



NGA.STND.0080-1_1.0_CRSD
2025-02-25

NGA STANDARDIZATION DOCUMENT

COMPENSATED RADAR SIGNAL DATA (CRSD)

Volume 1

Design & Implementation Description Document

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

(2025-02-25)

Version 1.0

The National Geospatial-Intelligence Agency's Office of General Counsel has determined that the standards and information set forth in this document are not subject to the export restrictions of the Arms Export Control Act and the International Traffic in Arms Regulations.

REVISION HISTORY

Date	Version	Description
The initial name of the format was Compensated Receive Signal Data . The versions and dates of the draft design artifacts using this name are as follows.		
2021-07-14	1.0.x	Document & schema provided to the NTB for technical review. The work to formally adopt the CRSD format was not completed
The name of the format was changed to Compensated Radar Signal Data . The name was changed to better reflect what data may be contained in a CRSD product. The versions and dates of the design artifacts using this name are as follows.		
2025-02-25	V1.0	Revised format submitted for NTB technical review and acceptance. The changes include the following. • The name of the format is changed. The proposed format is assigned NGA standard number NGA.STND.0080. • The format defines three types of CRSD products: CRSD:SAR, CRSD:RCV, and CRSD:TX. • Transmit signal metadata and receive signal metadata structures are now separate. • The transmit signal metadata structure now supports both LFM pulse waveforms and arbitrary pulse waveforms. • All products contain a complete set of antenna metadata that includes antenna orientation, mainlobe pointing, and beam shape metadata. • All products that include transmit signal metadata also include estimated transmit signal power parameters. • All products that include receive signal arrays and supporting metadata also include estimated receive signal gain parameters.

TABLE OF CONTENTS

1	Introduction.....	1
1.1	Scope	2
1.2	Conformance	3
1.2.1	Conformance Requirements.....	3
1.2.2	Conformance Testing.....	3
1.3	Design and Reference Documents	4
1.4	Terms and Definitions	5
1.5	CRSD Format Overview	6
1.5.1	Product Types	6
1.5.2	Data Structure	7
1.5.3	Transmit Pulse Sequences.....	7
1.5.4	Receive Data Channels	8
1.5.5	SAR Imaging Metadata.....	8
2	Data Structure and File Format.....	11
2.1	Product File Hierarchy	13
2.2	File Header	13
2.2.1	File Type Header.....	14
2.2.2	Key-Value Pair List	14
2.2.3	Section Terminator.....	15
2.3	XML Block	16
2.4	Support Block.....	17
2.5	PPP Block.....	18
2.6	PVP Block and Signal Block	20
2.7	PVP Arrays and Signal Arrays.....	21
2.8	Signal Array Compression	23
3	Product Design.....	26
3.1	Product Design Guidance.....	26
3.1.1	Product & Sensor Information.....	26
3.1.2	Transmit Waveform & PPP Array Content	27
3.1.3	Signal Array Format and PVP Array Content	27
3.1.4	Receive Data Channels	28
3.1.5	Antenna Metadata Parameters	28
3.2	Product File Naming	29
3.3	Optional Information Parameters	29
3.3.1	Added Parameters	29
3.3.2	Geographic Information Parameters	29
4	CRSD Signal Model	30
4.1	Signal Model Parameters	30
4.1.1	Transmit Signal Model Parameters.....	30
4.1.2	Receive Signal Model Parameters	34
4.1.3	Format for PPP/PVP Times & Phases	38
4.2	Transmit & Receive Geometry	39
4.3	Signal Complex Envelope.....	42
4.4	Transmit Pulse Parameters.....	44
4.5	Ideal Waveform Generator Model	45

4.5.1	Input Pulse Modulation Function	47
4.6	Transmit Pulse Waveform.....	47
4.6.1	Select $T_s_XS(p)$ & $NXS(p)$	48
4.6.2	Compute Input Vector $\{ CE_{XIN}(p, sx) \}$	49
4.6.3	Compute the DFT: $\{ S_{XIN}(p, k) \}$	51
4.6.4	Apply the Fx Response	52
4.6.5	Compute the IDFT: $\{ CE_{XMT}(p, sx) \}$	53
4.6.6	Apply the Antenna Gain & Phase Response.....	54
4.6.7	Compute the IDFT: $\{ CE_{XAP}(p, \mathbf{uAP}, sx) \}$	55
4.6.8	Compute Transmit Power: $P_{RI_{XAP}}(p, \mathbf{uAP})$	55
4.7	Signal Array Size and Sample Timing	56
4.8	Ideal Receiver Model	58
4.9	CRSD Formation Processing	62
4.9.1	Example 1: CFOR Demodulation.....	63
4.9.2	Example 2: DROR Demodulation	66
4.9.3	CRSD Sample Rate.....	69
4.10	SAR Signal Timing	70
5	Scene Coordinates.....	71
5.1	Guidance for CRSD:SAR	72
5.1.1	IARP & Reference Surface.....	72
5.1.2	Image Area.....	72
5.1.3	Image Grid	74
5.2	Guidance for CRSD:TX.....	75
5.3	Guidance for CRSD:RCV	76
6	Transmit Sequence Parameters	77
6.1	Tx Pulse Sequences.....	77
6.1.1	Reference Tx Sequence.....	77
6.1.2	Reference Pulse.....	77
6.2	Transmit Waveform Types.....	78
6.3	Pulse Sequence Parameters	79
6.3.1	Waveform Support Arrays.....	79
6.3.2	Frequency & Timeline Parameters	79
6.3.3	Transmit Reference Point	80
6.3.4	Transmit Polarization.....	81
6.4	Transmit Power Parameters	83
6.4.1	Base Pulse Power.....	83
6.4.2	Pulse Power w/ Antenna Beam Shape	84
6.4.3	Incident Power at a Scene Point.....	85
6.5	Fx Response Arrays	87
6.6	XM Arrays.....	89
7	Receive Channel Parameters.....	92
7.1	Receive Channels	92
7.1.1	Reference Channel.....	92
7.1.2	Reference Signal Vector	93
7.2	Required Sample Rate.....	94
7.3	Channel Parameters.....	95

7.3.1	Frequency & Timeline Parameters	95
7.3.2	Receive Reference Point	96
7.3.3	Receive Polarization	98
7.4	Receive Power Parameters	99
7.4.1	Receive Signal Power	100
7.4.2	Noise Power	101
7.5	SAR Image Parameters	102
7.5.1	Transmit Sequence	102
7.5.2	Image Area	102
7.5.3	COD Time & Dwell Time	103
7.5.4	Transmit Polarization	106
8	Reference Geometry Parameters	108
8.1	Reference Point & APC Parameters	108
8.2	Reference Point Parameters	110
8.3	APC Geometry Parameters	111
8.3.1	APC to PT Geometry Parameters	111
8.3.2	Transmit APC Parameters	116
8.3.3	Receive APC Parameters	117
8.4	SAR Image Parameters	118
8.4.1	Reference Time	118
8.4.2	ARP to RPT Geometry	119
8.4.3	SAR XML Parameters	126
9	Antenna Parameters	128
9.1	Antenna Orientation, Position, & Velocity	129
9.1.1	ACF Orientation Parameters	129
9.1.2	APC Parameters	130
9.1.3	Example ACF & APC Configurations	130
9.2	Pointing Vectors	134
9.2.1	LOS Pointing Vectors	134
9.2.2	Antenna Pointing Vectors	135
9.2.3	EB Steering Vectors	135
9.2.4	EB Shift vs. Frequency	137
9.3	Antenna Beam Shape Patterns	138
9.3.1	Antenna Gain/Phase Support Arrays	139
9.3.2	Computing Gain/Phase from a Support Array	141
9.3.3	Antenna Gain/Phase Function Pairs	142
9.3.4	Computing Antenna Beam Shape Gain/Phase	144
9.4	Polarization Parameters	147
9.4.1	Polarization Orientation: LOS = +ACZ	147
9.4.2	Polarization Orientation: Arbitrary LOS	147
9.4.3	Polarization (H, V) Directions	148
9.4.4	Polarization Relative to (H, V) Directions	150
9.4.5	Polarization ID	153
10	Error Parameters	155
10.1	Position & Velocity Error Parameters	155
10.1.1	PV Error Coordinate Frames	156

10.1.2	Position & Velocity Error Statistics	158
10.1.3	Error Decorrelation Parameters	159
10.2	Timing & Frequency Error Parameters	160
10.2.1	SAR Timing & Control Model.....	160
10.2.2	Timing & Frequency Errors	161
10.2.3	Time & Frequency Error Statistics.....	164
10.2.4	Error Decorrelation Parameters.....	165
10.3	Atmospheric Error Parameters	165
11	CRSD XML Description.....	166
11.1	XML Parameter Types	166
11.2	Binary Parameter Formats	169
11.3	XML Enumeration List	170
12	CRSD XML Structure.....	171
12.1	XML: SAR Imaging	171
12.2	XML: Transmit Only.....	172
12.3	XML: Receive Only	172
12.4	Color Scheme for XML Tables	173
12.5	CRSD XML Tables	178
12.5.1	XML: ProductInfo / SARInfo / TxInfo / RcvInfo	178
12.5.2	XML: Global	181
12.5.3	XML: SceneCoordinates	183
12.5.4	XML: Data	187
12.5.5	XML: TxSequence	191
12.5.6	XML: Channel.....	194
12.5.7	XML: ReferenceGeometry.....	199
12.5.8	XML: DwellPolynomials	203
12.5.9	XML: SupportArray	204
12.5.10	XML: PPP	209
12.5.11	XML: PVP.....	211
12.5.12	XML: Antenna	213
12.5.13	XML: ErrorParameters.....	216
12.5.14	XML: GeoInfo.....	222
13	Conformance Guidance	223
13.1	Conformance Description.....	223
13.2	Abstract Test Suite.....	224
13.2.1	Module 1: Product File Format	224
13.2.2	Module 2: XML Format and Content	225
13.2.3	Module 3: Binary Data Block Sizes.....	226
13.3	Implementation Conformance Statement	227

LIST OF FIGURES

Figure 1-1 SAR Image Signal & Metadata Arrays	10
Figure 2-1 Product File Format – CRSD:SAR	11
Figure 2-2 File Content by Product Type	12
Figure 2-3 Support Block.....	18
Figure 2-4 PPP Array & PPP Block	19
Figure 2-5 PVP Block and Signal Block	20
Figure 2-6 PVP Array and Signal Array.....	22
Figure 2-7 Per Vector Parameter Set	23
Figure 2-8 Standard & Compressed Signal Arrays.....	24
Figure 4-1 SAR Signal & Metadata Arrays	39
Figure 4-2 SAR Imaging Geometry	40
Figure 4-3 SAR Imaging Timeline	40
Figure 4-4 Receive Only Geometry	41
Figure 4-5 Receive Only Timeline	41
Figure 4-6 Band-Limited Spectrums	43
Figure 4-7 Transmit Pulse & Spectrum	44
Figure 4-8 Ideal Waveform Generator Model	46
Figure 4-9 XMA Vector Select.....	50
Figure 4-10 XM Vector Resample.....	50
Figure 4-11 Fx Response Applied to Spectrum	53
Figure 4-12 PVP Array and Fast Time Signal Array	57
Figure 4-13 Ideal SAR Receiver Model	58
Figure 4-14 Receiver Frequency Bands.....	59
Figure 4-15 CRSD Vector Digital Processing	63
Figure 4-16 Example Vector Formation – No Resampling	64
Figure 4-17 CFOR Frequency vs. Fast Time.....	66
Figure 4-18 Example Vector Formation – With Resampling.....	67
Figure 4-19 DROR Frequency vs. Fast Time	68
Figure 4-20 SAR Pulse Timing.....	70
Figure 5-1 Image Area Polygon.....	73
Figure 5-2 Image Area Rectangle.....	73
Figure 5-3 Image Area for Multiple Channels.....	74
Figure 6-1 Reference Sequence & Pulses	78
Figure 6-2 Example Transmit Reference Point	81
Figure 6-3 Pulse Amplitude Functions	85
Figure 6-4 Example Pulse Geometry	86
Figure 6-5 Fx Response Array.....	87
Figure 6-6 XM Array	89
Figure 6-7 XM Spectral BW	91
Figure 7-1 Reference Channel and Vectors	93
Figure 7-2 Example Receive Reference Points	97
Figure 7-3 Receive Signal Vector Processing	101
Figure 7-4 Channel Image Areas	103
Figure 8-1 Reference Point ETP.....	110
Figure 8-2 APC to PT Geometry	113

Figure 8-3	Ground Squint Angle	114
Figure 8-4	APC Geometry Angles.....	115
Figure 8-5	Transmit APC Geometry.....	116
Figure 8-6	Receive APC Geometry	117
Figure 8-7	SAR Image Geometry	120
Figure 8-8	ARP Geometry Parameters	121
Figure 8-9	Squint Angle w.r.t. ARP Ground Track.....	123
Figure 8-10	Ground Plane Coordinates	124
Figure 8-11	Grazing Plane & Plane of Incidence	125
Figure 8-12	Azimuth & Layover Angles	126
Figure 9-1	Parabolic Reflector Antenna	131
Figure 9-2	Electronically Steered Antenna.....	132
Figure 9-3	Antennas for Bistatic SAR.....	133
Figure 9-4	LOS Pointing Vector.....	134
Figure 9-5	EB Steering Vector	136
Figure 9-6	Antenna Gain & Phase Arrays	140
Figure 9-7	Array/Element Gain Functions	143
Figure 9-8	Array/Element Gain Functions	144
Figure 9-9	Instantaneous H & V Directions	149
Figure 9-10	Vectors ACXN & ACYN.....	151
Figure 10-1	RICF Coordinate Frame.....	157
Figure 10-2	SAR Collection Timeline.....	161
Figure 10-3	Transmit Time Errors	162
Figure 10-4	Receive Time Errors	163
Figure 12-1	SAR Imaging XML Metadata Structure	175
Figure 12-2	Transmit Only XML Metadata Structure	176
Figure 12-3	Receive Only XML Metadata Structure	177
Figure 13-1	Test Collection and CRSD Products	223

