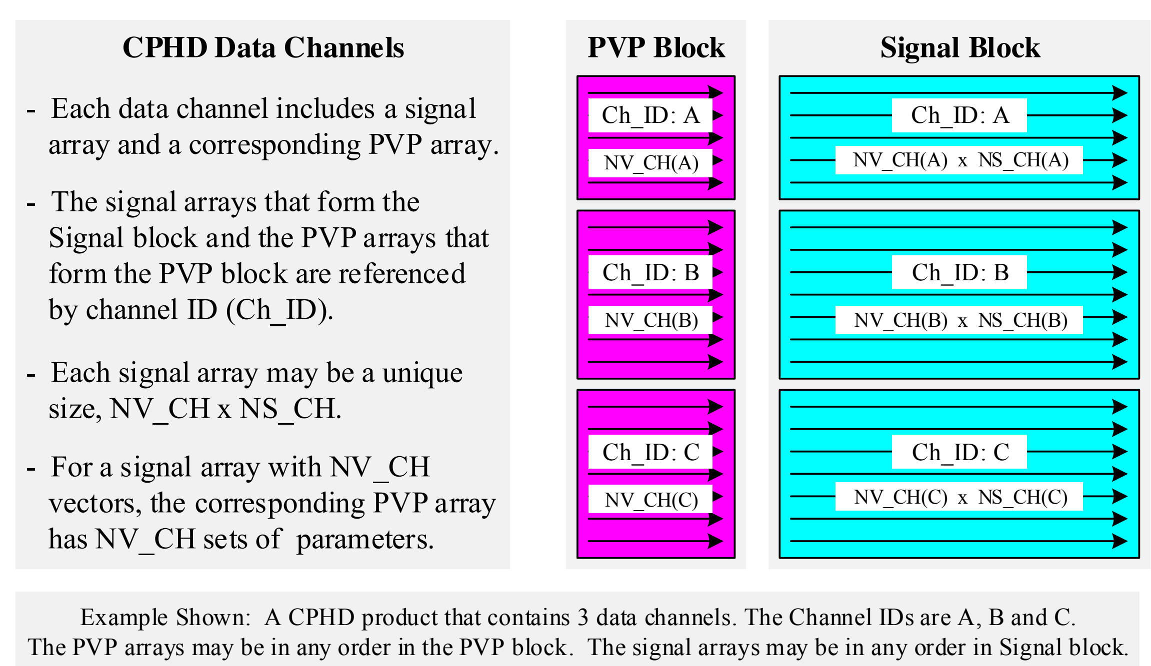


Figure 2-4 PVP Block & Signal Block
Each data channel includes a PVP array and signal array.

2.5 PVP Arrays & Signal Arrays

The PVP array describes the collection geometry and signal parameters for each vector of the corresponding signal array. Shown in Figure 2-5 is an example PVP array and signal array for a data channel in a given product. The signal array size is NV_CH(Ch_ID) vectors by NS_CH(Ch_ID) samples. The signal array size may be unique for each signal array in a given product. The signal array is indexed by vector index v and sample index s.

Vector Index: v = 0, 1, 2, . . . , NV_CH(Ch_ID) – 1
Sample Index: s = 0, 1, 2, . . . , NS_CH(Ch_ID) – 1

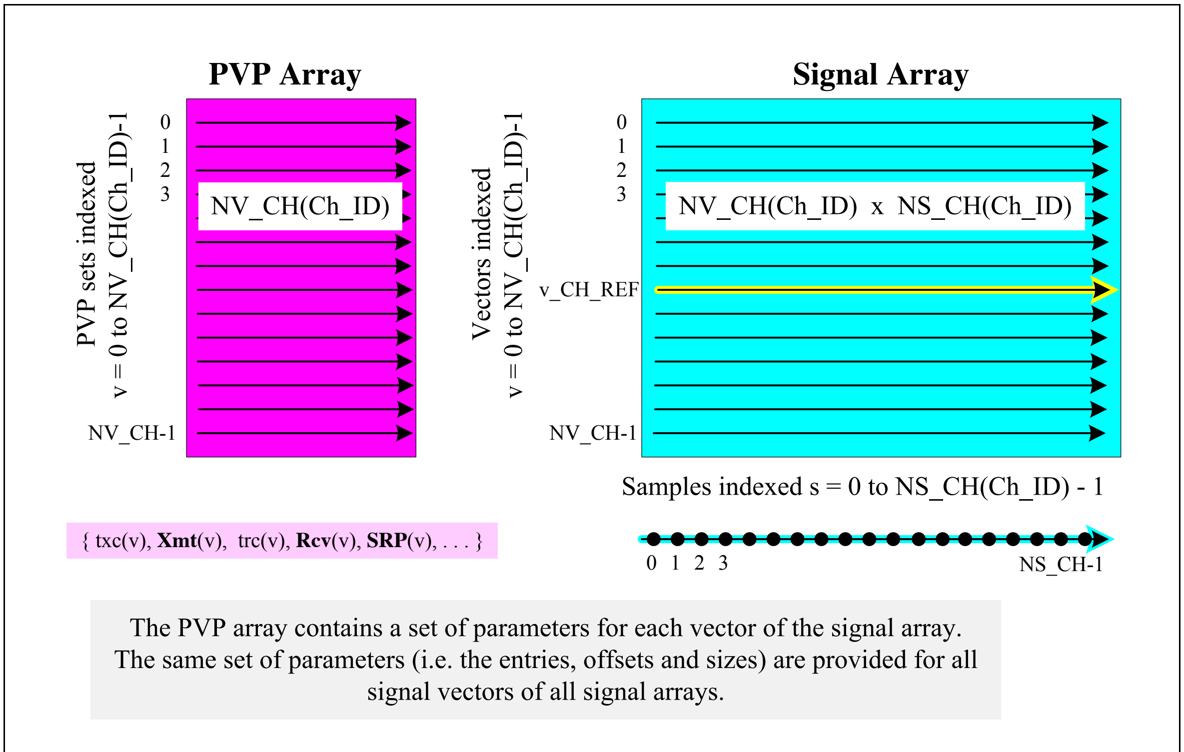


Figure 2-5 Per Vector Parameters & Signal Arrays
Parameters for each vector are stored in adjacent bytes and by increasing vector index.

The PVP array contains one PVP set for each vector of the signal array. The PVP sets are indexed by vector index v = 0 to NV_CH(Ch_ID) - 1. For a given CPHD product, the PVP set that is provided for all signal vectors is selected and specified per the following rules and guidance.

(1) For a given CPHD product, the parameters in a PVP set are specified in the PVP branch of the XML instance that describes the product.

(2) The PVP set is composed from the set of defined PVPs and may include one or more added PVPs. The PVP set is selected based on the attributes of the signal arrays in the product.

(3) The defined PVPs include both required parameters and optional parameters. The PVP set includes all required parameters. The optional parameters included in a given product are selected per the product design process.

(4) The defined PVPs are described in Table 2-2. Each defined PVP has a corresponding node in the PVP branch of the XML structure. All defined PVPs have a defined number of components, binary format and size. See Table 11-6.

(5) Added PVPs are optional parameters that may be included in the PVP set for a given product. The PVP set may include any number of added PVPs. The added PVPs are defined per the product design process and are specified per Product Design Document.

(6) For each added PVP, a unique AddedPVP node is included in the PVP branch of the XML instance. See Table 11-6.

(7) For each parameter, the binary-formatted parameter occupies 1 or more 8-byte words. The Size specifies the size of the parameter in 8-byte words.

(8) For a given product, the parameters may be placed in any order within the PVP set. The Offset specifies the offset from the start of the set in 8-byte words. The first parameter in the set has Offset value equal to 0.

(9) For a given product, the same set of PVPs (i.e. same entries, offsets and sizes) is provided for all signal vectors of all signal arrays.

Shown in Figure 2-6 is an example Per Vector Parameters set. For each parameter, the Size defines the number of 8-byte words that the parameter occupies. The Offset specifies the location of the parameter within the set. The Format specifies the number of components and the binary format for each component. The first parameter in the set will have Offset equal to 0.

For a given CPHD product, the signal array samples are in one of three allowed binary formats. The allowed formats are denoted CI2, CI4 and CF8 and are defined in Table 10-3. Each signal array sample is a complex-valued parameter with real and imaginary components. For each data sample, the real and imaginary components are stored in adjacent bytes with the real component first and the imaginary component second. The allowed sample formats permit balancing signal array and product file size versus the expected dynamic range of the signal arrays in a given product.

For a given product, the PVP set provided for each signal vector may include an optional amplitude scale factor. The amplitude scale factor, denoted Amp_SF, is a defined PVP that is a single real-valued parameter. For a given signal vector, the sample values of the signal vector are multiplied by the Amp_SF to create the proper signal values for the vector. The Amp_SF parameter is intended for use for signal arrays that a use a fixed-point binary format (i.e. the CI2 or CI4 format). The AmpSF allows for signal vectors that are formed initially in a floating-point binary format to be scaled prior to conversion to the selected fixed-point format. The Amp_SF allows each signal vector to be scaled separately in order to minimize the distortion that occurs when converting to the fixed-point sample format.

The Amp_SF PVP may be included in any product. It is strongly encouraged for use in products that use a fixed-point sample format for the signal arrays. For products that use the CF8 floating-point format, it will be of minimal benefit and may be omitted.

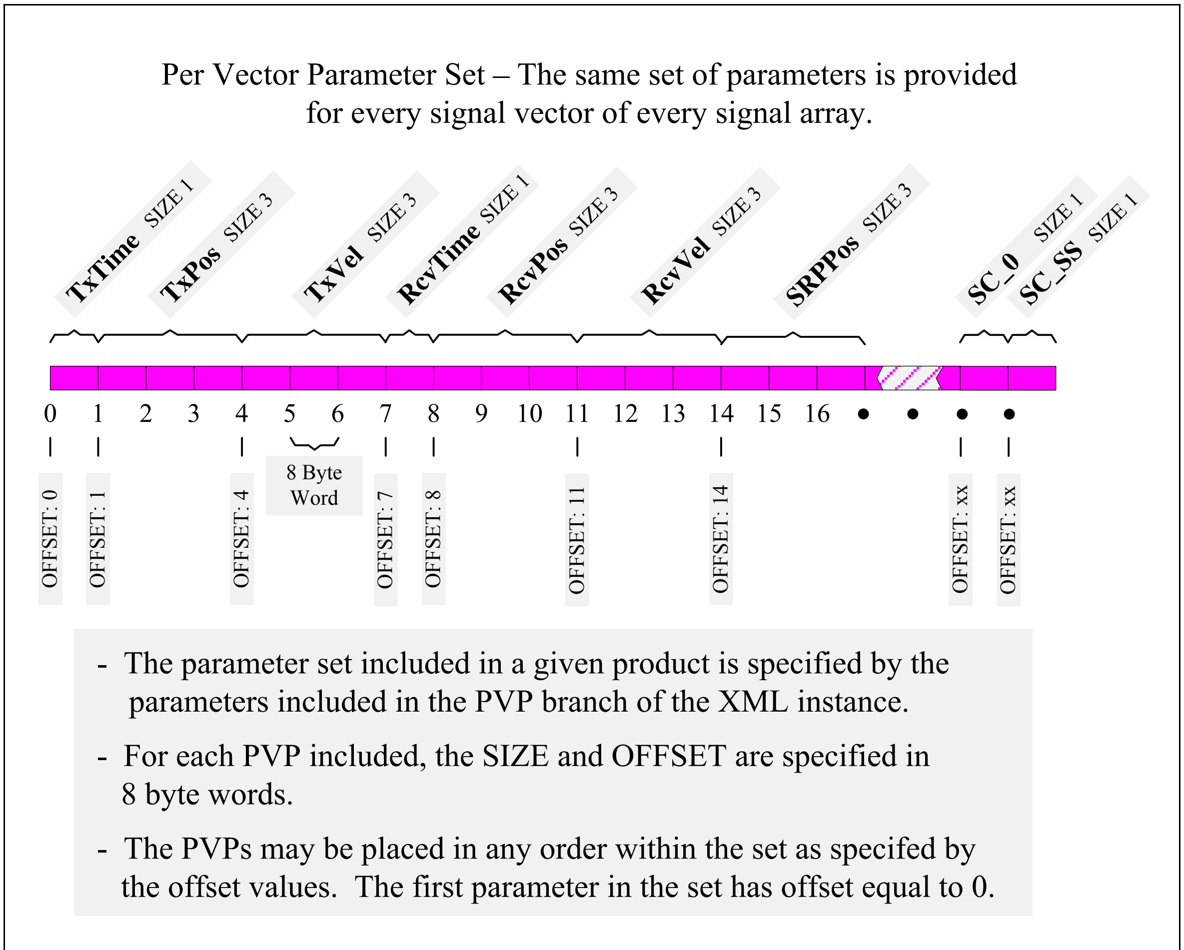


Figure 2-6 Per Vector Parameter Set
The same set of PVPs is provided for every signal vector of every signal array.

Table 2-2 Defined Per Vector Parameters		
Parameter & XML PVP	**Req / Opt**	**Description**
The Per Vector Parameter set provided in a given product is specified in the PVP branch of the XML instance in the product. See Table 11-6.		
txc(v) XML: TxTime	REQ	Transmit time for the center of the transmitted pulse relative to the transmit platform Collection Start Time (sec). Time the center of the pulse is at the Transmit APC. For all CPHD signal arrays, transmit times INCREASE with increasing vector index.
$\mathbf{Xmt}(v) = \begin{bmatrix} Xmt\_X(v) \\ Xmt\_Y(v) \\ Xmt\_Z(v) \end{bmatrix}$ XML: TxPos	REQ	Transmit APC position at time txc(v) in ECF coordinates (meters). Components in X, Y, Z order.
$\mathbf{VXmt}(v) = \begin{bmatrix} VXmt\_X(v) \\ VXmt\_Y(v) \\ VXmt\_Z(v) \end{bmatrix}$ XML: TxVel	REQ	Transmit APC velocity at time txc(v) in ECF coordinates (meters/sec).
$trc(v)^{SRP}$ XML: RcvTime	REQ	Receive time for the center of the echo from the SRP relative to the transmit platform Collection Start Time (sec). Time is the Time Of Arrival (TOA) of the received echo from the SRP for the signal transmitted at txc(v).
$\mathbf{Rcv}(v) = \begin{bmatrix} Rcv\_X(v) \\ Rcv\_Y(v) \\ Rcv\_Z(v) \end{bmatrix}$ XML: RcvPos	REQ	Receive APC position at time $trc(v)^{SRP}$ in ECF coordinates (meters). Components in X, Y, Z order.
$\mathbf{VRcv}(v) = \begin{bmatrix} VRcv\_X(v) \\ VRcv\_Y(v) \\ VRcv\_Z(v) \end{bmatrix}$ XML: RcvVel	REQ	Receive APC velocity at time $trc(v)^{SRP}$ in ECF coordinates (meters/sec).
$\mathbf{SRP}(v) = \begin{bmatrix} SRP\_X(v) \\ SRP\_Y(v) \\ SRP\_Z(v) \end{bmatrix}$ XML: SRPPos	REQ	Stabilization Reference Point (SRP) position in ECF coordinates (meters). Components in X, Y, Z order.
Amp_SF(v) XML: AmpSF	OPT	Amplitude Scale Factor to be applied to all samples of the signal vector. For signal vector v, each sample value is multiplied by Amp_SF(v) to yield the proper sample values for the vector. The Scale factor allows each signal vector to be scaled prior to converting into fixed-point binary format (i.e. C2I and C4I). For floating point format (CF8), scale factor may still be included but is of minimal utility.

Table 2-2 Defined Per Vector Parameters		
Parameter & XML PVP	**Req / Opt**	**Description**
Parameters aTOA_VRCV, aTOA_TROPO, aFDOP, aFRR1, aFRR2 are referred to as the signal model micro parameters. All parameters are dimensionless scale factors.		
aTOA_VRCV(v) XML: aTOAVRCV	REQ	The TOA Receive APC velocity micro parameter. Parameter accounts for effects of receive platform motion on the difference in propagation time between a given target and the SRP.
aTOA_TROPO(v) XML: aTOATROPO	REQ	The TOA TROPO micro parameter. Parameter accounts for effects of differential troposphere delay for targets displaced from the SRP, ΔTD_Tropo^{TGT}. Computed for locally level scene surrounding the SRP.
aFDOP(v) XML: aFDOP	REQ	The DOPPLER shift micro parameter. Parameter accounts for the time dilation/Doppler shift for the echoes from all targets with the same time dilation/Doppler shift as the SRP echo.
aFRR1(v) XML: aFRR1	REQ	First order phase micro parameter (i.e. linear phase). Accounts for linear phase vs. FX frequency for targets with time dilation/Doppler shift different than the echo from the SRP. Provides precise linear phase prediction for Linear FM waveforms.
aFRR2(v) XML: aFRR2	REQ	Second order phase micro parameter (i.e. quadratic phase). Accounts for quadratic phase vs. FX frequency for targets with time dilation/Doppler shift different than the echo from the SRP. Provides precise quadratic phase prediction for Linear FM waveforms.
Signal extent parameters in the FX domain: fx_1, fx_2, fx_N1 and fx_N2. **Optional parameters fx_N1 and fx_N2 are both included if out-of-band noise is retained.**		
fx_1(v), fx_2(v) XML: FX1, FX2	REQ	The FX domain frequency limits of the transmitted waveform retained in the signal vector (Hz). Saved transmit band is from $fx\_1(v) \leq fx \leq fx\_2(v)$ For the vector: $FX\_BW(v) = fx\_2(v) – fx\_1(v)$
fx_N1(v), fx_N2(v) XML: FXN1, FXN2	OPT	The FX domain frequency limits for out-of-band noise signal for frequencies below fx_1(v) and above fx_2(v). May ONLY be included for Domain_Type = FX. For any vector: $fx\_N1 \leq fx\_1$ & $fx\_2 \leq fx\_N2$ When included in a product, fx_N1 & fx_N2 are both included.
Signal extent parameters in the TOA domain: ΔTOA_1, ΔTOA_2, ΔTOA_E1 & ΔTOA_E2 **Optional parameters ΔTOA_E1 & ΔTOA_E2 are both included when extended swath is retained.**		
ΔTOA_1(v), ΔTOA_2(v) XML: TOA1, TOA2	REQ	The ΔTOA limits for the full resolution echoes retained in the signal vector (sec). Full resolution echoes are formed with FX_BW(v) saved bandwidth. Full resolution TOA limits: $\Delta TOA\_1 \leq \Delta TOA \leq \Delta TOA\_2$

Table 2-2 Defined Per Vector Parameters

Parameter & XML PVP	Req / Opt	Description
ΔTOA_E1(v), ΔTOA_E2(v) XML: TOAE1, TOAE2	OPT	The ΔTOA limits for all echoes retained in the signal vector (sec). Parameters are included when the saved swath has partially eclipsed echoes before and/or after the full resolution swath. For any vector: ΔTOA_E1 ≤ ΔTOA_1 & ΔTOA_2 ≤ ΔTOA_E2 When included in a product, ΔTOA_E1 & ΔTOA_E1 are both included.
The total propagation time for the SRP echo is: T_Prop(v)^{SRP} = trc(v)^{SRP} - txc(v). **The total propagation time is the sum of the free space propagation time, T_Prop_FS(v)^{SRP} , and the delay times added for the troposphere and the ionosphere (if applicable).** **T_Prop(v)^{SRP} = T_Prop_FS(v)^{SRP} + TD_Tropo(v)^{SRP} + TD_Iono(v)^{SRP}**		
TD_Tropo(v)^{SRP} XML: TDTropoSRP	REQ	Two-way time delay due to the troposphere (sec) that was added when computing the propagation time for the SRP. Sum of the delays from the transmit APC to the SRP and the delay from the SRP to receive APC. TD_Tropo(v)^{SRP} = TD_Tropo_Xmt(v)^{SRP} + TD_Tropo_Rcv(v)^{SRP}
TD_Iono(v)^{SRP} XML: TDIonoSRP	OPT	Two-way time delay due to the ionosphere (sec) that was added when computing the propagation time for the SRP (if applicable). Sum of the delays from the transmit APC to the SRP and the delay from the SRP to receive APC. TD_Iono(v)^{SRP} = TD_Iono_Xmt(v)^{SRP} + TD_Iono_Rcv(v)^{SRP}
Parameters SC_0(v) and SC_SS(v) define the signal vector sample coordinate values for the vector. **For signal arrays in the FX domain: SC_0(v) ➔fx_0(v) & SC_SS ➔fx_SS(v).** **For signal arrays in the TOA domain: SC_0(v) ➔ ΔTOA_0(v) & SC_SS ➔ΔTOA_SS(v).**		
SC_0(v), SC_SS(v) XML: SC0, SCSS	REQ	FX DOMAIN: The FX domain signal vector coordinate value for sample s = 0 and the signal coordinate sample spacing (Hz). fx_0(v) = SC_0(v) and fx_SS(v) = SC_SS(v) For all vectors, require fx_0(v) > 0 and fx_SS(v) > 0 TOA DOMAIN: The TOA domain signal vector coordinate value for sample s = 0 and the signal coordinate sample spacing (sec). ΔTOA_0(v) = SC_0(v) and ΔTOA_SS(v) = SC_SS(v) For all vectors, require ΔTOA_SS(v) > 0
SIGNAL(v) XML: SIGNAL	OPT	Integer parameter that may be included to indicate the signal content for some vectors is known or is likely to be distorted. Allowed values: SIGNAL(v) = 0 ➔ Signal vector samples set to zero. SIGNAL(v) = 1 ➔ Normal signal. SIGNAL(v) = 2 ➔ Noise Only / No Transmitted Signal SIGNAL(v) = 3 ➔ Signal content may be corrupted.

3 Product Design

The CPHD data structure is designed to accommodate the compensated PHD signal arrays for both conventional and advanced SAR sensors. It provides a robust set of metadata parameters that may be included to describe how the data was collected and processed to form the compensated signal arrays. For a given sensor, the CPHD products are dependent on the capabilities of the sensor. The products may also be dependent on the derived SAR data products that are to be formed by the subsequent processing.

For some SAR sensors, the CPHD products may contain a single signal array and a minimal set of supporting metadata. From these products, only a limited set of derived products are to be produced. For other SAR sensors, the CPHD products may contain multiple signal arrays. The number of signal arrays may be dependent upon the configuration and/or operating mode of the sensor during the collection. For these products, a larger set of metadata will be included that enables additional derived products and measurements to be made.

The CPHD product design process defines the elements of the data structure that are included in the products. The data structure includes many optional elements, allowing the CPHD product designer many options when creating products. The product content is selected based on the sensor and the desired derived products to be formed.

The product design process also defines the product information and support metadata included in the CPHD products. The informational metadata includes, for example, parameters that identify the sensor. It also includes parameters that identify the specific imaging mode that collected the initial PHD signal arrays. The data structure accommodates many optional information and support parameters that may be included. The elements of the data structure are sensor independent; however, all products generally include sensor and/or program specific parameters and parameter values. The program specific parameters may include parameters that are used by system(s) that store and disseminate the CPHD products.

For a given SAR sensor, the product design may be specified in one or more design artifacts that define the specific content of the products to be formed. In the descriptions that follow, the set of sensor or program specific design artifacts that define the products are collectively referred to as a CPHD Product Design Document (PDD). The PDD serves as the guidance for the developers of the applications that output the CPHD products to ensure the products produced will support the intended uses

A CPHD product is an intermediate data product. The utility is in the products and measurements that may be derived from it. The PDD, in combination with the CPHD standard document, serves to define the interface between the producers of CPHD products and the applications that accept CPHD as input. For a given set of products, the PDD defines important aspects of the content of the products. It also selects and limits what optional data elements will be included. The sections that follow provide guidance and a list of topics that should be addressed in a CPHD PDD.

3.1 Product Design Guidance

The CPHD data structure is composed of four data blocks. The CPHD product design addresses the content for all data blocks in the products. The XML structure includes the data elements that describe the imaging collection and that describe the content of the other data blocks. A key part of the product design is to define the nodes of the XML structure that are included and, in many cases, the allowed values.

For a given SAR sensor, the following guidance is provided for the design of the CPHD products to be produced. The items addressed in the Product Design Document should include the following.

Collection Identification Parameters

(1) Specify values for the required parameters in the CollectionID branch of the XML structure. See Table 11-1.

(2) Define the SAR platform ID text strings to be used. The platforms may be identified by class or by specific platform (e.g. by aircraft tail number).

(3) Specify the collection Mode Types and, if relevant, the ModeID text strings.

(4) Specify additional product information and support parameters to be included and provide the guidance for each parameter.

(5) For Bistatic CPHD products, the PDD should specify the platform IDs for both transmit and receive platforms. The PDD may also specify a product naming system that readily identifies the Bistatic CPHD products.

Signal Array Parameters

(1) Specify the domain type(s) of the signal arrays to be used, FX and/or TOA. The domain type used may be restricted based on the application(s) that accept the CPHD products as input.

(2) Specify the signal array sample type to be used. The signal array sample formats (2 bytes per sample, 4 bytes per sample or 8 bytes per sample) allow for the balancing of array and product file sizes and signal dynamic range.

(3) Specify the selected phase sign value, SGN = +1 or SGN = -1. It is strongly encouraged that all products are formed with the same SGN value. See Table 4-1 and Table 11-2.

Data Channels

(1) Specify the number of data channels that will be included in the products. For each data channel, a signal array and PVP array are included. Each data channel also includes a set of parameters in the Channel branch of the XML structure. See Table 11-5.

(2) Specify the Channel ID text strings to be used (i.e. define Channel IDs). The Channel ID values may be composed of multiple fields that convey how the signal array was collected and/or to support the subsequent processing.

(3) For products that contain multiple data channels, the PDD should describe the set(s) of channels that may be found in a given product. It is encouraged that the description makes use of the Channel IDs that will be used. For example, given a product with data channels separated by the transmit and/or receive polarizations, the channel ID values could identify the specific polarizations of the data channels.

(4) For products that contain multiple data channels, the PDD should specify which data channel is assigned as the reference channel. The method for selecting the reference vector index may also be specified. The center vector is the recommended choice.

(5) For products that contain multiple data channels that are to be combined in the subsequent processing, the PDD should provide guidance for the subsequent processing. For example, a product with data channels separated by FX band that are combined to yield improved resolution should be described.

(6) For signal arrays that will have varying FX bandwidth vector to vector, the PDD should describe the variation that is allowed within a given signal array.

(7) For signal arrays that will have varying TOA extent vector to vector, the PDD should describe the variation that is allowed within a given signal array.

Antenna Metadata Parameters

(1) The parameters that describe the transmit and receive antenna(s) may be included in a given product. The antenna parameters are optional but are strongly encouraged to be included for all products.

(2) The Antenna branch of the XML structure includes parameters that describe the antenna orientation versus time and the one-way illumination pattern versus time for each antenna used during the collection. See Table 11-10.

(3) For a collection that uses a single antenna for both transmit and receive, one set of parameters is included. For a collection that uses separate antennas for transmit and receive, separate parameters may be provided.

(4) Specify the Antenna Coordinate Frame (ACF) ID text string(s) and the Antenna Pattern ID text string(s) to be used.

3.2 Product File Naming

The choice of CPHD product identifiers and product file names is not specified or restricted by this standard. Product file naming is a product design choice and should be specified in the CPHD Product Design Document.

4 CPHD Signal Model

The CPHD signal model describes the signal response in the signal arrays for targets located in the imaged scene. For a given target location, the model describes the expected signal response of the received echoes of the transmitted pulses of the collection. The model may be applied to any target location and for any CPHD channel signal array. For a given target location, the model is applied to each signal vector to determine when the target signal will be present. For a signal vector for which the target signal is present, the signal phase may be computed.

The CPHD signal model is a combination of two models. The first model computes the times of arrival for the echoes of the transmitted pulses reflected from points in the imaged scene. The second model computes the predicted phase in the CPHD signal array for the received echoes that are demodulated and recorded by the radar receiver and retained by the compensation processing. For each CPHD signal vector, a fixed point in the imaged scene is selected as the Stabilization Reference Point (SRP). The SRP is the motion compensation point for the signal vector. The phase of the SRP signal is set to zero by the compensation processing. For each signal vector, the SRP serves as the reference point for both the Time of Arrival model and the Signal Phase model.

For each signal vector, the PVP set includes the SRP position as well as the Antenna Phase Center (APC) positions at the time of transmit and the time of receive. The Time of Arrival (TOA) model provides precise TOA predictions for monostatic and bistatic imaging collections. The effects of the troposphere and the motion the SAR platform(s) are accounted for in the model. The Signal Phase model provides precise phase predictions for the target signal as a function of the predicted Time of Arrival. For systems that use linear FM waveforms, the phase model also accounts for the differences in signal phase due to differences in the time dilation of the received echoes due to the motion of the platform(s).

The signal arrays are provided in one of two signal domains. The allowed domains are the FX domain and the TOA domain. For a given CPHD product, all signal arrays are in the same domain. For the FX domain, the sample dimension is the transmitted frequency domain and has units of Hertz. The FX signal samples are frequency samples of the transmitted pulse spectrum as observed at the transmit APC (prior to any time dilation or Doppler shift due to platform motion). For the TOA domain, the sample dimension is the TOA of the received echoes. The TOA signal samples are the TOA compressed values of the center of the received echoes as observed at the receive APC. For a monostatic collection, the TOA domain is equivalent to the range compressed domain. The TOA domain signal vector spans the received TOA swath, or for monostatic imaging, the received range swath. Any signal vector may be transformed from one domain to the other domain via the Discrete Fourier Transform (DFT). The PVP parameter set provided with the signal vector provides the signal content for both FX and TOA domains.

The CPHD signal model is a combination of two models that predict the signal properties in the allowed domains for signal arrays. The predicted properties are for the processed signals produced by the received echoes of the transmitted radar pulses. The signal model provides a precise signal description for a robust set of imaging conditions and for a large footprint centered on the SRP. The signal model, however, does not provide a precise description of signals generated external to the radar platform(s). Signal samples in the FX domain will only be an approximate representation of the frequency content of an external signal. Signal samples in the TOA domain, in general, will have no information about the time of arrival of an external signal.

For a given CPHD product, parameters may be included that enable the signal amplitude to be computed for the echoes received and retained by the compensation processing. The optional parameters may be included in the XML instance that describes the product. For a given data channel, parameters may be included to predict signal amplitude levels for ideal point scatterers located in the imaged scene. Parameters may be used to predict the variation in signal amplitude across the vectors of the signal array (i.e. variation in amplitude versus slow time). Parameters may also be included to predict the absolute amplitude level of the signal from a point scatterer of a given Radar Cross Section (RCS).

The signal amplitude variation may be predicted by including parameters that describe the antenna or set of antennas used during the collection. The parameters are included in the Antenna branch of the XML instance. For each antenna, the parameters describe the antenna orientation and mainlobe boresight steering as a function of time. The parameters also describe the shape of the antenna mainlobe as a function of time. For each data channel, the antenna used on transmit and on receive may be identified. For a given signal vector, the variation in signal level as a function of position in the scene may be predicted for an ideal point scatterer. For a fixed scatterer, the variation in signal level versus slow time may be predicted by the computing the variation in antenna gains and ranges from the APC positions. For sensors that are power and gain calibrated, absolute signal levels may be predicted by including a reference signal level for a point scatterer with a RCS of 1.0 square meter (i.e. 0 dBsm). The reference signal level may be used to predict the absolute signal level for any point scatterer located in the imaged scene.

4.1 Signal Arrays & Signal Model Parameters

The parameters used in the CPHD signal model are included in the XML instance and in the PVP array included with each signal array. The XML instance provides the parameters that are common to all signal arrays in a given CPHD product. The common parameters include the signal domain type and the signal phase sign. The XML instance also provides parameters that are unique for each data channel. The channel specific parameters include the size of the signal array and the reference vector index. They also include the parameters that describe the transmit bandwidth and saved TOA swath extent. The signal model parameters that may be provided in the XML instance are summarized in Table 4-1.

For each signal vector, the PVP set includes the precise collection geometry, signal timing and retained signal content. The defined parameters that support the TOA model and the phase model are required and are included in the PVP set for all products. Optional PVP parameters may also be included to describe signal arrays that include out-of-band noise (PVPs fx_N1 and fx_N2) or an extended TOA swath that includes partially eclipsed echoes (PVPs ΔTOA_E1 and ΔTOA_E2). The parameters that describe the content of the signal array are summarized in Table 4-2.

Table 4-1 Signal Model XML Parameters		
Parameter	**Type**	**Description**
Required parameters that are common across all channels.		
DOMAIN	CHAR	Indicates the domain represented by the sample dimension of the CPHD signal arrays. All signal arrays are the same domain type. Allowed values: FX and TOA See Table 11-2.
SGN	INT	Phase sign (SGN = +1 or -1) applied to target $\Delta TOA(v)^{TGT}$ when computing target phase function. See Table 11-2.
N0	FLT64	The refractivity of the troposphere. Value valid at the Image Area Center point. Value may be used to compute the troposphere delay for any point in the scene and any signal vector. See Table 11-2.
Optional parameters that may be included that may be used for all channels.		
Antenna Parameters		Antenna Parameters data structure that describes the antenna or set of antennas used during the collection. For each antenna, the included parameters describe the orientation and pointing as a function of time. See Table 11-10.
Required parameters that are included for each channel.		
NV_CH x NS_CH	2 x INT	Size of each signal array specified by the number of vectors and number of samples. See Table 11-4.
v_CH_REF	INT	Index of the reference vector for the channel. See Table 11-5.
Optional parameters that may be included for a given channel. **Note: The parameters included may be unique for each channel in a given product.**		
Antenna ID Parameters	4 x CHAR	The set of parameters that identify the antenna or pair of antennas used to collect the signal array. See Table 11-5 and Table 11-10.
PT_Ref	FLT64	Power level for the signal from an ideal point scatterer located at the SRP for the reference signal vector of the channel (v_CH_REF). Ideal point scatterer with a RCS = 1.0 sqm (i.e. 0 dBsm). See Table 11-5.

Table 4-2 Signal Model Per Vector Parameters		
Parameter	**Format**	**Description**
The defined Per Vector Parameters are listed in Table 2.2 and in Table 11.6. Parameters used in the TOA Model and the Phase Model are required and included for all products.		
txc(v)	F8	Time the center of the pulse is at the Transmit APC (sec). For a CPHD signal array, transmit times INCREASE with vector index.
$\mathbf{Xmt}(v) = \begin{bmatrix} Xmt\_X(v) \\ Xmt\_Y(v) \\ Xmt\_Z(v) \end{bmatrix}$	F8:F8:F8	Transmit APC position at time txc(v) in ECF coordinates (meters).
$\mathbf{VXmt}(v) = \begin{bmatrix} VXmt\_X(v) \\ VXmt\_Y(v) \\ VXmt\_Z(v) \end{bmatrix}$	F8:F8:F8	Transmit APC velocity at time txc(v) in ECF coordinates (meters/sec).
$trc(v)^{SRP}$	F8	Receive time for the center of the echo from the SRP relative to the transmit platform Collection Start Time (sec). Time is the Time Of Arrival (TOA) of received echo from the SRP for the signal transmitted at txc(v).
$\mathbf{Rcv}(v) = \begin{bmatrix} Rcv\_X(v) \\ Rcv\_Y(v) \\ Rcv\_Z(v) \end{bmatrix}$	F8:F8:F8	Receive APC position at time $trc(v)^{SRP}$ in ECF coordinates (meters).
$\mathbf{VRcv}(v) = \begin{bmatrix} VRcv\_X(v) \\ VRcv\_Y(v) \\ VRcv\_Z(v) \end{bmatrix}$	F8:F8:F8	Receive APC velocity at time $trc(v)^{SRP}$ in ECF coordinates (meters/sec).
$\mathbf{SRP}(v) = \begin{bmatrix} SRP\_X(v) \\ SRP\_Y(v) \\ SRP\_Z(v) \end{bmatrix}$	F8:F8:F8	Stabilization Reference Point (SRP) position in ECF coordinates (meters).
$TD\_Tropo(v)^{SRP}$	F8	Two-way time delay due to the troposphere (sec) that was added when computing the propagation time for the SRP. Sum of the delays from the transmit APC to the SRP and the delay from the SRP to receive APC. $TD\_Tropo(v)^{SRP} = TD\_Tropo\_Xmt(v)^{SRP} + TD\_Tropo\_Rcv(v)^{SRP}$
Amp_SF(v)	F8	Amplitude Scale Factor to be applied to the samples of the vector. Each sample is multiplied by Amp_SF to yield the correct sample value. Note: Amp_SF is an optional parameter.
Parameters aTOA_FS, aTOA_TROPO, aFDOP, aFRR1, aFRR2 are referred to as the signal model micro parameters. All parameters are dimensionless scale factors.		

Table 4-2 Signal Model Per Vector Parameters

Parameter	Format	Description
aTOA_VRCV(v)	F8	The TOA Receive APC velocity micro parameter. Parameter accounts for the effects of receive platform motion on the difference in propagation time between a given target and the SRP.
aTOA_TROPO(v)	F8	The TOA TROPO micro parameter. Parameter accounts for effects of differential troposphere delay for targets displaced from the SRP, ΔTD_Tropo^{TGT}. Computed for locally level scene surrounding the SRP.
aFDOP(v)	F8	The DOPPLER shift micro parameter. Parameter accounts for the time dilation/Doppler shift for the echoes from all targets with the same time dilation/Doppler shift as the SRP echo.
aFRR1(v)	F8	First order phase micro parameter (i.e. linear phase). Accounts for linear phase vs. FX frequency for targets with time dilation / Doppler shift different than the echo from the SRP. Provides precise linear phase prediction for Linear FM waveforms.
aFRR2(v)	F4	Second order phase micro parameter (i.e. quadratic phase). Accounts for quadratic phase vs. FX frequency for targets with time dilation /Doppler shift different than the echo from the SRP. Provides precise quadratic phase prediction for Linear FM waveforms.
Signal extent parameters in the FX domain: fx_1, fx_2, fx_N1 and fx_N2. **Optional parameters fx_N1 and fx_N2 are both included if out-of-band noise is retained.**		
fx_1(v), fx_2(v)	2 x F8	The FX domain frequency limits of the transmitted pulse waveform retained in the signal vector (Hz). Saved transmit band is from fx_1(v) ≤ fx ≤ fx_2(v) For the vector: FX_BW(v) = fx_2(v) – fx_1(v)
fx_N1(v), fx_N2(v)	2 x F8	The FX domain frequency limits for out-of-band noise signal for frequencies below fx_1(v) and above fx_2(v). May ONLY be included for Domain_Type = FX. For any vector: fx_N1 ≤ fx_1 & fx_2 ≤ fx_N2
Signal extent parameters in the TOA domain: ΔTOA_1, ΔTOA_2, ΔTOA_E1 & ΔTOA_E2 **Optional parameters ΔTOA_E1 & ΔTOA_E2 are both included when extended swath is retained.**		
ΔTOA_1(v), ΔTOA_2(v)	2 x F8	The ΔTOA limits for the full resolution echoes retained in the signal vector (sec). Full resolution echoes are formed with FX_BW(v) saved bandwidth. Full resolution TOA limits: ΔTOA_1 ≤ ΔTOA ≤ ΔTOA_2
ΔTOA_E1(v), ΔTOA_E2(v)	2 x F8	The ΔTOA limits for all echoes retained in the signal vector (sec). Parameters are included when the saved swath has partially eclipsed echoes before and/or after the full resolution swath. For any vector: ΔTOA_E1 ≤ ΔTOA_1 & ΔTOA_2 ≤ ΔTOA_E2

<table>
<tr><th colspan="3">Table 4-2 Signal Model Per Vector Parameters</th></tr>
<tr><th>Parameter</th><th>Format</th><th>Description</th></tr>
<tr><td colspan="3">Parameters SC_0(v) and SC_SS(v) define the signal vector sample coordinate values for the vector.
For signal arrays in the FX domain: SC_0(v) ➔fx_0(v) & SC_SS ➔fx_SS(v).
For signal arrays in the TOA domain: SC_0(v) ➔ ΔTOA_0(v) & SC_SS ➔ΔTOA_SS(v).</td></tr>
<tr><td>SC_0(v), SS_SS(v)</td><td>2 x F8</td><td>FX DOMAIN: The FX domain signal vector coordinate value for sample s = 0 and the signal coordinate sample spacing (Hz).
fx_0(v) = SC_0(v) and fx_SS(v) = SC_SS(v)
For all vectors, require fx_0(v) > 0 and fx_SS(v) > 0
TOA DOMAIN: The TOA domain signal vector coordinate value for sample s = 0 and the signal coordinate sample spacing (sec).
ΔTOA_0(v) = SC_0(v) and ΔTOA_SS(v) = SC_SS(v)
For all vectors, require ΔTOA_SS(v) > 0</td></tr>
<tr><td>SIGNAL(v)</td><td>I8</td><td>Parameter SIGNAL(v) may be included when one or more vectors of any signal array are known (or likely) to be corrupted or of degraded quality.
Allowed values:
SIGNAL(v) = 0 ➔ Signal vector samples set to zero.
SIGNAL(v) = 1 ➔ Normal signal.
SIGNAL(v) = 2 ➔ Noise Only / No Transmitted Signal
SIGNAL(v) = 3 ➔ Signal content may be corrupted.
Note: SIGNAL is an optional parameter.</td></tr>
</table>

Shown in Figure 4-1 is the PVP array and the signal array for a given data channel. For the example shown, the signal array is in the FX domain. The size of the signal array is NV_CH(Ch_ID) vectors by NS_CH(Ch_ID) samples. For all CPHD signal arrays, the signal vectors are ordered and oriented as follows.

(1) The vectors of the signal array are indexed by v = 0, 1, 2, . . . , NV_CH(Ch_ID) – 1. The samples of the signal array are indexed by s = 0, 1, 2, . . . , NS_CH(Ch_ID) – 1.

(2) For each signal array, one vector is selected as the reference vector for the channel, denoted v_CH_REF. The reference vector may be any vector in the signal array. A natural choice for the reference vector is the center vector, v_CH_CTR = FLOOR(NV_CH(Ch_ID)/2).

(3) The signal vector transmit times {txc(v)} increase with vector index. Time txc(0) is the earliest of the array and time txc(NV_CH-1) is latest. The vectors are ordered by increasing slow time.

(4) All APC times are in seconds relative to the collection start time on the transmit platform. For bistatic collections, receive times $\{trc(v)^{SRP}\}$ are converted, as necessary, as part of the compensation processing.

(5) All signal vectors have positive sample spacing values, fx_SS(v) > 0 or ΔTOA_SS(v) > 0.