LIST OF TABLES

Table 1-1 CRSD Design Documents	4
Table 1-2 Normative Reference Documents.....	4
Table 1-3 Informative Reference Documents.....	4
Table 1-4 Terms and Definitions	5
Table 2-1 File Header Key-Value Pair Keys	15
Table 4-1 Transmit Signal Model XML Parameters	31
Table 4-2 Transmit Signal Per Pulse Parameters.....	32
Table 4-3 Receive Signal Model XML Parameters	34
Table 4-4 Receive Signal Per Vector Parameters	35
Table 9-1 Polarization ID Values	153
Table 11-1 XML Parameter Types	166
Table 11-2 Allowed Binary Formats	169
Table 11-3 XML Enumerations	170
Table 12-1(a) Product Information	178
Table 12-1(b) SAR Imaging Information	179
Table 12-1(c) Transmit Sensor Information	180
Table 12-1(d) Receive Sensor Information.....	180
Table 12-2 Global Parameters	181
Table 12-3 Scene Geographic Coordinates.....	183
Table 12-4 Binary Data Parameters	187
Table 12-5 Transmit Sequence Parameters.....	191
Table 12-6 Receive Channel Parameters	194
Table 12-7 Reference Geometry Parameters	199
Table 12-8 Dwell Time Parameters	203
Table 12-9 Support Array Parameters	204
Table 12-10 Per Pulse Parameters	209
Table 12-11 Per Vector Parameters	211
Table 12-12 Antenna Parameters.....	213
Table 12-13 Error Parameters.....	216
Table 12-14 Geographic Information Parameters.....	222

LIST OF ABBREVIATIONS

Abbreviation & Acronyms	
Abbreviation	Phrase in Full – Reference for CRSD specific description.
ACF	Antenna Coordinate Frame – Section 9.1
ADC	Analog-to-Digital Converter
APAT	Antenna Pattern – See Section 9.3
APC	Antenna Phase Center – See Section 9.2
ARP	Aperture Reference Point – See Section 8.4
ATS	Abstract Test Suite – See Section 13
BW	Bandwidth
CC	Correlation Coefficient
CCW	Counterclockwise
CFOR	Constant Frequency on Receive
CH	Channel
COA	Center of Aperture
COD	Center of Dwell
CPHD	Compensated Phase History Data – See Table 1-2
CRSD	Compensated Radar Signal Data
CRSD:RCV	CRSD Receive Only
CRSD:TX	CRSD Transmit Only
CRSD:SAR	CRSD SAR Imaging
CRT	Collection Reference Time – See Section 4 & Table 4-1
CW	Clockwise or Continuous Wave
DAC	Digital-to-Analog Converter
DCA	Doppler Cone Angle
DEM	Digital Elevation Model
DFT& IDFT	Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) See Section 4.6
D&I DD	Design & Implementation Description Document
DROR	De-Ramp on Receive
EB SV	Electrical Boresight Steering Vector – See Section 9.2
ECI	Earth Centered Inertial (J2000) coordinate system.
ECEF or ECF	Earth Centered Earth Fixed (ECEF) or Earth Centered Fixed (ECF) – Used interchangeably to refer to the ECEF coordinate frame.
ENU	East, North, Up or Enumeration Type – See Table 11-3
ETP	Earth Tangent Plane – See Section 8.2
FTP A	Fast Time Phase Adjustment – See Section 4.9
Fx or FX	Frequency on Transmit
GP or G/P	Gain / Phase

Abbreviation & Acronyms	
Abbreviation	Phrase in Full – Reference for CRSD specific description.
HAE	Height Above the Ellipsoid – Height above the WGS 84 reference ellipsoid.
I&Q	In-Phase & Quadrature
IAC	Image Area Coordinates
IACP	Image Area Corner Point – See Section 5
IARP	Image Area Reference Point – See Section 5
ID	Identifier
IF	Intermediate Frequency
KVP	Key Value Pair – See Section 2.2
LFM	Linear Frequency Modulation
LLH	Latitude, Longitude, Height Above the Ellipsoid
LOS	Line of Sight
ML	Mainlobe
MSB	Most Significant Byte
NSG	National System for Geospatial-Intelligence
PDD	Product Design Document – See Section 3
PHD	Phase History Data
POI	Plane of Incidence
PPP	Per Pulse Parameter – See Table 4-2
PVP	Per Vector Parameter – See Table 4-4
RF	Radio Frequency
RI	Radiant Intensity
RIC	Radial, In-Track, Cross-Track – See Section 10.1
RMS	Root Mean Square
RRP	Receive Reference Point – See Section 7.3
SA	Support Array
SAR	Synthetic Aperture Radar
SICD	Sensor Independent Complex Data – See Table 1-3.
TOA	Time of Arrival
TRP	Transmit Reference Point – See Section 6.3
URL	Uniform Resource Locator
UTC	Coordinated Universal Time
UTF	Unicode Transformation Format
WF	Waveform
WGS 84	World Geodetic System 1984
XM	Transmit Modulation – XM from Xmt Modulation
XML	Extensible Markup Language

1 Introduction

The Compensated Radar Signal Data (CRSD) format is designed to accommodate the signal data that is received and recorded by a Synthetic Aperture Radar (SAR) sensor. The supporting metadata specify the collection geometry and timing. For a given collection, the receive signal metadata specifies the timing and receive processing used to form the signal data arrays. The transmit signal metadata specifies pulse waveforms used to illuminate the imaged scene. The primary motivations for the development of the CRSD format are:

- (1) To enable the detection and analysis of received signals from sources external to the radar sensor that collected the radar signal data.
- (2) To enable processing to isolate and/or mitigate interfering signals that may degrade the utility of the SAR images.

The CRSD format is designed to enable the development of SAR data processing applications that are independent of the SAR sensors that collect the initial signal data.

The CRSD format provides flexibility in what may be included in a given product. Using a common data structure and product file format, a CRSD product may be one of three types.

- (1) CRSD SAR Imaging: A SAR imaging product, denoted CRSD:SAR, contains receive signal data and metadata for SAR image formation.
- (2) CRSD Transmit Only: A Transmit Only product, denoted CRSD:TX, contains the metadata for one or more transmit pulse sequences.
- (3) CRSD Receive Only: A Receive Only product, denoted CRSD:RCV, contains one or more receive data channels.

The SAR signal data received and recorded during an imaging collection is commonly referred to as Phase History Data (PHD). The recorded signals may be from a variety of sources. The primary signals are the echoes of the transmitted pulses from the imaged scene. The recorded signal data will also include thermal noise from sources both internal and external to the radar receiver. The signal data may also contain signals from radio frequency (RF) emitters operating in the same frequency band as the SAR sensor.

The PHD that is recorded on the SAR sensor is referred to as the initial PHD. The initial PHD signal array is typically a two-dimensional data array indexed by lines and samples. Each line of the signal array, also referred to as a signal vector, corresponds to the signal received during a single receive listening window. For each receive window, the processing applied to form the PHD signal vector includes both analog and digital signal processing. The analog processing includes one or more stages of amplification, demodulation, and filtering prior to analog-to-digital conversion. The digital processing may also apply a digital demodulation, additional filtering, or both. The filtering applied will typically reject out-of-band signals and, in many cases, may also reject or distort in-band signals received from an external RF emitter.

The processing that transforms an initial PHD signal array into a CRSD signal array will form a digital signal that represents the signal that was incident at the receive Antenna Phase Center (APC). One vector of the initial PHD array is processed to form one vector of the CRSD array. The CRSD vector is a complex-valued signal vector that spans the fast time receive window. The CRSD signal is an estimate of the complex envelope of the analog signal that was incident at the APC. For a signal that was incident at the receive APC and retained undistorted in the initial PHD vector, the signal in the CRSD vector will be restored to the amplitude, phase, and timing that would be observed at the receive APC.

The CRSD format is designed to accommodate all signal data that was collected during a given SAR imaging event. A CRSD:SAR product may contain one or more receive signal data arrays that were collected during the event. The signal arrays and supporting metadata, referred to as receive data channels, may be collected simultaneously or sequentially. A product may contain metadata that specifies one or more sets of transmit pulses that provided the radar illumination. For each set of transmit pulses, referred to as a transmit sequence, the metadata specifies the precise timing and signal content of each pulse. The metadata that may be provided can specify conventional Linear Frequency Modulated (LFM) waveforms as well as waveforms of arbitrary amplitude and/or phase modulation. For each receive signal array, the transmit sequence is specified that provided the illumination of the imaged scene. The metadata for the sequence may be used to form the SAR images from the receive signal data.

While the CRSD format is designed for SAR imaging collections, a CRSD:RCV product may be formed for the signal data collected by a receive-only sensor. In general, the signal data from any sensor that receives and records a fixed band of frequencies may be processed to form a CRSD signal array. The received signal may be collected continuously during a single time period or during multiple time intervals of fixed duration.

1.1 Scope

This document specifies the CRSD format for SAR signal data and the supporting metadata included in a product. The CRSD format includes a sensor-independent data structure and file format for the storage and transmission of SAR PHD. This document and the companion CRSD XML schema fully define the CRSD format.

- (1) The Design & Implementation Description Document (this document) provides the description needed by producers of SAR PHD to design a CRSD product and select the set of metadata that support it. It also provides the information needed by users of CRSD products to input the data and create SAR image products.
- (2) The CRSD format defines a common data structure that is used to create three types of CRSD products: CRSD:SAR, CRSD:TX, and CRSD:RCV. This document provides guidance for what portions of the data structure are included for each type of product
- (3) The CRSD format is designed to accommodate the SAR PHD that is received and recorded by a single sensor during a single imaging event. The radar

illumination of the imaged scene is provided by a single radar sensor during the imaging event.

- (4) The CRSD format provides full support of both monostatic SAR imaging events and bistatic SAR imaging events. The document provides guidance for creating CRSD products for both monostatic and bistatic SAR imaging events.

1.2 Conformance

A primary objective in the development of the sensor-independent product formats is to enable the interoperability of sensors and the data processing systems that produce the intermediate and exploitation-ready data products. The ability of the sensors and systems to work together relies on the data products conforming to the standard.

1.2.1 Conformance Requirements

A data processing system that forms CRSD products conforms to this standard when the output products fulfill the following general requirements.

- (1) Products conform to the requirements of the standard that apply to all products.
- (2) Products conform to the conditional requirements of the standard for the types of events and/or processing options that meet the conditions.
- (3) Products conform to the optional requirements of the standard for the types of events and products that include optional metadata elements in the output products.

The requirements of this standard are specified in Sections 2 through 12 and in the CRSD XML schema that defines the XML data structure. The same sections and the schema also specify the conditional and optional requirements.

1.2.2 Conformance Testing

A suite of tests is defined to show a basic level of conformance to the standard. See Section 13. The method of testing and the suite of tests are defined in the Abstract Test Suite (ATS). For a data processing system to conform to the CRSD standard, all data products shall successfully pass all tests in the ATS.

1.3 Design and Reference Documents

The CRSD format is defined by this document and the CRSD XML schema which defines the XML structure used for the metadata that is included in all products. The design artifacts are listed in Table 1-1.

Table 1-1 CRSD Design Documents		
Number	Title	Version / Date
NGA.STND.0080-1	Compensated Radar Signal Data (CRSD) Design & Implementation Description Document See: https://nsgreg.nga.mil/ntb.jsp	V1.0 2025-02-25
N/A	CRSD XML Schema: CRSD_schema_V1.0_2025_02_25.xsd See: https://nsgreg.nga.mil/ntb.jsp	V1.0 2025-02-25

The CRSD format design is closely aligned with the Compensated Phase History Data (CPHD) format for SAR PHD products. The CPHD format is defined in NGA.STND.0068. The CPHD design artifacts are available on the National System for Geospatial-Intelligence (NSG) Standards Registry (<https://nsgreg.nga.mil>). Some portions of the CRSD XML metadata structure are identical to portions of the CPHD XML metadata structure. The guidance for implementing those portions of the CRSD data structure include references to the applicable sections of the CPHD design document. The CPHD design document and its reference URL are listed in Table 1-2.

Table 1-2 Normative Reference Documents		
Number	Title	Date
NGA.STND.0068	Compensated Phase History Data (CPHD) Design & Implementation Description Document See https://nsgreg.nga.mil/doc/view?i=5388	V1.1.0 2021-11-30

The CRSD format design is related to the Sensor Independent Complex Data (SICD) format for complex image products. The SICD format for complex image products is defined in NGA.STND.0024. The SICD design artifacts are also available on the NSG Standards Registry. The SICD design document and reference URL are listed in Table 1-3.

Table 1-3 Informative Reference Documents		
Number	Title	Date
NGA.STND.0024	Sensor Independent Complex Data (SICD), Volume 1, Design & Implementation Description Document See https://nsgreg.nga.mil/doc/view?i=5529	Version 1.4.0 26 Oct 2023

1.4 Terms and Definitions

The key terms used to specify the CRSD format and product file format are defined in Table 1-4. Also see the List of Abbreviations provided in the initial section following the Table of Contents.

Table 1-4 Terms and Definitions	
Term	Definition
Collection Reference Time	A time specified in UTC that provides a reference time for all timing metadata included in the product. All timing metadata is specified in seconds relative to the CRT. See Section 4.
Compensated Phase History Data	Compensated Phase History Data (CPHD) is an NGA standard data format for SAR PHD. The CRSD format is closely aligned with the CPHD format. See Table 1-2.
CRSD:RCV	A CRSD data product that contains receive signal arrays and receive event metadata. It does not contain transmit pulse sequence metadata.
CRSD:SAR	A CRSD data product that contains receive signal arrays and all metadata needed to form the SAR images of the illuminated scene.
CRSD:TX	A CRSD data product that contains transmit pulse sequence metadata. It does not contain receive signal arrays or receive metadata.
Fx Response Array	A defined support array that contains one or more Fx Response functions. See Section 6.5.
Initial PHD	Initial PHD is the SAR signal data that is received, digitized, and recorded on the SAR sensor.
Phase History Data	Phase History Data (PHD) is the SAR signal data that contains the received echoes of the transmitted pulses from the imaged scene.
Per Pulse Parameter	Parameter that is provided for each transmit pulse of a transmit pulse sequence.
Per Vector Parameter	Parameter that is provided for each signal vector of a receive channel signal array.
Receive Data Channel	A receive signal array and its supporting metadata for signal data collected using a fixed receive configuration. See Section 7.
Signal Array	A two-dimensional data array that contains the signal data received and recorded by the SAR sensor and processed, as required, to be included in a CRSD product.
Support Array	A two-dimensional data array that contains metadata that may describe the SAR sensor, the imaging collection, and/or the imaged scene.