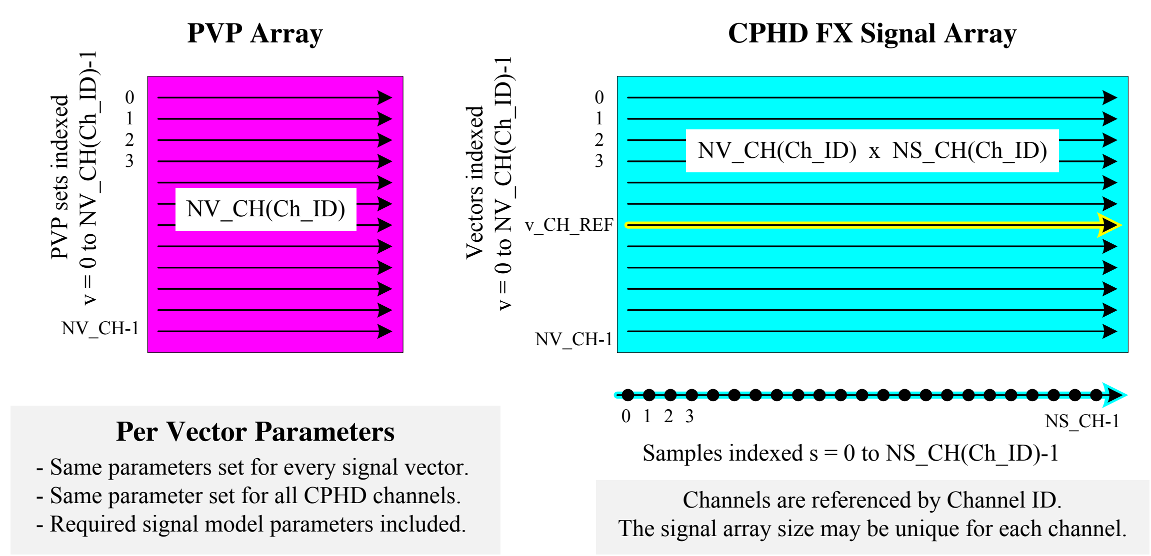


Figure 4-1 PVP Array & FX Signal Array

Example PVP array and FX domain signal array for a signal data channel.

4.2 Signal Vectors

A signal vector is formed from the received and processed echoes of the transmitted radar pulses. For each signal vector, the transmit bandwidth retained and the span in time of arrival of the echoes is specified in the PVP set for the vector. The provided metadata allows for the precise description of a signal array formed from a collection for which the parameters of the transmitted waveform vary from pulse to pulse. The FX domain parameters define the transmitted bandwidth used to form the vector. Shown in Figure 4-2 is an example transmitted pulse and the corresponding FX domain bandwidth. For a given transmitted pulse and signal vector formed from the full echoes of the entire pulse, the signal parameters are as follows.

(1) The signal vector transmit time, txc(v), is the time the center of the transmitted pulse is present at the Transmit APC. Internal delays in the transmit signal path are assumed to be accounted for in time txc(v).

(2) The transmitted pulse length, T_Xmt(v), is not used in the signal model and is not included in the PVP set. The transmit pulse length may be provided for each transmit waveform. See Table 11-11.

(3) For a given target echo, the signal amplitude vs. FX frequency is assumed to be constant. Distortion compensation, if needed, has been applied. The compensation applied may be to balance gain versus frequency distortion in the transmit signal path and/or receive signal path.

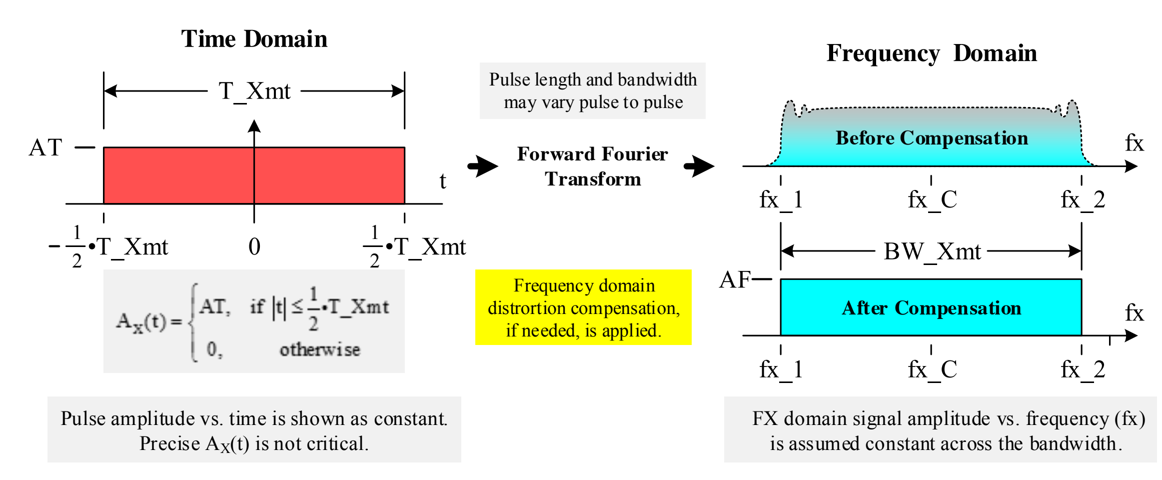


Figure 4-2 Transmit Pulse Length & Bandwidth
The pulse frequency content from fx_1 to fx_2 is measured on the transmit platform.

Shown in Figure 4-3 is a FX domain signal vector. The signal vector shown was formed from the entire received signal bandwidth. The received echoes from the transmitted pulse span FX frequency values fx_1(v) to fx_2(v). For the vector, the center frequency, fx_C(v), and the retained FX bandwidth, FX_BW(v), are computed as follows.

$$\text{fx\_C}(v) = \frac{1}{2} \bullet (\text{fx\_2}(v) + \text{fx\_1}(v)) \qquad\qquad \text{FX\_BW}(v) = \text{fx\_2}(v) - \text{fx\_1}(v)$$

For the example vector, the signal bandwidth below and above the transmitted bandwidth was retained during the compensation processing. The optional PVPs fx_N1 and fx_N2 are included in the PVP set. For the example shown, the noise signal spans from fx_N1(v) to fx_N2(v). The total FX noise bandwidth, FX_BWN(v), is computed as follows.

$$\text{FX\_BWN}(v) = \text{fx\_N2}(v) - \text{fx\_N1}(v)$$

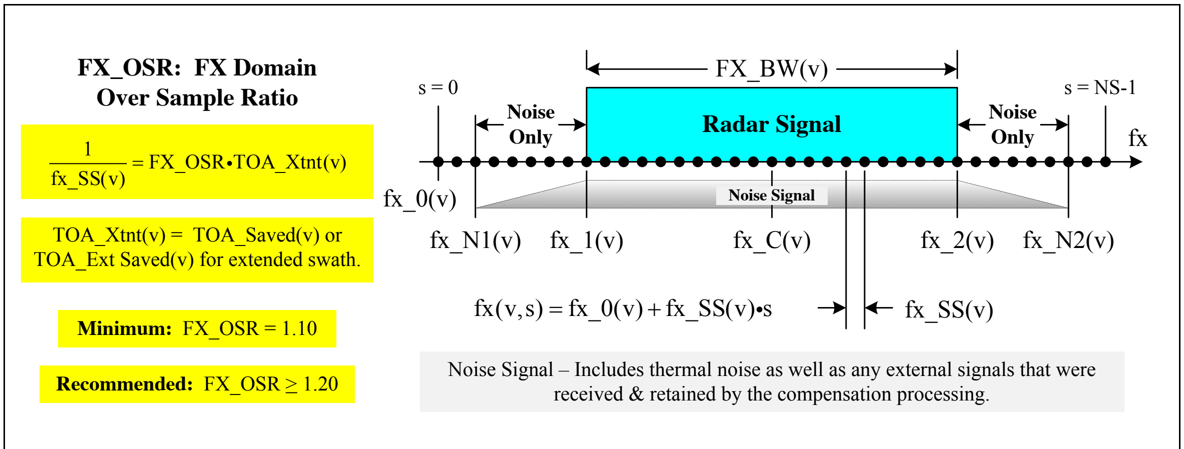


Figure 4-3 FX Domain Signal Vector
Example vector formed from the full bandwidth of the radar receiver.

A TOA domain signal vector may be formed from the FX domain signal vector via the Discrete Fourier Transform (DFT). The TOA domain vector is formed from the samples that span from fx_1(v) to fx_2(v). For a given FX domain vector, the TOA domain vector is formed from samples s_FX1(v) to s_FX2(v). The samples below s_FX1(v) and above s_FX2(v) are discarded before transforming to the TOA domain.

$$\text{s\_FX1}(v) = \text{ROUND}\left\{ \frac{1}{\text{fx\_SS}(v)} \bullet (\text{fx\_1}(v) - \text{fx\_0}(v)) \right\}$$

$$\text{s\_FX2}(v) = \text{ROUND}\left\{ \frac{1}{\text{fx\_SS}(v)} \bullet (\text{fx\_2}(v) - \text{fx\_0}(v)) \right\}$$

Shown in Figure 4-4 is a TOA domain signal vector. For the example shown, the TOA domain vector includes both the full resolution swath and the extended swath at early and late TOA. The full resolution TOA swath has all samples formed with bandwidth FX_BW(v). The full resolution swath, denoted TOA_Saved(v), is from ΔTOA_1(v) to ΔTOA_2(v) and is computed as follows.

$$\text{TOA\_Saved}(v) = \Delta\text{TOA\_2}(v) - \Delta\text{TOA\_1}(v)$$

The TOA extended swath includes the echoes at early TOA and late TOA that were not formed with the full bandwidth FX_BW(v). The extended swath is typically formed by including the partially eclipsed echoes at early and late TOA. The optional PVPs ΔTOA_E1 to ΔTOA_E2 are included in the PVP set. The early extended swath is from ΔTOA_E1(v) to ΔTOA_1(v) and the late extended swath is from ΔTOA_2(v) to ΔTOA_E2(v). The extended TOA swath, denoted TOA_Ext_Saved(v), is computed as follows.

$$\text{TOA\_Ext\_Saved}(v) = \Delta\text{TOA\_E2}(v) - \Delta\text{TOA\_E1}(v)$$

Define parameter TOA_Xtnt(v) that is the total extent of the TOA swath that has been retained for subsequent processing.

$$\text{TOA\_Xtnt}(v) = \begin{cases} \text{TOA\_Ext\_Saved}(v), & \begin{array}{c}\text{If extended swath is retained \&} \\ \Delta\text{TOA\_E1 and } \Delta\text{TOA\_E2 are included}\end{array} \\ \text{TOA\_Saved}(v), & \text{Otherwise} \end{cases}$$

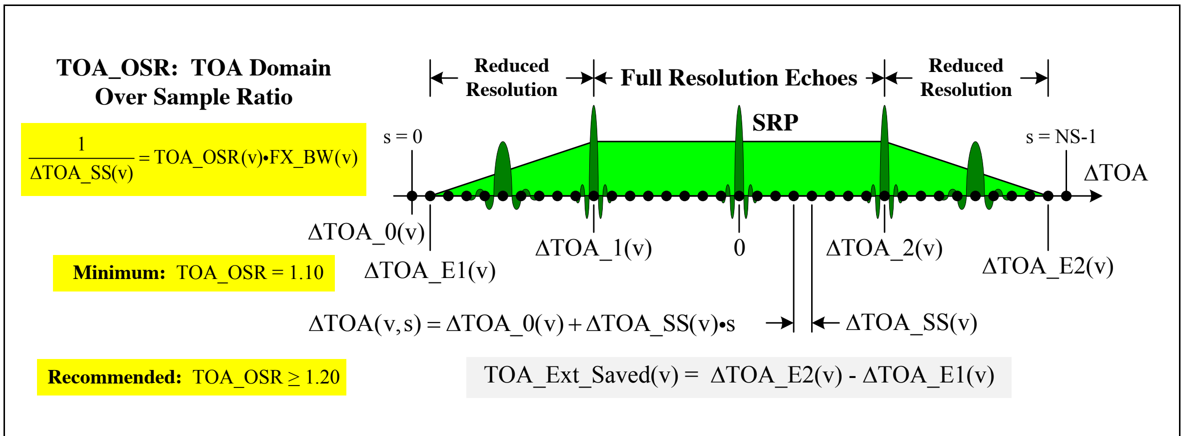


Figure 4-4 TOA Domain Signal Vector
Example TOA vector that includes the extended TOA swath.

The sample coordinate values are computed from the parameters SC_0(v) and SC_SS(v). For vectors in the FX domain, parameter SC_0(v) is the FX frequency value for sample s = 0 and SC_SS(v) is the FX frequency sample spacing (Hz). For vectors in the TOA domain, parameter SC_0(v) is the ΔTOA value for sample s = 0 and SC_SS(v) is the ΔTOA sample spacing (sec). The sample coordinate of a given vector is computed as follows.

FX Domain: $\quad \text{fx}(v,s) = \text{fx\_0}(v) + \text{fx\_SS}(v) \cdot s$

TOA Domain: $\quad \Delta\text{TOA}(v,s) = \Delta\text{TOA\_0}(v) + \Delta\text{TOA\_SS}(v) \cdot s$

Signal vectors in the FX domain have the following attributes.

(1) The FX signal vector may or may not have samples at frequency values fx_1(v), fx_2(v) or fx_C(v). This is also true for noise signal frequency limits fx_N1(v) and fx_N2(v).

(2) For a FX domain vector, the phase of the SRP signal is set equal to 0 during the compensation processing.

For all samples where fx_1(v) ≤ fx(v,s) ≤ fx_2(v): $\Phi(\mathrm{v},\mathrm{s})^{\mathrm{SRP}} = 0$

Note: For error free collection and processing, the phase of the SRP signal is set to a constant value that may or may not be precisely zero. The SRP phase is set to the same constant value for all vectors of the signal array.

(3) The FX Domain Over-Sample Ratio, FX_OSR, for the vector is defined as follows.

$$\mathrm{FX\_OSR(v)} = \frac{1}{\mathrm{fx\_SS(v) \bullet TOA\_Xtnt(v)}}$$

(4) The minimum allowed value for FX_OSR(v) is 1.10 with a recommended value of FX_OSR(v) = 1.20 or greater.

Minimum: FX_OSR = 1.10   Recommended: FX_OSR ≥ 1.20

(5) The TOA domain vector may be formed from the FX domain vector via the DFT. The TOA domain response will be nominally centered at ΔTOA = 0. The TOA domain vector must be formed with a sample at ΔTOA = 0.

(6) When forming the TOA domain vector, the valid signal content in the TOA domain is limited to the interval from ΔTOA_1(v) to ΔTOA_2(v) or from ΔTOA_E1(v) to ΔTOA_E2(v) for signal arrays with extended swath. The excess portion of the unambiguous TOA domain, equal to (FX_OSR – 1) x TOA_Xtnt(v), is referred to as the TOA guard band. The TOA guard band may contain aliased or corrupted data and should be discarded

(7) The FX frequency parameters are for the waveform as observed on the transmit platform. The time dilation/Doppler shift of the received echoes due to platform motion does not modify the FX domain frequency values.

(8) For receiver noise or for signals generated external to the radar, the FX frequency values may not be true values as would be measured at the signal source. To estimate a true frequency value at the signal source, an adjustment must be made for the time dilation/Doppler shift on the signal (if any) relative to the dilation/Doppler shift of the received radar pulse from the SRP. An FX sample value is the true value for any signal whose source has the same time dilation factor as the received radar pulse from the SRP.

Signal vectors in the TOA domain have the following attributes.

(1) The TOA signal vector will ALWAYS have a sample at ΔTOA = 0 which is the peak of the SRP compressed signal response. The TOA vector may or may not have samples at ΔTOA values ΔTOA_1(v), ΔTOA_2(v), ΔTOA_E1(v) or ΔTOA_E2(v).

(2) For a TOA domain vector, the phase the mainlobe of the compressed SRP signal at ΔTOA = 0 is set equal to 0 during the compensation processing.

For the SRP signal at ΔTOA = 0: $\Phi_{ML}^{SRP} = 0$

Note: For error free collection and processing, the phase of the SRP mainlobe at ΔTOA = 0 is set to a constant value that may or may not be precisely zero. The phase of the SRP mainlobe at ΔTOA = 0 is set to the same constant value for all vectors of the signal array.

(3) The TOA Domain Over-Sample Ratio, TOA_OSR(v), for the vector is defined as follows.

$$\text{TOA\_OSR}(v) = \frac{1}{\Delta\text{TOA\_SS}(v) \bullet \text{FX\_BW}(v)}$$

(4) The minimum allowed value for TOA_OSR(v) is 1.10 with a recommended value of TOA_OSR(v) = 1.20 or greater.

Minimum: TOA_OSR = 1.10 Recommended: TOA_OSR ≥ 1.20

(5) The TOA domain vector should include both the mainlobe and sidelobes for all full resolution target of responses formed with FX_BW(v). For full resolution responses, the compressed response is essentially contained in the interval ΔTOA_MLSL(v) centered on the peak of the mainlobe.

$$\Delta\text{TOA\_MLSL}(v) = \text{NTOA\_MLSL} \bullet \frac{1}{\text{FX\_BW}(v)}$$

The minimum allowed value for NTOA_MLSL is 100 with a recommended value NTOA_MLSL = 200 or greater. A value of 100 spans the mainlobe and the first 98 sidelobes the response. For partially eclipsed echoes, if any, there is no guidance provided on the retained response.

Minimum: NTOA_MLSL = 100 Recommended: NTOA_MLSL ≥ 200

(6) The full resolution responses are centered from ΔTOA_1(v) to ΔTOA_2(v). The saved vector should span the following extent in ΔTOA.

Sample s = 0 with sample coordinate ΔTOA(v, 0):

$$\Delta\text{TOA}(v,0) \leq \text{MIN}\left(\Delta\text{TOA\_1}(v) - \frac{1}{2} \bullet \Delta\text{TOA\_MLSL}(v) \text{ , } \Delta\text{TOA\_E1}(v) \right)$$

Sample s = NS - 1 with sample coordinate ΔTOA(v, NS - 1):

$$\Delta\text{TOA(v,NS-1)} \geq \text{MAX}\left(\Delta\text{TOA\_2(v)} + \frac{1}{2}\bullet\Delta\text{TOA\_MLSL(v)}\ ,\ \Delta\text{TOA\_E2(v)} \right)$$

(7) The FX domain vector may be formed from the TOA domain vector via the DFT. The FX domain response will be centered at fx = fx_C(v). The FX domain vector is not required to be formed with a sample at fx = fx_C(v). Forming the FX vector with a sample at fx = fx_C(v) is encouraged.

(8) When forming the FX domain vector, the valid signal content in the FX domain spans the interval from fx_1(v) to fx_2(v). The excess portion of the unambiguous FX domain, equal to (TOA_OSR – 1) x FX_BW(v), is referred to as the FX guard band. Upon transforming to the FX domain, the guard band may contain aliased or corrupted data signal and should be discarded.

For most SAR systems, the collections are executed with a fixed transmitted waveform. The radar receiver operates with a fixed receive bandwidth and a fixed duration receive window. For a given collection, the same pulse length and RF bandwidth are transmitted on all pulses. The same TOA swath (i.e. the same range swath for monostatic imaging) is collected during all receive periods. The compensated PHD signal arrays are formed with a fixed bandwidth for all vectors and parameters fx_1 and fx_2 are constant. The array is also formed with a constant TOA swath that is fixed relative to the SRP. For all vectors, parameters ΔTOA_1 and ΔTOA_2 are constant.

For all data channels, a pair of Boolean parameters is provided in the XML instance that summarize the signal content of the signal array. The parameters provide a simple method for identifying that a given channel was formed with fixed parameters without examining all values of the per vector parameters array. See Table 11-5.

FXFixed — Parameter FXFixed = “true” indicates the signal array is formed with fixed FX domain bandwidth. Parameters fx_1 and fx_2 are constant for all vectors. For arrays with out-of-band noise, parameters fx_N1 and fx_N2 are also constant for all vectors. Parameter FXFixed = “false” otherwise.

TOAFixed — Parameter TOAFixed = “true” indicates the signal array is formed with fixed TOA domain swath. Parameters ΔTOA_1 and ΔTOA _2 are constant for all vectors. For arrays with extended swath, parameters ΔTOA_E1 and ΔTOA _E2 are also constant for all vectors. TOAFixed = “false” otherwise.

4.3 Collection Geometry

The collection geometry for a data channel is specified by the APC positions and the SRP positions provided in the PVP array. The transmit APC positions and velocities are at transmit times {txc(v)} and the receive APC positions and velocities at times $\{trc(v)^{SRP}\}$. Shown in Figure 4-5 is the collection geometry for a given data channel. The example shown is for a bistatic spotlight collection. The signal array was processed with a single fixed point SRP for all signal vectors. The CPHD signal model computes parameters based on the bistatic geometry. The bistatic geometry is handled precisely in the Time of Arrival model and the Signal Phase model. For monostatic collections, the Time of Arrival model may be simplified slightly with no loss in accuracy.

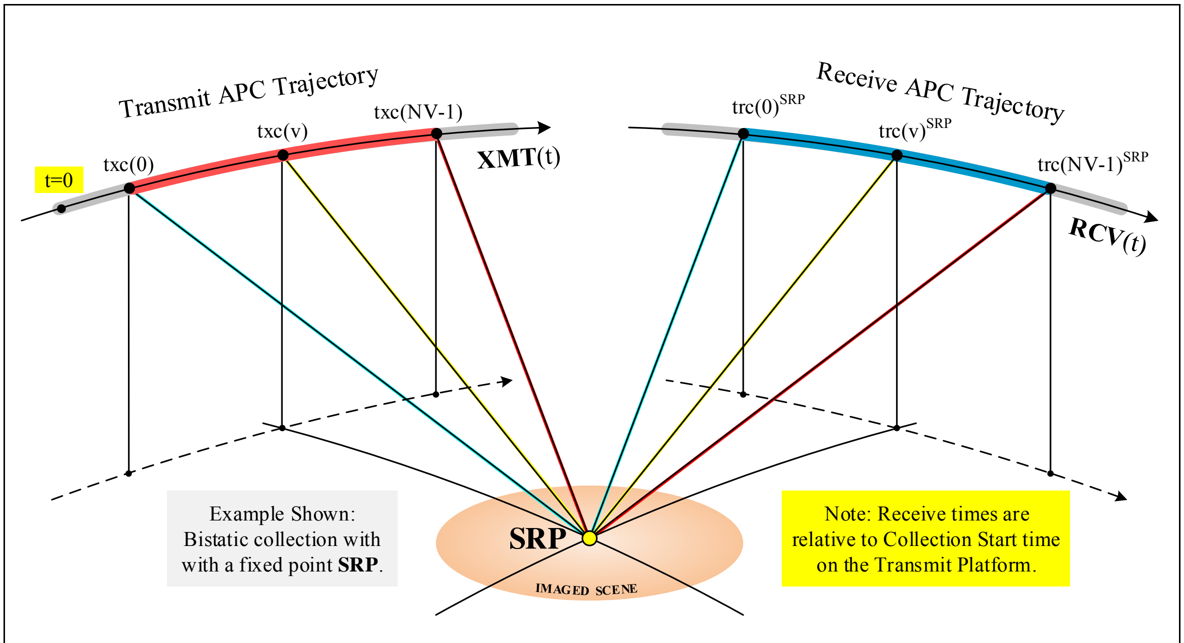


Figure 4-5 Signal Array Collection Geometry
Example bistatic spotlight mode collection geometry for a single CPHD channel.

The signal model is applied to each vector of the signal array. The PVP array specifies the geometry for each vector. Shown in Figure 4-6 is the geometry for a single signal vector. The Transmit APC position and velocity, **Xmt**(v) and **VXmt**(v), are at time txc(v). For the Receive APC position and velocity, **Rcv**(v) and **VRcv**(v), are at time $trc(v)^{SRP}$. For a given echo, the propagation time, T_Prop(v), is defined to be the propagation time for the center of the transmitted pulse. The receive time, trc(v), is defined to be the time the center of the echo is received at the Receive APC. The receive time is also referred to as the Time of Arrival for the echo, TOA(v). For the echo from the SRP, the propagation time is $T\_Prop(v)^{SRP}$ and the receive time is $trc(v)^{SRP}$. The precise times txc(v) and $trc(v)^{SRP}$ are computed as part of the compensation processing.

$$\mathrm{T\_Prop}(v)^{SRP} = \mathrm{trc}(v)^{SRP} - \mathrm{txc}(v) \qquad \underbrace{\mathrm{TOA}(v)^{SRP} = \mathrm{trc}(v)^{SRP} = \mathrm{txc}(v) + \mathrm{T\_Prop}(v)^{SRP}}_{\text{The Time of Arrival (TOA) is the "Receive Time of the Center" of the echo.}}$$

Note: The terms receive time and Time of Arrival both refer to the receive time of the center the echo. Both terms have been used in previous descriptions of the CPHD data structure.

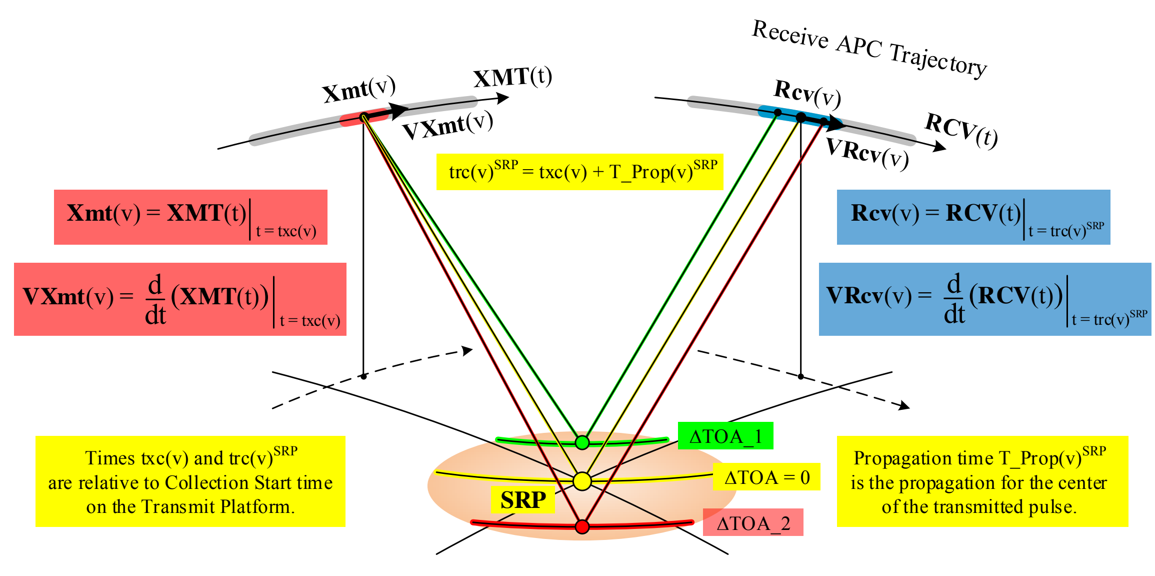


Figure 4-6 Signal Vector Collection Geometry
The collection geometry for a signal vector used to compute signal model parameters.

For the vector geometry shown in Figure 4-6, the signal propagation path is shown for the echoes from the SRP and for two other scene points. Shown in green is an "early" scene point with TOA earlier than the SRP echo. Also shown is a "late" scene point with TOA later than the SRP echo. For each of the points, the locus of points on the scene surface with the same TOA is shown. For a given signal vector, the locus of points with the same TOA is referred to as an iso-TOA contour. For monostatic collections, an iso-TOA contour is typically referred to as an iso-range contour.

The transmit timing and receive timing are shown in Figure 4-7 for the collection geometry shown in Figure 4-6. The timing for the earliest full resolution echo retained is shown in green with receive time $\mathrm{trc}(v)^{TGT1}$. The timing for the latest full resolution echo retained is shown in red with receive time $\mathrm{trc}(v)^{TGT2}$. The Per Vector parameters that describe the saved full resolution TOA swath, ΔTOA_1(v) and ΔTOA_2(v), are also shown and computed as follows.

$$\Delta\mathrm{TOA\_1}(v) = \mathrm{T\_Prop}(v)^{TGT1} - \mathrm{T\_Prop}(v)^{SRP} \qquad \Delta\mathrm{TOA\_2}(v) = \mathrm{T\_Prop}(v)^{TGT2} - \mathrm{T\_Prop}(v)^{SRP}$$

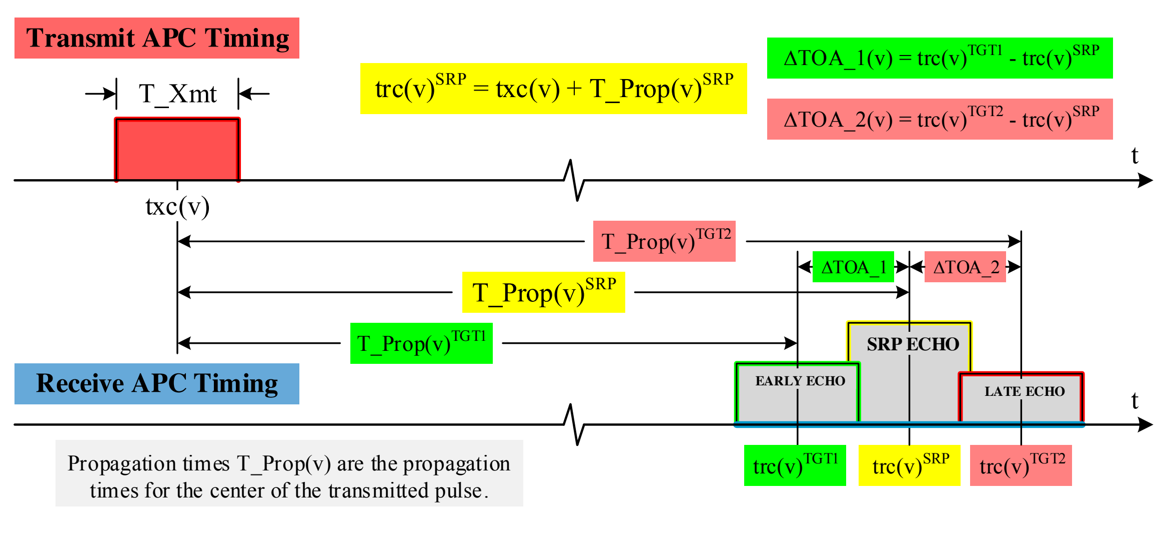


Figure 4-7 Signal Vector Collection Timing

The transmit time and receive timing for the received echoes for a single signal vector.

For the collection geometry shown in Figure 4-6, the range from the SRP to the transmit APC and the range from the SRP to the receive APC may be computed. The ranges are in meters.

$$R\_Xmt(v)^{SRP} = \left|\mathbf{Xmt}(v) - \mathbf{SRP}(v)\right| \qquad R\_Rcv(v)^{SRP} = \left|\mathbf{Rcv}(v) - \mathbf{SRP}(v)\right|$$

For each signal vector, a reference time may be computed. The reference time is approximately equal to the time the center of the transmitted pulse is incident at the SRP position. The reference time, denoted t_Ref(v), is in seconds relative to the start of collection and is computed as shown.

$$t\_Ref(v) = txc(v) + \frac{R\_Xmt(v)^{SRP}}{R\_Xmt(v)^{SRP} + R\_Rcv(v)^{SRP}} \bullet \left(trc(v)^{SRP} - txc(v)\right)$$

For each vector, the reference time is the slow time value associated with the signal vector. For monostatic collections, the reference time may be accurately approximated by the average of the transmit time and the receive time.

4.4 Time of Arrival Model

The Time of Arrival model may be used to compute the precise TOA for the echo from any point in the imaged scene. For a given signal vector, the model first computes the difference in TOA relative to the TOA for the SRP echo. For a point target TGT located at a fixed point in the imaged scene, the difference in Time of Arrival is $\Delta\text{TOA(v)}^{\text{TGT}}$. The TOA for the target echo, $\text{trc(v)}^{\text{TGT}}$, is computed by adding the $\Delta\text{TOA(v)}^{\text{TGT}}$ to the TOA for SRP provided in the PVP set.

$$\text{trc(v)}^{\text{TGT}} = \text{trc(v)}^{\text{SRP}} + \Delta\text{TOA(v)}^{\text{TGT}}$$

For signal vector v, compute the following parameters. All parameters are in ECF coordinates. All positions are in meters and all velocities are in meters/sec. All ranges are in meters and all range rates are in meters/sec.

(1) Compute the range and range rate to the SRP from the transmit APC at time txc(v) and from the receive APC at time $\text{trc(v)}^{\text{SRP}}$. Also, compute the average of the two range rates.

$$\text{R\_Xmt}^{\text{SRP}} = \left|\mathbf{Xmt}(\text{v}) - \mathbf{SRP}(\text{v})\right| \qquad \text{R\_Rcv}^{\text{SRP}} = \left|\mathbf{Rcv}(\text{v}) - \mathbf{SRP}(\text{v})\right|$$

$$\text{Rdot\_Xmt}^{\text{SRP}} = \frac{1}{\text{R\_Xmt}^{\text{SRP}}} \cdot \mathbf{VXmt}(\text{v}) \bullet \left(\mathbf{Xmt}(\text{v}) - \mathbf{SRP}(\text{v})\right)$$

$$\text{Rdot\_Rcv}^{\text{SRP}} = \frac{1}{\text{R\_Rcv}^{\text{SRP}}} \cdot \mathbf{VRcv}(\text{v}) \bullet \left(\mathbf{Rcv}(\text{v}) - \mathbf{SRP}(\text{v})\right)$$

$$\text{Rdot\_Avg}^{\text{SRP}} = \frac{1}{2} \cdot \left(\text{Rdot\_Xmt}^{\text{SRP}} + \text{Rdot\_Rcv}^{\text{SRP}}\right)$$

(2) Compute the range and range rate to the TGT from the transmit APC at time txc(v) and from the receive APC at time $\text{trc(v)}^{\text{SRP}}$. Also, compute the average of the two range rates.

$$\text{R\_Xmt}^{\text{TGT}} = \left|\mathbf{Xmt}(\text{v}) - \mathbf{TGT}(\text{v})\right| \qquad \text{R\_Rcv}^{\text{TGT}} = \left|\mathbf{Rcv}(\text{v}) - \mathbf{TGT}(\text{v})\right|$$

$$\text{Rdot\_Xmt}^{\text{TGT}} = \frac{1}{\text{R\_Xmt}^{\text{TGT}}} \cdot \mathbf{VXmt}(\text{v}) \bullet \left(\mathbf{Xmt}(\text{v}) - \mathbf{TGT}(\text{v})\right)$$

$$\text{Rdot\_Rcv}^{\text{TGT}} = \frac{1}{\text{R\_Rcv}^{\text{TGT}}} \cdot \mathbf{VRcv}(\text{v}) \bullet \left(\mathbf{Rcv}(\text{v}) - \mathbf{TGT}(\text{v})\right)$$

$$\text{Rdot\_Avg}^{\text{TGT}} = \frac{1}{2} \cdot \left(\text{Rdot\_Xmt}^{\text{TGT}} + \text{Rdot\_Rcv}^{\text{TGT}}\right)$$

(3) Compute difference in range to the TGT relative to the range to the SRP for the transmit APC at time txc(v) and for the receive APC at time $trc(v)^{SRP}$. Also, compute the difference in average range rate to the target relative to the average range rate to the SRP.

$$\Delta R\_Xmt^{TGT} = R\_Xmt^{TGT} - R\_Xmt^{SRP} \qquad \Delta R\_Rcv^{TGT} = R\_Rcv^{TGT} - R\_Rcv^{SRP}$$

$$\Delta Rdot\_Avg^{TGT} = Rdot\_Avg^{TGT} - Rdot\_Avg^{SRP}$$

(4) Compute the ΔTOA using the simple model. The simple model assumes the APC positions are fixed relative to the imaged scene (i.e. zero range rates) and the propagation delay due to the troposphere for the target echo is same as troposphere delay to the SRP (i.e. zero differential troposphere delay).

SIMPLE MODEL: $$\Delta TOA_0(v)^{TGT} = \frac{1}{c} \bullet \left(\Delta R\_Xmt^{TGT} + \Delta R\_Rcv^{TGT} \right)$$

$\Delta TOA_0(v)^{TGT}$ – Zero Range Rates & Zero Difference in Troposphere Delay

The precise $\Delta TOA(v)^{TGT}$ for the target is computed starting with the value from the simple model. The precise value is computed by adjusting for the effect of the motion of the receive APC and for the difference in troposphere delay between the target position and the SRP position. Two methods for computing precise $\Delta TOA(v)^{TGT}$ are defined in Steps 5 and 6 below

(5) The motion of receive platform APC between the TOA for the SRP echo and the TOA for the TGT echo is accounted for by the aTOA_VRCV(v) micro parameter. The difference in troposphere delay is accounted using the aTOA_TROPO(v) micro parameter. The troposphere delay micro parameter is precise for scenes that are locally level near the SRP.

PRECISE MODEL:

$$\Delta TOA(v)^{TGT} = \underbrace{\Delta TOA_0(v)^{TGT}}_{\substack{\Delta \text{TOA From The} \\ \text{Simple Model}}} \bullet \underbrace{\left(1 + aTOA\_VRCV(v) + aTOA\_TROPO(v)\right)}_{\substack{\text{Accounts for motion of the Receive APC} \\ \text{and the difference in troposhpere delay relative to the SRP.}}}$$

(6) The difference in troposphere delay may also be computed explicitly using a troposphere delay model. A global value of troposphere refractivity for the imaged scene, N0, is provided with every product. The total troposphere delay for the SRP used in the compensation processing, $TD\_Tropo(v)^{SRP}$, is provided with every signal vector. The troposphere delay may be computed for the transmit path, $TD\_Tropo\_Xmt^{TGT}$, and for the receive path, $TD\_Tropo\_Rcv^{TGT}$. The difference in total delay relative to the SRP echo, ΔTD_Tropo^{TGT}, is then computed. Function TROPO_DELAY is a user-supplied model that computes the one-way troposphere as a function of the collection geometry.

$TD\_Tropo\_Xmt^{TGT}$ = TROPO_DELAY(**Xmt**(v), **TGT**, N0)

$$\text{TD\_Tropo\_Rcv}^{\text{TGT}} = \text{TROPO\_DELAY}(\,\mathbf{Rcv}(\text{v}), \mathbf{TGT}, \text{N0})$$

$$\Delta\text{TD\_Tropo}^{\text{TGT}} = \left(\text{TD\_Tropo\_Xmt}^{\text{TGT}} + \text{TD\_Tropo\_Rcv}^{\text{TGT}}\right) - \text{TD\_Tropo(v)}^{\text{SRP}}$$

The precise $\Delta\text{TOA(v)}^{\text{TGT}}$ is computed as follows.

PRECISE MODEL w/ Alternative Troposphere Delay:

$$\Delta\text{TOA(v)}^{\text{TGT}} = \underbrace{\Delta\text{TOA}_0\text{(v)}^{\text{TGT}}}_{\substack{\Delta\text{TOA From The}\\ \text{Simple Model}}} \bullet \underbrace{\left(1 + \text{aTOA\_VRCV(v)}\right)}_{\substack{\text{Accounts for motion of}\\ \text{the ReceiveAPC}}} + \underbrace{\Delta\text{TD\_Tropo}^{\text{TGT}}}_{\substack{\text{The precise difference in}\\ \text{troposhpere delay.}}}$$

Note: The troposphere delay model, TROPO_DELAY(:, :, :), is not defined as part of the CPHD design standard. The model would be defined as part of the application processor that inputs the CPHD and, for example, forms the SAR image.

(7) The signal from target TGT may or may not be present in the signal vector. To determine if the signal is present, compare $\Delta\text{TOA(v)}^{\text{TGT}}$ to parameters ΔTOA_1(v) and ΔTOA_2(v), and if included in the product, parameters ΔTOA_E1(v) and ΔTOA_E2(v).

For a signal array formed with only the full resolution swath, parameters ΔTOA_E1(v) and ΔTOA_E2(v) are not included. Determine if the target signal is present as follows.

Full Resolution echo is present:

$$\Delta\text{TOA\_1(v)} \le \Delta\text{TOA(v)}^{\text{TGT}} \le \Delta\text{TOA\_2(v)}$$

Signal is NOT present:

$$\Delta\text{TOA(v)}^{\text{TGT}} < \Delta\text{TOA\_1(v)} \quad \text{OR} \quad \Delta\text{TOA\_2(v)} < \Delta\text{TOA(v)}^{\text{TGT}}$$

For a signal array formed with both the full resolution swath and the extended swath, parameters ΔTOA_E1(v) and ΔTOA_E2(v) are included. Determine if the signal is present as follows.

Full Resolution echo is present:

$$\Delta\text{TOA\_1(v)} \le \Delta\text{TOA(v)}^{\text{TGT}} \le \Delta\text{TOA\_2(v)}$$

Partially Eclipsed early echo is present:

$$\Delta\text{TOA\_E1(v)} \le \Delta\text{TOA(v)}^{\text{TGT}} < \Delta\text{TOA\_1(v)}$$

Partially Eclipsed late echo is present:

$$\Delta\text{TOA\_2(v)} < \Delta\text{TOA(v)}^{\text{TGT}} \le \Delta\text{TOA\_E2(v)}$$

Signal is NOT present:

$$\Delta\text{TOA(v)}^{\text{TGT}} < \Delta\text{TOA\_E1(v)} \quad \text{OR} \quad \Delta\text{TOA\_E2(v)} < \Delta\text{TOA(v)}^{\text{TGT}}$$

4.5 Signal Phase Model

The Signal Phase model computes the phase of the TGT signal as a function of the FX domain frequency values. For full resolution echoes, the signal phase is valid on the interval from fx_1(v) to fx_2(v). For partially collected echoes, the signal phase will be valid over portion of the fx band spanned by the partially collected echo. The signal model may also be used to compute the phase of the TOA domain mainlobe response.

$$\text{FX Domain:} \quad \text{fx}(\text{v},\text{s}) = \text{fx\_0}(\text{v}) + \text{fx\_SS}(\text{v}) \bullet \text{s}$$

$$\text{TOA Domain:} \quad \Delta\text{TOA}(\text{v},\text{s}) = \Delta\text{TOA\_0}(\text{v}) + \Delta\text{TOA\_SS}(\text{v}) \bullet \text{s}$$

(1) Compute the signal phase using the simple linear model.

$$\textbf{SIMPLE MODEL:} \quad \Delta\Phi_0(\text{v},\text{s})^{\text{TGT}} = \text{SGN} \bullet \text{fx}(\text{v},\text{s}) \bullet \Delta\text{TOA}(\text{v})^{\text{TGT}}$$

(2) The precise signal phase may be computed using the micro parameters. The aFDOP(v) micro parameter accounts time dilation of the SRP echo due the motion of the phase centers. The aFRR1(v) and aFRR2(v) micro parameters account the difference in time dilation for the TGT echo relative to the SRP echo.