Table 1-4 Terms and Definitions	
Term	Definition
Transmit Pulse Sequence	A sequence of transmit pulses that are transmitted using a fixed transmit configuration. See Section 6.
XM Array	A defined support array that contains one or more XM functions. See Section 6.6.

1.5 CRSD Format Overview

The CRSD format for SAR PHD data products is designed to accommodate the signal data that a single radar sensor receives and records during a single imaging event. The primary application is the storage and transmission of the PHD recorded by a SAR sensor during a single imaging event. Such a product includes the received signal data and all metadata needed to form SAR images of the imaged scene.

The CRSD format may also be used for two secondary applications. First, the format may be used to provide only the transmit signal metadata for a SAR imaging event. The transmit signal information may be used to support bistatic SAR imaging collection and data processing. Second, the format may be used to accommodate some types of receive only signal data collections that do not support SAR image formation. Such a product includes metadata that specifies how the data was collected and processed.

1.5.1 Product Types

The CRSD format includes a sensor independent data structure and file format. The format defines three types of CRSD products.

- (1) CRSD SAR Imaging: A SAR imaging product, denoted CRSD:SAR, contains one or more receive channel signal arrays and all supporting metadata required to form the SAR images of the illuminated scene. The product contains transmit pulse metadata and receive signal metadata.
- (2) CRSD Transmit Only: A Transmit Only product, denoted CRSD:TX, contains transmit pulse metadata for a SAR imaging event. The CRSD:TX product does not contain receive channel signal arrays or receive signal metadata.
- (3) CRSD Receive Only: A Receive Only product, denoted CRSD:RCV, contains one or more receive channel signal arrays. For each signal array, it contains the receive signal metadata specifying the receive timing and signal processing. A CRSD:RCV product does not contain transmit pulse metadata.

1.5.2 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 five data blocks. The defined blocks are the XML block, Support block, PPP block, PVP block, and the Signal block. The data blocks included in a given product depend on the type of CRSD product.
- (2) The XML block is included in all products and contains an XML instance that specifies the product type. The XML instance includes metadata that identifies the radar sensors, the collection event, and identifies the CRSD product. The XML instance also specifies the content of the other data blocks contained in the product.
- (3) The Support block is included in all products and contains one or more support arrays. Each support array (SA) is a two-dimensional array of data elements that specify aspects of the radar sensors, the imaged scene, and/or the transmit pulse waveforms used to illuminate the imaged scene.
- (4) The PPP block is included in CRSD:SAR and CRSD:TX products. The Per Pulse Parameter (PPP) block includes one or more arrays of parameters that specify transmit pulse sequences for the event. Each PPP array specifies the timing and waveform for each pulse in a given sequence.
- (5) The Signal block is included in CRSD:SAR and CRSD:RCV products. The Signal block contains one or more receive signal arrays. Each signal array contains the PHD that was collected using a single receive configuration.
- (6) The PVP block is included in CRSD:SAR and CRSD:RCV products. The Per Vector Parameter (PVP) block includes one array of parameters for each receive signal array. Each PVP array specifies the timing and receive processing for each signal vector in a given signal array.

1.5.3 Transmit Pulse Sequences

All CRSD:SAR and CRSD:TX products contain metadata for one or more transmit pulse sequences. For each transmit sequence, the XML metadata includes a set of transmit sequence specific parameters. Each transmit sequence includes a PPP array. The metadata provided for all transmit pulse sequences have the following attributes.

- (1) Each sequence is referenced by a unique text-based transmit sequence identifier, denoted Tx_ID. The sequence specific XML metadata specifies the Tx_ID.
- (2) The number of pulses in the sequence denoted NP_TX. The pulses in the sequence are indexed by $p = 0, 1, 2, \dots, NP_TX - 1$. The transmit pulses in a sequence are ordered by increasing transmit center time.

- (3) The PPP array contains one set of metadata parameters for each pulse in the sequence. The parameters include the transmit APC position and velocity, the pulse center time, and the pulse length.
- (4) For each pulse, the PPP array includes parameters to specify a Linear Frequency Modulation (LFM) waveform.
- (5) All transmit sequences reference an Fx Response array. An Fx Response array contains one or more sampled Fx Response functions. For each transmit pulse, one Fx Response function is used to compute the transmit pulse waveform.
- (6) For transmit pulse sequences that use pulse modulation schemes other than LFM, each pulse sequence references an XM array. An XM array contains one or more sampled XM functions. For each pulse, one XM function is used to in computing the transmit pulse waveform.

1.5.4 Receive Data Channels

All CRSD:SAR and CRSD:RCV products contain one or more receive data channels. For each receive channel, the XML metadata includes a set of channel specific parameters. Each data channel includes a signal array and a corresponding PVP array. All receive data channels have the following attributes.

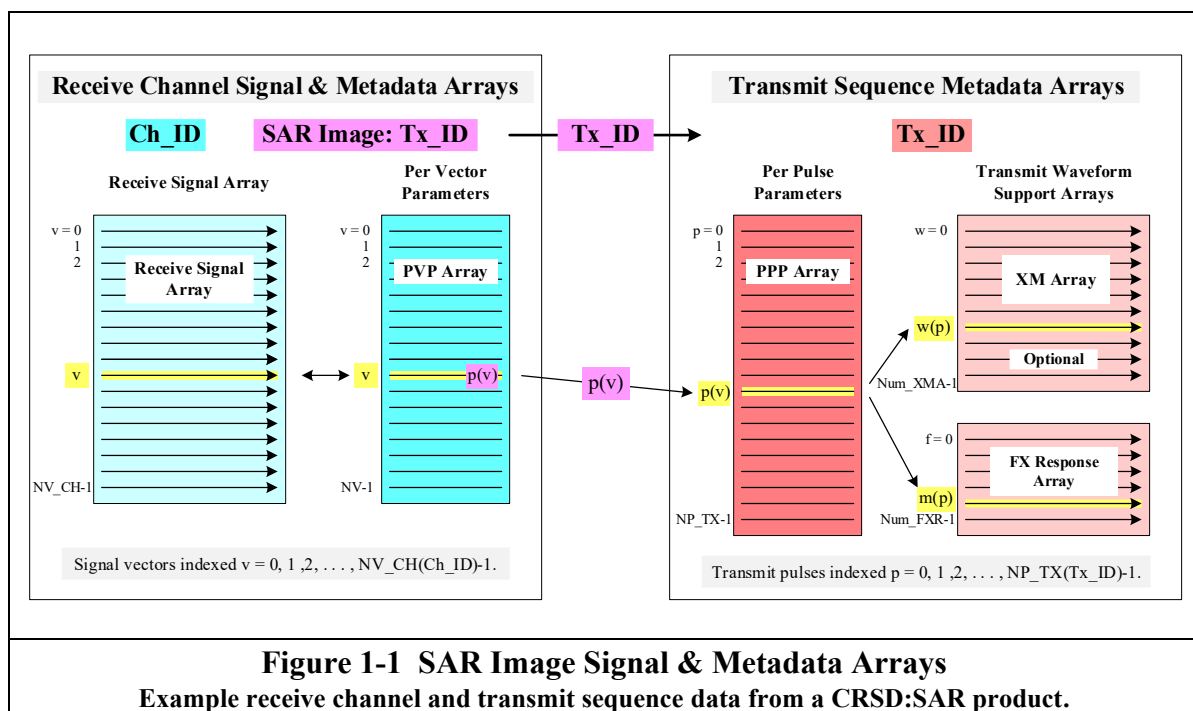
- (1) Each receive channel is referenced by a unique text-based channel identifier, denoted Ch_ID. The channel specific XML metadata specifies the Ch_ID.
- (2) The signal array is a two-dimensional array of complex-valued samples. Each row of the signal array is referred to as a signal vector and contains the signal data that was received during a single receive period. The number of vectors in the array is NV_CH. The vectors in a given signal array are indexed by $v = 0, 1, 2, \dots, NV_CH - 1$.
- (3) The vectors are ordered by increasing receive time. The vector dimension is commonly referred to as “slow time” and is measured in seconds relative to the Collection Reference Time (CRT). The sample dimension is commonly referred to as “fast time”.
- (4) Each signal array in a product may be a unique size and may contain signal data received during a unique collection period and frequency band.
- (5) The PVP array contains one set of metadata parameters for each vector of the signal array.

1.5.5 SAR Imaging Metadata

All CRSD:SAR products provide metadata that is used to form SAR image products of the illuminated scene. For each receive channel, a set of SAR specific metadata is provided that is used to form the SAR images from the channel signal array. For each receive channel, the SAR image metadata provided includes the following.

- (1) For the channel, a single transmit sequence is specified for image formation. The transmit sequence is specified by its Tx_ID. The signal array for the channel contains the echoes from the imaged scene for the pulses specified in the sequence.
- (2) For each receive signal vector v , a pulse index is specified, denoted $p(v)$. Pulse index $p(v)$ specifies the pulse for which the echoes from the imaged scene were received when the initial PHD for signal vector v was received, digitized, and recorded by the receive radar sensor.
- (3) For signal vector v , the pulse timing and waveform metadata for pulse $p(v)$ are used in the initial SAR processing applied to signal vector v . The initial processing applied is typically based upon the predicted signal echoes for point scatterers located in the imaged scene.
- (4) For the receive channel, the portion of the imaged scene is specified that may be covered by the SAR images formed from the signal array. The portion of the imaged scene covered by the images is the channel image area.
- (5) For all points in the channel image area, the SAR dwell time parameters are provided. For a scene point in image area, the dwell time parameters specify which portion of the channel signal array is used to form an image pixel centered on the scene point.

The key components of the CRSD data structure for receive data channels and transmit pulse sequences are shown in Figure 1-1. Shown in the left-hand portion is a receive channel signal array and the supporting metadata components included in a CRSD:SAR product. Shown in the right-hand portion are the metadata components for the transmit pulse sequence to be used for SAR image formation processing. Receive channel components are shaded in blue and transmit channel components are shaded in red. The SAR image specific metadata provided for the receive channel are shaded in purple. The SAR Image Tx_ID identifies the pulse sequence. The transmit pulse index $p(v)$ specifies the pulse for which the echo signals from the imaged scene are in signal vector v data. For the example shown, the transmit pulse waveforms are specified using both an XM array and an Fx Response array. For each pulse p , the XM function used is specified by index $w(p)$ and the Fx Response function used is specified by index $m(p)$. See Section 4, Section 6, and Section 7 for descriptions of the transmit and receive metadata structures.



2 Data Structure and File Format

The CRSD data structure is composed of five data blocks. A CRSD 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. The data blocks included in a product are dependent upon the CRSD product type. For each product type, the set of data blocks included and the order they are included in the file shall be as listed below.

CRSD:SAR:

- (1) File Header
- (2) XML Block
- (3) Support Block
- (4) PPP Block
- (5) PVP Block
- (6) Signal Block

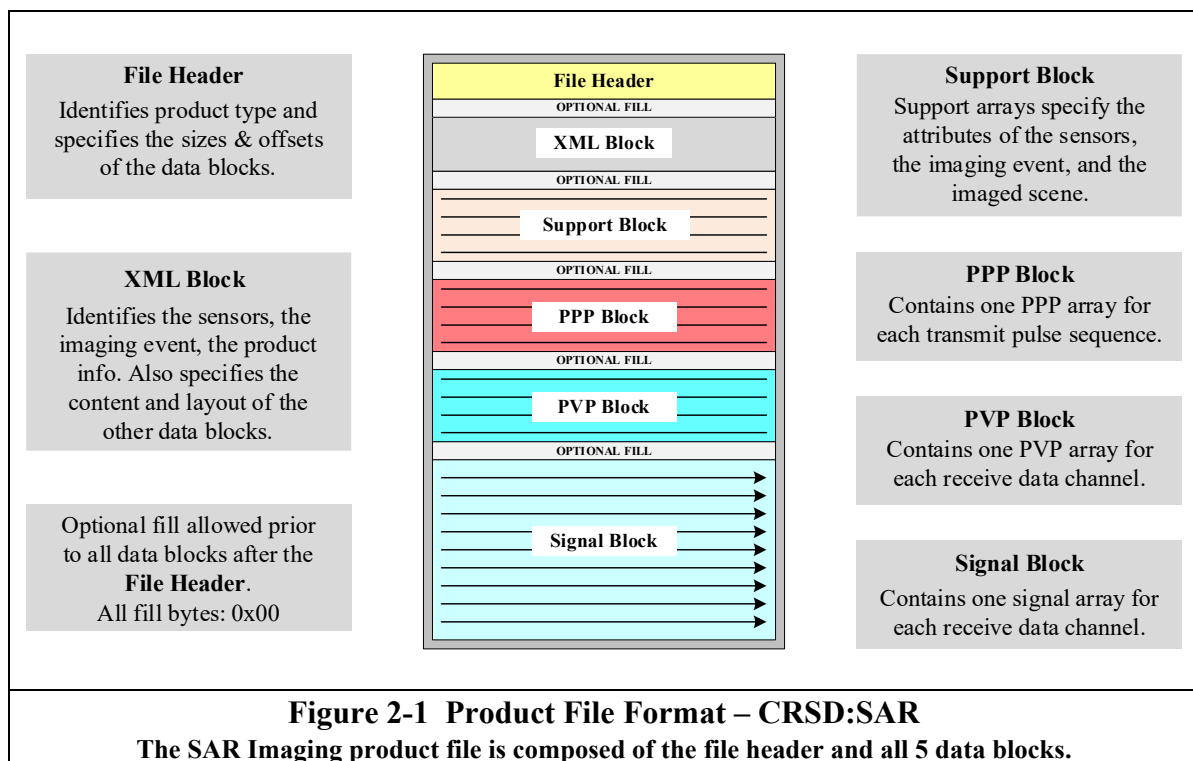
CRSD:TX:

- (1) File Header
- (2) XML Block
- (3) Support Block
- (4) PPP Block

CRSD:RCV:

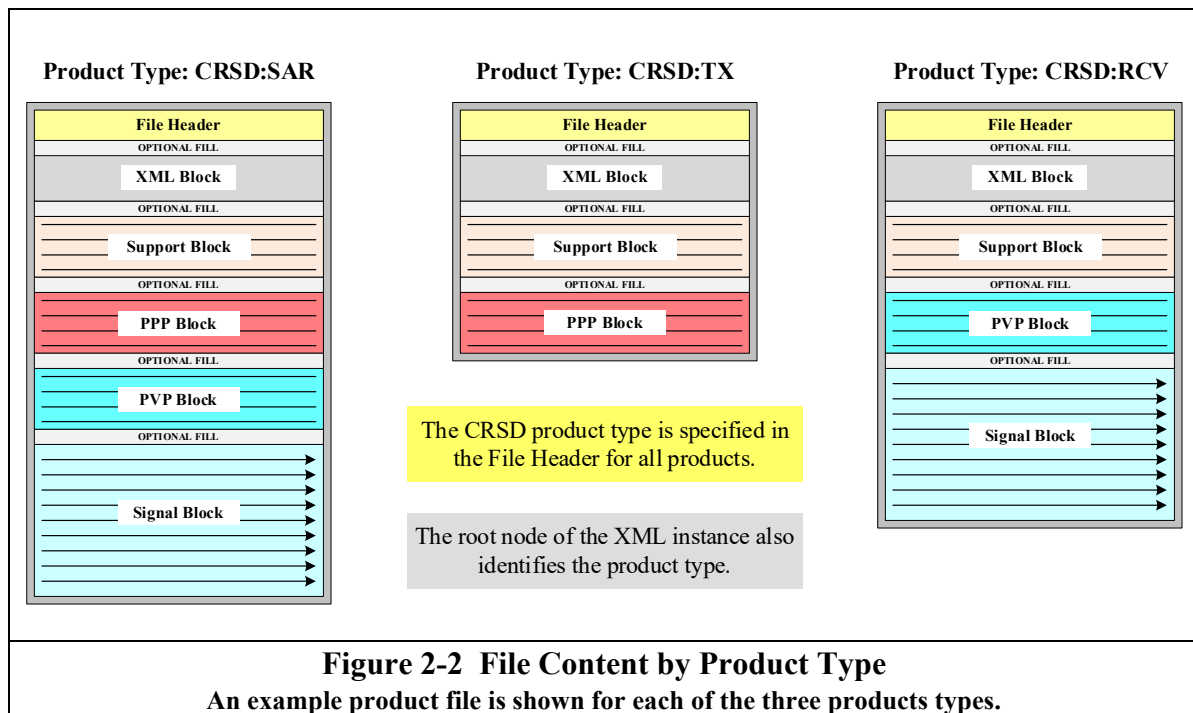
- (1) File Header
- (2) XML Block
- (3) Support Block
- (4) PVP Block
- (5) Signal Block

The File Header contains UTF-8 text and is included in all CRSD product files. The XML block also contains UTF-8 text and is included in all products. The Support block, PPP block, PVP block, and Signal block contain binary-formatted data. The components of a CRSD:SAR product are 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. Optional fill bytes may be included prior to any data block following the File Header.



The components of all three product types are shown in Figure 2-2. For all product files, the File Header shall be located at the start of the file with no offset allowed. For the example shown, all three product files were created from the same SAR imaging collection. For the CRSD:TX product, the XML block and Support block contain a subset of the metadata contained in XML block and Support block of the CRSD:SAR product. The PPP block in the CRSD:TX product is the same as the PPP block in the CRSD:SAR product file.

The CRSD:RCV product may be created in a similar way. The CRSD:RCV XML block and Support block contain a subset of the metadata contained in XML block and Support block of the CRSD:SAR product. The PVP block in CRSD:RCV product contains the same receive metadata as the PVP block in the CRSD:SAR product. The Signal block in the CRSD:RCV product contains same signal data as the Signal block of the CRSD:SAR product.



2.1 Product File Hierarchy

The logical hierarchy of the format of a CRSD 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">+

<crsd:xx file> ::= <file header>
 [<fill>]
 <XML block>
 [<fill>]
 <support block>
 [<fill>]
 <ppp block> Required for CRSD:SAR & CRSD:TX
 [<fill>]
 <pvp block> Required for CRSD:SAR & CRSD:RCV
 [<fill>]
 <signal block> Required for CRSD:SAR & CRSD:RCV

Note: In all CRSD product files, all binary parameters are formatted with the Most Significant Byte (MSB) stored first (i.e., binary data in Big Endian format). See Section 11-2.

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).

2.2 File Header

The File Header contains UTF-8 text that identifies the product type and the 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 the (3) Section Terminator. The structure of the File Header block is shown below.

<file header> ::= <file type header>
 <key-value pair list>
 <section terminator>

2.2.1 File Type Header

The File Type Header specifies the CRSD product type and specifies the version number of the format. The File Type Header is a variable length field. The file header form for each of the three product types is as shown below:

CRSD SAR Imaging:

<file type header> ::= <"CRSDsar"> <"/"> <version> <"\n">

CRSD Transmit Only:

<file type header> ::= <"CRSDtx"> <"/"> <version> <"\n">

CRSD Receive Only:

<file type header> ::= <"CRSDrcv"> <"/"> <version> <"\n">

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

2.2.2 Key-Value Pair List

The Key-Value Pair List is a variable length block that is formed by concatenating the selected Key-Value Pairs. For all product types, the KVP list is of the following form.

<key-value pair list> ::= <key-value pair>+

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

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

A set of KVP keys is defined in Table 2-1. The required KVPs are dependent on the CRSD product type. Additional optional KVP keys may be defined per a program-specific Product Design Document (PDD). 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 four-character sequence " :=" (0x20, 0x3A, 0x3D, 0x20) and terminated by a newline "\n" (0x0A). All product files shall include the required KVPs. A given KVP key shall occur only once in a given product. The KVPs may occur in any order. A product may include any number of optional KVPs. All KVPs have text-based keys and values and may not use the "\n", "\f", or the four-character sequence " :=" in the text string that is the key or the value.

2.2.3 Section Terminator

The two-byte section terminator “\fn” (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 “less” command on a Linux system).

<section terminator> ::= <“\fn”>

Table 2-1 File Header Key-Value Pair Keys		
Key Name	Req'd for Product Types	Description
XML_BLOCK_SIZE	ALL	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 “\fn”
XML_BLOCK_BYTE_OFFSET	ALL	Offset to the first byte of the XML block (in bytes, decimal integer format).
SUPPORT_BLOCK_SIZE	ALL	Size of the Support block (in bytes, decimal integer format).
SUPPORT_BLOCK_BYTE_OFFSET	ALL	Offset to the first byte of the Support block (in bytes, decimal integer format).
PPP_BLOCK_SIZE	SAR TX	Size of the PPP block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:TX products. Omitted for all CRSD:RCV products.
PPP_BLOCK_BYTE_OFFSET	SAR TX	Offset to the first byte of the PPP block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:TX products. Omitted for all CRSD:RCV products
PVP_BLOCK_SIZE	SAR RCV	Size of the PVP block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:RCV products. Omitted for all CRSD:TX products
PVP_BLOCK_BYTE_OFFSET	SAR RCV	Offset to the first byte of the PVP block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:RCV products. Omitted for all CRSD:TX products.
SIGNAL_BLOCK_SIZE	SAR RCV	Size of the Signal block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:RCV products. Omitted for all CRSD:TX products.

Table 2-1 File Header Key-Value Pair Keys		
Key Name	Req'd for Product Types	Description
SIGNAL_BLOCK_BYTE_OFFSET	SAR RCV	Offset to the first byte of the Signal block (in bytes, decimal integer format). Included in all CRSD:SAR and CRSD:RCV products. Omitted for all CRSD:TX products.
CLASSIFICATION	ALL	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	ALL	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 CLASSIFICATION and RELEASE_INFO, values shall match the corresponding values in the XML instance. See Table 12-1(a), XML elements Classification and ReleaseInfo.		

2.3 XML Block

The XML block shall be formed by 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> ::= <"\n">

The XML instance describes the imaging or collection event 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 schema defines a distinct root element for each of the CRSD product types.

CRSD SAR Imaging: <CRSDsar . . . > . . . </CRSDsar>
 CRSD Transmit Only: <CRSDtx . . . > . . . </CRSDtx>
 CRSD Receive Only: <CRSDrcv . . . > . . . </CRSDrcv>

The CRSD XML structure is described in Section 11 and Section 12 and is defined by the CRSD XML schema. A given XML instance shall be well-formed and valid as specified by the XML schema.

2.4 Support Block

The Support block is a set of one or more support arrays that are included to describe the sensors, the imaging event, and/or the imaged scene. The Support block shall be formed by the concatenation of the support arrays in the given product.

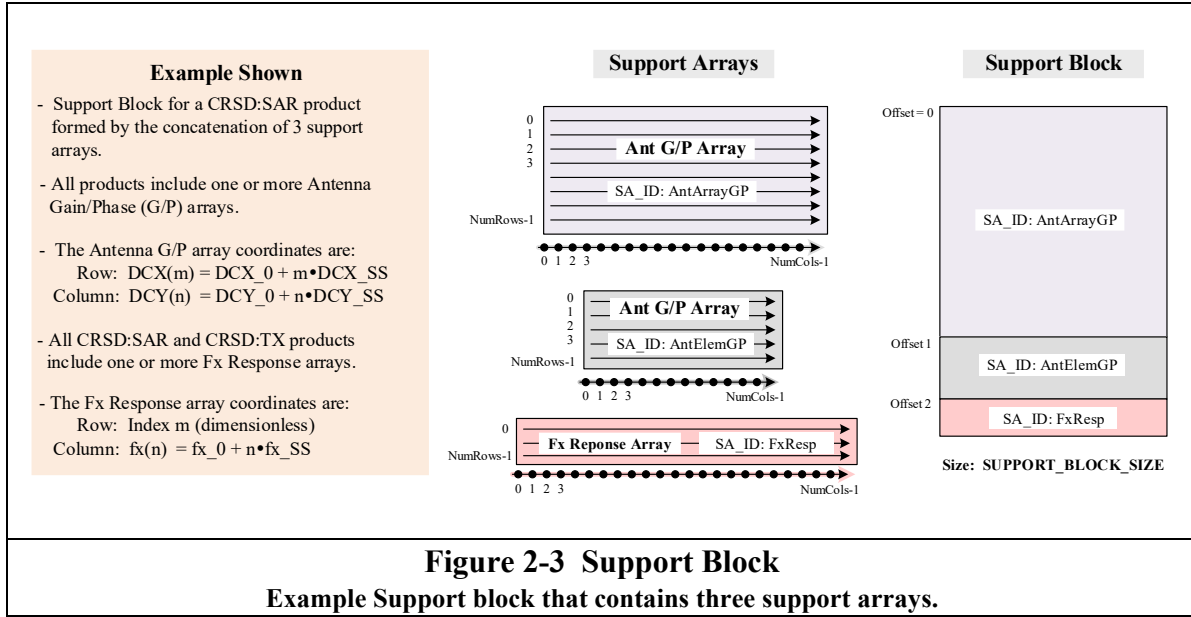
`<support block> ::= <support array>+`

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 attributes of the radar sensor, the transmit pulse waveforms, and the imaged scene (e.g., a two-dimensional array of scene surface heights). The data structure also allows for one or more support arrays to be included that are defined per a PDD (i.e., a user-defined or added support arrays).

For all product types, the set of support arrays included shall be specified in the / CRSDxx / SupportArray branch of the XML instance. The size of each array and its location within the Support block is specified in the / CRSDxx / Data branch of the XML instance. See Table 12-4 and Table 12-9.

Shown in Figure 2-3 is an example Support block that includes three support arrays. 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 12-4. The support arrays shall be formatted and stored as specified below.

- (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 ArrayByteOffset values. Fill bytes between arrays are not allowed.
- (2) A support array is indexed by (row, column). The rows of the array are indexed by $m = 0, 1, 2, \dots, \text{NumRows}(\text{SA_ID}) - 1$. The columns of the array are indexed by $n = 0, 1, 2, \dots, \text{NumCols}(\text{SA_ID}) - 1$. The number of rows and columns may be unique for each array.
- (3) For each support array, the data element format may be unique. A 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.
- (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 11-2.
- (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.



2.5 PPP Block

All CRSD:SAR and CRSD:TX products contain one or more transmit pulse sequences. A PPP array is provided for each pulse sequence. The PPP block shall be formed by the concatenation of the PPP arrays in the given product.

`<ppp block> ::= <ppp array>+`

The XML structure specifies the number of pulse sequences in the product and the number of pulses contained in each sequence. Each transmit pulse sequence may have a unique number of pulses. The XML instance also specifies the set of PPPs provided for each pulse.