PRECISE MODEL:

$$\Delta\Phi(\text{v},\text{s})^{\text{TGT}} = \underbrace{\Delta\Phi_0(\text{v},\text{s})^{\text{TGT}}}_{\substack{\text{Computed w/ the} \\ \text{simple phase model.}}} \bullet \underbrace{\big(1 + \text{aFDOP}(\text{v})\big)}_{\substack{\text{Accounts for SRP} \\ \text{time dilation/Doppler shift.}}}$$

$$+ \underbrace{\text{SGN} \bullet \text{aFRR1}(\text{v}) \bullet \big(\text{fx}(\text{v},\text{s}) - \text{fx\_C}(\text{v})\big) \bullet \Delta\text{Rdot\_Avg}(\text{v})^{\text{TGT}}}_{\substack{\text{Accounts for the additional Linear Phase due to the} \\ \text{difference in time dilation/Doppler shift of the TGT relative to the SRP.}}}$$

$$+ \underbrace{\text{SGN} \bullet \text{aFRR2}(\text{v}) \bullet \big(\text{fx}(\text{v},\text{s}) - \text{fx\_C}(\text{v})\big)^2 \bullet \Delta\text{Rdot\_Avg}(\text{v})^{\text{TGT}}}_{\substack{\text{Accounts for the additional Quadratic Phase due to the} \\ \text{difference in time dilation/Doppler shift of the TGT relative to the SRP.}}}$$

(3) For a TOA domain signal vector, the phase of the TGT signal mainlobe can be computed for the full resolution echoes. The phase of the center of the TOA domain mainlobe is computed using the precise phase model.

$$\Delta\Phi_{\text{ML}}^{\text{TGT}} = \text{SGN} \bullet \text{fx\_C}(\text{v}) \bullet \big(1 + \text{aFDOP}(\text{v})\big) \bullet \Delta\text{TOA}(\text{v})^{\text{TGT}}$$

(4) For a target with the same average range rate as the SRP, $\Delta\text{Rdot\_Avg}(\text{v})^{\text{TGT}} = 0$, the peak of the mainlobe response will be located at sample location $\text{s\_TOA\_0}(\text{v})^{\text{TGT}}$ that corresponds to the computed value of $\Delta\text{TOA}(\text{v})^{\text{TGT}}$.

$$\text{s\_TOA\_0(v)}^{\text{TGT}} = \frac{1}{\Delta\text{TOA\_SS(v)}} \bullet \left(\Delta\text{TOA(v)}^{\text{TGT}} - \Delta\text{TOA\_0(v)}\right)$$

For a target with $\Delta\text{Rdot\_Avg(v)}^{\text{TGT}} \neq 0$, the peak of the mainlobe response will be located at sample $\text{s\_TOA(v)}^{\text{TGT}}$ that includes a slight shift due to the linear phase versus frequency that is computed using the aFRR1(v) micro parameter. The sample location shift, $\Delta\text{s\_TOA(v)}^{\text{TGT}}$ is computed as shown. Sample location $\text{s\_TOA(v)}^{\text{TGT}}$ is the sum of $\text{s\_TOA\_0(v)}^{\text{TGT}}$ and $\Delta\text{s\_TOA(v)}^{\text{TGT}}$.

$$\text{s\_TOA(v)}^{\text{TGT}} = \text{s\_TOA\_0(v)}^{\text{TGT}} + \bullet \Delta\text{s\_TOA(v)}^{\text{TGT}}$$

$$\Delta\text{s\_TOA(v)}^{\text{TGT}} = \frac{1}{\Delta\text{TOA\_SS(v)}} \bullet \text{aFRR1(v)} \bullet \Delta\text{Rdot\_Avg(v)}^{\text{TGT}}$$

> Note: For an imaging collection for which the PRF is greater than the Doppler extent of the instantaneous footprint, the magnitude of the shift $\Delta\text{s\_TOA(v)}^{\text{TGT}}$ is always less than one quarter times the TOA Nyquist spacing equal to 1/FX_BW(v): $\left|\Delta\text{s\_TOA(v)}^{\text{TGT}}\right| < 0.25 / \text{FX\_BW(v)}$.

4.6 Signal Amplitude

For a given CPHD product, the XML instance may include optional parameters that are used to predict signal amplitude levels for ideal point target scatterers located in the imaged scene. For a given data channel, the parameters that describe the antenna (or pair of antennas) and the per vector geometry are used to predict the variation in signal amplitude level for ideal scatterers. For sensors and processing systems that are power and gain calibrated, absolute signal levels may be predicted by including a reference signal level for each data channel. The method for computing the signal amplitudes for ideal point target scatterers is summarized below.

In description that follows, the signal amplitudes and power values are for signal vectors and signal arrays that have had the per vector amplitude scale factor (if included) applied to the sample values stored in the signal array. The Amp_SF is an optional per vector parameter that may be included in a given product. For a given signal vector, the power values, denoted P_SIG(v,s), are computed as shown. For a product that includes the Amp_SF per vector parameter, the power value is the power after the scale factor is applied. The power values may also be expressed in dB relative to a power value of 1.0.

$$\text{P\_SIG(v,s)} = \underbrace{\left(\text{Amp\_SF(v)}\right)^2}_{\substack{\text{Scale Factor is applied} \\ \text{(if included in the product).}}} \bullet \underbrace{\left(\text{Real}\left(\text{Sig\_Array(v,s)}\right)^2 + \text{Imag}\left(\text{Sig\_Array(v,s)}\right)^2\right)}_{\substack{\text{Sig\_Array(v,s) = Signal array sample value stored in signal array} \\ \text{prior to applying the Amp\_SF(v).}}}$$

$$\text{P\_SIG\_dB(v,s)} = 10 \bullet \log_{10}\left(\text{P\_SIG(v,s)}\right)$$

The compensation processing that forms the signal arrays applies a minimal set of amplitude and gain compensations. For a given signal array, the signal amplitudes for ideal point scatterers will have the following characteristics.

(1) For a given signal vector, an ideal scatterer will have a constant amplitude in the FX domain. The compensation processing may have applied, if necessary, frequency dependent gain compensation. See Figure 4.2.

(2) The effects of receiver gain variation have been compensated. Receiver gain variation across the fast time window or gain variation versus slow time, if any, has been compensated to yield a constant combined receive and processing gain.

(3) The signal power (equal to the amplitude squared) varies with one-way antenna beamshape gain on transmit, G_Xmt, and on receive, G_Rcv. The antenna beamshape gain is unity (i.e. 0 dB) at the mainlobe boresight.

(4) The signal power varies inversely as the square of the range on transmit, $1/\text{R\_Xmt}^2$, and the square of the range on receive, $1/\text{R\_Rcv}^2$.

The signal power for an ideal scatterer will vary with position within the imaged scene and across signal vectors due to the variation in antenna beamshape and range dependent propagation loss. For a given target and a given signal vector, the signal power will vary per the combined geometric gain for the target. The geometric gain expressed in dB is denoted $\text{GG\_dB(v)}^{\text{TGT}}$ and is computed as shown.

$$\text{GG\_dB(v)}^{\text{TGT}} = 10 \bullet \log \left\{ \frac{\text{G\_Xmt(v)}^{\text{TGT}}}{\left(\text{R\_Xmt(v)}^{\text{TGT}}\right)^2} \bullet \frac{\text{G\_Rcv(v)}^{\text{TGT}}}{\left(\text{R\_Rcv(v)}^{\text{TGT}}\right)^2} \right\}$$

For many SAR sensors, a given collection is executed with fixed radar parameters. The same waveform and power level is transmitted on all pulses. The radar receiver operates with a fixed gain during all receive periods. The processing that forms the compensated PHD signal array applies a constant processing gain for all vectors. Gain compensations for antenna beamshape and/or $1/R^4$ propagation loss are not applied. For a given target, the signal power in the initial PHD signal array and in the compensated signal array varies per the combined geometric gain term shown above.

For a given signal array, the reference signal vector is used to determine a reference geometric gain for the data channel. The index of the reference vector is v_CH_REF. The SRP position is **SRP_REF** = **SRP**(v_CH_REF). The reference geometric gain expressed in dB, GG_REF_dB, is computed from the antenna beamshape gains and the ranges from the APC positions.

$$\text{GG\_REF\_dB} = 10 \bullet \log_{10} \left\{ \frac{\text{G\_Xmt(v\_CH\_REF)}^{\text{SRP\_REF}}}{\left(\text{R\_Xmt(v\_CH\_REF)}^{\text{SRP\_REF}}\right)^2} \bullet \frac{\text{G\_Rcv(v\_CH\_REF)}^{\text{SRP\_REF}}}{\left(\text{R\_Rcv(v\_CH\_REF)}^{\text{SRP\_REF}}\right)^2} \right\}$$

For a given target position in the imaged scene, the difference in geometric gain relative to the reference gain for the channel may be computed. For a given signal vector, the target differential geometric gain is $\Delta GG\_dB(v)^{TGT}$.

$$\Delta GG\_dB(v)^{TGT} = GG\_dB(v)^{TGT} - GG\_REF\_dB$$

The variation in signal amplitude is greatest for stripmap mode collections. For a fixed scene point, the received signal level varies as the mainlobe of the antenna(s) scan across the point. Shown in Figure 4-8 is an example stripmap collection geometry and timeline. In the example shown, a single antenna was used on transmit and receive. The antenna was scanned along the centerline of the imaged strip. The compensated signal array was formed from all vectors of the initial PHD signal array. For each signal vector, the SRP position is located on the centerline at the instantaneous antenna aim point. The collection timeline is shown in the upper right portion of the figure. The signal array vector indices (v) and the vector reference times (t_Ref(v)) are shown.

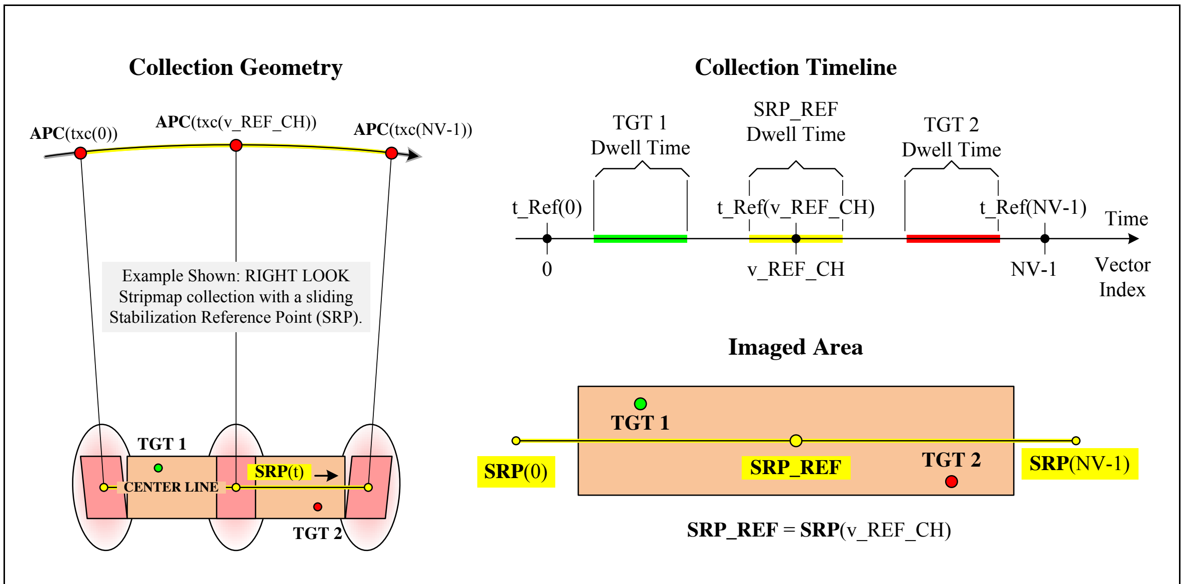


Figure 4-8 Stripmap Geometry & Timeline
The timeline shows the dwell times for the SRP_REF & two example targets.

Shown in Figure 4-8 are three points in the imaged scene: the SRP for the reference vector, SRP_REF, and two example targets, TGT 1 and TGT2. For each of the three scene points, the dwell time is shown on the timeline. The dwell time is the time the PHD is collected that is used to form the SAR image pixel for point. For a given point, the dwell time is typically centered at the time the point receives the maximum illumination from the antenna mainlobe. Shown in Figure 4-9 is a plot of the differential geometric gain for the three points. For the SRP_REF, the differential geometric gain peaks at 0 dB at the reference time for the channel, t_Ref(v_CH_REF). For targets TGT 1 and TGT 2, the peak differential geometric gains are lower due to the slightly lower peak beamshape gain for points off the centerline. For stripmap collections, the variation in geometric gain is primarily due to the variation in antenna beamshape gain as the mainlobe scans across the point.

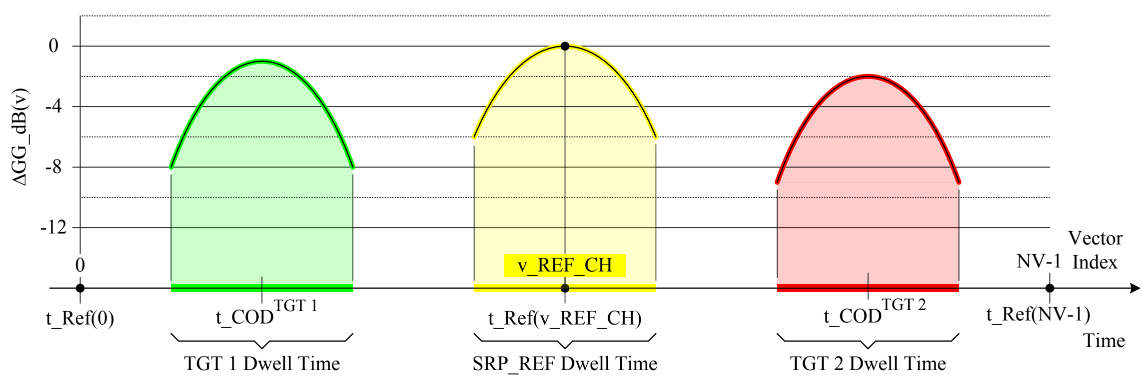


Figure 4-9 Differential Geometric Gain
The example ΔGG_dB(v) plot is shown for the SRP_REF & two example targets.

For SAR sensors and data processing systems that are power and gain calibrated, the compensated PHD signal arrays may be formed such that absolute signal levels may be predicted. For each data channel, a reference power level may be included in the Channel / Parameters branch of the XML instance. See Table 11-5. The reference power level is the predicted power level for an ideal point scatterer with RCS equal to 1.0 square meter (0 dBsm). For a given channel, the reference power level is for the reference vector (v_CH_REF) and for the scatterer located at the SRP_REF = SRP(v_CH_REF) position.

For a given channel, the reference power level is denoted PT_REF. For a signal array in the FX domain, the reference power level is the power at center frequency fx_C(v_CH_REF) and is constant across retained bandwidth FX_BW(v_CH_REF). For a signal array in the TOA domain, the reference power level is the power at the peak of the compressed signal mainlobe at ΔTOA = 0. The reference power level includes all system losses and gains. The reference power level also includes the effects of the two-way propagation loss due to the troposphere.

The reference power level and differential geometric gain may be used to predict the signal levels for a 0 dBsm ideal scatterer located at any point in the imaged scene. For any signal vector for which the full resolution echo from the scene point is present, the signal level may be predicted. For the example collection shown in Figure 4-8, consider a 0 dBsm scatterer located at the TGT 1 scene point. For a given signal vector collected during the TGT 1 dwell time, the signal level is predicted as shown. The predicted signal level is expressed in dB relative to a digital power value of 1.0.

$$\mathrm{PT\_dB}(v)^{TGT1} = 10 \bullet \log_{10}\left(\mathrm{PT\_REF}\right) + \Delta \mathrm{GG\_dB}(v)^{TGT1}$$

4.7 Signal Model Micro Parameters

The method for computing the micro parameters that are used in the precise TOA model and the precise phase model are summarized below. The set of five parameters are included the PVP set for every signal vector. All parameters are dimensionless.

(1) The parameter aTOA_VRCV accounts for the dilation in TOA due to the motion of the receive APC. The micro parameter aTOA_VRCV(v) is computed as follows.

$$\text{aTOA\_VRCV(v)} = +\frac{1}{c}\bullet \text{Rdot\_Rcv}^{\text{SRP}}$$

(2) The micro parameter aTOA_TROPO accounts the difference in two-way delay due to the troposphere. The parameter is based on a locally level scene surface that contains the SRP. The micro parameter aTOA_TROPO(v) is computed as follows.

$$\text{aTOA\_TROPO(v)} = +\frac{2}{c}\bullet\left\{\left.\frac{\partial\left(\text{TD\_Tropo\_Xmt}\right)}{\partial(\text{R\_Xmt})}\right|_{\text{SRP}} + \left.\frac{\partial\left(\text{TD\_Tropo\_Rcv}\right)}{\partial(\text{R\_Rcv})}\right|_{\text{SRP}}\right\}$$

Parameter $\partial(\text{TD\_Tropo\_Xmt})/\partial(\text{R\_Xmt})$ is the change in one-way tropospheric delay per unit change in range for signals that propagate from the transmit APC position to the scene surface measured at the SRP. Parameter $\partial(\text{TD\_Tropo\_Rcv})/\partial(\text{R\_Rcv})$ is the change in one-way tropospheric delay per unit change in range for signals that propagate from the scene surface to the receive APC position measured at the SRP. For a monostatic collection, the variation in delay versus range is essentially the same for all APCs on the platform. The aTOA_TROPO(v) may be computed using twice the variation in one-way delay based on the transmit APC position.

For MONSTATIC collections: $\text{aTOA\_TROPO(v)} = +\frac{4}{c}\bullet\left\{\left.\frac{\partial\left(\text{TD\_Tropo\_Xmt}\right)}{\partial(\text{R\_Xmt})}\right|_{\text{SRP}}\right\}$

(3) The micro parameter aFDOP accounts for the dilation of the received echo from the SRP and for all targets that have the same average range rate as the SRP (i.e. all targets with $\text{Rdot\_Avg}^{\text{TGT}} = \text{Rdot\_Avg}^{\text{SRP}}$). The micro parameter aFDOP(v) is computed as shown.

$$\text{aFDOP(v)} = -\frac{2}{c}\bullet \text{Rdot\_Avg}^{\text{SRP}}$$

(4) The micro parameters aFRR1 and aFRR2 have been developed for systems that use Linear Frequency Modulated (LFM) waveforms. The LFM waveforms are used by most SAR sensors. For a given LFM waveform, the transmitted pulse length is T_Xmt (sec), the center transmit frequency is fx_C (Hz), and the transmitted bandwidth is BW_Xmt (Hz). See Figure 4-2. Let the LFM rate on transmit be fx_Rate (Hz/sec). For the transmitted pulse, the phase versus time, $\Phi_X(t)$, and the instantaneous frequency versus time, fx(t), may be

computed as shown below. Phase $\Phi_X(t)$ is in cycles and frequency fx(t) is in Hertz. The transmit FM rate, fx_Rate, is typically referred to as the chirp rate of the waveform.

$$\text{For } |t| \le \frac{1}{2} \bullet \text{T\_Xmt}: \quad \Phi_X(t) = \text{fx\_C} \bullet t + \frac{1}{2} \bullet \text{fx\_Rate} \bullet t^2$$

$$\text{fx}(t) = \frac{d}{dt}\left(\Phi_X(t)\right) = \text{fx\_C} + \text{fx\_Rate} \bullet t$$

The transmitted bandwidth for the waveform is computed as follows.

$$\text{BW\_Xmt} = |\text{fx\_Rate}| \bullet \text{T\_Xmt}$$

The parameters aFRR1 and aFRR2 account for the differential phase that arises for echoes with different average range rate than SRP. The micro parameters aFRR1(v) and aFRR2(v) are computed as shown.

$$\text{aFRR1}(v) = \text{fx\_C}(v) \bullet \frac{1}{\text{fx\_Rate}} \bullet \frac{2}{c} \qquad \text{aFRR2}(v) = \frac{1}{\text{fx\_Rate}} \bullet \frac{2}{c}$$

For a SAR sensor that does not use a LFM waveform, the difference in phase due to the difference in range rate will be dependent upon the waveform. The terms aFRR1 and aFRR2 may be set equal to zero if they do not provide a correct or improved phase vs. frequency description for FX domain signal vectors.

5 Information Parameters

The parameters that identify radar platform(s) and the image collection are summarized below. The optional information parameter blocks are also described.

5.1 Required Information Parameters

The XML structure includes required nodes that are used to identify the collection and provide releasability information.

5.1.1 Collection Identification Parameters

The CollectionID branch of the XML metadata is used to identify the platform(s) used to perform the collection, identify the unique collection used to form this CPHD product, specify the collection type and mode, and specify the classification and releasability of the contents. The precise structure of this branch is defined in the XML schema and also described in Table 11-1.

The required CollectorName identifies the name of the platform that received the data contained in this CPHD product. The contents of this node should uniquely identify the hardware used. Such a naming technique might use an aircraft tail number and radar payload serial number. To provide consistency and repeatability, the naming technique should be specified in a program specific Product Description Document.

The IlluminatorName is optional and is intended to be used for bistatic collections. As with the CollectorName, this should uniquely identify the hardware used to illuminate the scene as per the PDD.

The required CoreName is a string that uniquely identifies this radar collection. The exact string necessary to accomplish this will vary by system and program and should be specified by a PDD.

The required parameters CollectType and RadarMode / ModeType are enumerations. The following is guidance on which enumerated value to use:

- CollectType
    - “MONOSTATIC” – Platform used to illuminate the scene is same as the platform used to collect the returned echoes
    - “BISTATIC” – Platform used to illuminate the scene is not the same as the platform used to collect the returned echoes
- ModeType
    - “SPOTLIGHT” – Antenna boresight is steered to the same location on the ReferenceSurface throughout the collect
    - “STRIPMAP” – Antenna boresight is maintained at a constant angle off the platform’s velocity vector.
    - “DYNAMIC STRIPMAP” – Antenna boresight does not meet the criteria to be classified as “SPOTLIGHT” or “STRIPMAP”

The optional parameter ModeID can be used to provide additional information on the imaging mode (e.g., “5m Strip”, “1m Spot”, etc).

The required parameters ReleaseInfo and Classification should match the release info and classification provided in the File Header. The contents of these fields will vary based upon the originating organization and should be specified in a program specific Product Description Document.

The optional CountryCode may be used to specify which countries are covered by the radar collection or data included in this CPHD product. This is primarily useful for product discovery.

The optional and repeatable Parameter node may be used to provide any other metadata that that is used in product identification or discovery. The parameter names and contents may be specified in a PDD.

5.2 Optional Information Parameters

The XML structure includes optional nodes that may be used to provide support information for the product, the imaged scene or other related imaging collections.

5.2.1 Product Information Parameters

The optional CPHD / ProductInfo branch of the XML metadata can be used to specify an applicable profile, to describe the processing history of the CPHD metadata and/or signal arrays, or to include user-defined parameters that further describe the CPHD product. The ProductInfo branch is defined in the XML schema and described in Table 11-13. Below we will consider a single radar system and processing chain and how the ProductInfo branch might be used.

The optional Profile node is used to indicate which profile this CPHD product adheres to. A common sensor type and simple processing chain could involve two or more profiles. Shown in Figure 5-1 below is an example collection and processing chain for a step chirp radar system.

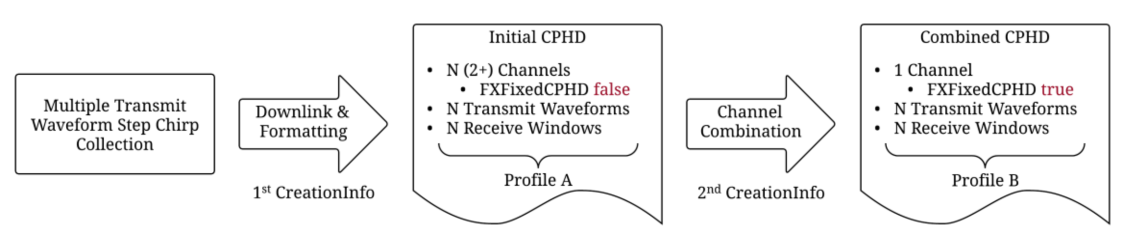


Figure 5-1 Processing Chain

Diagram showing processing chain with multiple profiles & creation info.

The initial and combined CPHD products clearly have different characteristics, the most significant of which is multi vs single channel. Profile A defines the initial multichannel CPHD product from this sensor by placing further restrictions on the CPHD specification. This would involve defining the contents of some XML nodes (such as FXFixedCPHD = false), restrictions on others (NumCPHDChannels > 2), and which optional parameters (such as support arrays and XML nodes/branches) are be included in the product. Profile B would restrict the CPHD specification in a different way (FXFixedCPHD = true), NumCPHDChannels = 1, etc).

The optional CreationInfo branch provides the ability to document the CPHD product processing chain.

- The initial multi-channel CPHD product would include a CreationInfo branch specifying the Application ("Downlink & Formatting Software V1.0"), DateTime ("2006-09-13T16:12:01.140520Z"), Site ("Ground Station Alpha"). Further repeatable parameters might include the capture hostname, runtime parameters or command line. These additional user-defined parameters, and indeed Profile A itself, would be specified and described in the program specific Product Design Document.
- The combined single-channel CPHD product would include two CreationInfo branches. The 1st would be copied over from the input multi-channel CPHD product. The 2nd would specify the channel combination Application ("Channel Combiner V1.0"), DateTime ("2006-09-13T16:12:21.2015Z"), Site ("Ground Station Alpha"). Additional parameters might include the channel combination technique used and the data-derived amplitude and phase imbalance corrections. Again, these parameters and the rest of Profile B would be specified in the program specific Product Design Document.

The optional and repeatable Parameter node accommodates any other product description that a CPHD product designer might wish to include.

5.2.2 Geographic Information Parameters

The optional CPHD / GeoInfo branch provides the capability to include geographic feature definitions with the CPHD product. The GeoInfo branch can be included inside itself, supporting hierarchical geographic information. The exact structure is defined in the XML schema and further described in Table 11-14.

An airport in the scene might be described in a multi-level GeoInfo tree. A GeoInfo node containing a polygon could be used to specify the airport perimeter. Inside this perimeter, a GeoInfo node consisting of two lines could delineate two runways. Another nested GeoInfo node could indicate the location of the control tower. Below is some sample XML demonstrating the flexibility illustrated by the following example.

```xml
<GeoInfo>
  <Desc name="ID">Airport</Desc>
  <Polygon size="4">
    <Vertex index="1">
      <Lat>0.0</Lat>
      <Lon>0.0</Lon>
    </Vertex>
    <Vertex index="2">
      <Lat>0.1</Lat>
      <Lon>0.0</Lon>
    </Vertex>
    <Vertex index="3">
      <Lat>0.1</Lat>
      <Lon>0.1</Lon>
    </Vertex>
    <Vertex index="4">
      <Lat>0.0</Lat>
      <Lon>0.0</Lon>
    </Vertex>
  </Polygon>
  <GeoInfo>
    <Desc name="ID">Runways</Desc>
    <Line size="2">
      <Endpoint index="1">
        <Lat>0.02</Lat>
        <Lon>0.02</Lon>
      </Endpoint>
      <Endpoint index="2">
        <Lat>0.02</Lat>
        <Lon>0.08</Lon>
      </Endpoint>
    </Line>
    <Line size="2">
      <Endpoint index="1">
        <Lat>0.08</Lat>
        <Lon>0.08</Lon>
      </Endpoint>
      <Endpoint index="2">
        <Lat>0.02</Lat>
        <Lon>0.08</Lon>
      </Endpoint>
    </Line>
    <Line size="2">
      <Endpoint index="1">
        <Lat>0.08</Lat>
        <Lon>0.08</Lon>
      </Endpoint>
      <Endpoint index="2">
        <Lat>0.02</Lat>
        <Lon>0.08</Lon>
      </Endpoint>
    </Line>
  </GeoInfo>
  <GeoInfo>
    <Desc name="ID">Control Tower</Desc>
    <Point>
      <Lat>0.5</Lat>
      <Lon>0.5</Lon>
    </Point>
  </GeoInfo>
</GeoInfo>
```

5.2.3 Matched Collection Parameters

The parameters in the CPHD / MatchInfo XML branch identify other imaging collections that are matched to the current collection. For the MatchInfo parameters, the “current collection” refers to the imaging collection for which the CPHD product was produced. The precise structure of this branch is defined in the XML schema and described in Table 11-15. The use of these parameters is selected as part of the product design and defined by the relevant Product Design Document.

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 MatchType. 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 MatchType. For each MatchType, 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 CurrentIndex. For a matched collection, the sequence index is referred to as the MatchIndex.

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 selected as part of the product design and defined by the relevant Product Design Document.

6 Scene Coordinates & Collection Geometry

The parameters that specify the geographic coordinates of the imaged scene are described in this section. The image area is the portion of the illuminated scene for which a SAR image may be formed from the signal array(s) contained in the CPHD product. The image area is specified as an area on a geolocated surface. The geolocated surface is referred to as the image reference surface. The image reference surface (or reference surface) may be either a plane or a surface of constant height above the WGS 84 reference ellipsoid. The parameters that define the reference surface and image area are contained in SceneCoordinates branch of the XML structure. See Table 11-3.

Image Reference Surface

The Image Area Reference Point (IARP) is a point in the imaged scene that is located on the reference surface. For a given product, the selected reference surface is specified by the choice of unit vectors included in the XML instance. The surface types are referred to as PLANAR and HAE. For a PLANAR surface, the reference surface is a plane that contains the IARP. For a HAE surface, the reference surface is a surface of constant Height Above the Ellipsoid (HAE) that contains the IARP (i.e. the surface of constant HAE equal to the IARP HAE). The IARP and the parameters computed from the IARP position are described in Section 6.1

For all products, the Image Area Coordinate (IAC) system is a three-dimensional coordinate system that is used to locate points in the imaged scene. The origin of the coordinate system is the IARP. The image area coordinates are (IAX, IAY, IAZ) and are expressed in units of meters unless otherwise noted. For points on the reference surface, the image coordinate IAZ = 0 and image coordinates IAX and IAY specify displacements relative to the IARP. For any point, image coordinate IAZ is the distance from the surface to the point and is measured along a normal to the reference surface. For points above (below) the surface, the IAZ coordinate is positive (negative). The method for specifying the image reference surface and the IAC coordinates is described in Section 6.2.

Image Area

The Image Area is the portion of the scene for which a SAR image may be formed from one or more of the data channels contained in the CPHD product. For a given product, the image area is specified by one or more image area polygons. Each image area polygon defines an area on the image reference surface. For all products, the SceneCoordinates / ImageArea branch specifies an image area polygon that bounds the image area(s) covered by the product. For each data channel, an optional channel-specific image area polygon may be included in the Channel / Parameters branch. The channel-specific image area polygon describes the image area that may be formed from the signal array for the given channel. The parameters that specify the Image Area are described in Section 6.3.

Image Pixel Grid

For many SAR systems, a collection planning and/or setup function determines the parameters needed to execute the imaging collections. For a given collection, the setup function determines the area to be imaged and selects the radar control parameters that are needed. For some SAR systems, the setup function also determines an image pixel grid for the output image products. The image grid is a geo-referenced pixel grid that typically spans the image area covered by the collection. For any product CPHD, an optional set of image grid parameters may be included in the XML instance that describes the product. The image grid parameters are then available to the applications that use the CPHD as input and form the image products. The image grid parameters specify the size and precise location of the image grid. The optional image grid parameters are described in Section 6.4.

Reference Geometry Parameters

For the signal arrays in a given product, the collection geometry is specified by the parameters included in the Per Vector Parameters (PVP) arrays. For every signal vector, the Antenna Phase Center (APC) positions and times define the instantaneous geometry. See Section 2 and Section 4. From the positions and velocities, the instantaneous ranges and range rates may be computed. For all products, a set of reference geometry parameters is provided. The reference geometry parameters are computed from the position and velocity parameters provided for a single signal vector. The selected vector is the reference vector for the reference data channel. See Table 11-5. The reference geometry parameters are a set of derived parameters that are included in the ReferenceGeometry branch of the XML structure. See Table 11-9. The reference geometry parameters are included to provide a simple method to determine the relevant SAR parameters associated with the CPHD product. The reference geometry parameters include the range to the SRP and the Side of Track for the collection. The method for computing the reference geometry parameters is described in Section 6.5.

6.1 Image Area Reference Point

The Image Area Reference Point (IARP) is a point located in the imaged scene. The IARP position is provided in all products. The IARP position in ECF coordinates is **IARP** and in geodetic coordinates is **IARP_LLH**.

$$\mathbf{IARP} = \begin{bmatrix} \text{IARP\_X} \\ \text{IARP\_Y} \\ \text{IARP\_Z} \end{bmatrix} \qquad \mathbf{IARP\_LLH} = \begin{bmatrix} \text{IARP\_Lat} \\ \text{IARP\_Lon} \\ \text{IARP\_HAE} \end{bmatrix}$$

At the IARP, the unit vectors in the east, north and "up" directions are computed from the geodetic latitude and longitude, IARP_Lat and IARP_Lon. Unit vectors **uEAST**, **uNOR** and **uUP** in ECF coordinates are computed as shown below. See Figure 6-1.

$$\mathbf{uEAST} = \begin{bmatrix} -\sin(\text{IARP\_Lon}) \\ \cos(\text{IARP\_Lon}) \\ 0 \end{bmatrix} \qquad \mathbf{uNOR} = \begin{bmatrix} -\sin(\text{IARP\_Lat})\bullet\cos(\text{IARP\_Lon}) \\ -\sin(\text{IARP\_Lat})\bullet\sin(\text{IARP\_Lon}) \\ \cos(\text{IARP\_Lat}) \end{bmatrix}$$

$$\mathbf{uUP} = \begin{bmatrix} \cos(\text{IARP\_Lat})\bullet\cos(\text{IARP\_Lon}) \\ \cos(\text{IARP\_Lat})\bullet\sin(\text{IARP\_Lon}) \\ \sin(\text{IARP\_Lat}) \end{bmatrix}$$

Unit vector **uUP** is normal to the surface of constant HAE at the IARP. Unit vectors **uEAST** and **uNOR** lie in the plane that is tangent to the surface of constant HAE at the IARP. The IARP position is used to define the reference surface and the IAC coordinate frame.

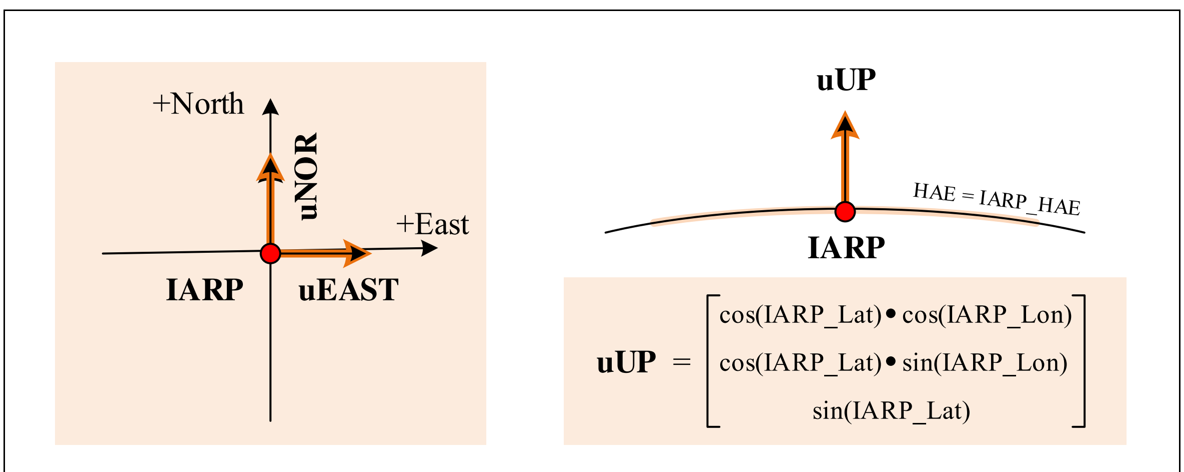


Figure 6-1 Image Area Reference Point
Unit vectors uEAST, uNOR and uUP are defined at the IARP in ECF coordinates.

For the IARP position displaced from both the north and south poles (i.e. -90 degrees < IARP_Lat < +90 degrees), the position for points near the IARP and on the surface of constant HAE = IARP_HAE may be expressed as an increment in latitude and longitude relative to the IARP latitude and longitude. For a displacement of ΔDist_E = 1.0 meter east from the IARP, the increment in longitude is ΔLon_E. The increment in longitude ΔLon_E is computed as follows. Distance IARP_XY is in meters. Increment ΔLon_E is in radians per meter.

$$\text{IARP\_XY} = \left(\text{IARP\_X}^2 + \text{IARP\_Y}^2\right)^{1/2} \qquad \Delta\text{Lon\_E} = \frac{1}{\text{IARP\_XY}}$$

For a displacement of ΔDist_N = 1.0 meter north from the IARP, increment in latitude is ΔLat_N. The increment in latitude ΔLat_N is approximated as follows. The position of scene point N1 is computed in ECF coordinates and converted to geodetic coordinates. Latitudes IARP_Lat and N1_Lat are in radians.

$$\Delta\text{Dist\_N} = 1.0 \qquad \mathbf{N1} = \mathbf{IARP} + \text{Dist\_N}\bullet\mathbf{uNOR}$$

$$\mathbf{N1} = \begin{bmatrix} \text{N1\_X} \\ \text{N1\_Y} \\ \text{N1\_Z} \end{bmatrix} \rightarrow \boxed{\begin{matrix}\text{Transform} \\ \textbf{ECF}\text{ to }\textbf{LLH}\end{matrix}} \rightarrow \mathbf{N1\_LLH} = \begin{bmatrix} \text{N1\_Lat} \\ \text{N1\_Lon} \\ \text{N1\_HAE} \end{bmatrix}$$

$$\Delta\text{Lat\_N} = \frac{1}{\Delta\text{Dist\_N}}\bullet\left(\text{N1\_Lat} - \text{IARP\_Lat}\right)$$

Note: The equation above assumes that latitudes IARP_Lat and N1_Lat are in radians and for all cases: $-\pi/2 <$ IARP_Lat < N1_Lat $< +\pi/2$ and 0 < N1_Lat - IARP_Lat < 0.000,001 radians.

Define vectors **uNOR_LL** and **uEAST_LL** that are the "unit" vectors that scale displacements in east and north from the IARP to displacements in latitude and longitude from the IARP.

$$\mathbf{uEAST\_LL} = \begin{bmatrix} 0 \\ \Delta\text{Lon\_E} \end{bmatrix} \qquad \mathbf{uNOR\_LL} = \begin{bmatrix} \Delta\text{Lat\_N} \\ 0 \end{bmatrix}$$

For a point PT located on the surface of constant HAE = IARP_HAE and displaced ΔPT_E meters east and ΔPT_N meters north of the IARP, the displacement in latitude and longitude from the IARP may be approximated using the vectors **uNOR_LL** and **uEAST_LL**.

$$\mathbf{\Delta PT\_LL} = \begin{bmatrix} \Delta\text{PT\_Lat} \\ \Delta\text{PT\_Lon} \end{bmatrix} = \mathbf{uEAST\_LL}\bullet\Delta\text{PT\_E} + \mathbf{uNOR\_LL}\bullet\Delta\text{PT\_N}$$

6.2 Image Reference Surface

The allowed image reference surface types are PLANAR and HAE. The allowed surface types and the Image Area Coordinate system for surface type are defined below. The reference surface type is specified in the SceneCoordinates node of the XML structure. For the surface type selected in a given product, the IAX and IAY vectors are also specified. See Table 11-3.

Surface Type = PLANAR

For a PLANAR surface, the image reference surface is a plane that contains the IARP. The orientation of the plane is specified by unit vectors **uIAX** and **uIAY** that lie in the plane. The unit vectors are in ECF coordinates. See Figure 6-2. The normal to the plane is **uIAZ** and is computed as shown. The **uIAZ** vector is oriented away from the center of the earth. The slope of the plane at the IARP may not exceed 60 degrees in any direction.

$$\mathbf{uIAZ} = \mathbf{uIAX} \times \mathbf{uIAY} \qquad\qquad \mathbf{uIAZ} \bullet \mathbf{uUP} \geq 0.50$$

For a stripmap collection, the +IAX direction is always oriented in the direction of the scanning footprint as shown in the upper left portion of Figure 6.2. For a planar surface, the IAC frame is the Cartesian coordinate frame with unit basis vectors **uIAX**, **uIAY** and **uIAZ**. Points on the surface have IAZ = 0. For a planar surface, the IAC coordinates IAX and IAY are true distances from the IARP for all points in the scene.

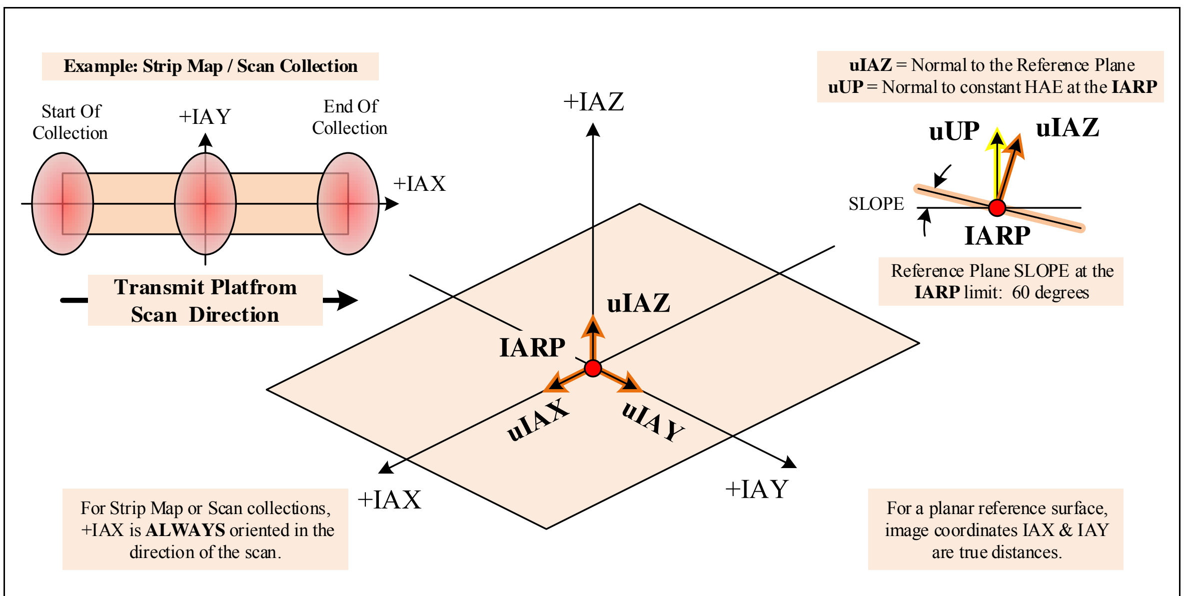


Figure 6-2 Planar Reference Surface
The reference surface is the plane defined by the uIAX and uIAY unit vectors.

For a given point in the scene, let **PT** be the position in ECF coordinates and **PT_IAC** be the position in IAC coordinates. All coordinates are in meters.

$$\text{ECF coordinates: } \mathbf{PT} = \begin{bmatrix} \mathrm{PT\_X} \\ \mathrm{PT\_Y} \\ \mathrm{PT\_Z} \end{bmatrix} \qquad \text{IAC coordinates: } \mathbf{PT\_IAC} = \begin{bmatrix} \mathrm{PT\_IAX} \\ \mathrm{PT\_IAY} \\ \mathrm{PT\_IAZ} \end{bmatrix}$$

For a planar surface type, the conversion between ECF and IAC coordinates is as follows.

ECF to IAC:

$$\begin{aligned} \mathrm{PT\_IAX} &= \mathbf{uIAX} \bullet (\mathbf{PT} - \mathbf{IARP}) \\ \mathrm{PT\_IAY} &= \mathbf{uIAY} \bullet (\mathbf{PT} - \mathbf{IARP}) \\ \mathrm{PT\_IAZ} &= \mathbf{uIAZ} \bullet (\mathbf{PT} - \mathbf{IARP}) \end{aligned}$$

IAC to ECF:

$$\mathbf{PT} = \mathbf{IARP} + \mathrm{PT\_IAX} \bullet \mathbf{uIAX} + \mathrm{PT\_IAY} \bullet \mathbf{uIAY} + \mathrm{PT\_IAZ} \bullet \mathbf{uIAZ}$$

Surface Type = HAE

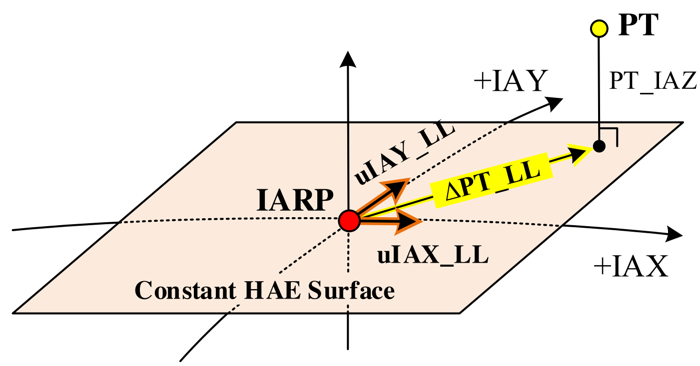
For a HAE surface, the image reference surface is the surface of constant HAE equal to the IARP HAE. Image coordinates IAX and IAY correspond to displacements in latitude and longitude from the IARP. Image coordinate IAZ is the displacement in HAE from the surface. See Figure 6-3. Image coordinates IAX and IAY are used to scale vectors **uIAX_LL** and **uIAY_LL** to compute the displacement in geodetic latitude and longitude.

Unit Vectors

$$\Delta\mathbf{PT\_LL} = \mathbf{uIAX\_LL} \bullet \mathrm{IAX} + \mathbf{uIAY\_LL} \bullet \mathrm{IAY}$$

$$\mathbf{uIAX\_LL} = \begin{bmatrix} \Delta\mathrm{Lat\_IAX} \\ \Delta\mathrm{Lon\_IAX} \end{bmatrix}$$

$$\mathbf{uIAY\_LL} = \begin{bmatrix} \Delta\mathrm{Lat\_IAY} \\ \Delta\mathrm{Lon\_IAY} \end{bmatrix}$$



Vectors **uIAX_LL** & **uIAY_LL** are increments in latitude and longitude for 1.0 meter displacements at the IARP.

Figure 6-3 HAE Reference Surface
The image coordinates IAX and IAY only true distances at the IARP.

For a HAE reference surface, image coordinates IAX and IAY are expressed in meters but represent only approximate distances from the IARP. The vector **uIAX_LL** defines the displacement in latitude and longitude from the IARP in +IAX direction. The vector **uIAY_LL** defines the displacement in latitude and longitude from the IARP in the +IAY direction. The components of the vectors **uIAX_LL** and **uIAY_LL** are in radians per meter. The vectors are referred to as "unit vectors" since they correspond to a displacement of 1.0 meter at the IARP. See Figure 6-4.

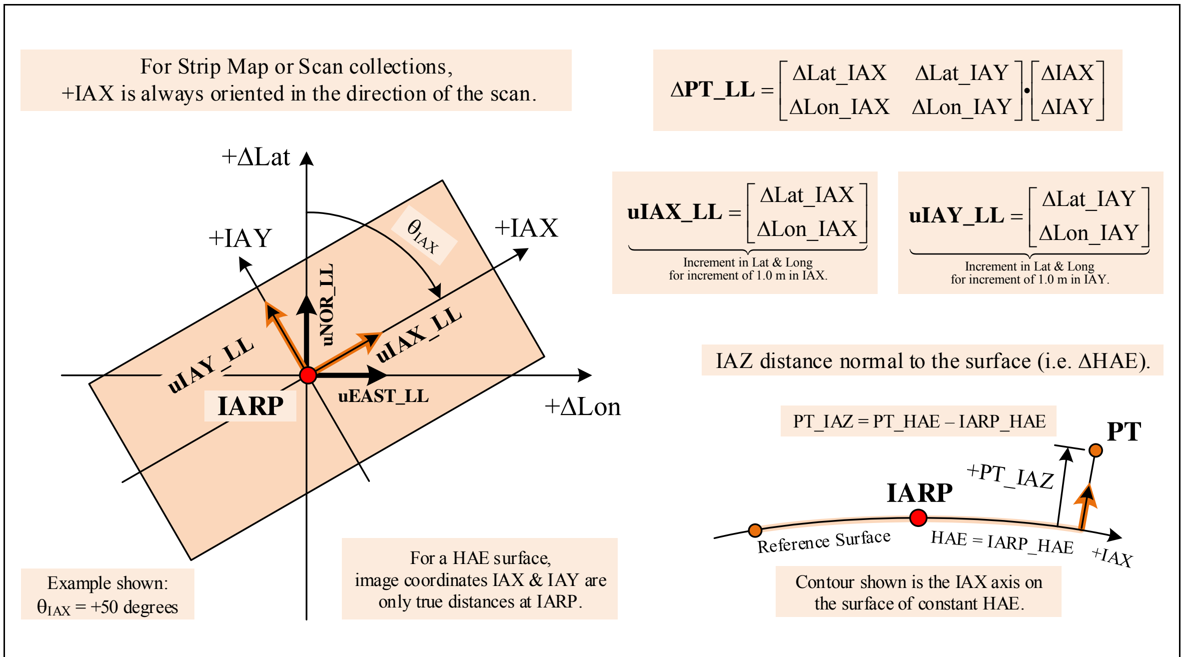


Figure 6-4 IAC Coordinates For HAE Surface
The IAX and IAY are in meters and are approximate distances along the HAE surface.

For a given product, the +IAX direction is determined by selecting the angle θ_{IAX}. Angle θ_{IAX} is the angle from north to the +IAX direction at the IARP. See Figure 6-5. The angle θ_{IAX} is positive from north toward east and may be referred to as the +IAX heading angle. For a stripmap collection, the angle is selected such the +IAX direction is aligned with the direction of the scanning footprint during time the IARP is being illuminated. For a spotlight collection, any orientation for the +IAX direction may be selected. Given the value of θ_{IAX}, vectors **uIAX_LL** and **uIAY_LL** are computed as shown.

$$\mathbf{uIAX\_LL} = \begin{bmatrix} \Delta\text{Lat\_IAX} \\ \Delta\text{Lon\_IAX} \end{bmatrix} = \cos(\theta_{IAX})\bullet\mathbf{uNOR\_LL} + \sin(\theta_{IAX})\bullet\mathbf{uEAST\_LL}$$

$$\mathbf{uIAY\_LL} = \begin{bmatrix} \Delta\text{Lat\_IAY} \\ \Delta\text{Lon\_IAY} \end{bmatrix} = \sin(\theta_{IAX})\bullet\mathbf{uNOR\_LL} - \cos(\theta_{IAX})\bullet\mathbf{uEAST\_LL}$$

The components of **uIAX_LL** and **uIAY_LL** are used to compute the 2 x 2 matrix **T_LL2XY** that is used to convert a displacement in latitude and longitude from the IARP to image coordinates **uIAX_LL** and **uIAY_LL**. The components of T_LL2XY are meters/radian.

$$\mathbf{T\_LL2XY} = \begin{bmatrix} \Delta\text{Lat\_IAX} & \Delta\text{Lat\_IAY} \\ \Delta\text{Lon\_IAX} & \Delta\text{Lon\_IAY} \end{bmatrix}^{-1}$$

Note: By the definitions of unit vectors **uIAX_LL** and **uIAY_LL**, the 2 x 2 matrix formed by concatenating the vectors is always non-singular.

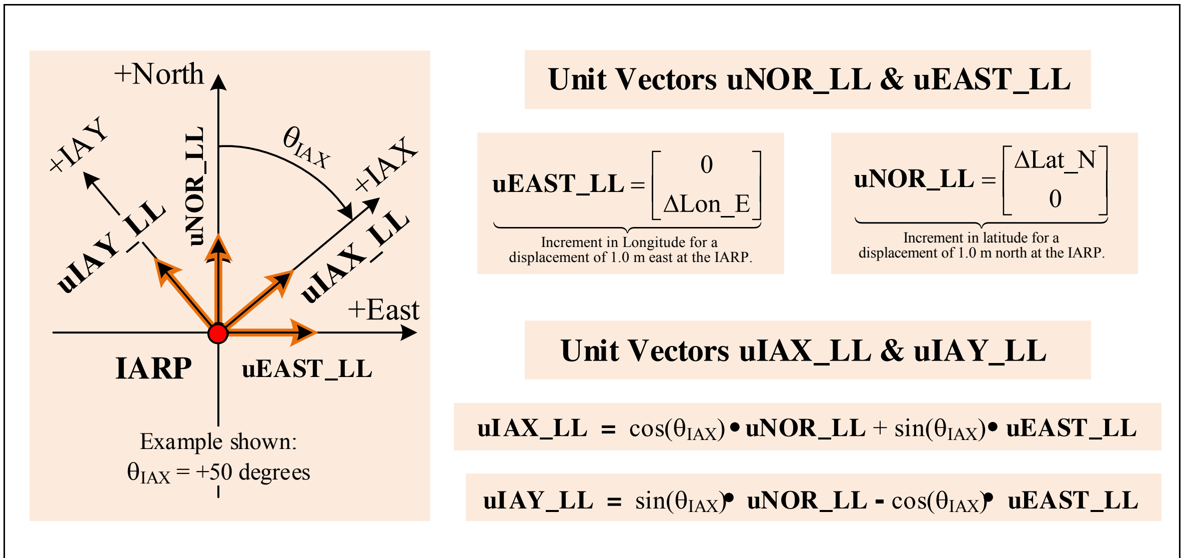


Figure 6-5 Unit Vectors uIAX & uIAY
Unit vectors uIAX and uIAY computed from vectors uNOR and uEAST at the IARP.

For a given point in the scene, let **PT_LLH** be the position in geodetic LLH coordinates and **PT_IAC** be the position in IAC coordinates. Coordinates PT_Lat and PT_Lon are in radians and PT_HAE is in meters. Coordinates IAX, IAY and IAZ are in meters.

$$\text{LLH coordinates: } \mathbf{PT\_LLH} = \begin{bmatrix} \text{PT\_Lat} \\ \text{PT\_Lon} \\ \text{PT\_HAE} \end{bmatrix} \qquad \text{IAC coordinates: } \mathbf{PT\_IAC} = \begin{bmatrix} \text{PT\_IAX} \\ \text{PT\_IAY} \\ \text{PT\_IAZ} \end{bmatrix}$$

For a HAE surface type, the conversion between geodetic LLH coordinates and IAC coordinates is as follows.

LLH to IAC:
$$\begin{bmatrix} \Delta\text{PT\_Lat} \\ \Delta\text{PT\_Lon} \end{bmatrix} = \begin{bmatrix} \text{PT\_Lat} - \text{IARP\_Lat} \\ \text{PT\_Lon} - \text{IARP\_Lon} \end{bmatrix}$$

$$\begin{bmatrix} \text{PT\_IAX} \\ \text{PT\_IAY} \end{bmatrix} = \mathbf{T\_LL2XY} \bullet \begin{bmatrix} \Delta\text{PT\_Lat} \\ \Delta\text{PT\_Lon} \end{bmatrix}$$

$$\text{PT\_IAZ} = \text{PT\_HAE} - \text{IARP\_HAE}$$

IAC to LLH:

$$\begin{bmatrix} \Delta\text{PT\_Lat} \\ \Delta\text{PT\_Lon} \end{bmatrix} = \mathbf{uIAX\_LL} \bullet \text{PT\_IAX} + \mathbf{uIAY\_LL} \bullet \text{PT\_IAY}$$

$$\mathbf{PT\_LLH} = \begin{bmatrix} \text{PT\_Lat} \\ \text{PT\_Lon} \\ \text{PT\_HAE} \end{bmatrix} = \mathbf{IARP\_LLH} + \begin{bmatrix} \Delta\text{PT\_Lat} \\ \Delta\text{PT\_Lon} \\ \text{PT\_IAZ} \end{bmatrix}$$

For a given CPHD product, the reference surface type is a product design choice. For an HAE reference surface, the IAC coordinates are defined such that they represent useful approximations to the true distances across the imaged scene. They are also defined such that for the imaged scene, the contours of constant IAX are approximately perpendicular to the contours of constant IAY. For a given imaged scene, the distortion in the IAX and IAY coordinates will be dependent upon the latitude of the IARP and size of the imaged scene. The use of the HAE surface for large scenes located near the north or south poles should be carefully considered. The HAE surface should not be used when the imaged area includes the point at 90 S latitude or the point at 90 N latitude.

6.3 Image Area

The image area is the portion of the imaged scene for which a full aperture SAR image can be formed. For a CPHD product containing multiple data channels, the image area is the area for which a full aperture image can be formed for one or more of the data channels in the product. See Section 7.4 for a description of the full aperture SAR image. For a given product, the image area is specified by one or more image area polygons. Each image area polygon defines an area on the image reference surface. For a given product, the image area is defined using one of two methods. The image area may be defined by a single image area polygon that is supported by all data channels or it may be defined separately for each data channel in the product.

For all products, the SceneCoordinates / ImageArea branch of the XML structure is included and defines the scene image area polygon. See Table 11-3. When all data channels support the scene image area, then only the scene image area polygon is included in the XML instance that describes the product. For products that contain a single data channel, the image area is always equal to the scene image area.

For a CPHD product that contains multiple data channels, the image area may be specified separately for each channel. For each data channel, the optional Channel / Parameters / ImageArea branch of the XML structure is included. See Table 11-5. For each channel, the specified image area is referred to as the channel image area and is the area supported by the data channel. The channel image areas may be unique for each data channel or may define overlapping areas that are supported by multiple channels. For a given product, the scene image area polygon may or may not be fully covered by the set of channel image area polygons.

The scene image area polygon is defined by a rectangle that is aligned with the image area coordinates IAX and IAY. The image area polygon parameters may also include an optional set of polygon vertices defining an area that is bounded by the rectangle. The optional vertices are specified in image area coordinates (IAX, IAY). Shown in Figure 6-6 is an example scene image area polygon that is a rectangle in the (IAX, IAY) space (the optional polygon parameters were omitted). Shown in Figure 6-7 is an example scene image area polygon that includes the bounding area rectangle and a set of 6 Image Area Vertices (IAVs).

For all products, a set of four Image Area Corner Point (IACP) positions are included. The IACP positions correspond to the corner points of the scene image area rectangle. The IACP positions are located on the image reference surface and are specified in geodetic latitude and longitude. The IACP positions are provided to support, for example, applications that query the product metadata and show the image area on a viewable display such as a digital globe. The IACPs are not intended for precise computations. As shown in Figure 6-7, the IACPs are the corner points of the scene image area rectangle even when the optional polygon vertices are included.

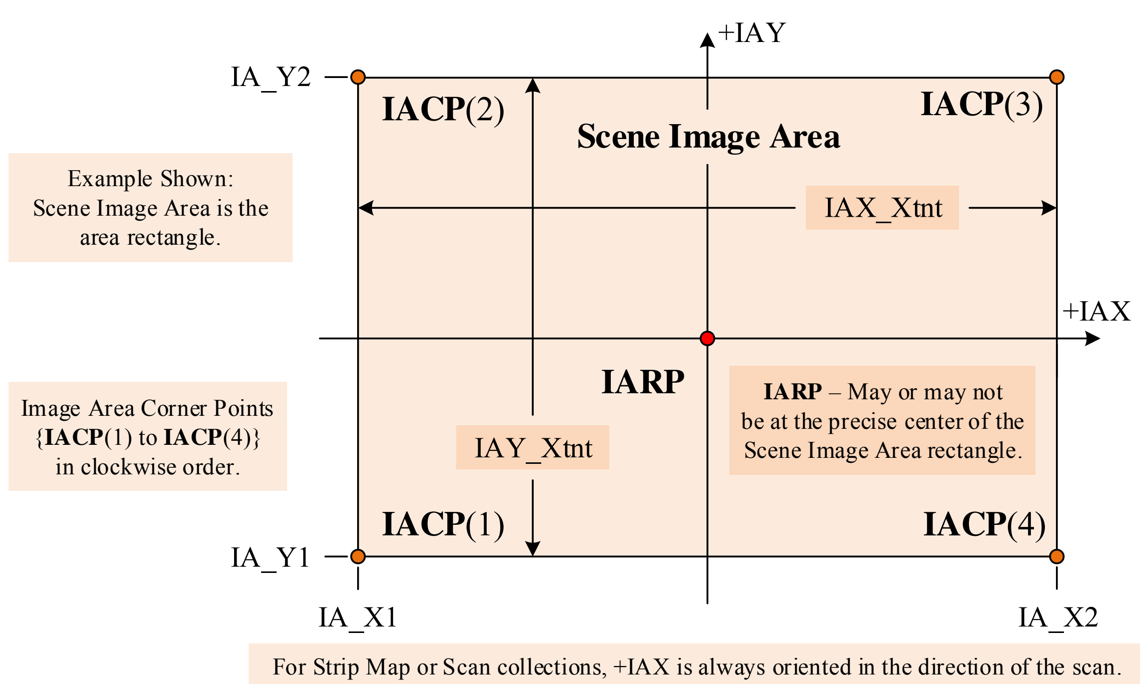


Figure 6-6 Scene Image Area
Example Scene Image Area that is a rectangle aligned with the IAX, IAY coordinates.

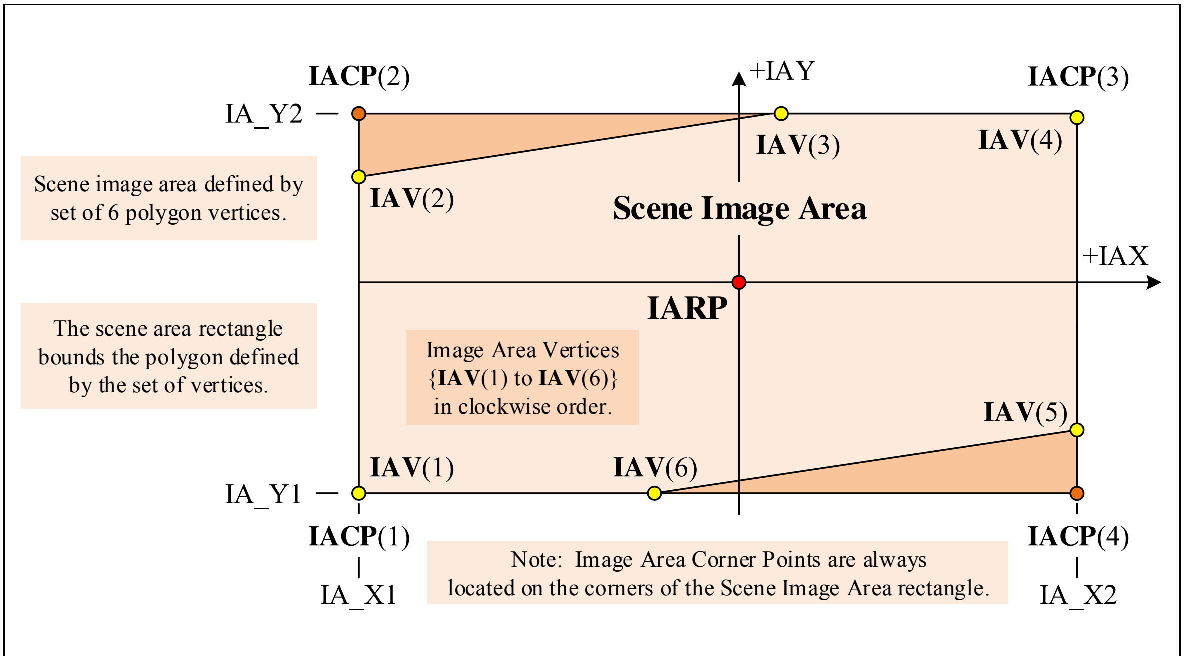


Figure 6-7 Scene Image Area Polygon
Example Scene Image Area that includes the optional polygon vertices..

For a product for which the image area is defined separately for each data channel, the scene image area rectangle is the minimal bounding rectangle for the set of image areas specified for the data channels. Shown in Figure 6-8 is an example product that includes three data channels. The image area for each data channel is a rectangle area aligned with the IAX and IAY coordinates. The IACP positions are the corners of the scene image area rectangle.

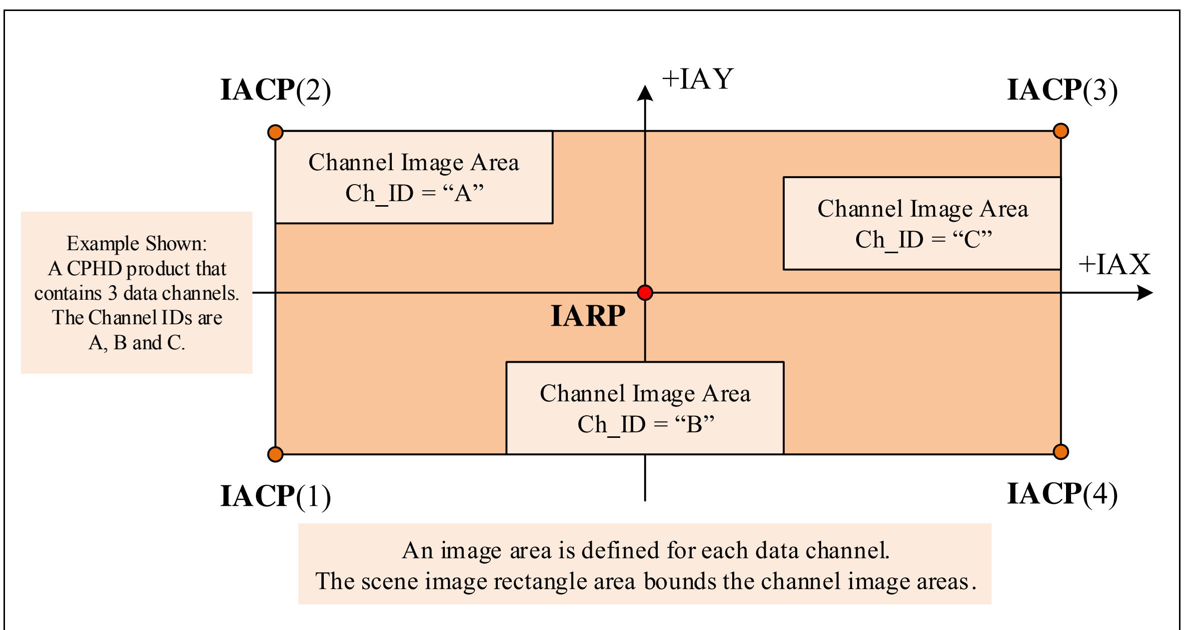


Figure 6-8 Channel Specific Image Areas
Example product for which the image area is defined for each data channel.

For all SAR sensors, the collected PHD signal arrays include the echoes from both the intended full resolution image area as well as the surrounding area. The compensation processing will often retain the received signals from the area surrounding the specified full aperture image area. The optional SceneCoordinates / ExtendedImageArea branch may be included to describe the additional image area that has been retained when forming the signal array(s). Shown in Figure 6-9 is an example of an extended area polygon. For the example shown, the extended area polygon is a rectangle aligned with the IAX and IAY axes.

For the extended area outside the full resolution area, the SAR images may be of degraded quality and/or reduced resolution. The expected use of the extended area polygon is for CPHD products that include signal arrays formed with extended TOA swaths. The extended TOA swath includes the partially eclipsed signal data in the initial PHD arrays. See Section 4. The use of the extended image area polygon is a product design choice. For a given SAR sensor, the criteria for including the extended area polygon is specified in the Product Design Document.

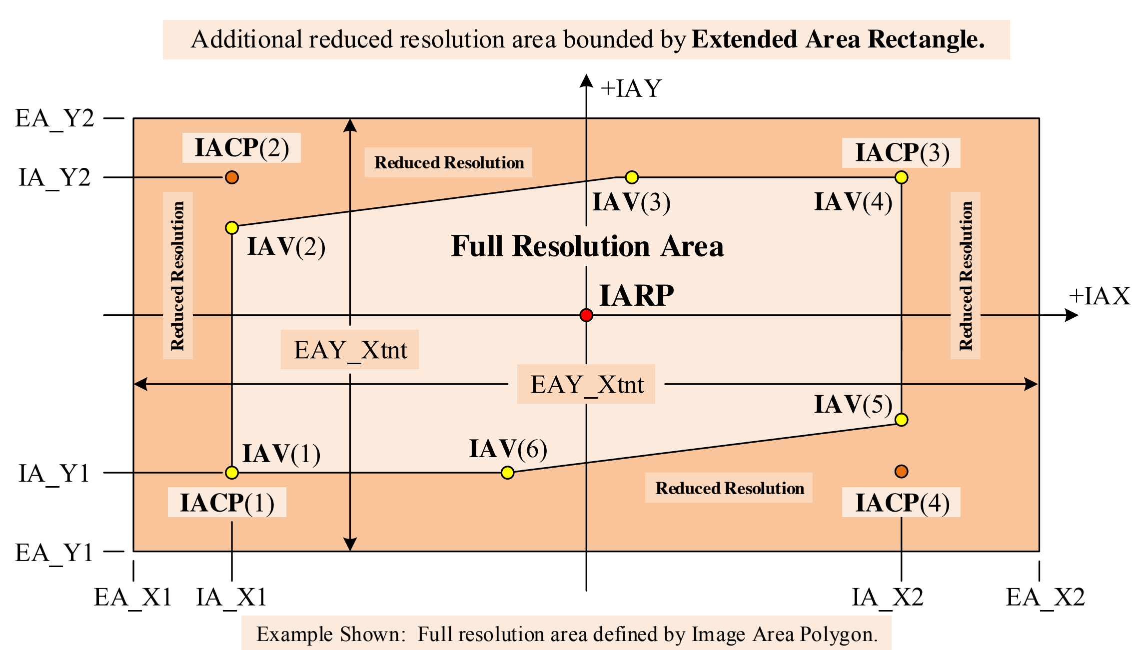


Figure 6-9 Extended Area Rectangle
The extended image area is provided to indicate the excess area covered in the product.

6.4 Image Grid

For any CPHD product, an optional set of parameters may be included that defines a geo-referenced image pixel grid. The pixel grid is for the image products that may be formed from the signal array(s) contained in the product. The image grid parameters are included in the SceneCoordinates / ImageGrid branch of the XML instance that describes the product.

See Table 11-3. A geo-referenced grid is a grid for which the precise geolocation of all grid points is determined using only the grid parameters. Such a grid is commonly used for the human-viewable image products.

The image grid is a two-dimensional grid that spans a rectangular area on the image reference surface. The image grid locations are indexed by line and sample. The size of the image grid is NL_IG lines by NS_IG samples. See Figure 6-10. The NL_IG lines are indexed by L = IG_L1 to IG_L2. The NS_IG samples are indexed by S = IG_S1 to IG_S2. Parameters NL_IG, NS_IG, IG_L1 and IG_S1 are specified using the XML nodes shown below. Parameters IG_L2 and IG_S2 are computed as shown.

NL_IG	=	XML: NumLines	NS_IG	=	XML: NumSamples
IG_L1	=	XML: FirstLine	IG_S1	=	XML: FirstSample
IG_L2	=	IG_L1 + NL_IG – 1	IG_S2	=	IG_S1 + NS_IG – 1

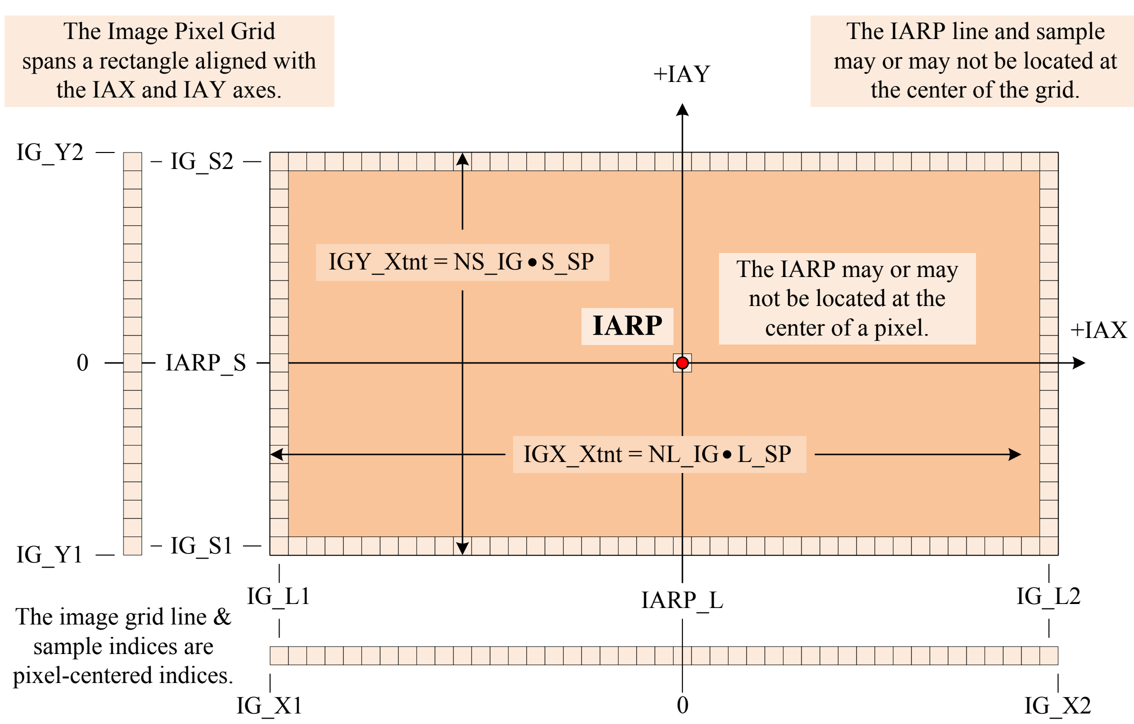


Figure 6-10 Image Display Grid
The image display grid spans a rectangular area on the image reference surface.

The image grid is aligned with the IAX and IAY axes of the image area coordinate system. The increasing line direction corresponds to the increasing IAX coordinate. The increasing sample direction corresponds to the increasing IAY coordinate. The image grid positions on the image reference surface are specified using the XML nodes shown below.

IARP_L	=	XML: IARPLocation/Line	NS_IG	=	XML: IARPLocation/Samp
L_SP	=	XML: LineSpacing (m)	S_SP	=	XML: SampleSpacing (m)

For image grid location (L, S), the corresponding position on the image reference surface is computed as shown. Image area coordinates IAX(L) and IAY(S) are in meters.

$$\mathrm{IAX(L)} = \mathrm{L\_SP} \bullet \left(\mathrm{L} - \mathrm{IARP\_L}\right) \qquad \mathrm{IAY(S)} = \mathrm{S\_SP} \bullet \left(\mathrm{S} - \mathrm{IARP\_S}\right)$$

The image grid indices L and S are pixel-centered indices. For a grid location with integer-valued line and sample indices, the computed position (IAX(L), IAY(S)) corresponds to the center of the pixel. The IARP image grid indices IARP_L and IARP_S are real-valued parameters that are not restricted to integer values. Hence, the IARP may or may not be located at the center of a pixel.

The set of NL_IG lines span a distance of IGX_Xtnt in IAX dimension. The set of NS_IG samples span a distance of IGY_Xtnt in IAY dimension. The limits of the rectangle in IAX are IG_X1 and IG_X2. The limits of the rectangle in IAY are IG_Y1 and IG_Y2. See Figure 6-10. All image area coordinate parameters are in meters.

$$\mathrm{IGX\_Xtnt} = \mathrm{L\_SP} \bullet \mathrm{NL\_IG} \qquad \mathrm{IGY\_Xtnt} = \mathrm{S\_SP} \bullet \mathrm{NS\_IG}$$

$$\mathrm{IG\_X1} = \mathrm{L\_SP} \bullet \left(\mathrm{L1} - 0.5 - \mathrm{IARP\_L}\right) \qquad \mathrm{IG\_Y1} = \mathrm{S\_SP} \bullet \left(\mathrm{S1} - 0.5 - \mathrm{IARP\_S}\right)$$

$$\mathrm{IG\_X2} = \mathrm{L\_SP} \bullet \left(\mathrm{L2} + 0.5 - \mathrm{IARP\_L}\right) \qquad \mathrm{IG\_Y2} = \mathrm{S\_SP} \bullet \left(\mathrm{S2} + 0.5 - \mathrm{IARP\_S}\right)$$

For a given product, the image grid parameters are selected per the following guidance. The intent to provide a minimal set of restrictions for the SAR sensors and data processing systems that choose to include them.

(1) The number lines NL_IG and the number of samples NS_IG are restricted to positive integer values. For all products: IG_L1 ≤ IG_L2 and IG_S1 ≤ IG_S2.

(2) The line and sample index values are not restricted. Index values for line or sample may be negative, positive or zero.

(3) The line spacing L_SP and the sample spacing S_SP are restricted to positive values. The values for the two spacings may or may not be equal.

(4) The rectangular area spanned by the image grid is not required to include the IARP position.

(5) The rectangular area spanned by the image grid is not required to match the scene image area rectangle or the image area supported by the product.

6.5 Reference Geometry Parameters

For all products, a set of reference geometry parameters is provided that describes the imaging geometry for the collection. The reference geometry parameters are computed from the position and velocity parameters provided for a single signal vector. The parameter set includes common SAR imaging parameters that describe the collection geometry (e.g. the slant range to the imaged scene). The parameters are provided to enable direct search and discovery of CPHD products based upon common SAR geometry parameters via a query of the XML instance.

The reference geometry parameters are included in the ReferenceGeometry branch of the XML structure. See Table 11-9. The parameters provided are dependent upon the Collect Type (i.e. monostatic or bistatic). For a product monostatic collection, the parameter set describes the geometry for the one SAR platform relative to the imaged scene. For a bistatic collection, the parameter set describes the bistatic geometry for the two SAR platforms relative to the imaged scene and relative to each other.

6.5.1 Reference Vector Parameters

The reference geometry parameters are computed for the reference vector of the reference data channel. The reference channel ID and the reference vector index (v_CH_REF) are specified in the Channel branch of the XML instance. See Table 11-5. The reference geometry parameters are computed from the positions and velocities included in the set of per vector parameters provided for the reference vector. The times are in seconds from collection start. The positions and velocities are in ECF coordinates. The postions are in meters and velocities in meters/sec.

txc	Transmit Time (PVP: TxTime(v_CH_REF))
Xmt	Transmit APC Position at txc (PVP: TxPos(v_CH_REF))
VXmt	Transmit APC Velocity at txc (PVP: TxVel(v_CH_REF))
trc_SRP	Receive Time for the SRP Echo (PVP: RcvTime(v_CH_REF))
Rcv	Receive APC Position (PVP: RcvPos(v_CH_REF))
VRcv	Transmit APC Velocity (PVP: TxVel(v_CH_REF))
SRP	SRP Position (PVP: SRPPos(v_CH_REF))

For the reference channel, the COD Time polynomial and the Dwell Time polynomial are specified by the reference channel COD_ID and the Dwell_ID. Let the COD Time and Dwell Time polynomials for the reference channel be represented by the following notation. The polynomials yield COD Time and Dwell time as a function of IAC coordinates (IAX, IAY). The times are in seconds from the start of the collection.

$$t\_COD = \underbrace{XY2COD(IAX, IAY)}_{\substack{\text{COD Time polynomial for} \\ \text{the Reference Channel}}} \qquad T\_Dwell = \underbrace{XY2DWELL(IAX, IAY)}_{\substack{\text{Dwell Time polynomial for} \\ \text{the Reference Channel}}}$$

(1) For the SRP position, compute the position in WGS 84 geodetic LLH. Also, compute the position in image area coordinates (IAX, IAY, IAZ). See Section 6.2 for the conversion to IAC coordinates. Image area coordinates are in meters. Parameter SRP_DEC is the SRP distance from the WGS 84 earth center point and is computed in meters.

$$\text{WGS 84 LLH: } \mathbf{SRP\_LLH} = \begin{bmatrix} \text{SRP\_Lat} \\ \text{SRP\_Lon} \\ \text{SRP\_HAE} \end{bmatrix} \qquad \text{IAC: } \mathbf{SRP\_IAC} = \begin{bmatrix} \text{SRP\_IAX} \\ \text{SRP\_IAY} \\ \text{SRP\_IAZ} \end{bmatrix}$$

(2) Compute the distance from the WGS 84 Earth Center (EC) to SRP, SRP_DEC. Also, compute the unit vector pointing from the EC to the SRP, **uEC_SRP**. The distance from the earth center is computed in meters.

$$\text{SRP\_DEC} = |\mathbf{SRP}| \qquad \mathbf{uEC\_SRP} = \frac{1}{\text{SRP\_DEC}} \bullet \mathbf{SRP}$$

(3) Compute the basis vectors for the East, North, Up (ENU) coordinate frame with origin at the SRP. Compute unit vectors **uEAST**, **uNOR** and **uUP** in ECF coordinates as shown below. The plane formed by the **uEAST** and **uNOR** vectors is referred as the Earth Tangent Plane (ETP) at the SRP.

$$\mathbf{uEAST} = \begin{bmatrix} -\sin(\text{SRP\_Lon}) \\ \cos(\text{SRP\_Lon}) \\ 0 \end{bmatrix} \qquad \mathbf{uNOR} = \begin{bmatrix} -\sin(\text{SRP\_Lat}) \bullet \cos(\text{SRP\_Lon}) \\ -\sin(\text{SRP\_Lat}) \bullet \sin(\text{SRP\_Lon}) \\ \cos(\text{SRP\_Lat}) \end{bmatrix}$$

$$\mathbf{uUP} = \begin{bmatrix} \cos(\text{SRP\_Lat}) \bullet \cos(\text{SRP\_Lon}) \\ \cos(\text{SRP\_Lat}) \bullet \sin(\text{SRP\_Lon}) \\ \sin(\text{SRP\_Lat}) \end{bmatrix}$$

(4) Compute the range from the transmit APC to the SRP, R_Xmt_SRP. Also, compute the range from the receive APC to the SRP, R_Rcv_SRP. The ranges are in meters.

$$\text{R\_Xmt\_SRP} = |\mathbf{Xmt} - \mathbf{SRP}| \qquad \text{R\_Rcv\_SRP} = |\mathbf{Rcv} - \mathbf{SRP}|$$

(5) For the signal vector, the reference time, t_Ref, is computed as shown. The reference time is approximately equal to the time the center of the transmitted pulse is incident at the SRP.

$$\text{t\_Ref} = \text{txc} + \frac{\text{R\_Xmt\_SRP}}{\text{R\_Xmt\_SRP} + \text{R\_Rcv\_SRP}} \bullet (\text{trc\_SRP} - \text{txc})$$

(6) For the SRP position projected normal to the image reference surface, compute the COD time, t_COD_SRP, and the dwell time, T_Dwell_SRP supported by the reference data channel. Dwell times are in seconds.

$$\text{t\_COD\_SRP} = \text{XY2COD}(\text{SRP\_IAX}, \text{SRP\_IAY})$$

$$\text{T\_Dwell\_SRP} = \text{XY2DWELL}(\text{SRP\_IAX}, \text{SRP\_IAY})$$

(7) The parameters of the ReferenceGeometry branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

SRP	➔	XML: SRP/ECF	meters
SRP_IAC	➔	XML: SRP/IAC	meters
t_Ref	➔	XML: ReferenceTime	sec
t_COD_SRP	➔	XML: SRPCODTime	sec
T_Dwell_SRP	➔	XML: SRPDwellTime	sec

6.5.2 Reference Geometry: Collect Type = MONOSTATIC

For a monostatic collection, the reference geometry parameters are included in the ReferenceGeometry / Monostatic branch of the XML structure. The monostatic geometry parameters are computed as follows.