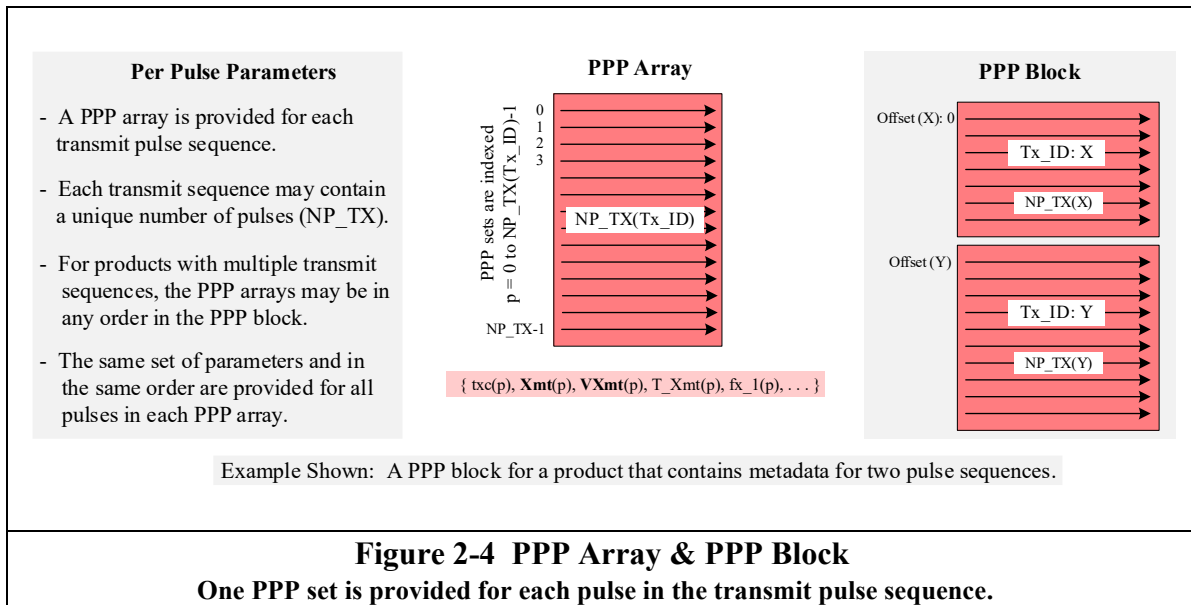
Each pulse sequence is referenced by its Tx_ID. Shown in Figure 2-4 is an example PPP block that contains two PPP arrays. For the example shown, the sequence identifiers are X and Y. The number of pulses in a given sequence is NP_TX(Tx_ID). The pulses in the sequence are indexed:

Pulse Index: $p = 0, 1, 2, \dots, NP_TX(Tx_ID) - 1$

The PPP array contains one PPP set for each pulse in the sequence. For a given CRSD:SAR or CRSD:TX product, the parameters included in the PPP set shall be specified per the following rules and guidance.

- (1) For a given CRSD product, the parameters in a PPP set are specified in the PPP branch of the XML instance contained in the product. See Table 12-10.
- (2) The PPP set is composed from the set of defined PPPs and may include one or more added PPPs. For a given product, the same set of PPPs (i.e., same entries, offsets, and sizes) is provided for all pulses of all pulse sequences.

- (3) The defined PPPs are described in Table 4-2. Each defined PPP has a corresponding node in the PPP branch of the XML structure. All defined PPPs have a defined number of components, binary format, and size
- (4) Added PPPs are optional parameters that may be included in the PPP set for a given product. The PPP set may include any number of added PPPs. The added PPPs are defined per the product design process.
- (5) For each added PPP, an AddedPPP element is included in the PPP branch of the XML instance. Each added PPP is specified with a unique name (i.e., the element / AddedPPP / Name has a unique value that is not the name of a defined PPP).
- (6) For each parameter, the binary-formatted parameter occupies one or more 8-byte words. The Size specifies the size of the parameter in 8-byte words.
- (7) For a given product, the parameters may be placed in any order within the PPP set. The Offset specifies the offset from the start of the set in 8-byte words. The first parameter in the set has an Offset value equal to 0.



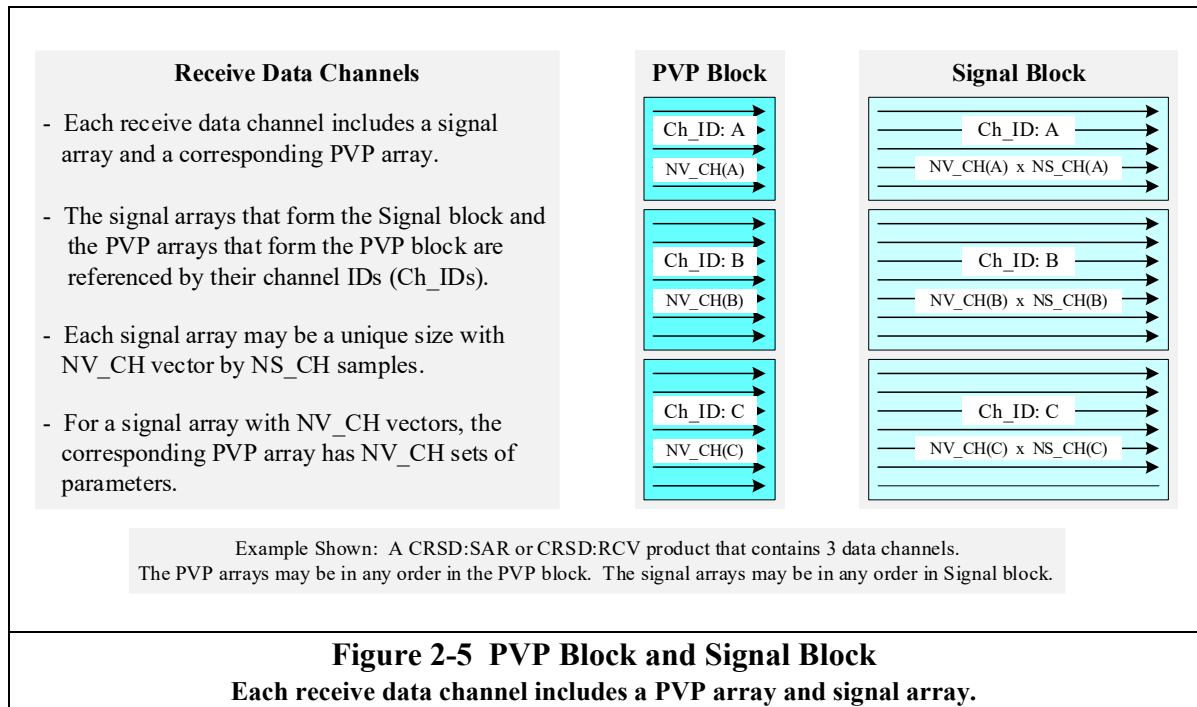
2.6 PVP Block and Signal Block

All CRSD:SAR and CRSD:RCV products contain one or more receive data channels. Each channel includes a signal array and a corresponding PVP array. The PVP block shall be formed by the concatenation of the PVP arrays. The Signal block shall be formed by the concatenation of the signal arrays.

$\langle \text{pvp block} \rangle ::= \langle \text{pvp array} \rangle^+$
 $\langle \text{signal block} \rangle ::= \langle \text{signal array} \rangle^+$

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 PVPs 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. Shown in Figure 2-5 are the PVP block and the Signal block for an example CRSD 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.

2.7 PVP Arrays and Signal Arrays

All signal arrays are two-dimensional arrays of complex-valued data samples. 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 channel in the product. The signal array is indexed by vector index v and sample index s .

Vector Index: $v = 0, 1, 2, \dots, NV_CH(Ch_ID) - 1$

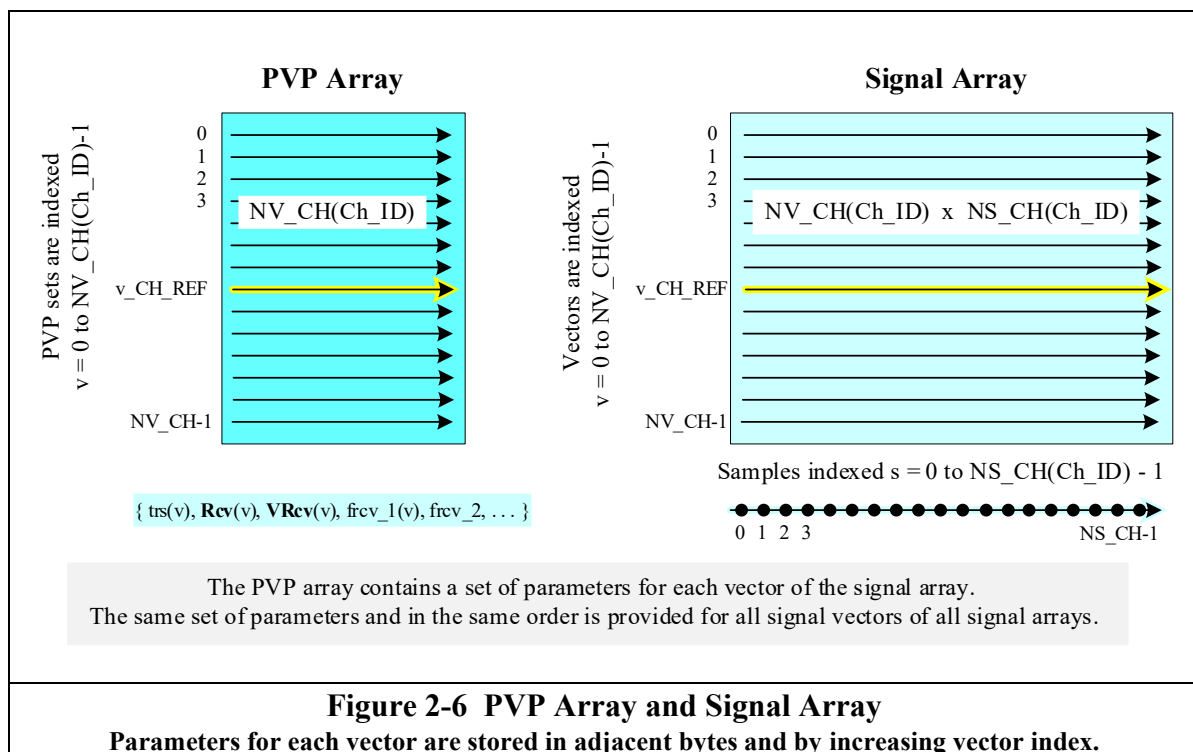
Sample Index: $s = 0, 1, 2, \dots, NS_CH(Ch_ID) - 1$

For a given CRSD product, the signal array samples are in one of three allowed binary formats. The allowed formats, denoted CI2, CI4, and CF8, are defined in Table 11-2. 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 size and product file size versus the expected dynamic range of the signals contained in the product.

Shown in Figure 2-6 is an example PVP array and signal array for a data channel in the product. 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 $NV_CH(Ch_ID) - 1$. The PVP set describes the collection geometry and signal parameters for each vector of the corresponding signal array. For a given CRSD:SAR or CRSD:RCV product, the PVP set that is provided for all signal vectors shall be specified per the following rules and guidance. Refer to Table 12-4 and Table 12-11.

- (1) For a given CRSD 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.
- (3) The defined PVPs include both required parameters and optional parameters. The PVP set includes all required parameters. The optional parameters included in the product are selected per the product design process.
- (4) The defined PVPs are described in Table 4-4. 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.
- (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 the PDD.
- (6) For each added PVP, an AddedPVP element is included in the PVP branch of the XML instance. Each added PVP is specified with a unique name (i.e., the element / AddedPVP / Name has a unique value that is not the name of a defined PVP).

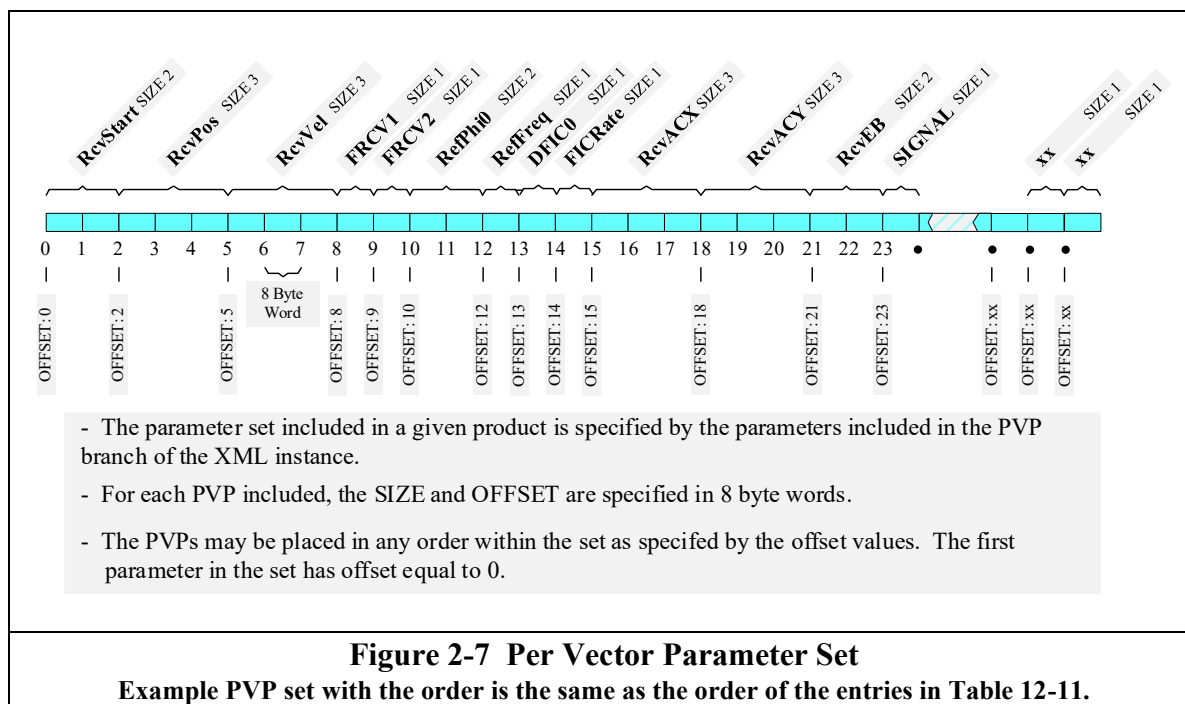
- (7) For each parameter, the binary-formatted parameter occupies one or more 8-byte words. The Size specifies the size of the parameter in 8-byte words.
- (8) For a given product, the parameters may be placed in any order within the PVP set. The Offset specifies the offset from the start of the set in 8-byte words. The first parameter in the set has an 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 2-7 is an example PVP set. For each parameter, Size defines the number of 8-byte words that the parameter occupies. Offset specifies the location of the parameter within the set. Format specifies the number of components and the binary format for each component. The first parameter in the set has an Offset value equal to 0. For a given product, the selected parameters may be placed in any order within the set. For the example shown in Figure 2-7 the parameters are ordered as they are ordered in the PVP XML branch as described in Table 12-11 and specified in the XML schema.