(1) Compute the monostatic aperture reference position and velocity, **ARP** and **VARP**, that are used to compute the geometry for the monostatic reference signal vector. See Figure 6-11. The position and velocity are in ECF coordinates. The position is meters and the velocity in meters/sec.

$$\mathbf{ARP} = \frac{1}{2} \bullet (\mathbf{Xmt} + \mathbf{Rcv}) \qquad \mathbf{VARP} = \frac{1}{2} \bullet (\mathbf{VXmt} + \mathbf{VRcv})$$

(2) Compute the parameters for the ARP position relative to the SRP. The parameters to be computed are the range, R_ARP_SRP, the range rate, Rdot_ARP_SRP and the unit vector **uRcv** that points from the SRP to the receive APC position. The range is in meters, the range rate is in meters per second, and the unit vector is in ECF coordinates.

$$\text{R\_ARP\_SRP} = |\mathbf{ARP} - \mathbf{SRP}| \qquad \mathbf{uARP} = \frac{1}{\text{R\_ARP\_SRP}} \bullet (\mathbf{ARP} - \mathbf{SRP})$$

$$\text{Rdot\_ARP\_SRP} = \mathbf{uARP} \bullet \mathbf{VARP}$$

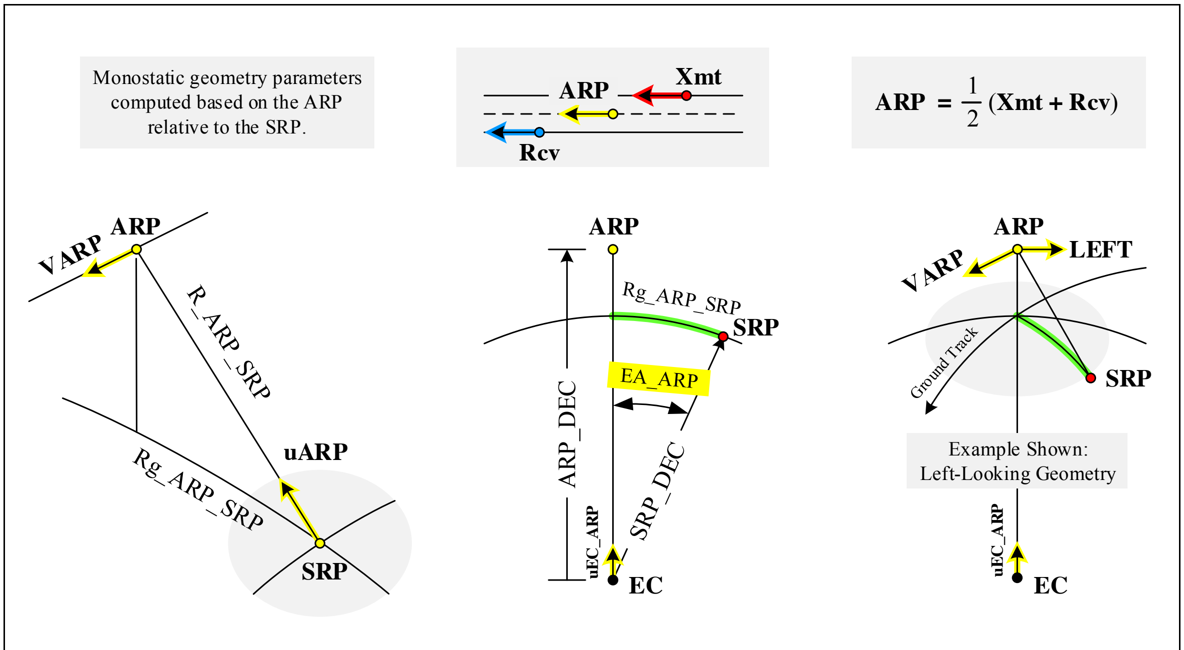


Figure 6-11 Monostatic Reference Geometry
The monostatic geometry parameters are computed from the ARP position and velocity.

(3) Compute the distance from the Earth Center (EC) to ARP, ARP_DEC. Also, compute the unit vector pointing from the EC to the ARP, **uEC_ARP**. The distance from the earth center is in meters. See Figure 6-11.

$$\mathrm{ARP\_DEC} = |\mathbf{ARP}| \qquad\qquad \mathbf{uEC\_ARP} = \frac{1}{\mathrm{ARP\_DEC}} \bullet \mathbf{ARP}$$

(4) The ground range from the ARP to the SRP is the distance measured on the spherical earth model that contains the SRP. Compute the angle between unit vectors **uEC_ARP** and **uEC_SRP**, EA_ARP. Compute the ground range from the ARP to the SRP, Rg_ARP_SRP, as shown. The angle EA_ARP is in radians and the ground range is in meters.

$$\mathrm{EA\_ARP} = \mathrm{acos}\left(\mathbf{uEC\_ARP} \bullet \mathbf{uEC\_SRP}\right)$$

$$\mathrm{Rg\_ARP\_SRP} = \mathrm{SRP\_DEC} \bullet \mathrm{EA\_ARP}$$

(5) Compute the magnitude of the ARP velocity vector, VARP_M. Compute the unit vector **uVARP**. Also, compute the vector **LEFT** that points to the left side of the ARP ground track. Parameter VARP_M is meters/sec.

$$\mathrm{VARP\_M} = |\mathbf{VARP}| \qquad\qquad \mathbf{uVARP} = \frac{1}{\mathrm{VARP\_M}} \bullet \mathbf{VARP}$$

$$\mathbf{LEFT} = \underbrace{\mathbf{uEC\_ARP} \times \mathbf{uVARP}}_{\text{Vector Cross Product}}$$

(6) Determine the side of track for the collection. Set parameter LOOK = +1 for a left-looking collection and LOOK = -1 for a right-looking collection. Also, assign the Side_Of_Track parameter to "L" or "R".

$$\mathrm{LOOK} = \begin{cases} +1, & \mathbf{LEFT} \bullet \mathbf{uARP} < 0 \\ -1, & \text{otherwise} \end{cases} \qquad \mathrm{Side\_Of\_Track} = \begin{cases} \mathrm{L}, & \text{if } \mathrm{LOOK} = +1 \\ \mathrm{R}, & \text{otherwise} \end{cases}$$

(7) Compute the Doppler Cone Angle (DCA) measured from the ARP velocity vector to the line of sight from the ARP to the SRP. The DCA is in degrees on the interval 0 to 180.0

$$\mathrm{DCA} = \underbrace{\cos^{-1}\left(-\frac{\mathrm{Rdot\_ARP\_SRP}}{\mathrm{VARP\_M}}\right)}_{\text{Angle on the interval 0 to 180 degrees.}}$$

(8) Define Ground Plane Coordinates (GPX, GPY, GPZ) with origin at the SRP. The +GPZ axis is normal to the plane and in the direction of increasing HAE (**uGPZ** = **uUP**). The GPX and GPY axes lie in the ETP at the SRP. The +GPX axis is defined by the projection of **uARP** into the plane. The +GPY axis is oriented such the GPC are a right-handed coordinate system. See Figure 6-12. The GPC unit vectors in ECF coordinates (**uGPX**, **uGPY**, **uGPZ**) are computed as follows.

$$\mathbf{uGPZ} = \mathbf{uUP} \qquad \mathbf{GPY} = \underbrace{\mathbf{uUP} \times \mathbf{uARP}}_{\text{Vector Cross Product}} \qquad \mathbf{uGPY} = \frac{1}{|\mathbf{GPY}|} \bullet \mathbf{GPY}$$

$$\mathbf{uGPX} = \underbrace{\mathbf{uGPY} \times \mathbf{uGPZ}}_{\text{Vector Cross Product}}$$

(9) Compute the grazing angle between the line of sight from the ARP to the SRP and the ground plane, GRAZ. Also, compute the incidence angle (INCD). Both angles are in degrees on the interval from 0 to 90 degrees.

$$\mathrm{GRAZ} = \underbrace{\cos^{-1}\left(\mathbf{uARP} \bullet \mathbf{uGPX}\right)}_{\substack{\text{Angle on the interval} \\ \text{0 to 90 degrees.}}} \qquad \mathrm{INCD} = 90 - \mathrm{GRAZ}$$

(10) The azimuth angle is the angle from north to the +GPX axis. Compute the azimuth angle, AZIM, as follows. The azimuth angle is in degrees and is on the interval from 0 $\leq$ AZIM < 360.0. See Figure 6-12.

$$\mathrm{GPX\_N} = \mathbf{uGPX} \bullet \mathbf{uNOR} \qquad \mathrm{GPX\_E} = \mathbf{uGPX} \bullet \mathbf{uEAST}$$

$$\mathrm{AZIM} = \underbrace{\tan^{-1}\left(\mathrm{GPX\_E} / \mathrm{GPX\_N}\right)}_{\text{Four Quadrant ArcTangent (East/North)}}$$

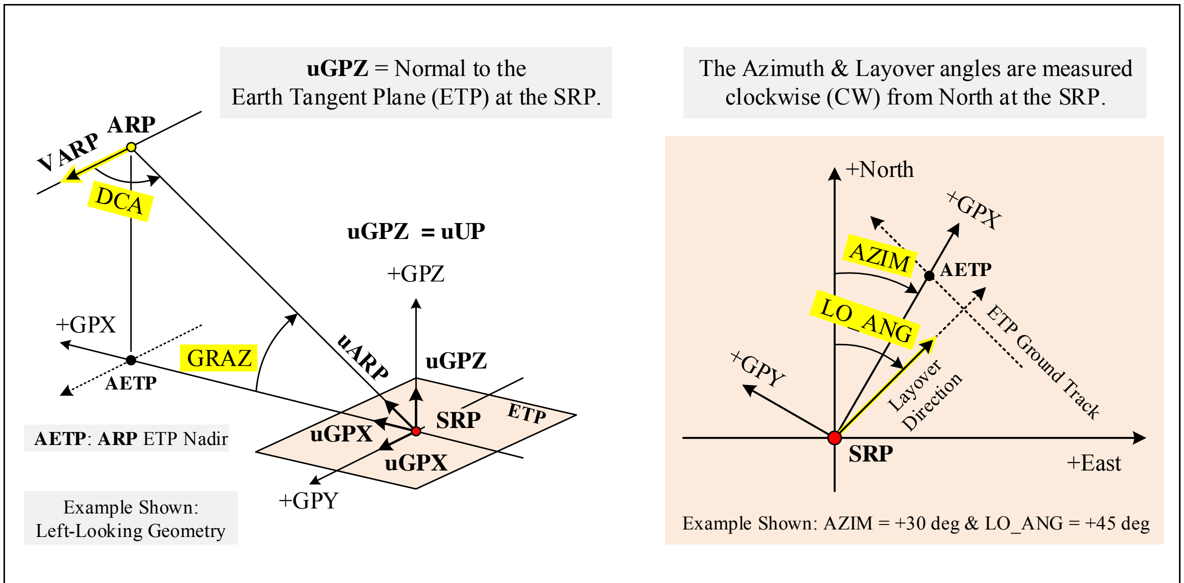


Figure 6-12 Ground Plane Coordinates
The Earth Tangent Plane (ETP) is the plane used to compute the GP coordinates.

(11) The slant plane is the plane defined by the ARP position and velocity and the SRP position. The unit normal to slant plane, **uSPN**, is computed as follows. The slant plane normal is oriented upward (i.e. away from the earth center).

$$\mathbf{SPN} = \mathrm{LOOK} \bullet \underbrace{\mathbf{uARP} \times \mathbf{uVARP}}_{\text{Vector Cross Product}} \qquad \mathbf{uSPN} = \frac{1}{|\mathbf{SPN}|} \bullet \mathbf{SPN}$$

(12) The twist angle is the angle between the cross range direction in slant plane and the cross range direction is ETP. See Figure 6-13. Compute the twist angle, TWST, as follows. The twist angle is on the interval from -90 to 90 degrees.

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

(13) The slope angle is the angle between the slant plane and the ETP. Compute the slope angle, SLOPE, as follows. The slope angle is in degrees on the interval from 0 to 90 degrees.

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

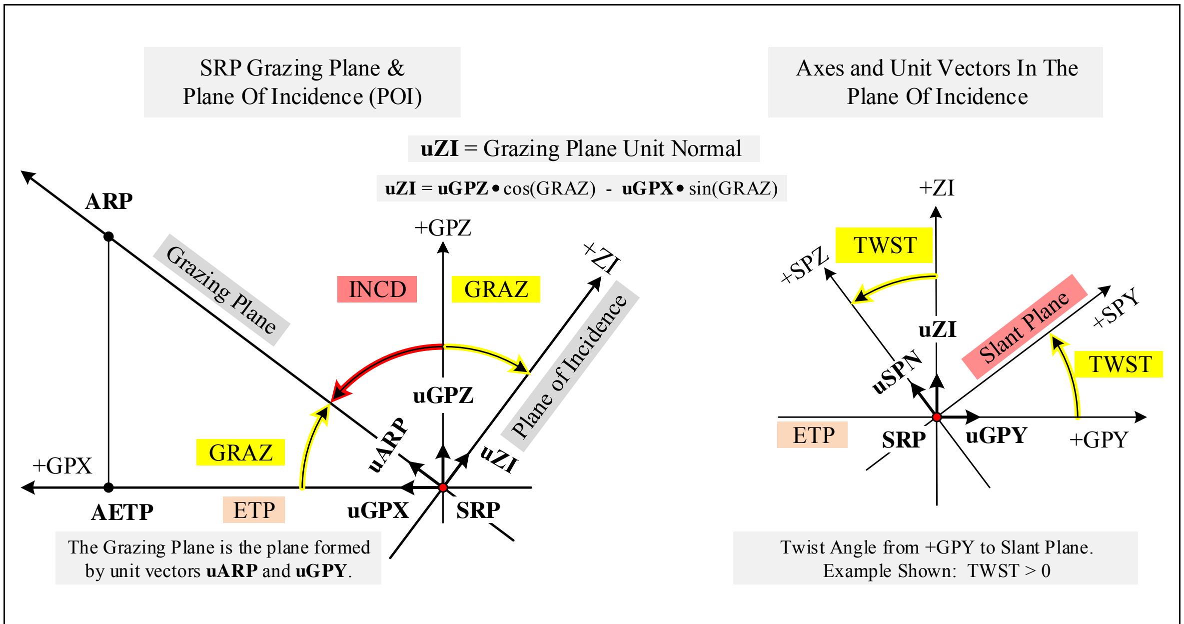


Figure 6-13 Grazing & Twist Angles
The grazing and twist angles are the angles the ETP and slant plane.

(14) The layover direction is the direction that elevated targets will be displaced (or "laid over") in a ground plane image. The layover angle is the angle from north to the layover direction. See Figure 6-12. Compute the layover angle, LO_ANG, as follows. The layover angle is in degrees and is on the interval from $0 \le \text{LO\_ANG} < 360.0$.

$$\text{LODIR\_N} = -\mathbf{uSPN} \bullet \mathbf{uNOR} \qquad \text{LODIR\_E} = -\mathbf{uSPN} \bullet \mathbf{uEAST}$$

$$\text{LO\_ANG} = \underbrace{\tan^{-1}\left(\text{LODIR\_E} \big/ \text{LODIR\_N}\right)}_{\text{Four Quadrant ArcTangent (East/North)}}$$

(15) The parameters of the ReferenceGeometry / Monostatic branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

ARP	➔	XML: ARPPos	meters
VARP	➔	XML: ARPVel	meters/sec
Side_Of_Track	➔	XML: SideOfTrack	
R_ARP_SRP	➔	XML: SlantRange	meters
Rg_ARP_SRP	➔	XML: GroundRange	meters
DCA	➔	XML: DopplerConeAngle	degrees

GRAZ	➔	XML: GrazeAngle	degrees
INCD	➔	XML: IncidenceAngle	degrees
AZIM	➔	XML: AzimuthAngle	degrees
TWST	➔	XML: TwistAngle	degrees
SLOPE	➔	XML: SlopeAngle	degrees
LO_ANG	➔	XML: LayoverAngle	degrees

6.5.3 Reference Geometry: Collect Type = BISTATIC

For a bistatic collection, the reference geometry parameters are included in the ReferenceGeometry / Bistatic branch of the XML structure. The bistatic geometry parameters are computed as described below. The parameters that describe the bistatic imaging geometry are computed from the unit vectors that point from the SRP to the transmit APC and from the SRP to receive APC, **uXmt** and **uRcv**. See Figure 6.14.

(1) Compute the parameters for the transmit APC relative to the SRP. Compute the unit vector that points from the SRP to the transmit APC position, **Xmt**. Compute the range rate of the SRP relative to the transmit position, Rdot_Xmt_SRP. Also, compute the derivative of the unit vector with respect to time, **uXmtDot** = d(**uXmt**)/dt. The unit vector and it derivative are in ECF coordinates. The range rate is in meters per second.

$$\mathbf{uXmt} = \frac{1}{\text{R\_Xmt\_SRP}} \bullet (\mathbf{Xmt} - \mathbf{SRP}) \qquad \text{Rdot\_Xmt\_SRP} = \mathbf{uXmt} \bullet \mathbf{VXmt}$$

$$\mathbf{uXmtDot} = \frac{1}{\text{R\_Xmt\_SRP}} \bullet \underbrace{(\mathbf{VXmt} - \text{Rdot\_Xmt\_SRP} \bullet \mathbf{uXmt})}_{\text{Component of } \mathbf{VXmt} \text{ normal to } \mathbf{uXmt}.}$$

(2) Compute the parameters for the receive APC relative to the SRP. Compute the unit vector that points from the SRP to the receive APC position, **Rcv**. Compute the range rate of the SRP relative to the receive position, Rdot_Rcv_SRP. Also, compute the derivative of the unit vector with respect to time, **uRcvDot** = d(**uRcv**)/dt. The unit vector and it derivative are in ECF coordinates. The range rate is in meters per second.

$$\mathbf{uRcv} = \frac{1}{\text{R\_Rcv\_SRP}} \bullet (\mathbf{Rcv} - \mathbf{SRP}) \qquad \text{Rdot\_Rcv\_SRP} = \mathbf{uRcv} \bullet \mathbf{VRcv}$$

$$\mathbf{uRcvDot} = \frac{1}{\text{R\_Rcv\_SRP}} \bullet \underbrace{(\mathbf{VRcv} - \text{Rdot\_Rcv\_SRP} \bullet \mathbf{uRcv})}_{\text{Component of } \mathbf{VRcv} \text{ normal to } \mathbf{uRcv}.}$$

(3) Compute the bistatic pointing vector, **bP**, as the vector average the unit vectors **uXmt** and **uRcv**. Also, compute the derivative with respect to time of the pointing vector, **bPDot** = d(**bP**)/dt, from the derivatives of the unit vectors. See Figure 6.13.

$$\mathbf{bP} = \frac{1}{2} \bullet (\mathbf{uXmt} + \mathbf{uRcv}) \qquad \mathbf{bPDot} = \frac{1}{2} \bullet (\mathbf{uXmtDot} + \mathbf{uRcvDot})$$

(4) Compute the magnitude of the pointing vector, bP_Mag, and the bistatic angle, Bistat_Ang.

$$\text{bP\_Mag} = |\mathbf{bP}| \qquad \text{Bistat\_Ang} = 2 \bullet \underbrace{\text{acos}(\text{bP\_Mag})}_{\substack{\text{Angle is the interval} \\ \text{0 to 90 degrees.}}}$$

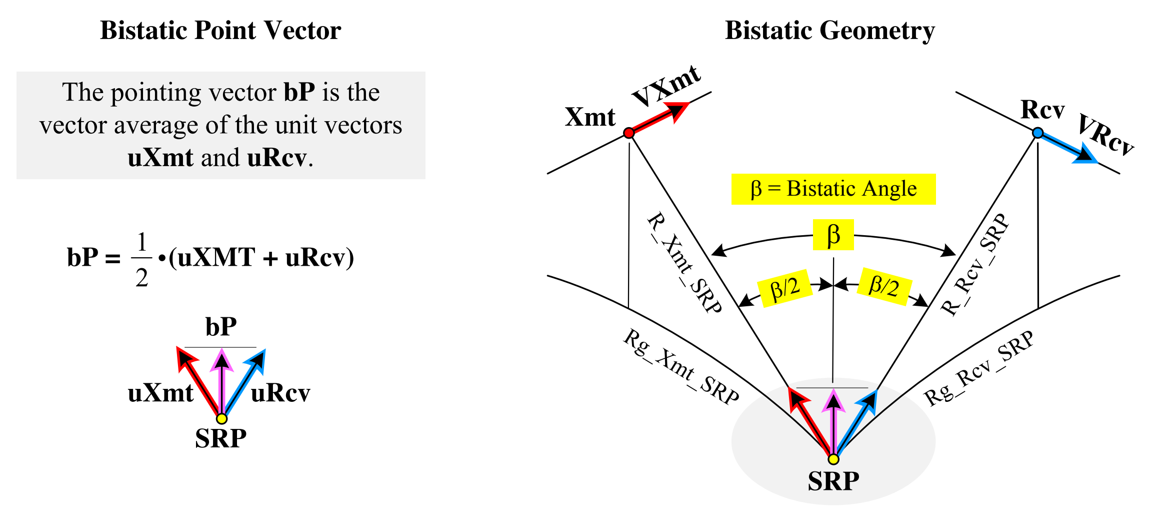


Figure 6-14 Bistatic Reference Geometry
The bistatic parameters are computed from the bistatic pointing vector (bP).

(5) Compute the bistatic angle rate, Bistat_Ang_Rate, equal to the rate of change of the bistatic angle. For magnitude of the pointing vector equal to 0 or equal to 1, set the rate equal to zero. The bistatic angle rate is in degrees/sec.

$$\text{For } 0.0 < \text{bP\_Mag} < 1.0: \quad \text{Bistat\_Ang\_Rate} = -\frac{180}{\pi} \bullet \frac{4}{\sin(\text{Bistat\_Ang})} \bullet (\mathbf{bP} \bullet \mathbf{bPDot})$$

$$\text{For bP\_Mag} = 0.0 \text{ or bP\_Mag} = 1.0: \text{ Bistat\_Ang\_Rate} = 0$$

Note: In general, the derivative of the bistatic angle versus time is undefined as the angle transitions through a value of 0 or 180 degrees.

(6) For a bistatic SAR imaging collection, the pointing vector **bP** must have a non-zero component parallel to the ground plane. For the ground plane equal to the ETP at the SRP, compute the component of the pointing vector in the ground plane, **bP_GP**. Compute the parameter bP_GPX that is equal to the magnitude of **bP_GP**. See Figure 6-15.

$$\mathbf{uGPZ} = \mathbf{uUP} \qquad \text{bP\_GPZ} = \mathbf{bP} \bullet \mathbf{uGPZ}$$

$$\mathbf{bP\_GP} = \mathbf{bP} - \text{bP\_GPZ}\cdot\mathbf{uGPZ} \qquad \text{bP\_GPX} = \left|\mathbf{bP\_GP}\right|$$

For bP_GPX = 0, the geometry does not support the formation of an image of the ground plane. Set the bistatic reference parameters that describe the bistatic image equal to 0.

For bP_GPX = 0:

Bistat_AZIM = 0 Bistat_TWST = 0

Bistat_AZIM_Rate = 0 Bistat_SLOPE = 0

Bistat_GRAZ = 0 Bistat_LO_ANG = 0

Continue with step 17 below.

For bP_GPX > 0, compute the reference parameters that describe the bistatic image as described in steps (7) through (16) below.

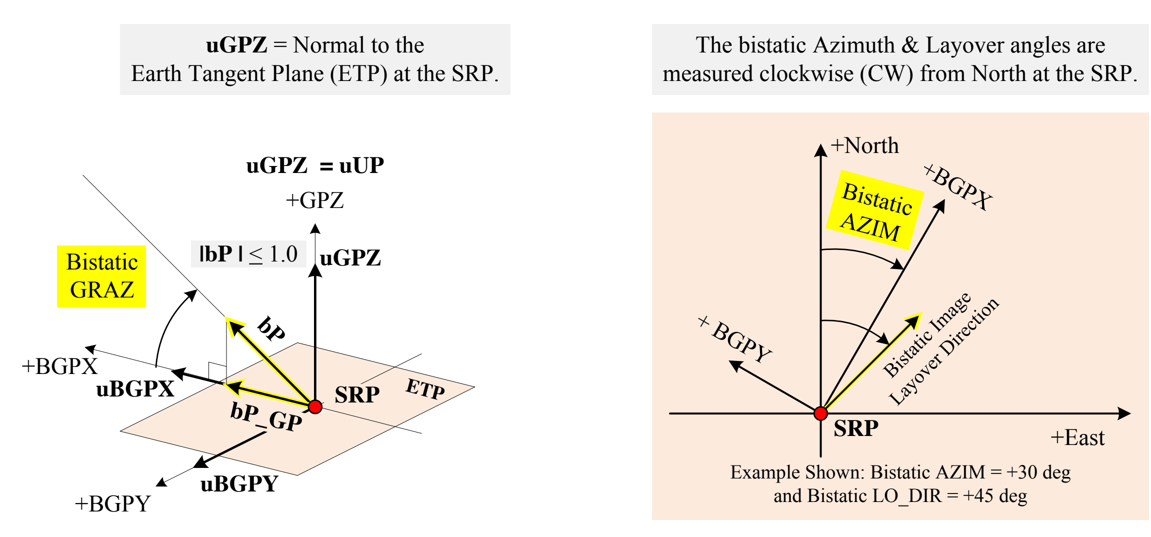


Figure 6-15 Bistatic Ground Plane Coordinates
The pointing vector (bP) projected onto the ETP determines +BGPX direction.

(7) Define the bistatic ground plane coordinates (BGPX, BGPY) with origin at the SRP. The +BGPX axis is aligned with the projection of the pointing vector **bP** onto the ETP, **bP_GP**. The +BGPY direction is orthogonal to +BPGX and oriented such that BGPX, BGPY, and GPZ from a right-handed coordinate system. Compute unit vectors **uBGPX** and **uBGPY** as shown. See Figure 6-15. Vectors **uBGPX** and **uBGPY** are in ECF coordinates

$$\mathbf{uBGPX} = \frac{1}{\text{bP\_GPX}} \bullet \mathbf{bP\_GP} \qquad \mathbf{uBGPY} = \underbrace{\mathbf{uGPZ} \times \mathbf{uBGPX}}_{\text{Vector Cross Product}}$$

(8) Compute the bistatic grazing angle, Bistat_GRAZ, that is the angle between the pointing vector **bP** and the +BGPX axis. See Figure 6-15. The bistatic grazing angle is in degrees.

$$\text{Bistat\_GRAZ} = \underbrace{\tan^{-1}\left(\text{bP\_GPZ} \big/ \text{bP\_GPX}\right)}_{\substack{\text{Angle on the interval} \\ \text{-90 to 90 degrees.}}}$$

(9) The bistatic azimuth angle is the angle from north to the +GPX axis. Compute the bistatic azimuth angle, Bistat_AZIM, as follows. The azimuth angle is in degrees and is on the interval from 0 ≤ Bistat_AZIM < 360.0. See Figure 6-15.

$$\text{BGPX\_N} = \mathbf{uBGPX} \bullet \mathbf{uNOR} \qquad \text{BGPX\_E} = \mathbf{uBGPX} \bullet \mathbf{uEAST}$$

$$\text{Bistat\_AZIM} = \underbrace{\tan^{-1}\left(\text{BGPX\_E} \big/ \text{BGPX\_N}\right)}_{\text{Four Quadrant ArcTangent (East/North)}}$$

(10) Compute the projection of **bPDot** in the +BGPY direction, bPDot_BGPY. Also, compute bistatic azimuth angle rate, Bistat_AZIM_Rate, that is rate of rotation the pointing vector about the +GPZ axis. The Bistat_AZIM_Rate is in degrees per second.

$$\text{bPDot\_BGPY} = \mathbf{bPDot} \bullet \mathbf{uBGPY} \qquad \text{Bistat\_AZIM\_Rate} = -\frac{180}{\pi} \bullet \frac{\text{bPDot\_BGPY}}{\text{bP\_GPX}}$$

For bPDot_BGPY = 0, the pointing vector is not rotating relative to the ground plane and the geometry does not support the formation of an image of the ground plane. Set the remaining parameters that describe the bistatic image equal to 0.

For bPDot_BGPY = 0:

Bistat_TWST = 0 Bistat_SLOPE = 0 Bistat_LO_ANG = 0

Continue with step 17 below.

For bPDot_GPX ≠ 0, compute the remaining parameters that describe the bistatic image as described in steps (11) through (16) below.

(11) Assign the parameter AZIM_SGN based upon the sign of the bistatic azimuth angle rate. Parameter AZIM_SGN is the equivalent of the LOOK parameter for monostatic collections.

$$\text{AZIM\_SGN} = \begin{cases} +1, & \text{Bistat\_AZIM\_Rate} > 0 \\ -1, & \text{otherwise} \end{cases}$$

(12) The derivative of the pointing vector, **bPDot,** may be expressed as the sum of two vectors, **bPDotP** and **bPDotN**. Component **bPDotP** is parallel to the pointing vector and component **bPDotN** is normal to it. Compute the components of **bPDot** as follows.

$$\mathbf{ubP} = \frac{1}{\text{bP\_Mag}} \cdot \mathbf{bP} \qquad \mathbf{bPDotP} = \underbrace{\left(\mathbf{bP} \bullet \mathbf{ubP}\right)}_{\text{Vector Dot Product}} \cdot \mathbf{ubP}$$

$$\mathbf{bPDotN} = \mathbf{bP} - \mathbf{bPDotP}$$

(13) Compute the vector **BIPN** that is normal to the bistatic image plane that is formed by the vectors **bP** and **bPDotN**. Also, compute the unit vector **uBIPN** that is normal to the plane. The bistatic image plane is the equivalent of the slant plane for a monostatic collection. For all collections, vector **BIPN** will point upward.

$$\mathbf{BIPN} = \text{AZIM\_SGN} \cdot \underbrace{\mathbf{bP} \times \mathbf{bPDotN}}_{\text{Vector Cross Product}} \qquad \mathbf{uBIPN} = \frac{1}{\left|\mathbf{BIPN}\right|} \cdot \mathbf{BIPN}$$

(14) The bistatic twist angle is the angle between the iso-TOA direction in the bistatic image plane and the iso-TOA direction in the ETP (i.e. in BGPY direction). Compute the bistatic twist angle, Bistat_TWST, as follows. The bistatic twist angle is on the interval from -90 to 90 degrees.

$$\text{Bistat\_TWST} = \underbrace{-\sin^{-1}\left(\mathbf{uBIPN} \bullet \mathbf{uBGPY}\right)}_{\substack{\text{Angle on the interval} \\ \text{-90 to 90 degrees.}}}$$

(15) The bistatic slope angle is the angle between the bistatic image plane and the ETP. Compute the bistatic slope angle, Bistat_SLOPE, as follows. The bistatic slope angle is in degrees on the interval from 0 to 90 degrees.

$$\text{Bistat\_SLOPE} = \underbrace{\cos^{-1}\left(\mathbf{uGPZ} \bullet \mathbf{uBIPN}\right)}_{\substack{\text{Angle on the interval} \\ \text{0 to 90 degrees.}}}$$

(16) The bistatic layover direction is the direction that elevated targets will be displaced (or "laid over") in a ground plane image. The layover angle is the angle from north to the layover direction. See Figure 6-15. Compute the layover angle, Bistat_LO_ANG, as follows. The layover angle is in degrees and is on the interval from 0 ≤ Bistat_LO_ANG < 360.0.

$$\text{B\_LODIR\_N} = -\mathbf{uBIPN} \bullet \mathbf{uNOR} \qquad \text{B\_LODIR\_E} = -\mathbf{uBIPN} \bullet \mathbf{uEAST}$$

$$\text{Bistat\_LO\_ANG} = \underbrace{\tan^{-1}\left(\text{B\_LODIR\_E} \big/ \text{B\_LODIR\_N}\right)}_{\text{Four Quadrant ArcTangent (East/North)}}$$

(17) The parameters of the ReferenceGeometry / Bistatic branch of the XML are assigned as shown. The units of the XML parameters are listed for convenience.

Bistat_AZIM	➔	XML: AzimuthAngle	degrees
Bistat_AZIM_Rate	➔	XML: AzimuthAngleRate	degrees/sec
Bistat_Ang	➔	XML: BistaticAngle	degrees
Bistat_Ang_Rate	➔	XML: BistaticAngleRate	degrees/sec
Bistat_GRAZ	➔	XML: GrazeAngle	degrees
Bistat_TWST	➔	XML: TwistAngle	degrees
Bistat_SLOPE	➔	XML: SlopeAngle	degrees
Bistat_LO_ANG	➔	XML: LayoverAngle	degrees

(18) Parameters that describe the transmit APC geometry relative the SRP are provided. The transmit APC parameters are computed from the transmit APC position and velocity, **Xmt** and **VXmt**. The method for computing the transmit APC parameters is identical to the computations described in Section 6.5.2 for a monostatic collection using the ARP position and velocity, **ARP** and **VARP**. The parameters of the ReferenceGeometry / Bistatic / TxPlatform branch of the XML are assigned as shown. The units of the XML parameters are listed for convenience.

txc	➔	XML: Time	seconds
Xmt	➔	XML: Pos	meters
VXmt	➔	XML: Vel	meters/sec
Xmt_Side_Of_Track	➔	XML: SideOfTrack	
R_Xmt_SRP	➔	XML: SlantRange	meters
Rg_Xmt_SRP	➔	XML: GroundRange	meters
Xmt_DCA	➔	XML: DopplerConeAngle	degrees
Xmt_GRAZ	➔	XML: GrazeAngle	degrees

Xmt_INCD	→	XML: IncidenceAngle	degrees
Xmt_AZIM	→	XML: AzimuthAngle	degrees

For the transmit APC parameters, the following conditions may occur that are unique to a bistatic imaging geometry.

(1) For a collection with a fixed transmit APC (i.e. |**VXmt**| = 0), set parameters Xmt_DCA = 90 and Xmt_Side_Of_Track = "L".

(2) For a collection with Rg_Xmt_SRP = 0 (i.e. the transmit APC directly above the SRP), set parameters Xmt_GRAZ = 90, Xmt_INCD = 0 and Xmt_AZIM = 0.

(19) Parameters that describe the receive APC geometry relative the SRP are provided. The receive APC parameters are computed from the receive APC position and velocity, **Rcv** and **VRcv**. The method for computing the receive APC parameters is identical to the computations described in Section 6.5.2 for a monostatic collection using the ARP position and velocity, **ARP** and **VARP**. The parameters of the ReferenceGeometry / Bistatic / RcvPlatform branch of the XML are assigned as shown. The units of the XML parameters are listed for convenience

trc_SRP	→	XML: Time	seconds
Rcv	→	XML: Pos	meters
VRcv	→	XML: Vel	meters/sec
Rcv_Side_Of_Track	→	XML: SideOfTrack	
R_Rcv_SRP	→	XML: SlantRange	meters
Rg_Rcv_SRP	→	XML: GroundRange	meters
Rcv_DCA	→	XML: DopplerConeAngle	degrees
Rcv_GRAZ	→	XML: GrazeAngle	degrees
Rcv_INCD	→	XML: IncidenceAngle	degrees
Rcv_AZIM	→	XML: AzimuthAngle	degrees

For receive APC parameters, the following conditions may occur that are unique to a bistatic imaging geometry.

(1) For a collection with a fixed receive APC (i.e. |**VRcv**| = 0), set parameters Rcv_DCA = 90 and Rcv_Side_Of_Track = "L".

(2) For a collection with Rg_Rcv_SRP = 0 (i.e. the receive APC directly above the SRP), set parameters Rcv_GRAZ = 90, Rcv_INCD = 0 and Rcv_AZIM = 0.

7 Channel & Dwell Parameters

A CPHD product contains one or more data channels. The XML data structure includes many parameters that describe the data channels contained in the product. The XML parameters that describe the data channels are of two types: common parameters and channel specific parameters. The common parameters apply to all channels and include the signal array domain type and sample format. The channel specific parameters in the XML structure are repeated for each data channel. The parameters that describe the data channels are included in the CPHD / Global, CPHD / Data and CPHD / Channel branches of the XML structure.

For all CPHD products, the Dwell parameters specify how each channel is used to form a SAR image of the scene. The Dwell parameters are in the form of polynomials that map a scene point position to the dwell period used to form the image pixel at the scene point. For each channel, the Dwell parameters specify a Center of Dwell (COD) Time polynomial and a Dwell Time polynomial. For a given scene point, the COD Time polynomial is used to compute the COD time, t_COD, that is the center of the dwell period to be used. The Dwell Time polynomial is used to compute the dwell time, T_Dwell, that is the duration of the imaging period for the scene point. The dwell parameters are provided in the CPHD / Dwell branch of the XML structure. For each channel, the channel specific parameters identify the COD and Dwell time polynomials that the channel supports.

The XML parameters that specify the attributes of the data channels are described in the following sections. The XML parameters that are common and/or based on the signal content of all data channels in a given product are described in Section 7.1. The channel specific XML parameters that are included and repeated for each data channel are described in Section 7.2. Also, the method for using the dwell parameters to form a SAR image for a given channel is described. The Dwell parameters are described in Section 7.3.

Each data channel in a given product is referenced by a unique identifier. The channel identifier, denoted Ch_ID, is a string that uniquely identifies the channel within the product. This unique identifier must appear in exactly one CPHD / Data / Channel branch and in exactly one CPHD / Channel / Parameters branch. The channel branch inside the Data branch specifies the size of the signal array and PVP array. It also specifies the locations of the signal array within the Signal block and the PVP array within the PVP block. The parameters branch inside the Channel branch has an extensive set of metadata that is used to convey the details and characteristics of the data channel.

For all products, one channel is selected as the reference channel. The reference channel may be any channel in a given product. For products that contain multiple data channels, the method for selecting the reference channel is a product design choice. The reference channel may be selected for use by the processing applications that input the CPHD and form the SAR image products. When creating a CPHD product, the choice of the reference channel only impacts the reference geometry parameters that are included in the product. See Table 11-9 and Section 6.5. No other parameters are dependent upon the choice of the reference channel. Shown in Figure 7.1 are the signal arrays for a product that contains three data channels. For the example shown, the channel identifiers are A, B and C. Channel B is the reference channel.

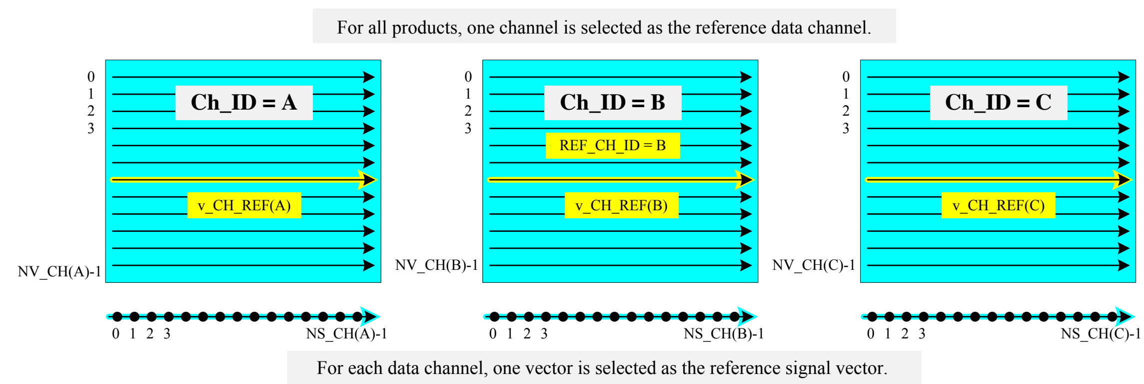


Figure 7-1 Reference Channel & Vectors
Example product with three data channels. Each signal array may be a unique size.

For each data channel, one signal vector is selected as the reference vector. The reference vector may be any vector in the signal array. When creating a CPHD product, the method for selecting the reference vector is a product design choice. The choice of the reference signal vector impacts several channel specific metadata parameters that may be included. For most data products, the center vector of each signal array represents the nominal geometry for the signal array and is a logical choice for the reference vector. For a signal array that contains NV_CH signal vectors, the index of the center vector, denoted v_CH_CTR, is computed as shown. For the example shown in Figure 7-1, the three signal arrays all have the same number of vectors. For each channel, the center vector was selected as the reference signal vector.

$$\mathrm{v\_CH\_CTR} = \mathrm{FLOOR}\left(\frac{1}{2}\bullet\mathrm{NV\_CH}\right)$$

7.1 Common Channel Parameters

The common parameters include the global parameters that apply to all data channels in a given product. The common parameters also include a set of Boolean parameters that indicate when all signal vectors and all data channels have been formed such that they have a common FX domain bandwidth and/or common TOA domain swath.

7.1.1 Global Parameters

The global parameters are included in the CPHD / Global branch of the XML structure. See Table 11-2. The global parameters include the domain type, either FX or TOA, and the phase sign parameter that applies to all signal arrays. The choice of the signal domain is often motivated by the primary SAR products to be formed from the CPHD signal arrays. The FX domain is often preferred if a single image is to be formed that spans the entire image area. The TOA domain may be the preferred if the primary use is the formation of small image patches. Sub-selecting the needed signals for relatively small image areas is quicker and easier from the TOA domain signal arrays. If minimizing the CPHD product data set size is a high priority, the FX domain is the preferred choice. More coherent gain has been applied in forming the TOA domain data and therefore a sample type with more dynamic range is required.

The Global / Timeline branch specifies the absolute collection time and the temporal extent of all signal arrays in the product. The CollectionStart time specifies the beginning of collection in UTC and is the origin for all relative times specified in CPHD product metadata. For a bistatic imaging collection, the RcvCollectionStart time in UTC is also provided for the receive platform. All other metadata times are specified in seconds relative to the collection start time on the transmit platform. Parameter TxTime1 is the minimum PVP TxTime value for any signal vector in any channel included in the CPHD product. Parameter TxTime2 is the maximum PVP TxTime value for any signal vector in any channel included in the CPHD product. See Figure 7-2.

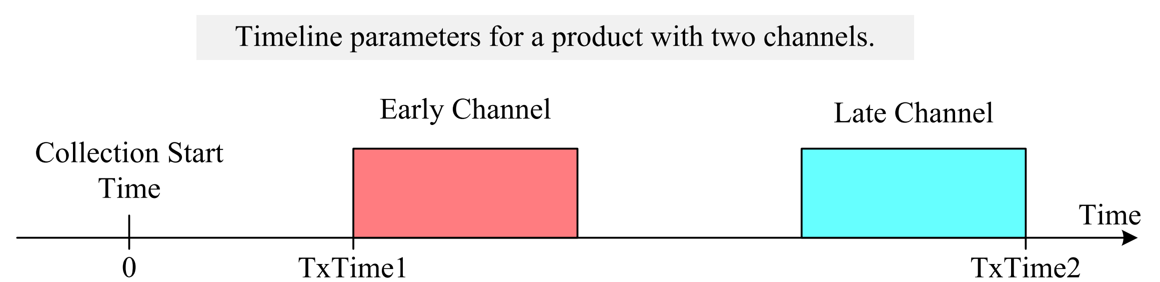


Figure 7-2 Timeline Parameters
Timeline for a product that contains two data channels with disjoint collection times.

The Global / FxBand branch specifies the FX domain signal extent for the signal vectors in the CPHD product. FxMin is the minimum PVP FX1 value for any signal vector in any channel included in the CPHD product. FxMax is the maximium PVP FX2 value for any vector in any channel included in the CPHD product. See Figure 7-3. Shown in Figure 7-3 is the FX domain extent for a product that contains three data channels. The channel IDs are A, B and C. The collection used a step-chirp waveform that included three steps. The initial PHD from each waveform was processed to form one of the data channels. The frequency FxMin is from the Channel A PVP array and FxMax is from the Channel C PVP array.

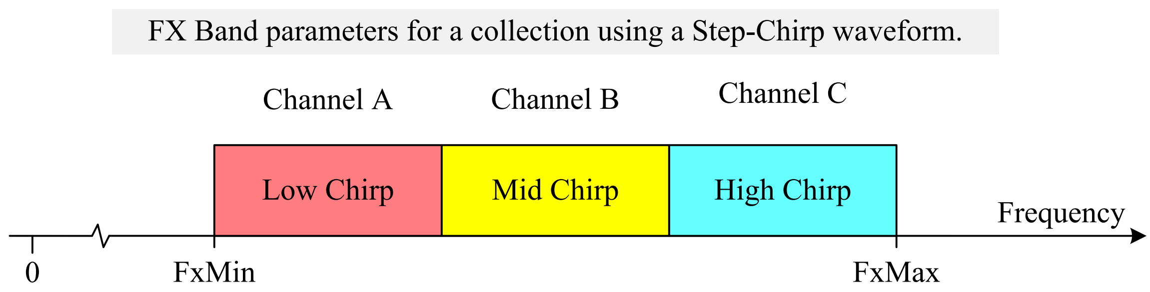


Figure 7-3 FxBand Parameters
FX extent for a product that contains three data channels for a step-chirp collection.

The Global / TOASwath branch specifies the delta time of arrival extent of all signal vectors in the CPHD product. TOAMin is the minimum PVP ΔTOA1 value for any vector in any channel included in the CPHD product. TOAMax is the maximum PVP ΔTOA2 value for any signal vector in any channel included in the CPHD product.

The tropospheric refractivity parameters used during compensation processing are required parameters for all products. The TropoParameters branch specifies the tropospheric refractivity used during prior processing to compute the tropospheric delay. Parameter N0 is the refractivity estimate used. Parameter RefHeight is the scene height for which the tropospheric refractivity estimate is valid. The Image Area Reference Point (IARP) height or the WGS-84 ellipsoid (ZERO) height are the allowed values. Use of these parameters is described in Section 4.

The ionospheric parameters used during processing may also be specified if applicable. The IonoParameters branch specifies the ionospheric total electron content (TEC) and the estimated F2 height of the ionosphere. The TECV is the total electron content estimate for a vertical path through the ionosphere. The units of this estimate are TECU (1 TECU = $10^{16}/m^2$ electrons). F2Height is the estimate of the location of the F2 layer of the ionosphere.

7.1.2 Common Signal Booleans

The CPHD / Channel branch includes a set of Boolean parameters that indicate when the data channels have been formed with a common and constant signal array content. See Table 11-5. The parameters provide a simple method for identifying that all channels were formed with fixed parameters without examining all values of the per vector parameters array.

FXFixedCPHD — Parameter FXFixedCPHD = "true" indicates all signal arrays are formed with a fixed FX domain bandwidth. Parameters fx_1 and fx_2 are constant for all vectors and all channels. For arrays with out-of-band noise, parameters fx_N1 and fx_N2 are also constant for all vectors and all channels. Parameter FXFixedCPHD = "false" otherwise.

TOAFixedCPHD Parameter TOAFixedCPHD = “true” indicates all signal arrays are formed with a fixed TOA domain swath. Parameters ΔTOA_1 and ΔTOA _2 are constant for all vectors and all channels. For arrays with extended swath, parameters ΔTOA_E1 and ΔTOA _E2 are also constant for all vectors and all channels. TOAFixedCPHD = “false” otherwise.

SRPFixedCPHD Parameter SRPFixedCPHD = “true” indicates the signal arrays are formed with a fixed SRP position. The SRP position is constant for all vectors and all channels. SRPFixedCPHD = “false” otherwise.

7.2 Channel Specific Parameters

The channel specific parameters in the XML structure are repeated for each data channel in a given product. For each channel, the channel specific parameters are specified in one instance of the CPHD / Data / Channel branch and in one instance of the CPHD / Channel / Parameters branch. For each channel specific branch, the data channel is specified by the channel ID value.

7.2.1 Signal Array & PVP Array Parameters

The parameters that specify the size and location of the signal array and the PVP array are in the Data / Channel branch of the XML structure. See Table 11-4. For a given channel, the size of the signal array is NV_CH vectors by NS_CH samples. The PVP array includes one set of PV parameters for each vector of the signal array. Each signal array may have a unique size.

NV_CH = XML: NumVectors NS_CH = XML: NumSamples

The signal array vectors are indexed by v = 0 to NV_CH – 1 and the samples of each vector are indexed by s = 0 to NS_CH – 1. The location of the signal array within the Signal block is specified by the byte offset from the start of the block. The location of the PVP array within the PVP block is also specified by the byte offset from the start of the block. See Section 2.4.

7.2.2 Signal Booleans

The Channel / Parameters branch includes a set of Boolean parameters that indicate when the channel signal array has been formed with constant signal content or with a fixed SRP for all signal vectors. The parameters provide a simple method for identifying that a given channel was formed with fixed parameters without examining all values of the per vector parameters array.

FXFixed Parameter FXFixed = “true” indicates the signal array is formed with fixed FX domain bandwidth. Parameters fx_1 and fx_2 are constant for all vectors. For arrays with out-of-band noise, parameters fx_N1 and fx_N2 are also constant for all vectors. Parameter FXFixed = “false” otherwise.

TOAFixed Parameter TOAFixed = "true" indicates the signal array is formed with fixed TOA domain swath. Parameters ΔTOA_1 and ΔTOA _2 are constant for all vectors. For arrays with extended swath, parameters ΔTOA_E1 and ΔTOA _E2 are also constant for all vectors. TOAFixed = "false" otherwise.

SRPFixed Parameter SRPFixed = "true" indicates the signal array is formed with a fixed SRP position. The SRP position is constant for all vectors. SRPFixed = "false" otherwise.

7.2.3 FX Signal Parameters

The Channel / Parameters branch includes parameters that describe the FX domain signal content of the signal array. Parameters fx_C and FX_BW are required parameters and provided for all channels.

fx_C = XML: FxC FX_BW = XML: FxBW

The FX domain signal content of each signal vector is specified by per vector parameters fx_1 and fx_2. Parameters fx_C and FX_BW are computed from the minimum value of the fx_1 array and the maximum value of the fx_2 array.

$$\text{fx\_Min} = \text{MIN}\{\ \text{fx\_1(v)}\ \} \qquad \text{fx\_Max} = \text{MAX}\{\ \text{fx\_2(v)}\ \}$$

$$\text{fx\_C} = \frac{1}{2} \bullet \left(\text{fx\_Max} + \text{fx\_Min} \right) \qquad \text{FX\_BW} = \text{fx\_Max} - \text{fx\_Min}$$

For a product with signal arrays in the FX domain (i.e. Domain_Type = FX), the signal arrays may be formed such that they include out-of-band signals that were received and recorded during the collection. See Section 4.2. The noise content of each signal vector is specified by per vector parameters fx_N1 and fx_N2. Parameter FX_BWN is computed from the minimum value of the fx_N1 array and the maximum value the fx_N2 array.

$$\text{fx\_N\_Min} = \text{MIN}\{\ \text{fx\_N1(v)}\ \} \qquad \text{fx\_N\_Max} = \text{MAX}\{\ \text{fx\_N2(v)}\ \}$$

FX_BWN = XML: FxBWNoise $\qquad \text{FX\_BWN} = \text{fx\_N\_Max} - \text{fx\_N\_Min}$

The fx_C, FX_BW, and FX_BWN parameters describe the frequency extent contained in the entire signal data. These parameters are computed from the entire signal array and, in general, are not indicative of the instantaneous bandwidth or center frequency for any given vector. Shown in See Figure 7-4 is an example FX domain signal array. For the example shown, the collection used a fixed transmitted bandwidth on every pulse but with a varying center frequency from pulse to pulse. The radar receiver was operated with a fixed receive bandwidth that exceeded the transmitted bandwidth of all pulses and received echoes. The entire receiver bandwidth was retained by the compensation processing that formed the signal array.

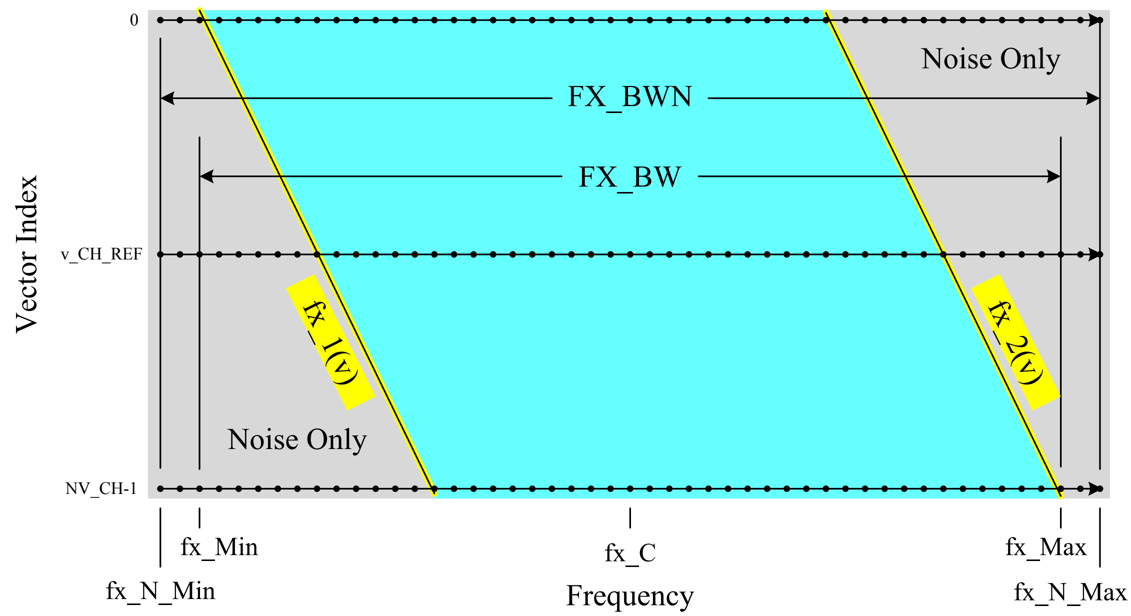


Figure 7-4 FX Signal Parameters
Example FX domain signal array that includes the out-of-band noise.

7.2.4 TOA Signal Parameters

The Channel / Parameters branch includes parameter TOA_Saved that describes the full resolution TOA swath content of the signal array. Parameter TOA_Saved is a required parameter and provided for all channels. The full resolution TOA swath retained in each signal vector is specified by per vector parameters ΔTOA_1 and ΔTOA_2. See Section 4.2. Parameter TOA_Saved is computed from the minimum value of the ΔTOA_1 array and the maximum value of the ΔTOA_2 array.

$$\Delta TOA\_Min = MIN\{\ \Delta TOA\_1(v)\ \} \qquad \Delta TOA\_Max = MAX\{\ \Delta TOA\_2(v)\ \}$$

$$TOA\_Saved\ =\ XML:\ TOASaved \qquad TOA\_Saved = \Delta TOA\_Max - \Delta TOA\_Min$$

For most SAR sensors, the received signals include both fully collected and partially collected echoes of the transmitted pulses. The portion of the TOA swath that contains the partially collected returns at early and late TOA is referred to as the extended TOA swath. For a given collection, the compensated PHD signal arrays may be formed such that the extended TOA swath at early and late TOA is retained. For signal arrays that include the extended swath, the optional per vector parameters ΔTOA_E1 and ΔTOA_E2 are included. The ΔTOA_E1 and ΔTOA_E2 parameters specify the limits of the extended TOA swath retained for each signal vector. The optional Channel / Parameters / TOAExtended branch is also included for each channel. See Table 11-5. For each channel, TOA_Ext_Saved describes the size of the extended TOA swath. Parameter TOA_Ext_Saved is computed from the minimum value of the ΔTOA_E1 array and the maximum value of the ΔTOA_E2 array.

$$\Delta\text{TOA\_E\_Min} = \text{MIN}\{\ \Delta\text{TOA\_E1(v)}\ \} \quad \Delta\text{TOA\_E\_Max} = \text{MAX}\{\ \Delta\text{TOA\_E2(v)}\ \}$$

$$\text{TOA\_Ext\_Saved} = \Delta\text{TOA\_E\_Max} - \Delta\text{TOA\_E\_Min}$$

$$\text{TOA\_Ext\_Saved} \ = \ \text{XML: TOAExtSaved}$$

The compensated signal arrays may include all or any portion of the extended swath at early and/or late TOA. Shown in Figure 7-5 is the TOA swath for one signal vector of a given signal array. For the example shown, the partially collected echoes retained at early and late TOA were limited. For a target at ΔTOA_E1 or ΔTOA_E2, the echo signal received was 75% of the transmitted pulse (i.e. the echoes were 25% eclipsed).

For a collection that uses a Linear FM (LFM) waveform, the target echoes that are partially eclipsed by the radar receiver will have a loss in RF bandwidth. The loss in bandwidth is proportional to the fraction of the pulse that is eclipsed. For the compensated signal vectors, targets in the early or late extended TOA swath will have a predictable FX domain signal bandwidth. For such a product, the TOAExtended / LFMEclipse branch may be included for each channel in the XML instance.

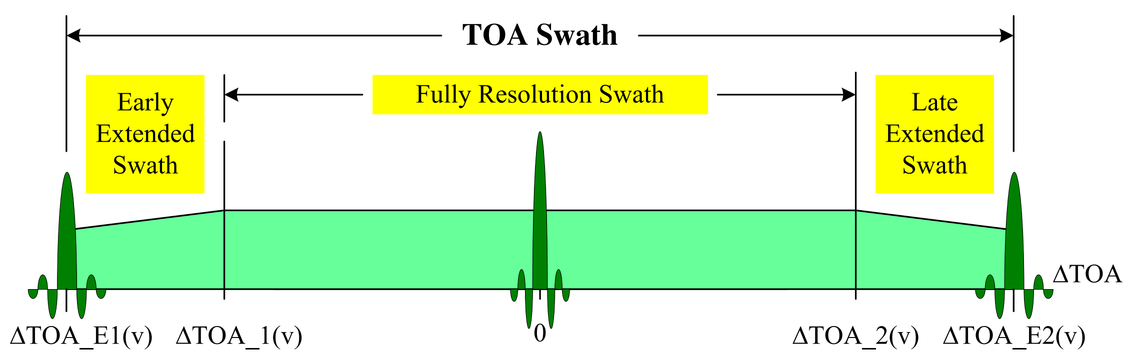


Figure 7-5 Extended TOA Swath
Example TOA parameters for a signal vector formed with an extended TOA swath.

The parameters in the LFMEclipse branch allow the FX domain bandwidth to be computed for all echoes in the early and late extended TOA swath. The LMFEclipse parameters may be included for collections and signal arrays that meet the following conditions.

(1) The collection used a fixed LFM waveform for all transmitted pulses. For all pulses, the waveform had a fixed pulse length, T_Xmt, a fixed LFM chirp rate, fx_Rate, and a fixed center frequency, fx_C. For all pulses, the transmitted bandwidth was BW_Xmt = |fx_Rate| x T_Xmt.

(2) The signal array is formed such that for all vectors, parameters fx_1 and fx_2 are constant. For all vectors, fx_2 – fx_1 = BW_Xmt.

(3) The signal array is formed such that for all vectors, parameters ΔTOA_1, ΔTOA_2, ΔTOA_E1, and ΔTOA_E2 are constant. For all vectors, the TOA swath and the extended TOA swath are fixed.

The LMFEclipse branch includes four parameters. The parameters specify the retained FX bandwidth at the limits of the extended TOA swath. Parameters fx_E1_L and fx_E1_H are the frequency limits for a target with ΔTOA^{TGT} = ΔTOA_E1. Parameters fx_E2_L and fx_E2_H are the frequency limits for a target with ΔTOA^{TGT} = ΔTOA_E2.

fx_E1_L = XML: FxEarlyLow	fx_E2_L = XML: FxLateLow
fx_E1_H = XML: FxEarlyHigh	fx_E2_L = XML: FxLateHigh

Shown in Figure 7-6 is an example showing the FX bandwidth versus ΔTOA for a signal array that was formed with the extended TOA swath shown in Figure 7-5. For the example shown, the collection used an LFM waveform with fixed fx_Rate > 0. A target at ΔTOA^{TGT} = ΔTOA_E1 is missing the lower 25% of the FX band. A target at ΔTOA^{TGT} = ΔTOA_E2 is missing the upper 25% of the FX band. The LFMEclipse parameters may be used to compute the FX signal content for the partially eclipsed echoes in the early and late extended TOA swath.

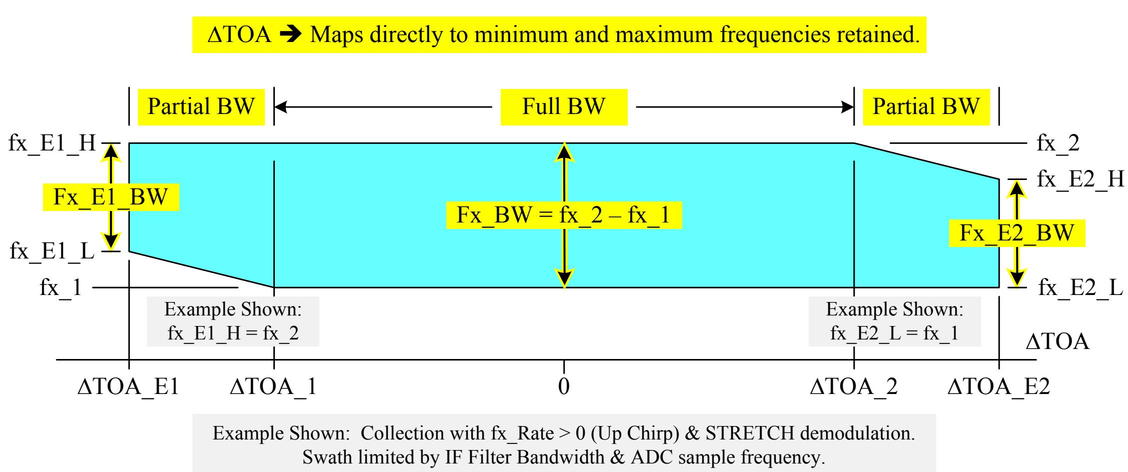


Figure 7-6 FX Signal For Extended Swath

FX domain signal content vs. ΔTOA for a vector formed with an extended TOA swath.

For a target in the early extended swath, the FX domain bandwidth retained is from frequency fx_1^{TGT} to frequency fx_2^{TGT}. Frequencies fx_1^{TGT} and fx_2^{TGT} are computed using parameters fx_E1_L and fx_E1_H.

For $\Delta TOA\_E1 \leq \Delta TOA^{TGT} < \Delta TOA\_1$:

$$fx\_1^{TGT} = fx\_1 + \frac{fx\_E1\_L - fx\_1}{\Delta TOA\_E1 - \Delta TOA\_1} \bullet \left(\Delta TOA^{TGT} - \Delta TOA\_1 \right)$$

$$fx\_2^{TGT} = fx\_2 + \frac{fx\_E1\_H - fx\_2}{\Delta TOA\_E1 - \Delta TOA\_1} \bullet \left(\Delta TOA^{TGT} - \Delta TOA\_1 \right)$$

For a target in the late extended swath, the FX domain bandwidth retained is from frequency fx_1^{TGT} to frequency fx_2^{TGT}. Frequencies fx_1^{TGT} and fx_2^{TGT} are computed using parameters fx_E2_L and fx_E2_H.

For $\Delta TOA\_2 < \Delta TOA^{TGT} \leq \Delta TOA\_E2$:

$$fx\_1^{TGT} = fx\_1 + \frac{fx\_E2\_L - fx\_1}{\Delta TOA\_E2 - \Delta TOA\_2} \bullet \left(\Delta TOA^{TGT} - \Delta TOA\_2 \right)$$

$$fx\_2^{TGT} = fx\_2 + \frac{fx\_E2\_H - fx\_2}{\Delta TOA\_E2 - \Delta TOA\_2} \bullet \left(\Delta TOA^{TGT} - \Delta TOA\_2 \right)$$

7.2.5 Polarization Parameters

The Channel / Parameters branch includes the required Polarization branch for all channels. The parameter TxPol specifies the polarization of the transmitted signals. The parameter RcvPol specifies the receive polarization for the antenna and receiver channel that collected the echoes. The permissible polarizations are enumerated in Table 10-3. In the rare case that the polarization is not known or none of the enumerations are appropriate, a value of "UNSPECIFIED" may be used.

7.2.6 Dwell Time Parameters

The Channel / Parameters branch includes the required DwellTimes branch for all channels. The DwellTimes branch identifies the Center of Dwell (COD) Time polynomial and the Dwell Time polynomial that the data channel supports. The COD Time polynomial is specified by the CODId value. The Dwell Time polynomial is specified by the DwellId value. The COD Time and Dwell Time polynomials are described in Section 7.3.

The image area supported by a given product is described in Section 6.3. The image area that is supported by a given channel is specified as an area on the image reference surface. For any channel, the image area is defined by a rectangle or other simple polygon. For a product that contains multiple data channels, the image area may be specified separately for each channel by including the Channel / Parameters / ImageArea branch for each data channel.

7.2.7 Antenna Parameters

For a given CPHD product, a description of the antennas used for the collection may be included. The parameters that describe the antennas are included in the optional CPHD / Antenna branch of the XML instance. For each data channel, the transmit antenna and receive antenna are specified by including the optional Channel / Parameters / Antenna branch for each data channel. For each channel, the parameters identify the transmit and receive aperture phase centers and antenna gain and phase patterns:

- TxAPCId—Identifier of the transmit aperture phase center for this channel
- TxAPATId—Identifier of the transmit antenna pattern for this channel
- RcvAPCId—Identifier of the receive aperture phase center for this channel
- RcvAPATId—Identifier of the receive antenna pattern for this channel

These identifiers reference locations and patterns listed in the optional CPHD / Antenna branch described in Section 8.2 and Table 11-10.

7.2.8 Transmit & Receive Parameters

The optional TxRcv branch provides the identifiers of the transmit waveform (TxWFId) and the receive configuration (RcvId) used to collect data included in this channel. These identifiers reference waveforms and receive configurations that are described in Section 8.1 and Table 11-11.

7.2.9 Target Signal Level

For SAR sensors and data processing systems that are power and gain calibrated, the compensated PHD signal arrays may be formed such that absolute signal levels may be predicted. For each data channel, a reference power level may be included in the Channel / Parameters / TgtRefLevel branch of the XML instance. The reference power level is the predicted power level for an ideal point scatterer with RCS equal to 1.0 square meters (i.e. 0 dBsm). For a given channel, the reference power level is for the reference signal vector (v_CH_REF) and for the scatterer located at the SRP_REF = SRP(v_CH_REF) position.

For a given channel, the reference power level is denoted PT_REF. For a signal array in the FX domain, the reference power level is the power at center frequency fx_C(v_CH_REF) and is constant across retained bandwidth FX_BW(v_CH_REF). For a signal array in the TOA domain, the reference power level is the power at the peak of the compressed signal mainlobe at ΔTOA = 0. The reference power level includes all system losses and gains. The reference power level also includes the effects of the two-way propagation loss due to the troposphere. The reference power level may be used to predict the signal levels for a 0 dBsm ideal scatterer located at any point in the imaged scene. The signal model used to predict signal amplitude and power levels is described in Section 4.6.

7.2.10 Noise Level Parameters

For SAR sensors and data processing systems that are receive gain calibrated, the compensated PHD signal arrays may be formed such that the absolute thermal noise level is known and constant for all signal vectors. For each data channel, the thermal noise power level may be included in the Channel / Parameters / NoiseLevel branch of the XML instance. The noise level parameters may be included for collections and signal arrays that meet the following conditions.

(1) The collection used a fixed receiver configuration for all received echoes that were used to form the signal array.

(2) The variation in receiver gain, if any, during the collection was after the initial amplification circuitry (e.g. after the first Low Noise Amplifier (LNA) in the RF signal path) and was compensated as part of the gain compensation. The noise power signal has constant statistics for all vectors.

(3) The signal array is formed such that for all vectors, parameters fx_1 and fx_2 are constant.

(4) The signal array is formed such that for all vectors, parameters ΔTOA_1, ΔTOA_2, ΔTOA_E1, and ΔTOA_E2 are constant. For all vectors, the TOA swath and the extended TOA swath are fixed.

The noise level parameters include the noise power, PN_Ref, and a noise bandwidth, BN_Ref. The noise power PN_Ref is the expected value of the thermal noise signal power. For a signal array in the FX domain, PN_Ref is the noise power at frequency fx = fx_C. For signal arrays in the TOA domain, PN_Ref is the noise power at ΔTOA = 0 (i.e. the noise level in sample with the SRP peak signal). The noise signal bandwidth is expressed as a fraction of the sample bandwidth and, for all cases, is on the interval $0 < \text{BN\_Ref} \leq 1.0$. The noise signal bandwidth is an indication of the sample-to-sample correlation of the noise signal. For a value of BN_Ref = 1.0, the noise signal is uncorrelated sample to sample (i.e. typically referred to as white noise).

The noise signal parameters are for a simple model that may be used to estimate noise power values in the SAR images that may be formed from the signal arrays. For the noise signal in each vector, the power spectral density is modelled as a constant level, SN_Ref, over the noise bandwidth BN_Ref. The value of SN_Ref is computed from PN_Ref and BN_Ref as shown.

$$\text{SN\_Ref} = \frac{1}{\text{BN\_Ref}} \bullet \text{PN\_Ref}$$

Shown in Figure 7-7 is an example of a FX domain signal vector for which the noise level parameters are provided. The power level and signal bandwidth are for the signal samples centered at fx = fx_C. For the example shown, the noise power is constant across the vector. Shown in the right half of the figure is the noise power spectral density with a constant level

SN_Ref and bandwidth BN_Ref. For BN_Ref = 0.8, the spectral density spans 80% of the sample bandwidth of 1/fx_SS and is centered at 0.

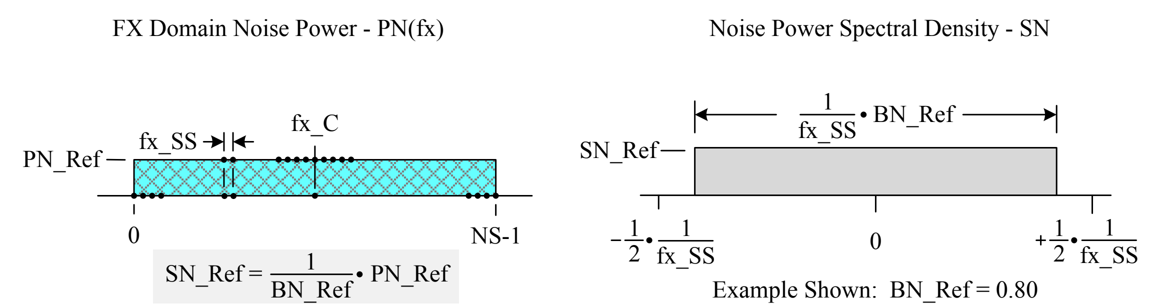


Figure 7-7 FX Domain Noise
Example FX domain of noise level, PN_Ref, and noise bandwidth, BN_Ref.

Shown in Figure 7-8 is an example of a TOA domain signal vector for which the noise level parameters are provided. The power level and signal bandwidth are for the signal samples centered at ΔTOA = 0. For the example shown, the noise power is constant across the vector. Shown in the right half of the figure is the noise power spectral density for a constant level SN_Ref and bandwidth BN_Ref. For BN_Ref = 0.5, the spectral density spans 50% of the sample bandwidth of 1/ΔTOA_SS and is centered at 0.

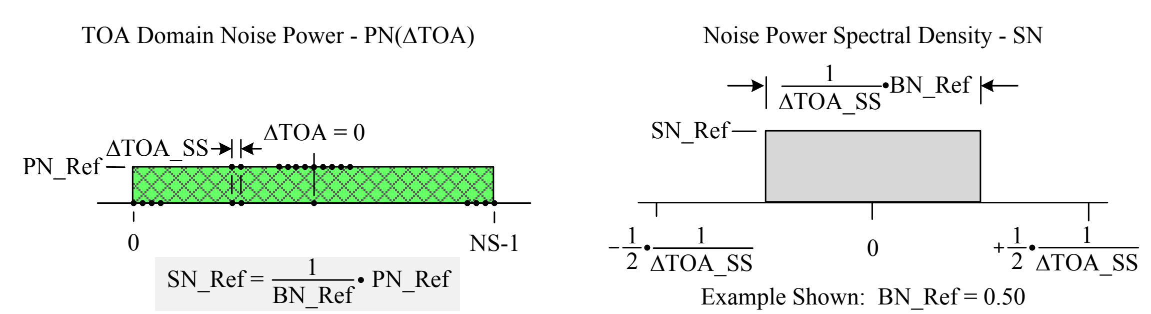


Figure 7-8 TOA Domain Noise
Example FX domain of noise level, PN_Ref, and noise bandwidth, BN_Ref.

The optional AddedParameters branch provides flexibility in the design of a CPHD product. The repeatable Parameter node can be used to supply metadata not foreseen by the XML structure or to provide additional detail for any of the defined metadata parameters.

7.3 Dwell Parameters

The Dwell parameters specify how each channel may be used to form a SAR image of the scene. The parameters are in the form of polynomials that map scene position to the dwell period used to form the image pixel at the scene point. The Dwell parameters are specified in the CPHD / Dwell branch of the XML structure. See Table 11-8. For a given product, they include one or more COD Time polynomials and one or more Dwell Time polynomials. For a product that contains multiple data channels, a unique COD Time polynomial and/or a unique Dwell Time polynomial may be provided for each data channel.

7.3.1 Dwell Polynomials Description

The dwell polynomials map a scene position to a dwell period to be used to form the image pixel of the point. The scene points are located on the image reference surface. The positions are specified in coordinates IAX and IAY. See Section 6.1 and 6.2. For any point, the dwell period is defined by the COD Time, t_COA, and the duration of the dwell period, T_Dwell.

The COD Time polynomial maps a position in (IAX, IAY) to the COD time, t_COD(IAX, IAY). The COD Time is in seconds from Collection Start. The initial COD Time polynomials naturally follow from the collection geometry, transmit waveform and receive window. However, subsequent processing can change the COD if vectors are discarded or spatial filtering of the signal array is performed.

$$\text{t\_COD}(\text{IAX},\text{IAY}) = \sum_{m=0}^{\text{COD\_ORDER1}} \sum_{n=0}^{\text{COD\_ORDER2}} \text{cTCOD}(m,n) \bullet (\text{IAX})^m \bullet (\text{IAY})^n$$

The Dwell Time polynomial maps a position (IAX, IAY) to the Dwell time duration, T_Dwell(IAX, IAY). The dwell time duration is in seconds and is centered on the COD time. The initial Dwell Time polynomials naturally follow from the collection geometry, transmit waveform and receive window. As with the COD Time polynomials, subsequent processing can change the Dwell Time polynomial if vectors are discarded or spatial filtering of the signal array is performed.

$$\text{T\_Dwell}(\text{IAX},\text{IAY}) = \sum_{m=0}^{\text{DT\_ORDER1}} \sum_{n=0}^{\text{DT\_ORDER2}} \text{cDTIME}(m,n) \bullet (\text{IAX})^m \bullet (\text{IAY})^n$$

7.3.2 Dwell Polynomials Examples

The simplest imaging mode with respect to COD Time and Dwell Time polynomials is spotlight as shown in Figure 1-2. In such a scenario, the entire imaged scene is illuminated by the transmit and receive beams for the entire collect duration. The result is that the COD Time and Dwell Time polynomials are trivial constants. For a spotlight collection, where t_Ref(0) and t_Ref(NV_CH-1) are the earliest and latest reference times for the signal arrays, the coefficients would be computed as shown.

$$\text{cTCOD}(0,0) = \frac{1}{2} \bullet \left(\text{t\_Ref(NV\_CH-1)} + \text{t\_Ref}(0) \right)$$

$$\text{cDTIME}(0,0) = \text{t\_Ref(NV\_CH-1)} - \text{t\_Ref}(0)$$

Another common imaging mode is a stripmap as shown in Figure 1-1. In this type of imaging scenario, only a portion of the imaged scene is illuminated by the transmit and receive beams at a given time. The beams are scanned along the reference surface at a constant rate (ScanRate) so that the time duration spent imaging any point is the constant. This results in a constant dwell time (T_Dwell) and a 1^{st} order COD Time polynomial whose linear term depends on the scan rate. For this type of stripmap collection:

$$\text{cTCOD}(0,0) = \text{t\_COD\_IARP} \qquad \text{cTCOD}(1,0) = \frac{1}{\text{ScanRate}}$$

$$\text{cDTIME}(0,0) = \text{T\_Dwell}$$

7.3.3 Full Aperture SAR Image

For each data channel, the image area supported by the channel is defined as described in Section 6.3. The Channel / Parameters / Dwell Time branch of the XML structure identifies the COD Time polynomial and the Dwell Time polynomial that are supported by the channel signal array. For the image area supported by the channel, the COD Time and Dwell Time polynomials define the full aperture SAR image that may be formed from the channel signal array.

For a point PT in the image area for a given channel, the full aperture SAR image pixel is defined as follows. Point PT is located at position (PT_IAX, PT_IAY, 0) in the Image Area Coordinate frame. The coordinates PT_IAX and PT_IAY are expressed in meters.

(1) For point PT, the COD Time is computed from the COD Time polynomial for the given channel. Time t_COD_PT is in seconds.

$$\text{t\_COD\_PT} = \sum_{m=0}^{\text{COD\_ORDER1}} \sum_{n=0}^{\text{COD\_ORDER2}} \text{cTCOD}(m,n) \bullet \left(\text{PT\_IAX}\right)^m \bullet \left(\text{PT\_IAY}\right)^n$$

(2) For point PT, the Dwell Time is computed from the Dwell Time polynomial for the given channel. Time T_Dwell_PT is in seconds.

$$\text{T\_Dwell\_PT} = \sum_{m=0}^{\text{DT\_ORDER1}} \sum_{n=0}^{\text{DT\_ORDER2}} \text{cDTIME}(m,n) \bullet \left(\text{PT\_IAX}\right)^m \bullet \left(\text{PT\_IAY}\right)^n$$

(3) Compute aperture start time t_PT1 and aperture end time t_PT2.

$$\text{t\_PT1} = \text{t\_COD\_PT} - \frac{1}{2} \bullet \text{T\_Dwell\_PT}$$

$$t\_PT2 = t\_COD\_PT + \frac{1}{2} \bullet T\_Dwell\_PT$$

(4) For the given data channel, determine the signal vector index values v_PT1 and v_PT2 as follows. For each vector, the reference time t_Ref(v) is computed as defined in Section 4.3.

(a) Vector v_PT1 is the first vector for which t_Ref(v_PT1) ≥ t_PT1.

(b) Vector v_PT2 is last vector for which t_Ref(v_PT2) ≤ t_PT2.

(5) For all vectors from v = v_PT1 to v_PT2, the full bandwidth echo for point PT is supported by the signal array. For vector v, the full bandwidth echo is from fx_1(v) to fx_2(v).

(6) For the full aperture image, the pixel for scene point PT is formed by the coherent summation of the signal array from v_PT1 to v_PT2. For each signal vector, the signal data from fx_1(v) to fx_2(v) is phase compensated to set the signal for point PT to a constant phase.

8 Radar Collection Parameters

This section summarizes optional radar specific parameters that may be provided with a given product. These parameters allow the producer of the CPHD product to describe the transmit waveform, the manner in which it was demodulated and sampled, and the antenna(s) used during transmission and reception.

8.1 Transmit & Receive Parameters

CPHD provides support for describing the details of the collection's transmit waveform(s) and receive window(s). There are many collection paradigms that could result in multiple transmit waveforms and their corresponding receive windows. Most prominent among these are orthogonal phase codes and step chirp pulse sequences.

The basics of a transmit waveform are captured by the four required parameters—pulse length (PulseLength), bandwidth (RFBandwidth), center frequency (FreqCenter), and polarization (Polarization). The optional chirp rate parameter (LFMRate) should be included if the waveform is a linear frequency modulation chirp (LFMC). The relationship of the metadata parameters to the transmit waveform is depicted in Figure 8-1.

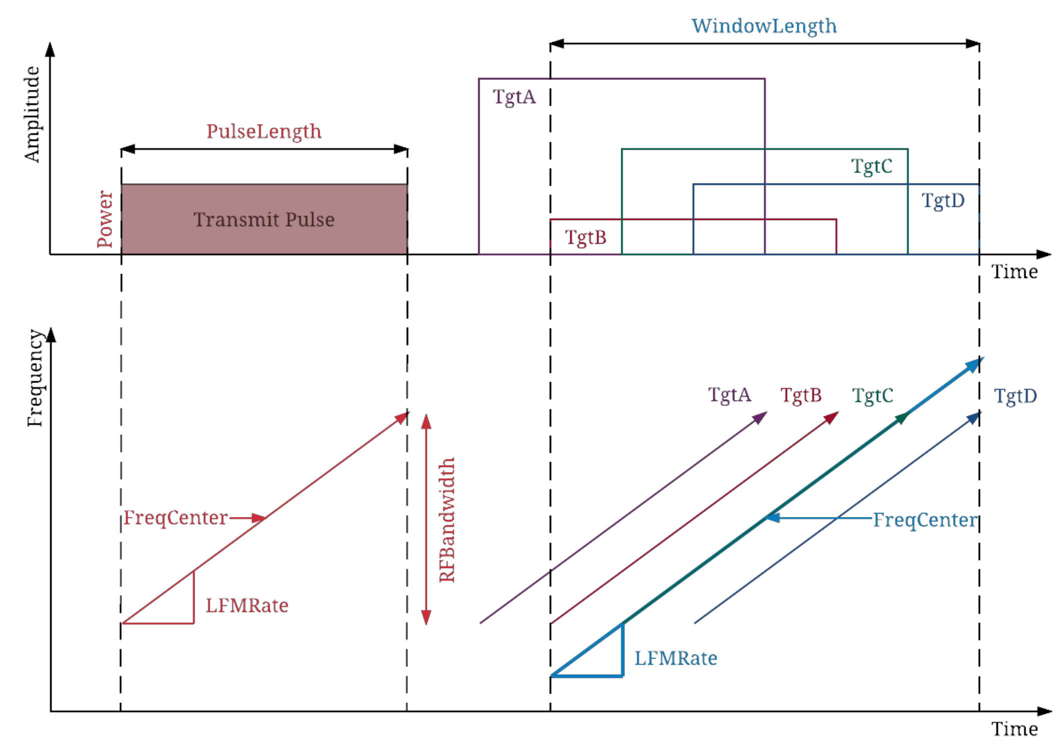


Figure 8-1 Transmit Waveform and Receive Window for LFM
Diagram showing the time vs power and frequency for 4 targets.

The receive window is described by five required parameters—window length (WindowLength), sample rate (SampleRate), filter bandwidth (IFFilterBW), center frequency (FreqCenter), and polarization (Polarization). Figure 8-1 shows how two of these parameters along with the optional demodulation chirp rate (LFMRate) describe the demodulation signal for an LFMC.

The impact of the other two parameters—sample rate and filter bandwidth—is shown in Figure 8-2 below. Targets B, C, & D are fully captured by the receive window and post-demodulation passband. Target A is closer to the scene and arrives too early to be fully captured by the receive window. Additionally, while the sample rate is high enough to capture Target A's signal unaliased, its post-demodulation frequency is outside the anti-aliasing filter's passband. Its echo is at least attenuated and likely phase distorted.

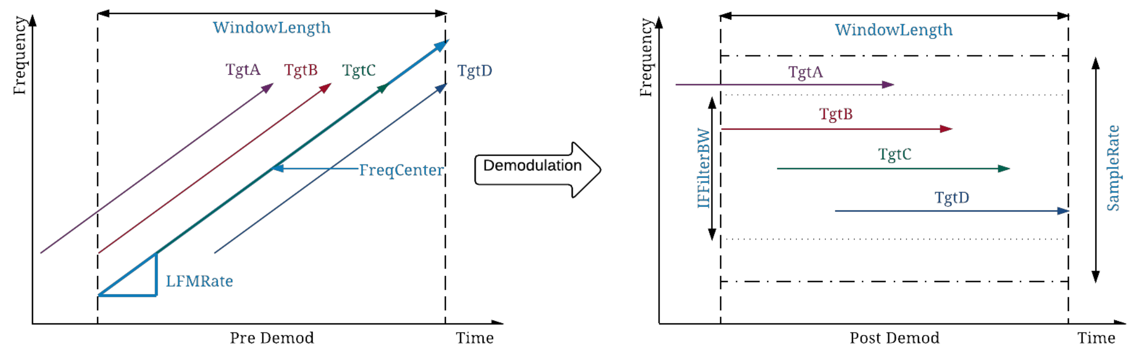


Figure 8-2 Receive Window Details for LFM Chirp
Diagram showing time vs frequency pre and post demodulation.

The transmit waveform and receive descriptions each contain an optional parameter that deals with signal power. The peak transmit power (TxWF / Power) is used to describe the peak transmit power at the antenna interface. The receiver path gain (Rcv / PathGain) is used to describe the total gain the signal will experience after the antenna interface. The PathGain includes both the analog signal gain from the antenna reference point to the A/D converters and the processing gain applied in in compensation processing.

This power/gain segmentation of the radar payload is depicted for a monostatic collect with a single antenna in Figure 8-3. Note that the antenna interface is the same for the transmit and receive signal paths. This means that the output power intensity along the boresight is a combination of the peak transmit power and absolute antenna boresight gain (GainZero). The boresight GainZero is a combination of the aperture efficiency and the boresight directivity. The total gain on receive is a combination of the receiver path gain and the absolute antenna gain. Given the optional parameters of transmit power, receiver path gain, absolute gain for the antenna(s), and the involved geometry, power intensity at the scene and of the observed echoes can be derived. For a bistatic collection, the transmit and receive antennas are separate and, in general, will have unique boresight gain values. Figure 8-4 shows an example bistatic system.