For a given product, the PVP set provided for each signal vector includes an amplitude scale factor. See Table 4-4. The amplitude scale factor, denoted Amp_SF, is a defined PVP that is a single real-valued, positive parameter. For each signal vector, the sample values of the signal vector are multiplied by the Amp_SF to create the proper signal values for the vector. See Table 12-4. The Amp_SF allows for signal vectors that are formed initially in a floating-point binary format to be scaled prior to conversion to a fixed-point format (CI2 or CI4 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. For products that use the CF8 floating-point format, the Amp_SF parameter is of minimal benefit. A recommended choice is to set Amp_SF = 1.0 for all vectors of all channels.

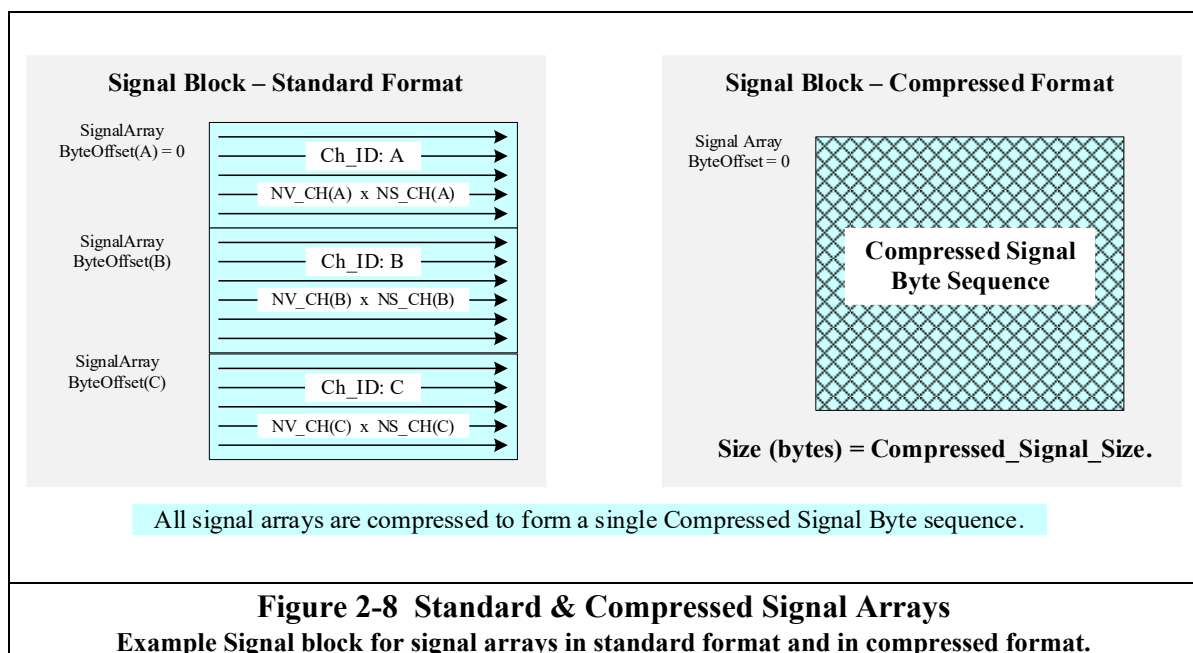


2.8 Signal Array Compression

The CRSD receive signal arrays are in all cases defined to be two-dimensional arrays of complex-valued data samples. The parameters that describe the signal arrays are included in the / CRSDxx / Data branch of the XML instance that describes the product. See Table 12-4. For most products, the signal arrays are formatted and stored as described above. For such a product, the signal arrays are defined to be in standard format. The size of each signal array (in bytes) may be computed from the dimensions of the array and the number of bytes per sample (2, 4 or 8) for the selected sample format.

$$\text{Array_Size}(\text{Ch_ID}) = \text{NV_CH}(\text{Ch_ID}) \cdot \text{NS_CH}(\text{Ch_ID}) \cdot \text{Bytes_Per_Sample}$$

A CRSD:SAR or CRSD:RCV product may also be formed with the signal arrays stored in a compressed format. All signal arrays in the product are compressed to form a single compressed signal byte sequence. The size of the compressed signal byte sequence is denoted Compressed_Signal_Size. The Signal block is then formed from the compressed signal byte sequence with zero byte offset. For such a product, the signal arrays are defined to be in compressed format. Shown in Figure 2-8 are example signal blocks for a product that contains 3 data channels. The Signal block is shown for the arrays in standard format and for the arrays in compressed format.



Products with signal arrays stored in compressed format are intended for use within a given data storage or transmission system. The methods of compression and decompression are not specified or defined as part of the CRSD standard format. The method of compression used is a design choice within the given system.

The parameters that specify the signal arrays and the Signal block are included in the / CRSDxx / Data branch of the XML instance. For a product with signal arrays in compressed format, optional elements are included in the XML instance to indicate the use of a compressed format. Other required XML array size parameters are set as follows. Refer to Table 12-4.

- (1) The / CRSDxx / Data / SignalCompression branch is included to indicate the signal arrays are in compressed format. The branch includes required elements Identifier and CompressedSignalSize.
- (2) The Identifier element identifies the method of compression. The text-string may also include information needed for decompression.
- (3) The CompressedSignalSize specifies the size (in bytes) of the compressed signal byte sequence.
- (4) The Signal block is formed from the compressed signal byte sequence with no offset. The Signal block size in the File Header is set equal to size of the compressed signal byte sequence.
- (5) The value for / CRSDxx / Data / SignalArrayFormat is set to the recommended sample format to be used for the signal arrays after decompression.

- (6) For each channel, the NumVectors and NumSamples are set to the values for the signal array in standard format. The values specify the dimensions of the signal array after decompression.
- (7) For each channel, the parameter SignalArrayByteOffset is set equal to 0.

3 Product Design

The CRSD data structure is primarily designed to accommodate the signal data received and recorded on a SAR sensor. 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. It also provides metadata parameters to describe the transmit signals that provided the illumination of the image scene.

For a given sensor, the CRSD product content is dependent on the capabilities of the sensor and the types of derived products to be made from it. The CRSD product design process defines the elements of the data structure that are included in the products for a given sensor. The data structure includes optional elements that allow the CRSD product designer flexibility when creating products.

For a given sensor and data processing element, 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 is collectively referred to as a CRSD Product Design Document (PDD). The PDD serves as the guidance for the developers of the applications that output the CRSD products to ensure the products support the intended uses.

3.1 Product Design Guidance

The CRSD data structure is composed of five data blocks. The CRSD product design addresses: (1) types of products to be produced, and (2) the content for all data blocks included in a given product type. The XML structure includes the parameters that describe the illumination or imaging event and 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. The following guidance is provided for the design of the CRSD products to be produced.

3.1.1 Product & Sensor Information

- (1) Specify values for the required parameters in the ProductInfo branch of the XML structure. Provide guidance for the values of the product classification and release information fields in the product File Header and the XML structure. See Table 2-1 and Table 12-1(a).
- (2) For CRSD:SAR products, specify the SAR collect types (i.e., monostatic and/or bistatic) for which the products are produced. Also specify the collection mode types and optional mode IDs (if included) in the SARInfo branch. See Table 12-1(b).
- (3) Define the sensor name and event name ID text strings to be used. The sensors may be identified by class or by specific platform (e.g., by aircraft tail number). See Table 12-1(c) and Table 12-1(d).

- (4) Specify additional product information parameters to be included using the optional “Parameter” element available in each of the information branches. Define parameter “name” attributes and allowed values.

3.1.2 Transmit Waveform & PPP Array Content

For CRSD:SAR and CRSD:TX products, specify the following design choices.

- (1) Specify the number of transmit pulse sequences that are included in the products. Specify the waveform types that are used to specify the pulse modulations functions. All pulse sequences in a product are specified using the same WF Type. See Table 12-4 and Table 12-5.
- (2) Specify the Tx Sequence ID text strings to be used. The Tx_ID values may be composed of multiple fields that convey attributes of the pulse sequence configuration.
- (3) The transmit sequence metadata provides three transmit waveform types. The metadata provided is dependent on the waveform type, denoted TxWFType. Specify the transmit waveform types to be used in the products.
- (4) Specify the number of Fx Response arrays to be included in a product. Specify the number Fx Response functions in each array. See Section 6.5.
- (5) For TxWF types “LFM w XM” and “XM”, specify the number of XM arrays to be included in a product. Specify the number of XM functions in each array. For each XM array, specify the range of pulse lengths and modulation bandwidths supported. Also, specify the XM function sample spacing Ts_XMA.
- (6) For products that contain multiple transmit pulse sequences, the PDD specifies which sequence is assigned as the reference sequence. For CRSD:SAR products, the reference transmit pulse sequence is determined by the choice of reference receive data channel. See Section 6.1.1.

3.1.3 Signal Array Format and PVP Array Content

For CRSD:SAR and CRSD:RCV products, specify the following design choices.

- (1) 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.
- (2) Specify the optional PVPs to be included in each PVP set.
- (3) For SAR imaging collections, the PulseIndex PVP is included. The PDD specifies if, and under what conditions, the pulse index may be set equal to the “no pulse” value.
- (4) Specify the minimum sample rates or minimum over-sample ratios to be used for the signal arrays. For systems that use De-Ramp on Receive (DROR) demodulation, specify if the over-sample rates are relative to the

instantaneous bandwidth or to the total received bandwidth. See Section 7.2 for guidance.

3.1.4 Receive Data Channels

For CRSD:SAR and CRSD:RCV products, specify the following design choices.

- (1) Specify the number of data channels that are 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 12-4 and Table 12-6.
- (2) Specify the Channel ID text strings to be used. The Ch_ID values may be composed of multiple fields that convey how the signal array was collected and to support the subsequent processing.
- (3) For products that contain multiple data channels, the PDD describes the sets of channels that may be found in a given product. It is encouraged that the description makes use of the Channel IDs that are used. For example, given a product with data channels separated by the transmit or receive polarizations, the channel ID values may identify the specific polarizations of the data channels.
- (4) For products that contain multiple data channels, the PDD specifies which data channel is the reference channel. The PDD may also specify the method for selecting the reference vector index. The center vector is the recommended choice.

3.1.5 Antenna Metadata Parameters

The parameters that specify the antennas used during the imaging collection, the transmit only event, or the receive only collection are included in all products. The PDD specifies the following design choices.

- (1) The Antenna branch of the XML structure specifies the number of Antenna Coordinate Frames (ACFs) and the number of APCs. See Table 12-12.
- (2) The PDD specifies the ACF ID and APAT ID text strings to be used.
- (3) For a SAR imaging collection that uses a single antenna for both transmit and receive, one set of antenna parameters may be provided. For a bistatic collection that uses separate antennas for transmit and receive, two ACFs are specified, and two or more sets of antenna pattern parameters are provided.
- (4) For each antenna pattern, one set of parameters is provided in the XML instance. The PDD specifies the number of antenna patterns and the allowed values for the parameters in the AntPolRef structure.

3.2 Product File Naming

The choice of CRSD product identifiers and product file names is not specified or restricted by this standard. Product file naming is a product design choice and is specified in the CRSD PDD.

3.3 Optional Information Parameters

The XML structure includes optional elements that may be used to provide support information for the product, a given sensor, and/or the imaged scene.

3.3.1 Added Parameters

Many of the XML structures and branches include an optional element “Parameter” that may be included one or more times to include additional information. The Parameter element includes a required attribute “name” that is used to identify the parameter and has a value that is text string. The use of the Parameter element in any of the various structures is a product design choice. The allowed values for the name attribute and the text string are selected and defined per the relevant Product Design Document.

The “Parameter” element may be included, for example, in the / CRSDxx / ProductInfo branch of a given product. The use of the element to include the value of a system specific parameter “Order Number” with a value of “99999” could be implemented as shown.

```
<ProductInfo>
  •
  •
  <Parameter name="Order Number">99999</Parameter>
</ProductInfo>
```

3.3.2 Geographic Information Parameters

The optional / CRSDxx / GeoInfo branch provides the capability to include geographic feature information within the CRSD product. The GeoInfo branch may be included one or more times. The GeoInfo branch may also be nested in another GeoInfo branch to support a hierarchical geographic information structure. The exact structure is defined in the XML schema and is described in Table 12-14.

Additional guidance for use of the GeoInfo structure is provided in Section 5.2.2 of the CPHD Design & Implementation Description Document. See Table 1-2.

4 CRSD Signal Model

The CRSD signal model specifies the metadata and methods used to compute the transmit pulse waveforms and the receive signal processing applied to the receive signal vectors. The CRSD signal model is a combination of two signal models. The signal model on transmit specifies the methods used to compute the transmit pulse timing and waveform modulation for each pulse. The signal model on receive specifies the methods used to compute the receive signal timing and signal processing applied for each signal vector in a signal array.

For a SAR Imaging product, the signal timing parameters on transmit and receive may be combined with the Antenna Phase Center (APC) position and velocity metadata to compute when the echo signals of the transmit pulses from the imaged scene were incident at the receive APC. The transmit pulse waveform parameters and the receive signal processing parameters may be used to determine which incident pulse echoes were retained in the CRSD signal vector. For the signals that are received and retained in the recorded signal data, the variation in echo signal amplitude and phase versus time may be predicted.

4.1 Signal Model Parameters

The transmit signal model specifies the input parameters and methods used to compute the precise pulse timing and waveform for a single transmit pulse. The receive signal model specifies the input parameters and methods used to compute the effective receive timing, signal demodulation, and filtering applied for a single receive signal vector. The transmit signal model inputs are summarized in Section 4.1.1. The receive signal model inputs are summarized in Section 4.1.2.

4.1.1 Transmit Signal Model Parameters

Transmit signal metadata is provided for each transmit pulse sequence. The transmit signal metadata is included in the XML instance, in the Per Pulse Parameters (PPP) array, and in the support arrays provided with the product. Provided in the XML instance is the transmit waveform type, denoted TxWFTType. The TxWFTType specifies the type of pulse modulation metadata that is provided and used for computing the pulse waveforms for all pulses in all sequences in a given product. The transmit signal model inputs provided in the XML instance are summarized in Table 4-1.

Each transmit pulse sequence uses a fixed transmit configuration. The transmit configuration specifies a single transmit APC (TxAPC) and a single transmit antenna pattern (TxAPAT). Each pulse sequence references a single Fx Response array. For TxWFTType equal to “XM” or “LFM w XM”, each pulse sequence also references a single XM array. The Fx Response array and the XM array (if applicable) are used to specify the transmit pulse waveforms for all pulses in the sequence.

Table 4-1 Transmit Signal Model XML Parameters		
Parameter	Type	Description
Required parameters that are common across all transmit pulse sequences.		
t_CRT	XDT	Specifies the Collection Reference Time for the transmit pulse waveforms (in UTC). All times are in seconds relative to t_CRT. See Table 12-2: Global / CollectionRefTime
TxWFType	ENU	Specifies the transmit waveform type. Waveform type determines the metadata used to specify the pulse modulation. See Table 12-5: TxSequence / TxWFType
Parameters that are included or computed for each transmit pulse sequence.		
Tx_ID	TXT	Transmit sequence identifier that uniquely identifies the transmit sequence. See Table 12-5: TxSequence / Parameters / Identifier
NP_TX	INT	Number of pulses in the transmit pulse sequence. See Figure 2-4. See Table 12-4: Data / Transmit / TxSequence / NumPulses
p_TX_REF	INT	Index of the reference pulse for the pulse sequence. See Table 12-5: TxSequence / Parameters / RefPulseIndex
FxResponse_ID	TXT	Fx Response support array ID that identifies Fx Response array used for computing pulse waveforms. See Table 12-5: TxSequence / Parameters / FxResponseId
Fx Response Array Size: Num_FXR = Num of rows / Fx Response functions NS_FXR = Num of samples per function Sample spacing parameters: fx_0_FXR, fx_SS_FXR	2 x INT 2 x DBL	Parameters that specify the Fx Response array size & sample spacing. See Sect 6.5. Array contains one or more Fx Response functions – Amp/Phase vs. Frequency (fx). See Table 12-4: / Data / Support / SupportArray See Table 12-9: / SupportArray / FxResponseArray
Tx Antenna APC & APAT TxAPC_ID TxAPAT_ID	TXT TXT	Parameters that identify the transmit APC and Antenna Pattern (APAT) for the sequence. See Table 12-5 and Table 12-12.
P_RI_Ref _{XMT}	DBL	Transmit radiant intensity (dBW/sr) for the reference pulse for beam shape gain $G_{XBS}(f) = 0$ dB and $\Phi_{XBS}(f) = 0$ cycles. Value equal to PPP TxRadInt(p_TX_REF). See Table 4-2.
Parameters specified for each Tx sequence for TxWFType = “XM” or “LFM w XM”		
XM_ID	TXT	XM support array ID that identifies the XM array used for computing pulse waveforms. See Table 12-5: TxSequence / Parameters / XMId

Table 4-1 Transmit Signal Model XML Parameters		
Parameter	Type	Description
XM Array Size: Num_XMA = Num of Rows NS_XMA = Num of Samples Sample spacing: Ts_XMA Max BW: Max_XMBW	INT INT DBL DBL	Parameters that specify the XM array size & sample spacing. Array contains one or more XM functions – Real/Imaginary vs. Fast Time (Δt_x) relative to time txc. See Table 12-4: / Data / Support / SupportArray See Table 12-9: SupportArray / XMArray Sample spacing Ts_XMA (sec) and bandwidth Max_XMBW (Hz)

A PPP array is provided for each transmit pulse sequence. The set of parameters provided for each pulse is referred to as a PPP set. For a given product, the parameters included in the PPP set are specified in the XML instance. See Section 2.5. The defined parameters that may be included in a PPP set are described in Table 4-2.

Table 4-2 Transmit Signal Per Pulse Parameters			
Parameter	PPP XML Node	Format	Description
The PPPs in a product are specified in the / CRSDxx / PPP branch of the XML instance. Pulses are indexed by $p = 0, 1, 2, \dots, NP_TX(Tx_ID) - 1$.			
Required are PPPs included in all PPP sets. See Table 12-10.			
$txc(p) =$ $txc_Int(p) + txc_Frac(p)$ See Section 4.1.3	TxTime	I8:F8	Transmit center time for the pulse. Time the center of the pulse is at the Transmit APC (sec) relative to the CRT. Provided as two parameters: txc_Int(p) and txc_Frac(p). Require $0 \leq txc_Frac(p) < 1$.
$\mathbf{Xmt}(p) = \begin{bmatrix} Xmt_X(p) \\ Xmt_Y(p) \\ Xmt_Z(p) \end{bmatrix}$	TxPos	F8:F8:F8	Transmit APC position at time txc(p) in ECEF coordinates (meters).
$\mathbf{VXmt}(p) = \begin{bmatrix} VXmt_X(p) \\ VXmt_Y(p) \\ VXmt_Z(p) \end{bmatrix}$	TxVel	F8:F8:F8	Transmit APC velocity at time txc(p) in ECEF coordinates (meters/sec).
$fx_1(p)$ $fx_2(p)$	FX1 FX2	F8 F8	Minimum and maximum transmit frequency values (Hz) for the portion of the pulse spectrum to be used for SAR image formation. Frequency values for the pulse observed at the Transmit APC. Require $fx_1(p) < fx_2(p)$.
T_Xmt(p)	TXmt	F8	The pulse length of the transmit pulse (sec). Time T_Xmt(p) is the pulse length observed at the transmit APC centered on time txc(p).

Table 4-2 Transmit Signal Per Pulse Parameters

Parameter	PPP XML Node	Format	Description
$\Phi_{X0}(p) = \Phi_{X0_Int}(p) + \Phi_{X0_Frac}(p)$ See Section 4.1.3	PhiX0	I8:F8	Transmit phase offset (cycles) at time $txc(p)$. Provided as two parameters: $\Phi_{X0_Int}(p)$ and $\Phi_{X0_Frac}(p)$. Require $0 \leq \Phi_{X0_Frac}(p) < 1.0$
$fx_0(p)$	FxFreq0	F8	Transmit frequency offset (Hz) for pulse p. The transmit pulse modulation spectrum is shifted from $f = 0$ to $f = fx_0(p)$. Require $fx_0(p) > 0$. $\Phi_{XOFF}(p, t - txc(p)) = \Phi_{X0}(p) + fx_0(p) \cdot (t - txc(p))$
$fx_Rate(p)$	FxRate	F8	Transmit FM rate (Hz/sec) used for TxWFTType “LFM” or “LFM w XM”. Use to specify LFM pulse phase modulation. $\Phi_{XFM}(p, t - txc(p)) = \frac{1}{2} \cdot fx_Rate(p) \cdot (t - txc(p))^2$ For TxWFTType = “XM”, set $fx_Rate(p) = 0$ for all pulses.
$P_RI_0_{XMT}(p)$	TxRadInt	F8	Mean transmit radiant intensity (dBW/sr) for the base pulse. Value equal to $10 \cdot \log_{10}(\bullet)$ of the radiant intensity (W/sr) averaged across the pulse length $T_Xmt(p)$. Value is for the base pulse w/ beam shape gain $G_{XBS}(f) = 0$ dB and $\Phi_{XBS}(f) = 0$ cycles.
$Xmt_uACX(p) = \begin{bmatrix} Xmt_uACX_X(p) \\ Xmt_uACX_Y(p) \\ Xmt_uACX_Z(p) \end{bmatrix}$	TxACX	F8:F8:F8	Transmit ACF X-Axis (ACX) unit vector in ECEF coordinates at $t = txc(p)$. The ACF orientation is specified by orthogonal unit vectors $Xmt_uACX(p)$ and $Xmt_uACY(p)$. For all pulses: $Xmt_uACX(p) \bullet Xmt_uACY(p) = 0$
$Xmt_uACY(p) = \begin{bmatrix} Xmt_uACY_X(p) \\ Xmt_uACY_Y(p) \\ Xmt_uACY_Z(p) \end{bmatrix}$	TxACX	F8:F8:F8	Transmit ACF Y-Axis (ACY) unit vector in ECEF coordinates at $t = txc(p)$. The ACF boresight is along the ACF +Z-Axis. The ACF Z-Axis (ACZ) unit vector is computed by: $Xmt_uACZ(p) = Xmt_uACX(p) \times Xmt_uACY(p)$
$Xmt_EB_0(p) = \begin{bmatrix} Xmt_EB_DCX_0(p) \\ Xmt_EB_DCY_0(p) \end{bmatrix}$	TxEB	F8:F8	Transmit antenna Electrical Boresight steering vector for frequency $f = fa_0$ where fa_0 is the reference frequency of the pulse sequence TxAPAT. For a mechanically steered antenna, for all pulses set $Xmt_EB_DCX_0(p) = 0$ and $Xmt_EB_DCY_0(p) = 0$.
$m(p)$	Fx Response Index	I8	Index of the Fx Response function for pulse p. The Fx Response array rows/functions are indexed by: $m = 0, 1, \dots, Num_FXR-1$.
Parameter included if and only if TxWFTType = “XM” or “LFM w XM”			
$w(p)$	XMIndex	I8	Index of the XM function for pulse p. The XM array rows/functions are indexed by: $w = 0, 1, \dots, Num_XMA-1$.

4.1.2 Receive Signal Model Parameters

Receive signal metadata is provided for each receive data channel. The receive signal metadata is included in the XML instance, in the PVP array, and in the support arrays provided with the product. The receive signal model inputs provided in the XML instance are summarized in Table 4-3.

Each receive data channel was collected using a fixed receive configuration. The receive configuration specifies a single receive APC (RcvAPC) and a single receive antenna pattern (RcvAPAT). The received signal data was collected and/or processed to pass a fixed instantaneous bandwidth (BW_I). All vectors of the signal array span a fixed receive window time (T_Rcv). For a CRSD:SAR product, each receive channel is formed from PHD that contains the echo signals for transmit pulses specified in a single transmit pulse sequence. The Tx_ID for the sequence is specified in the XML instance.

Table 4-3 Receive Signal Model XML Parameters		
Parameter	Type	Description
Required parameters that are common across all receive data channels.		
t_CRT	XDT	Specifies the Collection Reference Time for the received signal data (in UTC). All times are in seconds relative to t_CRT. See Table 12-2: Global / CollectionRefTime
Sample_Format	ENU	Specifies the binary format of the signal array data samples. All signal array samples are complex-valued. Table 12-4: Data / Receive / SampleArrayFormat
Required parameters that are included or computed for each channel.		
Ch_ID	TXT	Receive channel identifier that uniquely identifies the receive data channel. See Table 12-6: Channel / Parameters / Identifier
NV_CH x NS_CH	2 x INT	Size of each signal array specified by the number of vectors and the number of samples. See Figure 2-6 and Figure 7-1. See Table 12-4: Data / Receive / Channel / NumVectors Data / Receive / Channel / NumSamples
v_CH_REF	INT	Index of the reference vector for the channel. See Table 12-6: Channel / Parameters / RefVectorIndex
fs Ts = 1/fs	DBL DBL	Fast time sample rate for the signal array (samples/sec) and fast time sample period (sec) for the channel. See Sect 7.2. See Table 12-6: Channel / Parameters / Fs
BW_I	DBL	Nominal instantaneous bandwidth for filter used to bandlimit the channel (Hz). See Table 12-6: Channel / Parameters / BWInst
Rcv Antenna Parameters RcvAPC_ID RcvAPAT_ID	TXT TXT	Parameters that identify the receive APC and Antenna Pattern (APAT) for the receive data channel. See Table 12-6 and Table 12-12.

Table 4-3 Receive Signal Model XML Parameters		
P_Irr_0 _{RCV}	DBL	Reference irradiance (dBW/m ²) for an in-band signal that yields PS _{CRSD} = 1.0 for beam shape gain G _{RBS} (f) = 0 dB.
PN _{CRSD} BN _{CRSD}	DBL DBL	PN _{CRSD} : Thermal noise power level. BN _{CRSD} : Noise bandwidth relative to the sample rate. See Table 12-6: Channel / Parameters / PNCRSD & BNCRSD
Parameters included for each channel in a CRSD:SAR product.		
SARImage/Tx_ID	TXT	Transmit sequence ID for the pulses transmitted and received to form the signal array. See Table 12-6: Channel / Parameters / SARImage / TxID

A PVP array is provided for each receive data channel. The set of parameters provided for each vector is referred to as a PVP set. For a given product, the parameters included in the PVP set are specified in the XML instance. See Section 2.7. The defined parameters that may be included in a PVP set are defined in Table 4-4.