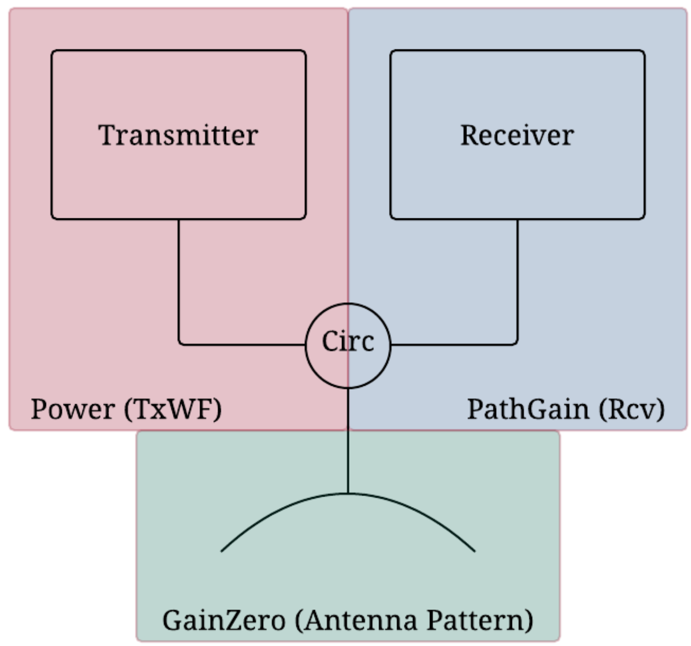


Figure 8-3 Monostatic Transmitter, Receiver, and Antenna Subsystems
Diagram showing a notional block diagram for a monostatic radar system.

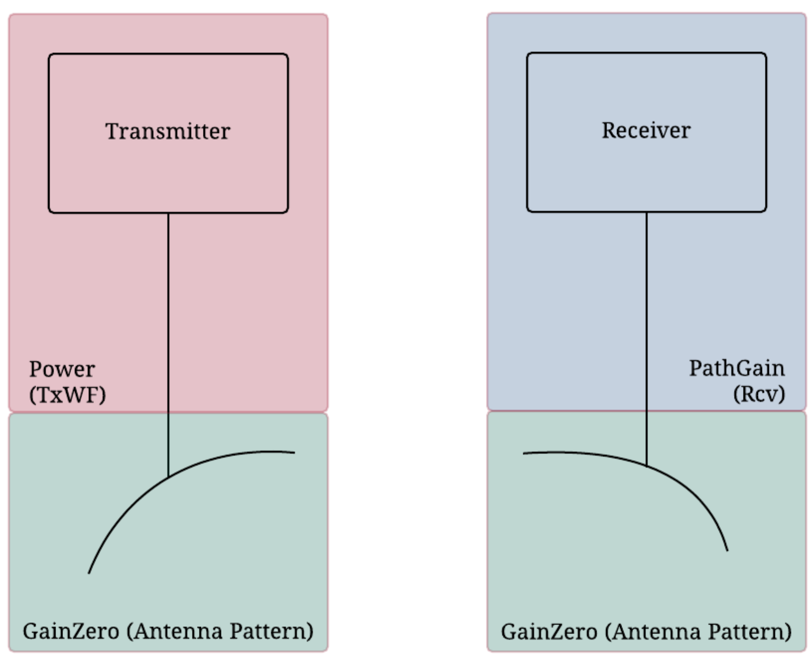


Figure 8-4 Bistatic Transmitter, Receiver, and Antenna Subsystems
Diagram showing a notional block diagram for a bistatic radar system.

8.2 Antenna Parameters

CPHD provides support for describing the antenna(s) used during collection. Antenna parameters that may be specified include their coordinate frame, position within that frame and the gain and phase pattern of the antenna. These parameters may be included within the Antenna branch of an XML instance included in the XML block.

There are three pieces that together define an antenna's position in space and its gain and phase pattern:

(1) Antenna Coordinate Frame (ACF)

(2) Antenna Phase Center (APC)

(3) Antenna Pattern (APAT)

An Antenna Coordinate Frame (ACF) is a coordinate system defined by its X and Y axes. These are specified as a function of time in an XYZ polynomial. The Z axis is not specified and is understood to be orthogonal to both X and Y. A monostatic collection with a single antenna, such as a phased array antenna (PAA) or parabolic dish would have a single ACF. See Figure 8-5. A bistatic collection, having two antennas with independent orientation, would have at least two ACFs as shown in Figure 8-6.

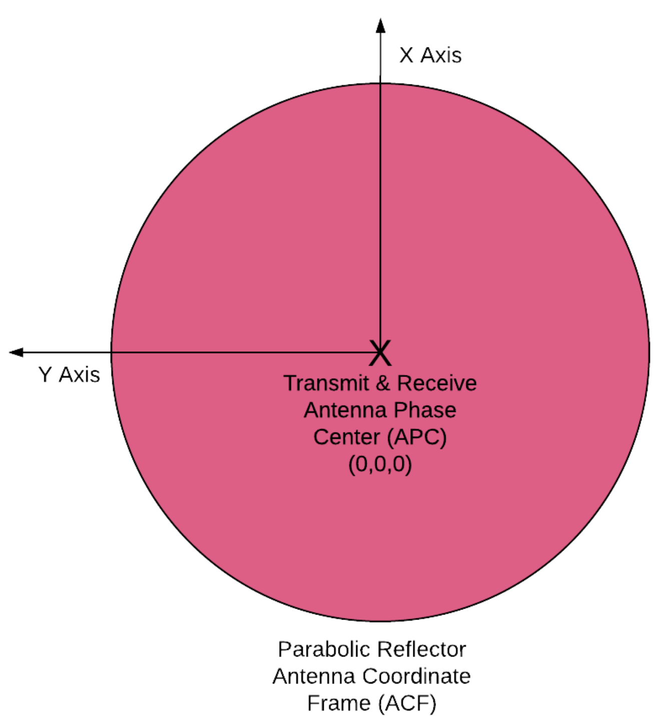


Figure 8-5 Single Parabolic Reflector ACF & APC
Diagram showing the simplest possible CPHD Antenna.

The Antenna Phase Center (APC) is a relative position in one of these coordinate frames. This allows a straightforward way to specify that while the baseline between two APCs may rotate during the collect, their displacement from each other remains constant within their ACF. Sensors expected to make use of this are PAAs with multiple phase centers or any other system with multiple phase centers that are structurally tied together. See Figure 8-7.

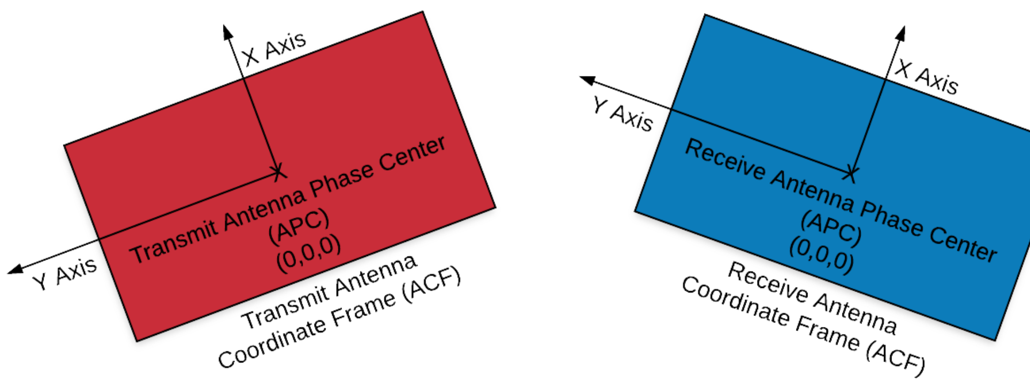


Figure 8-6 Bistatic Collection Antennas

Diagram showing a bistatic collection with two ACFs and their associated APCs.

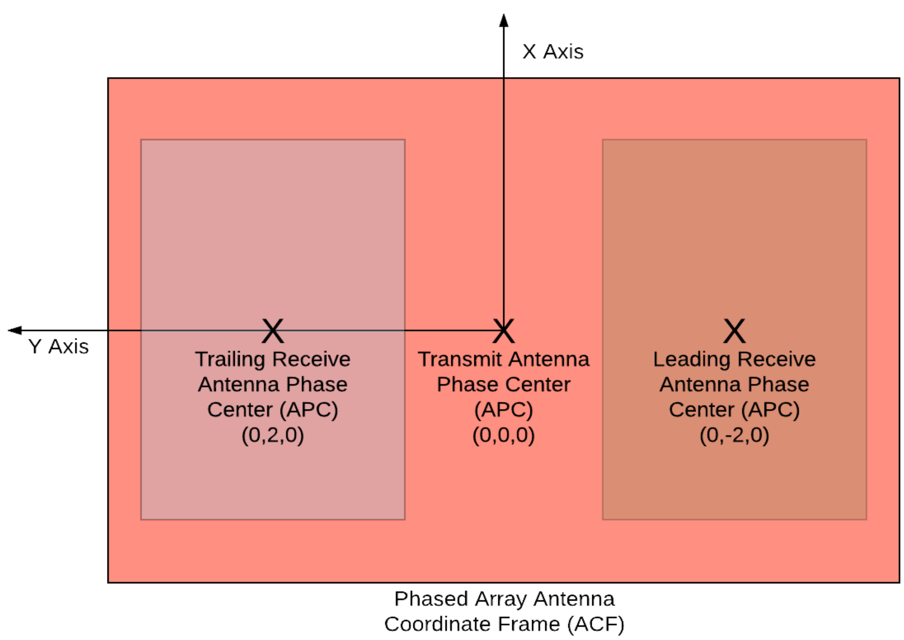


Figure 8-7 Multiple Phase Center PAA

Diagram showing a monostatic collection with multiple receive APCs in a single ACF.

An Antenna Pattern (APAT) specifies the gain and phase characteristics of an antenna. Most of the parameters in the AntPattern node describe the pattern mainlobe, but the sampled sidelobe pattern may be described in an AntGainPhase Support array. When antenna information is provided in the XML Channel / Parameters node, the transmit and receive APCs and APATs are specified. This is because the APCs and APATs are not one-to-one.

To illustrate this point, a PAA with three APCs is shown in Figure 8-7. A CPHD product made from such a sensor might have two channels of data, one from each receive APC. In such a case, the two channels will have the same identifier for the transmit antenna phase center (TxAPCId) and antenna pattern (TxAPATId). The two channels will have different receive antenna phase center identifiers (RcvAPCId) but will share a common receive antenna pattern identifier (RcvAPATId) as their extents on the phased array are identical and they are steered in the same direction.

For a monostatic collection, the transmit and receive antennas may have a common APC but have unique antenna patterns. Shown in Figure 8-8 is a PAA with a single APC used for both transmit and receive. The receive beam is formed using a slightly smaller portion of the array than used to form the transmit beam. The apertures will have a common phase center (APC) and unique patterns (APATs).

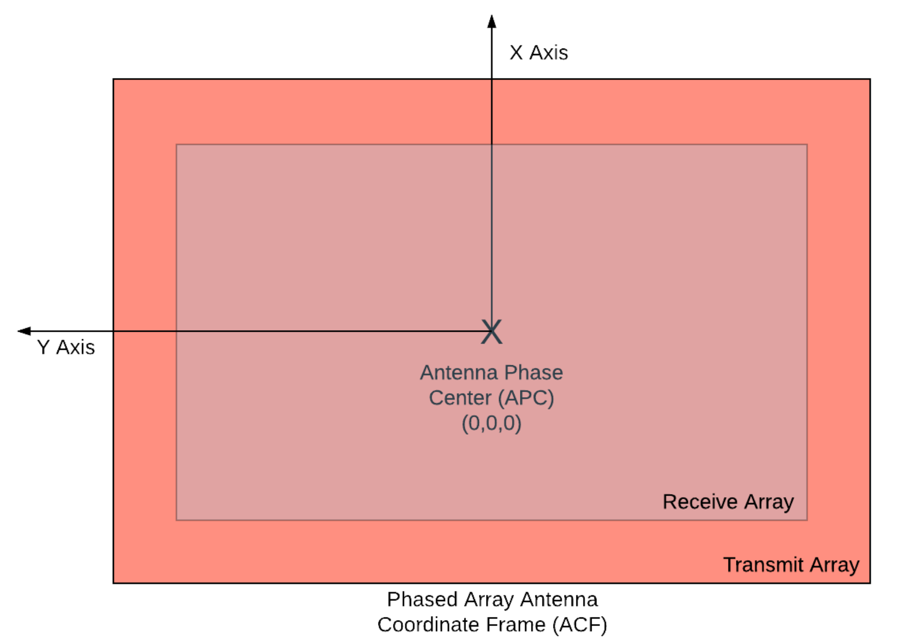


Figure 8-8 Single Phase Center PAA
Diagram showing a single receive APC with multiple associated APATs.

Equations detailing how to compute the ACF orientation and the APAT gain and phase patterns at given time are described in the SICD Design & Implementation Description Document, NGA.STND.0024-1.

9 Error Parameters

For any CPHD product, an optional set of metadata parameters may be included that are the error statistics for parameters that describe the collection and/or are used in the compensation processing to form the product. The set of parameters are included in the CPHD / ErrorParameters branch of the XML instance. See Table 11-12. The optional parameters are the expected statistics for the primary sources of error that lead to geolocation errors in a SAR image that is formed from the CPHD product. The error parameters support both monostatic and bistatic SAR imaging collections.

For a monostatic collection, the ErrorParameters / Monostatic branch is included in the XML instance. The Monostatic parameters include the expected statistics for errors in the estimated platform position and velocity, errors in the radar sensor timing, and errors in the estimated propagation delays. Monostatic SAR imaging systems are routinely designed such that the output SAR map products have precisely located pixel grids. The error statistics included in the CPHD product may be used to compute the expected statistics for the errors in geolocation estimates derived from the map products formed from the signal arrays.

For a bistatic collection, the ErrorParameters / Bistatic branch is included in the XML instance. The bistatic parameters include the expected error statistics for both the transmit platform and the receive platform. For each platform, the parameters include the statistics for errors in the estimated platform position and velocity and errors in the radar sensor timing. A bistatic SAR imaging system will include one or more methods to achieve accurate time synchronization between transmit and receive platforms. For a bistatic CPHD product, the error statistics include the expected accuracy of the time synchronization that was achieved when the compensation processing was performed. For a bistatic system, errors in time synchronization are typically the dominate source of geolocation error in the bistatic SAR image products.

9.1 Monostatic Error Parameters

For a monostatic CPHD (Collect Type = MONOSTATIC), the expected statistics are provided for the primary sources of geolocation error in the SAR map products. The statistics are provided for three types of errors.

Position & Velocity Errors

The elements of the position and velocity covariance matrix are included. The variance parameters (i.e. the terms along the main diagonal) 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.

Radar Sensor Errors

The primary error sources associated with the radar sensor are a range bias and an error in the radar timing clock frequency. The error in estimated collection start time may be included but is not required.

Propagation Model Errors

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

9.2 Bistatic Error Parameters

For a bistatic CPHD (Collect Type = BISTATIC), the expected statistics are provided for the transmit platform and the receive platform. The statistics are provided for two types of errors.

Position & Velocity Errors

The elements of the position and velocity covariance matrix are included. The variance parameters (i.e. the terms along the main diagonal) 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.

Radar Sensor Errors

For bistatic imaging, the error in geolocation is often dominated by the time synchronization error between transmit and receive platforms. For each platform, the expected statistics for the error in estimated collection start time is provided. Also provided are the expected statistics for the error in the radar payload clock frequency that leads to errors in the estimated transmit frequency and/or the estimated receive demodulation frequency.

10 CPHD XML Description

The CPHD XML structure is expressed using the eXtensible Markup Language (XML), Version 1.0. The XML structure is composed of required parameters, optional parameters and choice parameters. The defined set of parameters allows for a full description of the CPHD signal arrays and how they were collected and processed. Also provided is a method for including "added" or program specific parameters. The program specific parameters are defined per a program specific Product Design Document. See Section 3.

10.1 XML Parameter Types

The XML structure is composed of the parameter types listed in Table 10-1. These parameter types are formally defined in the CPHD XML schema that is also part of this standard. The parameter types listed in Table 10-1 are for convenience.

For reference: http://www.w3.org/TR/2004/REC-xmlschema-2-20041028

Table 10-1 XML Parameter Types

Type	Description	Guidance
TXT	Value is a string of text characters. See Datatype "string".	
ENU	Value can be a string of characters or an integer. For each ENU, a set of allowed values is specified. Integer values are specified in decimal format.	The list of allowed values specified uniquely for each parameter.
BOOL	Value is a Boolean with the usual range of values. Allow values are: "true" and "false" or "1" and "0" where 1 = true and 0 = false.	Encourage the use of true & false for clarity. Discourage the use of 1 & 0.
XDT	Value is a date and time in the XML dateTime format. See XML Datatype dateTime. The dateTime format is: YYYY-MM-DDThh:mm:ss.s+Z The fields are as follows: (1) YYYY specifies the year, (2) MM specifies the month, 01 to 12, (3) DD specifies the day of the month, 01 to 31, (4) "T" separates the date and time fields, (5) hh specifies the hour, 00 to 23, (6) mm specifies the minute, 00 to 59, (7) ss specifies the second, 00 to 59, and (8) s+ specifies fractional seconds.	All CPHD date and time parameters are specified in UTC (Coordinated Universal Time). The trailing "Z" indicates the value is in UTC. The decimal point & fractional seconds may be omitted. Any number of fractional second digits may be included. The number of digits included DOES NOT indicate the accuracy of the date-time value. Accuracy specified per program specific Product Design Document.
INT	Value is an integer in decimal format. Values may be positive, negative or zero. Value can be accurately stored in binary INT32 variable.	
DBL	Value is real-valued decimal number. See XML Datatype "double". Values may be accurately stored in an IEEE binary 64-bit floating point variable.	For CPHD, all values written with 17 digits of precision: ±x.xxxxxxxxxxxxxxxxE±xx

Table 10-1 XML Parameter Types		
Type	**Description**	**Guidance**
HEX	Value is a hexadecimal representation of an integral number of bytes. See XML type xs:hexBinary	
LS	Identifies a parent tag with children Line and Sample. The children are each of type DBL.	Use for specifying a location in a 2-D array indexed by Line and Samp.
XY	Identifies a parent tag with children X and Y. The children are each of type DBL. All components have the same units.	Use for specifying 2 component vector parameters (e.g. positions in ECF coordinates).
XYZ	Identifies a parent tag with children X, Y, and Z. The children are each of type DBL. All components have the same units.	Use for specifying a 3 component vector parameters (e.g. positions in ECF coordinates). All components have the same units.
LL	Identifies a parent tag with children Lat and Lon. The children are each of type DBL. All components have the same units.	Use for specifying a 2 component position in earth coordinates. For CPHD, all LL values are in WGS 84 geodetic coordinates.
LLH	Identifies a parent tag with children Lat, Lon, and HAE. The children are each of type DBL.	Use for specifying a 3 component position in earth coordinates. For CPHD, all LLH values are in WGS 84 geodetic coordinates.
POLY	Identifies a parent tag with one or more children Coef. The children are each of type DBL. The children contain the coefficients of a 1-D polynomial. The order of the polynomial is specified by parent tag attribute “order1”. The order of each coefficient is specified by the attribute “exponent1”. Coefficients that are zero may be omitted.	Use for specifying the coefficients of a 1-D polynomial. Example: Let M = order1 and c(m) = Coef w/ exponent1 = m. The input variable is Var1. The output parameter is Z(Var1): $Z(\mathrm{Var1}) = \sum_{m=0}^{M} c(m) \bullet (\mathrm{Var1})^m$
2D_POLY	Identifies a parent tag with one or more children Coef. The children are each of type DBL. The children contain the coefficients of a 2-D polynomial. The orders of the polynomial are specified by parent tag attributes “order1” and “order2”. The order of each coefficient is specified by the attributes “exponent1” and “exponent2”. Coefficients that are zero may be omitted.	Use for specifying the coefficients of a 2-D polynomial. Example: Let M = order1, N = order 2 and coefficient c(m,n) = Coef w/ exponent1 = m and exponent2 = n. The input variables are Var1 and Var2. The output parameter is Z(Var1,Var2): $Z(\mathrm{Var1},\mathrm{Var2}) = \sum_{m=0}^{M}\sum_{n=0}^{N} c(m,n) \bullet (\mathrm{Var1})^m \bullet (\mathrm{Var2})^n$

Table 10-1 XML Parameter Types

Type	Description	Guidance
XYZ_POLY	Identifies a parent tag with children X, Y, and Z. The children are each of type POLY. Each child has attribute "order1". Component polynomials may have unique orders. All components have the same units.	Use for specifying a 3 component vector that is a function of a single variable (e.g. a position in ECF coordinates vs. time). Example: Let MX = X order1, MY = Y order1 and MZ = Z order1. Let cx(m), cy(m) and cz(m) be the coefficients of the X, Y and Z polynomials. The input variable is Var1. The output is vector **V**(Var1): $\mathbf{V}(\mathrm{Var1}) = \begin{bmatrix} \mathrm{X(Var1)} \\ \mathrm{Y(Var1)} \\ \mathrm{Z(Var1)} \end{bmatrix}$ $\mathbf{V}(\mathrm{Var1}) = \begin{bmatrix} \sum_{mx=0}^{MX} c(mx) \bullet (\mathrm{Var1})^{mx} \\ \sum_{my=0}^{MY} c(my) \bullet (\mathrm{Var1})^{my} \\ \sum_{mz=0}^{MZ} c(mz) \bullet (\mathrm{Var1})^{mz} \end{bmatrix}$
PVP	Identifies a parent tag with children Offset, Size and Format. Offset and Size are type INT. Format is type TXT. Binary formats are specified per the guidance in Table 10.2.	Use for specifying a defined Per Vector Parameter. Size and Offset specify the size and placement of the binary parameter in the set of Per Vector parameters provided for each vector. Format specifies the binary format of the components of the parameter.
APVP	Identifies a parent tag with children Name, Offset, Size and Format. Size and Offset are type INT. Name and Format are type TXT.	Use for specifying an Added Per Vector Parameter. The value of Name identifies the Added PVP parameter. Use of Size, Offset and Format are the same as for defined PV Parameters (See PVP type above).

10.2 Binary Parameter Formats

The allowed binary formats are listed in Table 10-2.

Table 10-2 Allowed Binary Formats	
Binary data formats for Support Arrays and Per Vector Parameters.	
Format Strings	**Description & Guidance**
Unsigned Integer “U1”, “U2”, “U4”, “U8”	Unsigned integer (UINT) of size n bytes. Allow sizes n = 1, 2, 4, and 8 bytes.
Signed Integer “I1”, “I2”, “I4”, “I8”	Signed integer (INT) of size n bytes. Allowed sizes n = 1, 2, 4, and 8 bytes. Integer in 2’s complement form.
Floating Point “F4”, “F8”	Floating point format (FLT) of size n bytes. Allow sizes n = 4 and 8 bytes. Floating point formats are IEEE Binary32 or Binary64.
Complex Signed Integer “CI2”, “CI4”, “CI8”, “CI16”	Complex number formed from two signed integer format numbers, each signed integer of size n/2 bytes. Allowed sizes n = 2, 4, 8 and 16. Real and imaginary components in adjacent bytes with real component stored first, imaginary component stored second. CI2 = 2 Bytes, CI4 = 4 Bytes, CI8 = 8 Bytes, CI16 = 16 Bytes.
Complex Floating Point “CF8”, “CF16”	Complex number formed from two floating point format numbers, each floating point of size n/2 bytes. Allowed sizes n = 8 and 16. Real and imaginary components in adjacent bytes with real component stored first, imaginary component stored second. CF8 = 8 Bytes, CF16 = 16 Bytes.
Strings “S[1-9][0-9]*”	String of size n. Allowed sizes n > 0. S5 = 5 Bytes, S30 = 30 Bytes.
Multiple Parameters	Used to specify data elements that are formed from 2 or more parameters. Individual parameters may be of any allowed format. Each element is described by “<name>=<format_string>;” The multiple parameter format string comprises at least two of these concatenated together. For example: “A=U2;B=I2;C=F4;D=CF8;E=S32;”

10.3 XML Enumeration List

The enumerations used in the XML structure and the allowed values are listed in Table 10-3. The allowed values are defined in the CPHD XML schema.

Table 10-3 XML Enumerations

Enumeration	Allowed Values
CollectType	"MONOSTATIC" and "BISTATIC"
ModeType	"SPOTLIGHT", "STRIPMAP", and "DYNAMIC STRIPMAP"
DomainType	"FX" and "TOA" FX: Transmit Frequency TOA: Time of Arrival.
SGN	"+1" and "-1"
RefHeight	"IARP" and "ZERO"
EarthModel	"WGS84" All CPHD products use the WGS 84 reference ellipsoid.
SignalArrayFormat	"CI2", "CI4", and "CF8"
Polarization	"X", "Y", "V", "H", "RHC", "LHC", and "UNSPECIFIED"
SideOfTrack	"L" and "R"
Frame	"ECF", "RIC_ECF", and "RIC_ECI"

11 CPHD XML Structure

The CPHD XML structure is described in the Tables 11-1 through 11-15 below.

Table 11-1 Collection Identification						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
CPHD.CollectionID	R		1	General information about the collection.		
CollectorName	R	TXT	1	Radar platform identifier. For Bistatic collections, list the Receive platform.		Allowed values specified per Product Design Document.
IlluminatorName	O	TXT	1	Transmit platform identifier for Bistatic collections.		Allowed values specified per Product Design Document.
CoreName	R	TXT	1	Collection data set identifier that uniquely identifies imaging collection.		Allowed values specified per Product Design Document.
CollectType	R	ENU	1	For Monostatic collections, all transmitted and received signals from a single platform. For Bistatic collections, all transmitted signals from one platform and all received signals from one separate platform.		Allowed values: “MONOSTATIC” and “BISTATIC” See Table 10-3.
RadarMode	R		1			
ModeType	R	ENU	1	SAR imaging Mode Type.		Allowed values: “SPOTLIGHT”, “STRIPMAP” and “DYNAMIC STRIPMAP” See Table 10-3.
ModeID	O	TXT	1	SAR system specific mode identifier or mode name.		Allowed values specified per Product Design Document.
Classification	R	TXT	1	Text field containing human-readable banner. Classification, file control & handling, including proprietary markings. Value also included in product file header. See Table 2-1.		Allowed values specified per Product Design Document. Default value: “UNCLASSIFIED”
ReleaseInfo	R	TXT	1	Text field containing product release information. Value also included in product file header. See Table 2-1.		Allowed values specified per Product Design Document. Default value: “UNRESTRICTED”
CountryCode	O	TXT	1	List of country codes for region covered by the collection. Use comma separated values for multiple country codes.		List of Country Codes specified per Product Design Document.

Table 11-1 Collection Identification							
Field Name		**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
	Parameter	O	TXT	1+	Text field that may be included per Product Design Document.		Attribute: name = “xxx” identifies the parameter.

Table 11-2 Global Parameters								
Field Name			**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
CPHD.Global			R		1	Global parameters that apply to metadata components and CPHD signal arrays.		
	DomainType		R	ENU	1	Indicates the domain represented by the sample dimension of the CPHD signal array(s). FX Domain: Transmit Frequency TOA Domain: Difference in Time Of Arrival		Allowed values: "FX" and "TOA" See Table 10-3.
	SGN		R	ENU	1	Phase SGN applied to compute target signal phase as a function of target ΔTOA^{TGT}. Target phase in cycles. For simple phase model: $Phase(fx) = SGN \times fx \times \Delta TOA^{TGT}$ In TOA domain, phase of the mainlobe peak: $Phase(\Delta TOA^{TGT}) = SGN \times fx\_C \times \Delta TOA^{TGT}$		Allowed values: "+1" and "-1" See Table 10-3.
	Timeline		R		1	Parameters that describe the collection times for the data contained in the product.		
		CollectionStart	R	XDT	1	Collection Start date and time (UTC). Time reference used for times measured from collection start (i.e. slow time t = 0). For bistatic collections, the time is the transmit platform collection start time.	UTC	Resolution provided (i.e. number of decimal places) does NOT imply accuracy.
		RcvCollectionStart	O	XDT	1	Receive only platform collection date and start time.	UTC	Resolution provided (i.e. number of decimal places) does NOT imply accuracy.
		TxTime1	R	DBL	1	Earliest TxTime value for any signal vector in the product. Time relative to Collection Start.	sec	
		TxTime2	R	DBL	1	Latest TxTime value for any signal vector in the product. Time relative to Collection Start.	sec	
	FxBand		R		1	Parameters that describe the FX frequency limits for the signal array(s) contained in the product.		
		FxMin	R	DBL	1	Minimum fx_1 value for any signal vector in the product.	Hz	
		FxMax	R	DBL	1	Maximum fx_2 value for any signal vector in the product.	Hz	

Table 11-2 Global Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	TOASwath		R		1	Parameters that describe the TOA swath limits for the signal array(s) contained in the product.		
		TOAMin	R	DBL	1	Minimum ΔTOA_1 value for any signal vector in the product.	sec	
		TOAMax	R	DBL	1	Maximum ΔTOA_2 value for any signal vector in the product.	sec	
	TropoParameters		R			Parameters used to compute the propagation delay due to the troposphere.		
		N0	R	DBL	1	Refractivity value of the troposphere for the imaged scene used to form the product (dimensionless). Value at the IARP lat and lon.		
		RefHeight	R	ENU	1	Reference Height for the N0 value. IARP ➔ N0 value at the IARP HAE ZERO ➔ N0 value at zero HAE.		Allowed values: "IARP" and "ZERO" See Table 10-3.
	IonoParameters		O		1	Parameters used to compute propagation effects due to the ionosphere.		
		TECV	R	DBL	1	Total Electron Content (TEC) integrated along the Vertical (V) 1 TECU = 10^{16} e^{-}/m^2	TECU	
		F2Height	O	DBL	1	The F2 height of the ionosphere.	m	

Table 11-3 Scene Geographic Coordinates

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.SceneCoordinates	R		1	Parameters that define geographic coordinates for in the imaged scene.		
EarthModel	R	ENU	1	Specifies the earth model used for specifying geodetic coordinates. All heights are Height Above the Ellipsoid (HAE) unless specifically noted.		Allowed value: "WGS84" See Table 10-3.
IARP	R		1	Image Area Reference Point (IARP). The IARP is the origin of the Image Area Coordinates (IAC) Image Area Coordinates are (IAX, IAY, IAZ).		Note: The IARP is ALWAYS on the Reference Surface.
ECF	R	XYZ	1	IARP position in ECF coordinates.	m	Use ECF position for all precise computations.
LLH	R	LLH	1	IARP geodetic coordinates. $-90.0 \le \text{Lat} \le 90.0$, $-180.0 \le \text{Lon} \le 180.0$	dd, dd, m	Note: Lat and Lon in decimal degrees. Height in meters.
ReferenceSurface	R		1	Parameters that define the Reference Surface used for the product.		
The image reference surface is one of two allowed types: PLANAR or HAE. The surface type is specified by including one of the two branches below.						
Planar	C		1	Parameters for SurfaceType = PLANAR		Reference surface is a plane that contains the IARP.
uIAX	R	XYZ	1	Image Area X-coordinate (IAX) unit vector in ECF coordinates. Unit vector **uIAX** is in the +IAX direction.		For stripmap collections, +IAX is ALWAYS in the direction of the scanning footprint.
uIAY	R	XYZ	1	Image Area Y-coordinate (IAY) unit vector in ECF coordinates. Unit vector **uIAY** is in the +IAY direction. Unit vector **uIAZ** points "upward" away from the center of the earth.		Unit vectors **uIAX** and **uIAY** are orthogonal. $\mathbf{uIAX} \bullet \mathbf{uIAY} = 0$ $\mathbf{uIAZ} = \mathbf{uIAX} \times \mathbf{uIAY}$
HAE	C		1	Parameters for SurfaceType = HAE		Reference surface is the surface of constant HAE = IARP_HAE
uIAXLL	R	LL	1	Image coordinate IAX "unit vector" expressed as an increment in latitude and longitude. The precise increment in LL for a 1.0 meter increment in image coordinate value IAX.	rad/m	For stripmap collections, +IAX is ALWAYS in the direction of the scanning footprint.

Table 11-3 Scene Geographic Coordinates

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
uIAYLL	R	LL	1	Image coordinate IAY "unit vector" expressed as an increment in latitude and longitude. The precise increment in LL for a 1.0 meter increment in image coordinate IAY.	rad/m	
ImageArea	R		1	Image Area is defined by a rectangle aligned with Image Area coordinates (IAX, IAY). May be reduced by the optional polygon.		Image Area is a polygon on the Reference Surface.
X1Y1	R	XY	1	Corner of the Image Area Rectangle in Image Area coordinates, (IA_X1, IA_Y1).	m	Image area rectangle: IA_X1 ≤ IAX ≤ IA_X2 IA_Y1 ≤ IAY ≤ IA_Y2
X2Y2	R	XY	1	Corner of the Image Area Rectangle in Image Area coordinates, (IA_X2, IA_Y2).	m	Require: IA_X1 < IA_X2 & IA_Y1 < IA_Y2
Polygon	O		1	Polygon that reduces the full resolution image area within the Image Area Rectangle. Vertices are indexed: n = 1, 2, . . . , NumVertices.		Attribute: size = NumVertices Require NumVertices ≥ 3.
Vertex	R	XY	3+	Image Area Polygon vertex specified in image area coordinates (IAX, IAY). Vertices are in clockwise order.	m	Attribute: index = 1 to NumVertices
ImageAreaCornerPoints	R		1	Set of 4 Image Area Corner Points (IACPs) that bound the full resolution image area. Corner points are indexed: n = 1, 2, 3, 4.		The IACPs are approximate geographic locations and are not intended for analytical use.
IACP	R	LL	4	Corner points located on the Reference Surface. Convert Image Area Rectangle corner positions to LL. Compute IACP(1) from (IA_X1,IA_Y1). Corners in clockwise order. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd	Attribute: index = 1 to 4
ExtendedArea	O		1	Extended Area is defined by a rectangle aligned with Image Area coordinates (IAX, IAY). May be reduced by the optional polygon.		Extended Area is a polygon on the Reference Surface.
X1Y1	R	XY	1	Corner of the Extended Area Rectangle in Image Area coordinates, (EA_X1, EA_Y1).	m	Extended area rectangle: EA_X1 ≤ IAX ≤ EA_X2 EA_Y1 ≤ IAY ≤ EA_Y2

Table 11-3 Scene Geographic Coordinates

Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		X2Y2		R	XY	1	Corner of the Extended Area Rectangle in Image Area coordinates, (EA_X2, EA_Y2).		Require: EA_X1 < EA_X2 & EA_Y1 < EA_Y2
		Polygon		O		1	Polygon that reduces the extended area within the Extended Area Rectangle. Vertices are indexed: n = 1, 2, . . . , NumVertices.		Attribute: size = NumVertices Require NumVertices ≥ 3.
			Vertex	R	XY	3+	Image Area Polygon vertex specified in image area coordinates (IAX, IAY). Vertices are in clockwise order.	m	Attribute: index = 1 to NumVertices
	ImageGrid			O		1	Parameters that describe a geo-referenced image grid for image data products that may be formed from the CPHD signal array(s).		
		Identifier		O	TXT	1	String that uniquely identifies the Image Grid (ImGrid_ID).		Allowed values specified per Product Design Document.
		IARPLocation		R	LS		IARP grid location. Grid locations indexed by (line, sample) or (L,S).		IARP indices not restricted to integer values.
		IAXExtent		R			Increasing line index is in the +IAX direction.		
			LineSpacing	R	DBL	1	Line spacing (L_SP).	m	Require LineSpacing > 0.
			FirstLine	R	INT	1	Index of the first line (IG_L1).		
			NumLines	R	INT	1	Number of Lines.		Require NumLines ≥ 1.
		IAYExtent		R		1	Increasing sample index is in the +IAY direction.		
			SampleSpacing	R	DBL	1	Line spacing (S_SP).	m	Require SampleSpacing > 0.
			FirstSample	R	INT	1	Index of the first line (IG_S1).		
			NumSamples	R	INT	1	Number of Samples.		Require NumSamples ≥ 1.
		SegmentList		O		1	List of 1 or more image grid segments defined relative to the image grid.		

Table 11-3 Scene Geographic Coordinates

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
NumSegments	R	INT	1	Number of image segments. Segments are referenced by their unique Segment ID.		
Segment	R		1+	Each segment is a rectangle from Line = L1 to L2 and from Sample = S1 to S2.		
Identifier	R	TXT	1	String that uniquely identifies the Image Segment (Seg_ID).		
StartLine	R	INT	1	Start line (L1) of the segment.		L1 < L2
StartSample	R	INT	1	Start sample (S1) of the segment.		S1 < S2
EndLine	R	INT	1	End line (L2) of the segment.		
EndSample	R	INT	1	End sample (S2) of the segment.		
SegmentPolygon	O		1	Polygon that describes the portion of the segment rectangle for image formation.		Attribute: size = NumVertices Require NumVertices ≥ 3.
SV	R	LS	3+	Segment Polygon vertex specified in line and sample. Vertices are in clockwise order.	m	Attribute: index = 1 to NumVertices

Table 11-4 Binary Data Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.Data	R		1	Parameters that describe binary data components contained in the product.		
SignalArrayFormat	R	ENU	1	Signal Array sample binary format of the CPHD signal array(s). All arrays in a product are the same sample format. CI2: Each component is a 1 byte signed integer parameter, 2's complement format. 2 Bytes Per Sample CI4: Each component is a 2 byte signed integer parameter, 2's complement format. 4 Bytes Per Sample CF8: Each component is a 4 byte floating point parameter. 8 Bytes Per Sample		Allowed values: "CI2", "CI4" and "CF8". See Table 10-3. For a CPHD product file: (1) The real and imaginary components stored in adjacent bytes, real component stored first. (2) All binary parameters stored in Big Endian format.
NumBytesPVP	R	INT	1	Number of bytes per set of Per Vector Parameters. One set of PVPs for each CPHD signal vector.		
NumCPHDChannels	R	INT	1	Number of CPHD channels (Num_CH) contained in the product. Channels are referenced by their unique Channel Identifier		Allowed values: Num_CH ≥ 1
Channel	R		1+	Parameters that define the Channel signal array and PVP array size and location.		
Identifier	R	TXT	1	String that uniquely identifies the CPHD channel (Ch_ID) for which the data applies.		
NumVectors	R	INT	1	Number of vectors in the signal array, NV_CH. Vectors are indexed: v = 0, 1, 2, 3, . . . , NV_CH (Ch_ID) – 1.		
NumSamples	R	INT	1	Number of samples per vector in the signal array, NS_CH. Samples are indexed: s = 0, 1, 2, 3, . . . , NS_CH (Ch_ID) – 1.		
SignalArrayByteOffset	R	INT	1	Signal Array offset from the start of the Signal block (in bytes) to the start of the Signal Array for the channel.		

Table 11-4 Binary Data Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
PVPArrayByteOffset	R	INT	1	PVP Array offset from the start of the PVP block (in bytes) to the start of the PVP Array for the channel.		
NumSupportArrays	R	INT	1	Number of binary support arrays contained in the product. Set equal to 0 for when Support Arrays are not included. Support Arrays are referenced by their unique Support Array ID.		Allowed values: NumSupportArrays ≥ 0
SupportArray	O		1+	Support Array size parameters. Branch repeated for each binary support array. Support Array referenced by its unique Support Array identifier (SA_ID).		
Identifier	R	TXT	1	Unique string that identifies this support array (SA_ID).		
NumRows	R	INT	1	Number of rows in the array, NumRowsSA. Rows are indexed: m = 0, 1, 2, 3, . . . , NumRowsSA(SA_ID) – 1.		
NumCols	R	INT	1	Number of columns per row in the array, NumColsSA. Columns are indexed: n = 0, 1, 2, 3, . . . , NumColsSA(SA_ID) – 1.		
BytesPerElement	R	INT	1	Indicates the size in bytes of each data element in the support array. Each element contains 1 or more binary-formatted components.		
ArrayByteOffset	R	INT	1	Array offset from the start of the Support block (in bytes) to the start of the support array.		

Table 11-5 Channel Parameters						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
CPHD.Channel	R		1	Parameters that describe the data channels contained in the product.		
RefChId	R	TXT	1	Channel ID (Ch_ID) for the Reference Channel in the product. Selected channel is used to compute referency geometry parameters.		For products with multiple data channels, method for selecting specified to be defined per Product Design Document.
FXFixedCPHD	R	BOOL	1	Flag to indicate when a constant FX band is saved for all signal vectors of all channels. For all vectors: fx_1 & fx_2 are constant.		
TOAFixedCPHD	R	BOOL	1	Flag to indicate when a constant TOA swath is saved for all signal vectors of all channels. For all vectors: ΔTOA_1 & ΔTOA_2 are constant.		
SRPFixedCPHD	R	BOOL	1	Flag to indicate when a constant SRP position is used all signal vectors of all channels.		
Parameters	R		1+	Parameter Set that describes a CPHD data channel. Channels referenced by their unique Channel ID (Ch_ID).		
Identifier	R	TXT	1	String that uniquely identifies this CPHD data channel (Ch_ID).		Allowed values may be per Product Design Document.
RefVectorIndex	R	INT	1	Index of the reference vector (v_CH_REF) for the channel.		May be any vector in the signal array.
FXFixed	R	BOOL	1	Flag to indicate when a constant FX band is saved for all signal vectors of the channel. For all vectors: fx_1 and fx_2 are constant.		
TOAFixed	R	BOOL	1	Flag to indicate when a constant TOA swath is saved for all signal vectors of the channel. For all vectors: ΔTOA_1 & ΔTOA_2 are constant.		
SRPFixed	R	BOOL	1	Flag to indicate when a constant SRP position is used all signal vectors of the channel.		
SignalNormal	O	BOOL	1	Flag to indicate when all signal array vectors are normal (indicated by the SIGNAL PVP being “1” for all vectors).		Included if and only if SIGNAL PVP is also included.

Table 11-5 Channel Parameters										
Field Name				**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
		Polarization		R		1	Polarization(s) of the signals that formed the signal array. Parameter describes the E-Field orientation of the signal.		
			TxPol	R	ENU	1	Transmitted signal polarization for the channel.		Allowed values listed in Table 10-3.
			RcvPol	R	ENU	1	Receive polarization for the channel.		Allowed values listed in Table 10-3.
		FxC		R	DBL	1	FX center frequency value for saved bandwidth for the channel. Computed from all vectors of the signal array. FxC = (FxMax + FxMin)/2	Hz	
		FxBW		R	DBL	1	FX band spanned for the saved bandwidth for the channel. Computed from all vectors of the signal array. FxBW = FxMax – FxMin		
		FxBWNoise		O	DBL	1	FX signal bandwidth saved that includes noise signal below or above the retained echo signal bandwidth. Included when fx_N1 < fx_1 or fx_2 < fx_N2 for any vector.		Only included for products with Domain_Type = FX and that include per vector parameters fx_N1 and fx_N2.
		TOASaved		R	DBL	1	TOA swath saved for the full resolution echoes for the channel. Computed from all vectors in the signal array. TOASaved = 2 x ΔTOAMax		
		TOAExtended		O		1	TOA extended swath information		
			TOAExtSaved	R	DBL	1	TOA extended swath saved that includes both full and partially eclipsed echoes. Parameter included when ΔTOA_E1 < ΔTOA_1 or ΔTOA_2 < ΔTOA_E2 for any channel vector. TOAExtSaved = 2 x ΔTOAExtMax		

Table 11-5 Channel Parameters

Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
			LFMEclipse		O		1	Parameters that describe the FX domain signal content for partially eclipsed echoes when the collection is performed with a Linear FM waveform.		Parameters set only included when partially eclipsed echoes are retained in the CPHD.
				FxEarlyLow	R	DBL	1	FX domain minimum frequency value for an echo at ΔTOA = ΔTOAE1 < ΔTOA1.	Hz	
				FxEarlyHigh	R	DBL	1	FX domain maximum frequency value for an echo at ΔTOA = ΔTOAE1 < ΔTOA1.	Hz	
				FxLateLow	R	DBL	1	FX domain minimum frequency value for an echo at ΔTOA = ΔTOAE2 > ΔTOA2.	Hz	
				FxLateHigh	R	DBL	1	FX domain maximum frequency value for an echo at ΔTOA = ΔTOAE2 > ΔTOA2.	Hz	
		DwellTimes			R		1	COD Time & Dwell Time polynomials over the image area. See Scene Coordinates or channel Image Area below.		
			CODId		R	TXT	1	Identifier of the Center of Dwell Time polynomial that maps reference surface position to COD time.		
			DwellId		R	TXT	1	Identifier of the Dwell Time polynomial that maps reference surface position to dwell time.		
		ImageArea			O		1	Image Area for the CPHD channel defined by a rectangle aligned with (IAX, IAY). May be reduced by the optional polygon.		Image Area is a rectangle on the Reference Surface.
			X1Y1		R	XY	1	Corner of the Image Area Rectangle in Image Area coordinates, (IA_X1, IA_Y1).	m	Image area rectangle: $IA\_X1 \le IAX \le IA\_X2$ $IA\_Y1 \le IAY \le IA\_Y2$
			X2Y2		R	XY	1	Corner of the Image Area Rectangle in Image Area coordinates, (IA_X2, IA_Y2).	m	Require: $IA\_X1 \le IAX \le IA\_X2$ $IA\_Y1 \le IAY \le IA\_Y2$
			Polygon		O		1	Polygon that defines the image area for the channel. Polygon is bounded by Rectangle. Vertices are indexed: n = 1, 2, . . ., NumVertices.		Attribute: size = NumVertices Require NumVertices ≥ 3.

Table 11-5 Channel Parameters						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
Vertex	R	XY	3+	Image Area Polygon vertex specified in image area coordinates (IAX, IAY). Vertices in clockwise order.	m	Attribute: index = 1 to NumVertices
Antenna	O		1	Antenna Phase Center and Antenna Pattern identifiers for the antenna(s) used to collect and form the signal array data.		Included when CPHD.Antenna parameters are provided.
TxAPCId	R	TXT	1	Identifier of Transmit APC to be used to compute the transmit antenna pattern as a function of time for the channel (APC_ID).		
TxAPATId	R	TXT	1	Identifier of Transmit Antenna pattern used to form the channel signal array (APAT_ID).		
RcvAPCId	R	TXT	1	Identifier of Receive APC to be used to compute the receive antenna pattern as a function of time for the channel (APC_ID).		Value may be equal to the TxAPCId.
RcvAPATId	R	TXT	1	Identifier of Receive Antenna pattern used to form the channel (APAT_ID).		Value may be equal to the TxAPATId.
TxRcv	O		1	Parameters to identify the Transmit and Receive parameter sets used to collect the signal array.		Included when CPHD.TxRcv parameters are provided.
TxWFId	R	TXT	1+	Identifier of the Transmit Waveform parameter set(s) that were used.		
RcvId	R	TXT	1+	Identifier of the Receive Parameter set(s) that were used.		
TgtRefLevel	O		1	Signal level for an ideal point scatterer located at the SRP for reference signal vector (v_CH_REF).		
PTRef	R	DBL	1	Target power level for a 1.0 square meter ideal point scatterer located at the SRP. For FX Domain signal arrays, PTRef is the signal level at fx = fx_C. For TOA Domain, PTRef is the peak signal level at ΔTOA = 0		Power = $Re(Sig)^2 + Im(Sig)^2$
NoiseLevel	O		1	Thermal noise level for the reference signal vector (v_CH_REF)		

Table 11-5 Channel Parameters						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
PNRef	R	DBL	1	Noise power level for thermal noise. For FX Domain signal arrays, PN is the noise level at fx = fx_C. For TOA Domain, PN is the noise level at ΔTOA = 0		PN = E{ $Re(Sig)^2 + Im(Sig)^2$ }
BNRef	R	DBL	1	Noise Equivalent BW for noise signal. Bandwidth BN is expressed relative to the sample bandwidth.		Allowed values: $0 < BNRef \leq 1.0$ BN = 1.0 ➔ noise signal has 0 correlation (i.e. white noise).
FxNoiseProfile	O		1	FX Domain Noise Level Profile. Power level for thermal noise (PN) vs. FX frequency values		
Point	R		2+	Points that describe the noise profile		Fx values are strictly increasing
Fx	R	DBL	1	Frequency value of this noise profile point	Hz	
PN	R	DBL	1	Power level of this noise profile point		
AddedParameters	O		1	Block for including additional parameters that describe the channels and/or signal arrays.		Parameters defined per Product Design Document.
Parameter	R	TXT	1+	Text-based string that conveys the value of the parameter.		Attribute: name = xxx identifies the parameter.

Table 11-6 Per Vector Parameters

Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.PVP		R		1	List of Per Vector parameters provided for each CPHD signal vector. See Table 10.1 for guidance. See Table 10.2 for allowed formats.		All PVP Size & Offset are specified in 8 byte fields.
	PVP: Defined PVP → Size & Format are fixed. Offset values allow parameters to be in any order in the binary PVP array.						
	TxTime	R	PVP	1	TxTime PVP Structure Size = 1 Format: "F8"	-	Size = 1 → Binary parameter is 1 x 8 bytes.
	TxPos	R	PVP	1	TxPos PVP Structure Size = 3 Format: "X=F8;Y=F8;Z=F8;"	-	Size = 3 → Binary parameter is 3 x 8 bytes.
	TxVel	R	PVP	1	TxVel PVP Structure Size = 3 Format: "X=F8;Y=F8;Z=F8;"	-	
	RcvTime	R	PVP	1	RcvTime PVP Structure Size = 1 Format: "F8"	-	Binary parameter is 1 F8 value.
	RcvPos	R	PVP	1	RcvPos PVP Structure Size = 3 Format: "X=F8;Y=F8;Z=F8;"	-	Binary parameter is 3 F8 values.
	RcvVel	R	PVP	1	RcvVel PVP Structure Size = 3 Format: "X=F8;Y=F8;Z=F8;"	-	
	SRPPos	R	PVP	1	SRPPos PVP Structure Size = 3 Format: "X=F8;Y=F8;Z=F8;"	-	
	AmpSF	O	PVP	1	AmpSF PVP Structure Size = 1 Format: "F8"	-	
	aTOAVRCV	R	PVP	1	aTOAVRCV PVP Structure Size = 1 Format: "F8"	-	
	aTOATROPO	R	PVP	1	aTOATROPO PVP Structure Size = 1 Format: "F8"	-	
	aFDOP	R	PVP	1	aFDOP PVP Structure Size = 1 Format: "F8"	-	
	aFRR1	R	PVP	1	aFRR1 PVP Structure Size = 1 Format: "F8"	-	
	aFRR2	R	PVP	1	aFRR2 PVP Structure Size = 1 Format: "F8"	-	

Table 11-6 Per Vector Parameters

	Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	FX1	R	PVP	1	FX1 PVP Structure Size = 1 Format: "F8"	-	
	FX2	R	PVP	1	FX2 PVP Structure Size = 1 Format: "F8"	-	
	FXN1	O	PVP	1	FXN1 PVP Structure Size = 1 Format: "F8"	-	Only allowed for FX domain. Must also include FXN2.
	FXN2	O	PVP	1	FXN2 PVP Structure Size = 1 Format: "F8"	-	Only allowed for FX domain. Must also include FXN1.
	TOA1	R	PVP	1	TOA1 PVP Structure Size = 1 Format: "F8"	-	
	TOA2	R	PVP	1	TOA2 PVP Structure Size = 1 Format: "F8"	-	
	TOAE1	O	PVP	1	TOAE1 PVP Structure Size = 1 Format: "F8"	-	Must also include TOAE2.
	TOAE2	O	PVP	1	TOAE2 PVP Structure Size = 1 Format: "F8"	-	Must also include TOAE1.
	TDTropoSRP	R	PVP	1	TDTropoSRP PVP Structure Size = 1 Format: "F8"	-	
	TDIonoSRP	O	PVP	1	TDIonoSRP PVP Structure Size = 1 Format: "F8"	-	
	SC0	R	PVP	1	SC0 PVP Structure Size = 1 Format: "F8"	-	
	SCSS	R	PVP	1	SCSS PVP Structure Size = 1 Format: "F8"	-	
	SIGNAL	O	PVP	1	SIGNAL PVP Structure Size = 1 Format: "I8"	-	
	AddedPVP	O	APVP	1+	Added PVP Structure – Used to include user defined PV parameters. See Table 10.1 for guidance. See Table 10.2 for allowed formats.		Added parameters defined in Product Design Document.

Table 11-7 Support Array Parameters						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
CPHD.SupportArray	O		1	Parameters that describe the binary support array(s) content and grid coordinates.		Optional Block
For the defined support arrays, the data elements, the grid coordinates and units of all parameters are defined and fixed. For any given support array, all data elements contain the same number of parameters and same binary format for each parameter.						
IAZArray	O		1+	IAZArray: IAZ(m,n) Array of scene surface heights expressed in image coordinate IAZ values (meters). Grid coordinates are image area coordinates (IAX, IAY). Each IAZArray is referenced by its unique SA identifier.		
Identifier	R	INT	1	The support array identifier (SA_ID). Array size is specified in Data node. See Table 11.4. Data.SupportArray		
ElementFormat	R	TXT	1	Data element format. Each element is one parameter (IAZ) formatted as one F4.	m	Allowed values: "IAZ=F4;"
X0	R	DBL	1	Row 0 X coordinate. Row coordinates are: IAX(m) = X0 + m * XSS	m	
Y0	R	DBL	1	Column 0 Y coordinate. Row coordinates are: IAY(n) = Y0 + n * YSS	m	
XSS	R	DBL	1	Row coordinate (X) sample spacing.	m	
YSS	R	DBL	1	Column coordinate (Y) sample spacing.	m	
NODATA	O	HEX	1	Hex bit mask that indicates this element does not contain valid data.	-	May be omitted if all elements contain valid data.
AntGainPhase	O		1+	Antenna Array: GP(m,n) Array values are antenna gain and phase expressed in dB and cycles. Array coordinates are direction cosines with respect to the ACF (DCX, DCY). Each AntGainPhase array is referenced by its unique SA identifier.		

Table 11-7 Support Array Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		Identifier	R	INT	1	The binary support array identifier (SA_ID). Array size and sample type specified in Data Parameters block. See Table 11.4. Data.SupportArray		
		ElementFormat	R	TXT	1	Data element format. Each element is one Gain and one Phase value, both formatted as F4.		Allowed values: "Gain=F4;Phase=F4;"
		X0	R	DBL	1	Row 0 X coordinate. Row coordinates are: DCX(m) = X0 + m * XSS	dir cos	
		Y0	R	DBL	1	Column 0 Y coordinate. Row coordinates are: DCY(n) = Y0 + n * YSS	dir cos	
		XSS	R	DBL	1	Row coordinate (X) sample spacing.	dir cos	
		YSS	R	DBL	1	Column coordinate (Y) sample spacing.	dir cos	
		NODATA	O	HEX	1	Hex bit mask that indicates this element does not contain valid data.	-	May be omitted if all elements contain valid data.
	AddedSupportArray		O		1+	Added Array: Z(m,n) Array values are sample evenly in X and Y.		
		Identifier	R	TXT	1	The binary support array identifier (SA_ID). Array size and sample type specified in Data Parameters block. See Table 11.4. Data.SupportArray		
		ElementFormat	R	TXT	1	Data element format.		Type is described as defined in Table 10-2
		X0	R	DBL	1	Row 0 X coordinate. Row coordinates are: X (m) = X0 + m * XSS		
		Y0	R	DBL	1	Column 0 Y coordinate. Row coordinates are: Y (n) = Y0 + n * YSS		
		XSS	R	DBL	1	Row coordinate (X) sample spacing.		

Table 11-7 Support Array Parameters								
Field Name			**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
		YSS	R	DBL	1	Column coordinate (Y) sample spacing.		
		NODATA	O	HEX	1	Hex bit mask that indicates this element does not contain valid data.	-	May be omitted if all elements contain valid data.
		XUnits	R	TXT	1	Defines the X units of the sampled grid		
		YUnits	R	TXT	1	Defines the Y units of the sampled grid		
		ZUnits	R	TXT	1	Defines the units of each component of the Data Element.		
		Parameter	O	TXT	1+	Text field that can be used to further describe the added Support Array		Attribute “name” identifies the parameter

Table 11-8 Dwell Time Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.Dwell			R		1	Parameters that define the dwell time supported by the signal arrays contained in the CPHD product.		
	NumCODTimes		R	INT	1	Number of COD Time polynomials included. COD polynomials are referenced by their unique COD ID.		
	CODTime		R		1+	Center of Dwell (COD) Time Polynomial		
		Identifier	R	TXT	1	String that uniquely identifies this COD Time polynomial (COD_ID).		
		CODTimePoly	R	2D POLY	1	Polynomial that yields COD Time as a function of IAX and IAY.	sec, sec/m	Attributes: order1 = IAX_Order and order2 = IAY_Order
	NumDwellTimes		R	INT	1	Number of Dwell Time polynomials included. Dwell Time polynomials are referenced by their unique Dwell ID.		
	DwellTime		R		1+	Dwell Time Polynomial		
		Identifier	R	TXT	1	String that uniquely identifies this Dwell Time polynomial (Dwell_ID).		
		DwellTimePoly	R	2D POLY	1	Polynomial that yields Dwell Time as a function of IAX and IAY.	sec, sec/m	Attributes: order1 = IAX_Order and order2 = IAY_Order

Table 11-9 Reference Geometry Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.ReferenceGeometry	R		1	Parameters that describe the collection geometry for the reference vector (v_REF) of the reference channel (Ch_Ref_ID).		
SRP	R		1	The SRP position for the reference vector of the reference channel.		
ECF	R	XYZ	1	SRP position in ECF coordinates.	m	
IAC	R	XYZ	1	SRP position in Image Area Coordinates (IAX, IAY, IAZ).	m	
ReferenceTime	R	DBL	1	Reference time for the selected reference vector. Time t_REF is approximately equal to the time the center of the pulse is incident at the SRP.	sec	
SRPCODTime	R	DBL	1	The COD Time for point on the reference surface at (SRP_IAX, SRP_IAY). Computed using the COD polynomial for the reference channel.	sec	
SRPDwellTime	R	DBL	1	The Dwell Time for point on the reference surface at (SRP_IAX, SRP_IAY). Computed using the Dwell Time polynomial for the reference channel.	sec	
Monostatic	C		1	Parameters for CollectType = "MONOSTATIC"		
ARPPos	R	XYZ	1	ARP position in ECF coordinates (**ARP**).	m	
ARPVel	R	XYZ	1	ARP velocity in ECF coordinates (**VARP**).	m/s	
SideOfTrack	R	ENU	1	Side of Track parameter for the collection. L ➔ Left-looking or R ➔Right-looking	-	Allowed values: "L" and "R" See Table 10-3.
SlantRange	R	DBL	1	Slant range from the ARP to the SRP.	m	
GroundRange	R	DBL	1	Ground range from the ARP nadir to the SRP. Distance measured along spherical earth model passing through the SRP.	m	
DopplerConeAngle	R	DBL	1	Doppler Cone Angle between ARP velocity and SRP Line of Sight (LOS).	deg	Range: [0, 180]

Table 11-9 Reference Geometry Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		GrazeAngle	R	DBL	1	Grazing angle for the ARP to SRP LOS and the Earth Tangent Plane (ETP) at the SRP.	deg	Range: [0, 90]
		IncidenceAngle	R	DBL	1	Incidence angle for the ARP to SRP LOS and the Earth Tangent Plane (ETP) at the SRP. Note: GRAZ + INCD = 90	deg	Range: [0, 90]
		AzimuthAngle	R	DBL	1	Angle from north to the line from the SRP to the ARP ETP Nadir (i.e. North to +GPX). Measured clockwise from +North toward +East.	deg	Range: [0, 360]
		TwistAngle	R	DBL	1	Twist angle between cross range in the ETP and cross range in the slant plane at the SRP.	deg	Range: [-90, 90]
		SlopeAngle	R	DBL	1	Angle between the ETP normal (**uUP**) and the slant plane normal (**uSPN**) at the SRP.	deg	Range: [0, 90]
		LayoverAngle	R	DBL	1	Angle from north to the layover direction in the ETP. Measured clockwise from +North toward +East.	deg	Range: [0, 360]
	Bistatic		C		1	Parameters for CollectType = "BISTATIC"		
		AzimuthAngle	R	DBL	1	Angle from north to the projection of the Bistatic pointing vector (**bP**) into the ETP. Measured clockwise from +North toward +East.	deg	Range: [0, 360]
		AzimuthAngleRate	R	DBL	1	Instantaneous rate of change of the Azimuth Angle (d(AZIM)/dt).	deg/s	
		BistaticAngle	R	DBL	1	Bistatic angle (Beta) between unit vector from SRP to transmit APC (**uXmt**) and the unit vector from the SRP to the receive APC (**uRcv**).	deg	Range: [0, 180]
		BistaticAngleRate	R	DBL	1	Instantaneous rate of change of the bistatic angle (d(Beta)/dt).	deg	
		GrazeAngle	R	DBL	1	Angle between the bistatic pointing vector and the ETP at the SRP.	deg	Range: [0, 90]

Table 11-9 Reference Geometry Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		TwistAngle		R	DBL	1	Angle between cross range in the ETP at the SRP and cross range in the instantaneous plane of maximum bistatic resolution. Note: For monostatic imaging, the plane of maximum resolution is the instantaneous slant plane.	deg	Range: [-90, 90]
		SlopeAngle		R	DBL	1	Angle between the ETP normal and the normal to the instantaneous plane of maximum bistatic resolution.	deg	Range: [0, 90]
		LayoverAngle		R	DBL	1	Angle from north to the bistatic layover direction in the ETP. Measured clockwise from +North toward +East.	deg	Range: [0, 360]
		TxPlatform		R		1	Parameters that describe the Transmit platform.		
			Time	R	DBL	1	The transmit time for the vector (txc = TxTime).	sec	
			Pos	R	XYZ	1	Transmit APC position (**Xmt**) in ECF coordinates at txc.	m	
			Vel	R	XYZ	1	Transmit APC velocity (**VXmt**) in ECF coordinates at txc.	m/s	
			SideOfTrack	R	ENU	1	Side of Track parameter for the transmit platform.	-	Allowed values: “L” and “R” See Table 10-3.
			SlantRange	R	DBL	1	Slant range from the transmit APC to the SRP.	m	
			GroundRange	R	DBL	1	Ground range from the transmit APC to the SRP (measured on the spherical surface containing the SRP).	m	
			DopplerConeAngle	R	DBL	1	Doppler Cone Angle between **VXmt** and line of sight to the **ARP**.	deg	Range: [0, 180]
			GrazeAngle	R	DBL	1	Grazing angle between the RefPt LOS and Earth Tangent Plane (ETP)	deg	Range: [0, 90]
			IncidenceAngle	R	DBL	1	Incidence angle between the RefPt LOS and ETP normal	deg	Range: [0, 90]
			AzimuthAngle	R	DBL	1	Angle from north to the line from the SCP to the Pos Nadir in the ETP. Measured clockwise.	deg	Range: [0, 360]

Table 11-9 Reference Geometry Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		RcvPlatform		R		1	Parameters that describe the Receive platform.		
			Time	R	DBL	1	The receive time for the vector (trc_SRP = RcvTime).	sec	
			Pos	R	XYZ	1	Receive APC position in ECF coordinates at trc_SRP.	m	
			Vel	R	XYZ	1	Receive APC velocity in ECF coordinates at trc_SRP.	m/s	
			SideOfTrack	R	ENU	1	Side of Track parameter for the Receive platform.	-	Allowed values: “L” and “R” See Table 10-3.
			SlantRange	R	DBL	1	Slant range from the Pos to the SCP	m	
			GroundRange	R	DBL	1	Ground range from the receive APC to the SRP (measured on the spherical surface containing the SRP).	m	
			DopplerConeAngle	R	DBL	1	Doppler cone angle between Vel and RepPt Line of Sight (LOS)	deg	Range: [0, 180]
			GrazeAngle	R	DBL	1	Grazing angle between the RefPt LOS and Earth Tangent Plane (ETP)	deg	Range: [0, 90]
			IncidenceAngle	R	DBL	1	Incidence angle between the RefPt LOS and ETP normal	deg	Range: [0, 90]
			AzimuthAngle	R	DBL	1	Angle from north to the line from the SCP to the Pos Nadir in the ETP. Measured clockwise.	deg	Range: [0, 360]

Table 11-10 Antenna Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.Antenna			O		1	Parameters that describe the transmit and receive antennas used to collect the signal array(s).		
	NumACFs		R	INT	1	Number of Antenna Coordinate Frames (ACFs) associated with the APCs in the product. ACFs are referenced by their unique ACF ID.		Allowed values: NumACFs $\geq$ 1
	NumAPCs		R	INT	1	Number of Antenna Phase Centers (APCs) associated with the signal array(s) in the product. APCs are referenced by their unique APC ID.		Allowed values: NumAPCs $\geq$ 1
	NumAntPats		R	INT	1	Number of sets of Antenna Patterns (AntPats) associated with the APCs in the product. Antenna Patterns are referenced by their unique APAT ID.		Allowed values: NumAntPats $\geq$ 1
	AntCoordFrame		R		1+	Unit vectors that describe the orientation of an Antenna Coordinate Frame (ACF) as function of time. Parameters set repeated for each ACF.		
		Identifier	R	TXT	1	String that uniquely identifies this ACF (ACF_ID).		
		XAxisPoly	R	XYZ POLY	1	Antenna coordinate frame X-Axis unit vector in ECF coordinates as a function time (sec). Time t = 0 is CST on the transmit platform.	1, 1/sec, etc.	Unit vectors **uX**(t) and **uY**(t) define the frame.
		YAxisPoly	R	XYZ POLY	1	Antenna coordinate frame Y-Axis unit vector in ECF coordinates as a function time (sec). Time t = 0 is CST on the transmit platform.	1, 1/sec, etc.	Antenna mechanical boresight is: **uZ**(t) = **uX**(t) x **uY**(t)
	AntPhaseCenter		R		1+	Parameters that describe each Antenna Phase Center (APC). Parameter set repeated for each APC.		
		Identifier	R	TXT	1	String that uniquely identifies this APC (APC_ID).		
		ACFId	R	TXT	1	Identifier of Antenna Coordinate Frame used for computing the antenna gain and phase patterns,		
		APCXYZ	R	XYZ	1	The APC location in the ACF XYZ coordinate frame.	m	

Table 11-10 Antenna Parameters

Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	AntPattern			R		1+	Parameter set that defines each Antenna Pattern as function time. Parameters set repeated for each Antenna Pattern.		
		Identifier		R	TXT	1	String that uniquely identifies this Antenna Pattern (APAT_ID).		Unique ID value for each set of AntPattern parameter set.
		FreqZero		R	DBL	1	The reference frequency (f_0) value for which the Electrical Boresight and array pattern polynomials are computed.	Hz	
		GainZero		O	DBL	1	The reference antenna gain (G_0) at zero steering angle at the reference frequency (f_0).	dB	
		EBFreqShift		O	BOOL	1	Parameter to indicate the EB steering direction shifts with frequency.		
		MLFreqDilation		O	BOOL	1	Parameter to indicate the mainlobe width varies with frequency.		
		GainBSPoly		O	POLY	1	Gain polynomial (dB) vs. frequency for the array pattern at boresight. Gain relative to gain at f_0.	dB, dB/Hz, etc.	
		EB		R		1	The Electrical Boresight steering direction versus time. Defines array pattern pointing direction.		
			DCXPoly	R	POLY	1	Electrical Boresight steering X-Axis direction cosine as a function of time, EB_DCX(t).	1, 1/sec, etc.	For mechanically steered antennas, set equal 0.
			DCYPoly	R	POLY	1	Electrical Boresight steering X-Axis direction cosine as a function of time, EB_DCY(t).	1, 1/sec, etc.	For mechanically steered antennas, set equal 0.
		Array		R		1	Array Pattern polynomials that describe the mainlobe gain and phase patterns. Patterns defined at f = f_0.		
			GainPoly	R	2D POLY	1	One-way gain pattern (in dB) as a function for ΔDCX and ΔDCY. Gain relative to ΔDCX = 0 and ΔDCY = 0.	dB	

Table 11-10 Antenna Parameters

Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
			PhasePoly	R	2D POLY	1	One-way phase pattern (in cycles) as a function for ΔDCX and ΔDCY. Phase relative to ΔDCX = 0 and ΔDCY = 0.	cycles	
		Element		R		1	Element Pattern polynomials that describe the gain and phase patterns.		
			GainPoly	R	2D POLY	1	One-way gain pattern (in dB) as a function of DCX and DCY. Gain relative to DCX = 0 and DCY = 0.	dB	
			PhasePoly	R	2D POLY	1	One-way phase pattern (in cycles) as a function for DCX and DCY. Phase relative to DCX = 0 and DCY = 0.		
		GainPhaseArray		O		1+	Parameters that identify 2-D sampled Gain & Phase patterns at single frequency value.		
			Freq	R	DBL	1	Frequency value for which the sampled Array & Element pattern(s) are provided.	Hz	
			ArrayId	R	TXT	1	Support Array identifier of the sampled Gain/Phase of the Array at RefFrequency		
			ElementId	O	TXT	1	Support Array identifier of the sampled Gain/Phase of the Element at RefFrequency		

Table 11-11 Transmit & Receive Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.TxRcv	O		1	Parameters that describe the transmitted waveform(s) and receiver configurations used in the collection.		
NumTxWFs	R	INT	1	Number of Transmit Waveforms used. Waveforms are referenced by their unique TxWF_ID.		
TxWFParameters	R		1+	Parameters that describe a Transmit Waveform		
Identifier	R	TXT	1	String that uniquely identifies this Transmit Waveform (TxWF_ID).		
PulseLength	R	DBL	1	Length of transmitted pulse	s	
RFBandwidth	R	DBL	1	Bandwidth of transmitted pulse	Hz	
FreqCenter	R	DBL	1	Center frequency of the transmitted waveform	Hz	
LFMRate	O	DBL	1	Chirp rate of transmitted pulse if LFM.	Hz/s	Allowed values: LFMRate $\neq 0$
Polarization	R	ENU	1	Transmit polarization		Allowed values listed in Table 10-3.
Power	O	DBL	1	Peak transmitted power at the interface to the antenna	dBW	
NumRcvs	R	INT	1	Number of Receive configurations used. Receive configurations are referenced by their unique Rcv_ID		
RcvParameters	R		1+	Parameters that describe a Receive configuration		
Identifier	R	TXT	1	String that uniquely identifies this Receive configuration (Rcv_ID).		
WindowLength	R	DBL	1	Length of the receive window	s	
SampleRate	R	DBL	1	Rate at which the signal in the receive window is sampled	Hz	
IFFilterBW	R	DBL	1	Bandwidth of the anti-aliasing filter prior to sampling		

Table 11-11 Transmit & Receive Parameters								
Field Name			**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
		FreqCenter	R	DBL	1	Center frequency of the demodulation signal	Hz	
		LFMRate	O	DBL	1	Chirp rate of the demodulation signal if LFM	Hz/s	Allowed values: LFMRate $\neq$ 0
		Polarization	R	ENU	1	Receive polarization		Allowed values listed in Table 10-3.
		PathGain	O	DBL	1	Receiver gain from the antenna interface to the ADC.	dB	

Table 11-12 Error Parameters						
Field Name	**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
CPHD.ErrorParameters	O		1	Parameters that describe the statistics of errors in measured or estimated parameters that describe the collection.		
The error parameters to be included are selected based upon CollectType.						
Monostatic	C		1	Parameters for CollectType = "MONOSTATIC"		
PosVelErr	R		1	Position and velocity error statistics for the sensor platform.		
Frame	R	ENU	1	Coordinate frame used for specifying position and velocity error statistics. RIC = Radial, In-Track, Cross-Track. Radial – From the earth center through the platform position.		Allowed values: "ECF", "RIC_ECF" and "RIC_ECI" See Table 10-3.
P1	R	DBL	1	Position coordinate 1 standard deviation.	m	
P2	R	DBL	1	Position coordinate 2 standard deviation.	m	
P3	R	DBL	1	Position coordinate 3 standard deviation.	m	
V1	R	DBL	1	Velocity coordinate 1 standard deviation.	m/sec	
V2	R	DBL	1	Velocity coordinate 2 standard deviation.	m/sec	
V3	R	DBL	1	Velocity coordinate 3 standard deviation.	m/sec	
CorrCoefs	O			Correlation Coefficient parameters		
P1P2	R	DBL	1	P1, P2 correlation coefficient.		
P1P3	R	DBL	1	P1, P3 correlation coefficient.		
P1V1	R	DBL	1	P1, V1 correlation coefficient.		
P1V2	R	DBL	1	P1, V2 correlation coefficient.		
P1V3	R	DBL	1	P1, V3 correlation coefficient.		
P2P3	R	DBL	1	P2, P3 correlation coefficient.		
P2V1	R	DBL	1	P2, V1 correlation coefficient.		

Table 11-12 Error Parameters										
Field Name					**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
				P2V2	R	DBL	1	P2, V2 correlation coefficient.		
				P2V3	R	DBL	1	P2, V3 correlation coefficient.		
				P3V1	R	DBL	1	P3, V1 correlation coefficient.		
				P3V2	R	DBL	1	P3, V2 correlation coefficient.		
				P3V3	R	DBL	1	P3, V3 correlation coefficient.		
				V1V2	R	DBL	1	V1, V2 correlation coefficient.		
				V1V3	R	DBL	1	V1, V3 correlation coefficient.		
				V2V3	R	DBL	1	V2, V3 correlation coefficient.		
			PositionDecorr		O			Platform position error decorrelation function.		
				CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
				DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))	1/sec	
		RadarSensor			R		1	Radar sensor error statistics.		
			RangeBias		R	DBL	1	Range bias error standard deviation.	m	
			ClockFreqSF		O	DBL	1	Payload clock frequency scale factor standard deviation. SF = Δf/f0.		
			CollectionStartTime		O	DBL	1	Collection Start time error standard deviation.	sec	
			RangeBiasDecorr		O			Range Bias error decorrelation function.		
				CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
				DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))	1/sec	
		TropoError			O					

Table 11-12 Error Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
TropoRangeVertical	O	DBL	1	Troposphere two-way delay error for normal incidence standard deviation. Expressed as a range error. ΔR = ΔTD_Tropo x c/2.	m	
TropoRangeSlant	O	DBL	1	Troposphere two-way delay error for the SRP for the reference vector of the reference channel. The standard deviation expressed as a range error. ΔR = ΔTD_Tropo x c/2.		
TropoRangeDecorr	O			Range Bias error decorrelation function.		
CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))	1/sec	
IonoError	O					
IonoRangeVertical	R	DBL	1	Ionosphere two-way delay error for normal incidence standard deviation. Expressed as a range error. ΔR = ΔTD_Iono x c/2.		
IonoRangeRateVertical	O	DBL	1	Ionosphere two-way delay rate of change error for normal incidence standard deviation. Expressed as a range rate error. ΔRdot = ΔTD_Iono_dot x c/2.		
IonoRgRgRateCC	O	DBL	1	Ionosphere range error and range rate error correlation coefficient.		
IonoRangeVertDecorr	O			Range Bias error decorrelation function.		
CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))	1/sec	
AddedParameters	O		1	Additional error parameters to be added for Monostatic collections.		

Table 11-12 Error Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
Parameter	R	TXT	1+	Added parameters that may be added per Product Design Document.		Attribute: name = "xxx" identifies the parameter.
Bistatic	C		1	Parameters for CollectType = "BISTATIC"		
TxPlatform	R		1	Error statistics for the Transmit platform.		
PosVelErr	R		1	Position and velocity error statistics for the Transmit platform.		
Frame	R	ENU	1	Coordinate frame used for specifying the position and velocity error statistics.		Allowed values: "ECF", "RIC_ECF" and "RIC_ECI" See Table 10-3.
P1	R	DBL	1	Position coordinate 1 standard deviation.	m	
P2	R	DBL	1	Position coordinate 2 standard deviation.	m	
P3	R	DBL	1	Position coordinate 3 standard deviation.	m	
V1	R	DBL	1	Velocity coordinate 1 standard deviation.	m/sec	
V2	R	DBL	1	Velocity coordinate 2 standard deviation.	m/sec	
V3	R	DBL	1	Velocity coordinate 3 standard deviation.	m/sec	
CorrCoefs	O			Correlation Coefficient parameters		
P1P2	R	DBL	1	P1, P2 correlation coefficient.		
P1P3	R	DBL	1	P1, P3 correlation coefficient.		
P1V1	R	DBL	1	P1, V1 correlation coefficient.		
P1V2	R	DBL	1	P1, V2 correlation coefficient.		
P1V3	R	DBL	1	P1, V3 correlation coefficient.		
P2P3	R	DBL	1	P2, P3 correlation coefficient.		
P2V1	R	DBL	1	P2, V1 correlation coefficient.		
P2V2	R	DBL	1	P2, V2 correlation coefficient.		
P2V3	R	DBL	1	P2, V3 correlation coefficient.		

Table 11-12 Error Parameters

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
P3V1	R	DBL	1	P3, V1 correlation coefficient.		
P3V2	R	DBL	1	P3, V2 correlation coefficient.		
P3V3	R	DBL	1	P3, V3 correlation coefficient.		
V1V2	R	DBL	1	V1, V2 correlation coefficient.		
V1V3	R	DBL	1	V1, V3 correlation coefficient.		
V2V3	R	DBL	1	V2, V3 correlation coefficient.		
PositionDecorr	O			Platform position error decorrelation function.		
CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). Δt = |t2 – t1| CC(Δt) = Min(1.0,Max(0.0,CC0 – DCR*Δt))		
RadarSensor	R		1	Transmit sensor error statistics. Statistics for the primary sources of geolocation errors in bistatic image products.		
ClockFreqSF	O	DBL	1	Payload clock frequency scale factor standard deviation. SF = Δf/f0.		
CollectionStartTime	R	DBL	1	Collection Start time error standard deviation.	sec	
RcvPlatform	R		1	Error statistics for the Receive Only platform.		
PosVelErr	R		1	Position and velocity error statistics for the Receive Only platform.		
Frame	R	ENU	1	Coordinate frame used for specifying the position and velocity error statistics.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI” See Table 10-3.
P1	R	DBL	1	Position coordinate 1 standard deviation.	m	
P2	R	DBL	1	Position coordinate 2 standard deviation.	m	
P3	R	DBL	1	Position coordinate 3 standard deviation.	m	

Table 11-12 Error Parameters										
Field Name						**Req/ Opt**	**Type**	**Num**	**Description**	**Units**	**Attributes & Allowed Values**
				V1		R	DBL	1	Velocity coordinate 1 standard deviation.	m/sec	
				V2		R	DBL	1	Velocity coordinate 2 standard deviation.	m/sec	
				V3		R	DBL	1	Velocity coordinate 3 standard deviation.	m/sec	
				CorrCoefs		O			Correlation Coefficient parameters		
					P1P2	R	DBL	1	P1, P2 correlation coefficient.		
					P1P3	R	DBL	1	P1, P3 correlation coefficient.		
					P1V1	R	DBL	1	P1, V1 correlation coefficient.		
					P1V2	R	DBL	1	P1, V2 correlation coefficient.		
					P1V3	R	DBL	1	P1, V3 correlation coefficient.		
					P2P3	R	DBL	1	P2, P3 correlation coefficient.		
					P2V1	R	DBL	1	P2, V1 correlation coefficient.		
					P2V2	R	DBL	1	P2, V2 correlation coefficient.		
					P2V3	R	DBL	1	P2, V3 correlation coefficient.		
					P3V1	R	DBL	1	P3, V1 correlation coefficient.		
					P3V2	R	DBL	1	P3, V2 correlation coefficient.		
					P3V3	R	DBL	1	P3, V3 correlation coefficient.		
					V1V2	R	DBL	1	V1, V2 correlation coefficient.		
					V1V3	R	DBL	1	V1, V3 correlation coefficient.		
					V2V3	R	DBL	1	V2, V3 correlation coefficient.		
				PositionDecorr		O			Platform position error decorrelation function.		
					CorrCoefZero	R	DBL	1	Error correlation coefficient for zero time difference (CC0).		
					DecorrRate	R	DBL	1	Error decorrelation rate. Simple linear decorrelation rate (DCR). $\Delta t = \|t2 - t1\|$ $CC(\Delta t) = Min(1.0, Max(0.0, CC0 - DCR*\Delta t))$		

Table 11-12 Error Parameters										
Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
			RadarSensor		R		1	Receive only sensor error statistics. Statistics for the primary sources of geolocation errors in bistatic image products.		
				ClockFreqSF	O	DBL	1	Payload clock frequency scale factor standard deviation. SF = $\Delta f/f0$.		
				CollectionStartTime	R	DBL	1	Collection Start time error standard deviation.	sec	
		AddedParameters			O		1	Additional error parameters to be added for Bistatic collections.		
			Parameter		R	TXT	1+	Added parameters that may be added per Product Design Document.		Attribute: name = "xxx" identifies the parameter.

Table 11-13 CPHD Product Information								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.ProductInfo			O		1	Parameters that provide general information about the CPHD product and/or the derived products that may be created from it.		
	Profile		O	TXT	1	Identifies what profile was used to create this CPHD product.		
	CreationInfo		O		1+	Parameters that provide general information about the CPHD product generation.		
		Application	O	TXT	1	Name and version of the applications that created the CPHD product.		Allowed names per the Product Design Document.
		DateTime	R	XDT	1	Date and time the CPHD product was created (UTC). Times specified per program specific Product Design Documentation.		Guidance for precise times specified per Product Design Documentation (e.g. Start or End of Processing).
		Site	O	TXT	1	Name of the site where the product was created.		Site names per Product Design Document.
		Parameter	O	TXT	1+	Text field that can be used for program specific parameter name & value.		Attribute “name” identifies the parameter.
	Parameter		O	TXT	1+	Text field that can be used for program specific parameter name & value.		Attribute “name” identifies the parameter.

Table 11-14 Geographic Information Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
GeoInfo			O		1	Parameters that describe a geographic feature. Note: The GeoInfo block may be used as block within itself.		Use of this block & parameters defined per program specific Product Design Document.
	Desc		O	TXT	1+	Used to provide a name and/or description of the geographic feature.		Attribute: "name" = descriptive name of the feature
	Point		O	LL	1+	Used to specific a single point in Lat and Lon. $-90.0 \leq Lat \leq 90.0$, $-180.0 \leq Lon \leq 180.0$	dd	Choose any number of Points, Lines or Polygons
	Line		O		1+	Used to specify a "linear" feature with connected line segments. Endpoints are indexed: n = 1,2, . . . , NumEndpoints.		Attribute: "size" = NumEndpoints Require NumEndpoints $\geq$ 2.
		Endpoint	R	LL	2+	Line segment endpoints specified in Lat and Lon. $-90.0 \leq Lat \leq 90.0$, $-180.0 \leq Lon \leq 180.0$	dd	Attribute: "index" = 1 to NumEndpoints
	Polygon		O		1+	Used to specify an area with a polygon. Vertices are indexed: n = 1, 2, . . . , NumVertices. Require NumVertices $\geq$ 3.		Attribute: "size" = NumVertices Require NumVertices $\geq$ 3.
		Vertex	R	LL	3+	Polygon vertices specified in Lat and Lon. Vertices are indexed clockwise. $-90.0 \leq Lat \leq 90.0$, $-180.0 \leq Lon \leq 180.0$	dd	Attribute: "index" = 1 to NumVertices
	GeoInfo		O		1+	Optional GeoInfo embedded within a GeoInfo		

Table 11-15 Matched Collection Information

Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CPHD.MatchInfo	O		1	Information about other collections that are matched to the collection from which this CPHD product was generated.		
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 Product Design Document.						
NumMatchTypes	R	INT	1	Number of types of matched collections. Match types are indexed mt = 1 to NumMatchTypes.		
MatchType	R		1+	Block containing information about match type mt. Block repeated for mt = 1 to NumMatchTypes.		Attribute: index = mt
TypeID	R	TXT	1	Text string identifying the match type. Examples: “COHERENT” ,“STEREO”		Allowed names defined per Product Design Document.
CurrentIndex	O	INT	1	Collection sequence index for the collection from which this CPHD product was generated.		
NumMatchCollections	R	INT	1	Number of matched collections for this match type. May be set to 0. Matched collections are indexed by mc = 1 to NumMatchCollections.		
MatchCollection	O		1+	Block containing information about match collection mc.		Attribute: index = mc
CoreName	R	TXT	1	Text string that uniquely identifies the matching collection.		Allowed names defined per Product Design Document.
MatchIndex	O	INT	1	Collection sequence index for the match collection.		
Parameter	O	TXT	1+	Relevant match parameter. Attribute name identifies the parameter.		Attribute: name = “xxx” Allowed names defined per Product Design Document.

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