Table 4-4 Receive Signal Per Vector Parameters			
Parameter	PVP XML Node	Format	Description
The PVPs in a product are specified in the / CRSDxx / PVP branch of the XML instance. Vectors are indexed by $v = 0, 1, 2, \dots, NV_CH(Ch_ID) - 1$. Samples are indexed by $s = 0, 1, 2, \dots, NS_CH(Ch_ID) - 1$.			
Required PVPs are included in all PVP sets. See Table 12-11.			
$trs(v) =$ $trs_Int(v) + trs_Frac(v)$ See Section 4.1.3	RcvStart	I8:F8	Receive start time equal to the receive time of the first sample of the signal vector (sec). Time relative to t _{CRT} . Provided as two parameters: trs_Int(v) and trs_Frac(v). Require $0 \leq trs_Frac(v) < 1$. For signal vector v, the time the signal in sample s was incident at the receive APC is: $t(v, s) = trs(v) + Ts \cdot s$
$Rcv(v) = \begin{bmatrix} Rcv_X(v) \\ Rcv_Y(v) \\ Rcv_Z(v) \end{bmatrix}$	RcvPos	F8:F8:F8	Receive APC position at time trs(v) in ECEF coordinates (meters).
$VRev(v) = \begin{bmatrix} VRcv_X(v) \\ VRcv_Y(v) \\ VRcv_Z(v) \end{bmatrix}$	RcvVel	F8:F8:F8	Receive APC velocity at time trs(v) in ECEF coordinates (meters/sec).
frcv_1(v) frcv_2(v)	FRCV1 FRCV2	F8 F8	Minimum and maximum receive frequency values received within the nominal instantaneous BW (Hz). $frcv_1(v) = \min\{f_IC(v, t)\} - BW_I/2$ $frcv_2(v) = \max\{f_IC(v, t)\} + BW_I/2$

Table 4-4 Receive Signal Per Vector Parameters

Parameter	PVP XML Node	Format	Description
$\Phi_0(v) =$ $\Phi_{0_Int}(v) + \Phi_{0_Frac}(v)$ See Section 4.1.3	RefPhi0	I8:F8	Reference phase value at time trs(v) (cycles). Provided as two parameters: $\Phi_{0_Int}(v)$ and $\Phi_{0_Frac}(v)$. Require $0 \leq \Phi_{0_Frac}(v) < 1.0$. For vector v, the reference phase function is: $\Phi_{REF}(v, t) = \Phi_0(v) + f_{-0}(v) \cdot (t - trs(v))$
$f_{-0}(v)$	RefFreq	F8	Reference frequency for the signal vector (Hz). For vector v, a signal with frequency $f_{-0}(v)$ incident at the receive APC will be at $f = 0$ in the CRSD signal vector.
$\Delta f_{IC_0}(v)$ $f_{IC_Rate}(v)$	DFIC0 FICRate	F8 F8	Parameters used to specify LFM demodulation on receive. For vector v, the Instantaneous Center (IC) frequency vs fast time is $f_{IC}(v, t)$ (Hz), where: $f_{IC}(v, t) = f_{-0}(v) + \Delta f_{IC_0}(v) + f_{IC_Rate}(v) \cdot (t - trs(v))$ Note: For $f_{IC_Rate}(v) = 0$, also set $\Delta f_{IC_0}(v) = 0$.
SIGNAL(v)	SIGNAL	I8	Parameter SIGNAL(v) is used to indicate the signal quality for the vector. May indicate the vector is known (or likely) to be corrupted or of degraded quality. Defined and allowed values: SIGNAL(v) = 0 → Signal vector samples set to zero. SIGNAL(v) = 1 → Normal signal data. For a SAR imaging collection, the echoes of a transmit pulse are received from the imaged scene. SIGNAL(v) = 2 → Signal contains only thermal noise and from sources external to the sensor. For a SAR imaging collection, no echoes of a transmit pulse are received from the scene. SIGNAL(v) = 3 → Signal content may be corrupted.
Amp_SF(v)	AmpSF	F8	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 to a fixed-point binary format (i.e., CI2 and CI4). See Section 2.7.
$Rcv_uACX(v) =$ $\begin{bmatrix} Rcv_uACX_X(v) \\ Rcv_uACX_Y(v) \\ Rcv_uACX_Z(v) \end{bmatrix}$	RcvACX	F8:F8:F8	Receive ACF X-Axis (ACX) unit vector in ECEF coordinates at $t = trs(v)$. The ACF orientation is specified by orthogonal unit vectors $Rcv_uACX(v)$ and $Rcv_uACY(v)$. For all vectors: $Rcv_uACX(v) \bullet Rcv_uACY(v) = 0$

Table 4-4 Receive Signal Per Vector Parameters			
Parameter	PVP XML Node	Format	Description
$\mathbf{Rcv_uACY}(v) = \begin{bmatrix} \mathbf{Rcv_uACY_X}(v) \\ \mathbf{Rcv_uACY_Y}(v) \\ \mathbf{Rcv_uACY_Z}(v) \end{bmatrix}$	RcvACY	F8:F8:F8	Receive ACF Y-Axis (ACY) unit vector in ECEF coordinates at $t = \text{trs}(v)$. The ACF boresight is along the ACF +Z-Axis. The ACF Z-Axis (ACZ) unit vector is computed by: $\mathbf{Rcv_uACZ}(v) = \mathbf{Rcv_uACX}(v) \times \mathbf{Rcv_uACY}(v)$
$\mathbf{Rcv_EB}_0(v) = \begin{bmatrix} \mathbf{Rcv_EB_DCX}_0(v) \\ \mathbf{Rcv_EB_DCY}_0(v) \end{bmatrix}$	RcvEB	F8:F8	Receive antenna Electrical Boresight steering vector for frequency $f = f_{a_0}$ where f_{a_0} is the reference frequency of the receive channel RcvAPAT. For a mechanically steered antenna, set $\mathbf{Rcv_EB_DCX}_0(v) = 0$ and $\mathbf{Rcv_EB_DCY}_0(v) = 0$.
$\Delta G_Rcv(v)$	DGRGC	F8	Receiver Gain Control (RGC) gain setting for the signal path during the receive window (dB). Gain value $\Delta G_Rcv(v)$ is relative to the nominal receiver gain for the channel.
Parameter that is included for all CRSD:SAR products.			
$p(v)$	TxPulse Index	I8	Index for the transmit pulse for which the echo signals from the imaged scene are contained in signal vector v . For a signal vector with no transmit pulse, set $p(v)$ equal to the “no pulse” value = -1.

4.1.3 Format for PPP/PVP Times & Phases

The time and phase parameters provided in a PPP array and in a PVP array are all provided using two 8-byte parameters: one integer parameter in I8 format and one floating point parameter in F8 format. Refer to Table 11-2. For each parameter, the integer part and fractional part are provided separately. The choice of the two-parameter format is to ensure the specified format has no significant impact on the accuracy of the stored values. The goal is that storing times and phases in the CRSD specified format does not impact the accuracy of the subsequent processing or analysis of the signal data stored in the product.

The format was selected based upon the following values for time t_0 and phase Φ_0 and for maximum quantization errors due to the binary format of Δt_{QE} and $\Delta \Phi_{QE}$. All times are in seconds and all phases are in cycles. Phase Φ_0 and time t_0 related by the reference frequency f_0 .

$$t_0 = 1000.0 (\approx 2^{10}) \quad \Phi_0 = 50.0 \cdot 10^{12} (\approx 2^{46}) \quad f_0 = \Phi_0/t_0 = 50.0 \cdot 10^9$$

$$\Delta t_{QE} = 1.0 \cdot 10^{-15} (\approx 2^{-50}) \quad \Delta \Phi_{QE} = 1.0 \cdot 10^{-5} (\approx 2^{-17}) (0.0036 \text{ deg})$$

The I8 integer parameters supports the integer portion of phase value of Φ_0 precisely. The F8 format supports all fractional time values $0 \leq t_{\text{Frac}} < 1$ with quantization error less than $\Delta t_{QE} = 1.0 \cdot 10^{-15}$. Note: The F8 format is defined to be the IEEE binary64 format which supports quantization error less than 1 part in 2^{52} .

The values for maximum quantization errors Δt_{QE} and $\Delta \Phi_{QE}$ were selected such that in the following computation for target echo phase in a CRSD signal vector, $\Phi_{\text{CRSD}}^{\text{TGT}}$, the maximum phase error due to quantization $|\Delta \Phi_{\text{CRSD}}^{\text{TGT}}| \leq 2.0 \cdot 10^{-4}$ (0.072 deg).

$$\Phi_{\text{CRSD}}^{\text{TGT}} = \Phi_{X0}(p) - \{ \Phi_0(v) + f_0 \cdot (txc(p) + T_Prop^{\text{TGT}} - trs(v)) \}$$

$$\Phi_{\text{CRSD}}^{\text{TGT}} = \Phi_{X0}(p) - \Phi_0(v) - f_0 \cdot T_Prop^{\text{TGT}} - f_0 \cdot (txc(p) - trs(v))$$

Writing the phases and times as the sum of the integer and fractional parts yields:

$$\Phi_{\text{CRSD}}^{\text{TGT}} = [\Phi_{X0_Int}(p) + \Phi_{X0_Frac}(p)] - [\Phi_0_Int(v) + \Phi_0_Frac(v)] - f_0 \cdot T_Prop^{\text{TGT}} \\ - f_0 \cdot ([txc_Int(p) + txc_Frac(p)] - [trs_Int(v) + trs_Frac(v)])$$

The error $\Delta \Phi_{\text{CRSD}}^{\text{TGT}}$ due to the quantization of the fractional phases and times stored in the PPP and the PVP array is computed by:

$$\Delta \Phi_{\text{CRSD}}^{\text{TGT}} = \Delta \Phi_{X0_FracQE}(p) - \Delta \Phi_0_FracQE(v) - f_0 \cdot (\Delta txc_FracQE(p) - \Delta trs_FracQE(v))$$

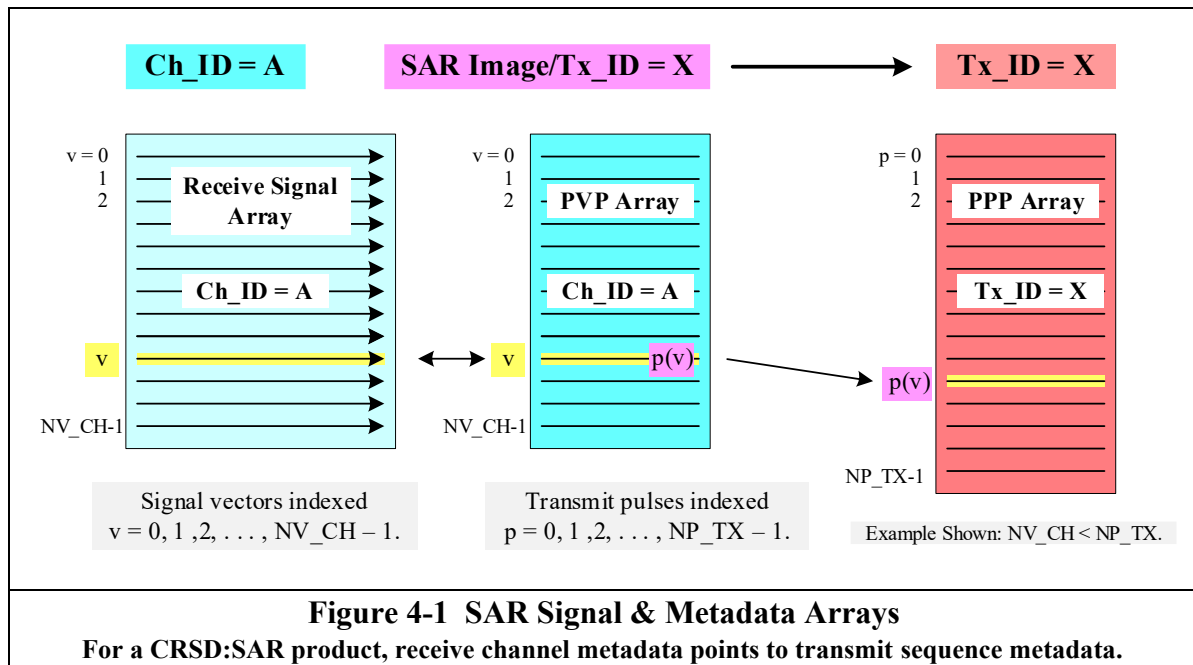
The magnitude of the phase error $\Delta \Phi_{\text{CRSD}}^{\text{TGT}}$ is bounded by:

$$|\Delta \Phi_{\text{CRSD}}^{\text{TGT}}| \leq 2 \cdot \Delta \Phi_{QE} + f_0 \cdot (2 \cdot \Delta t_{QE}) = 2.0 \cdot 10^{-5} + 1.0 \cdot 10^{-4} = 1.2 \cdot 10^{-4} \approx 0.043 \text{ degrees}$$

4.2 Transmit & Receive Geometry

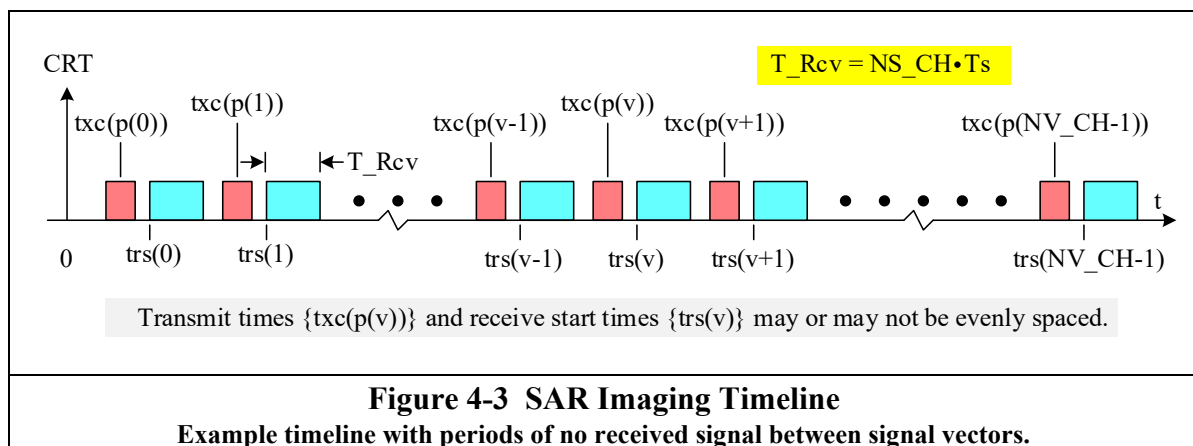
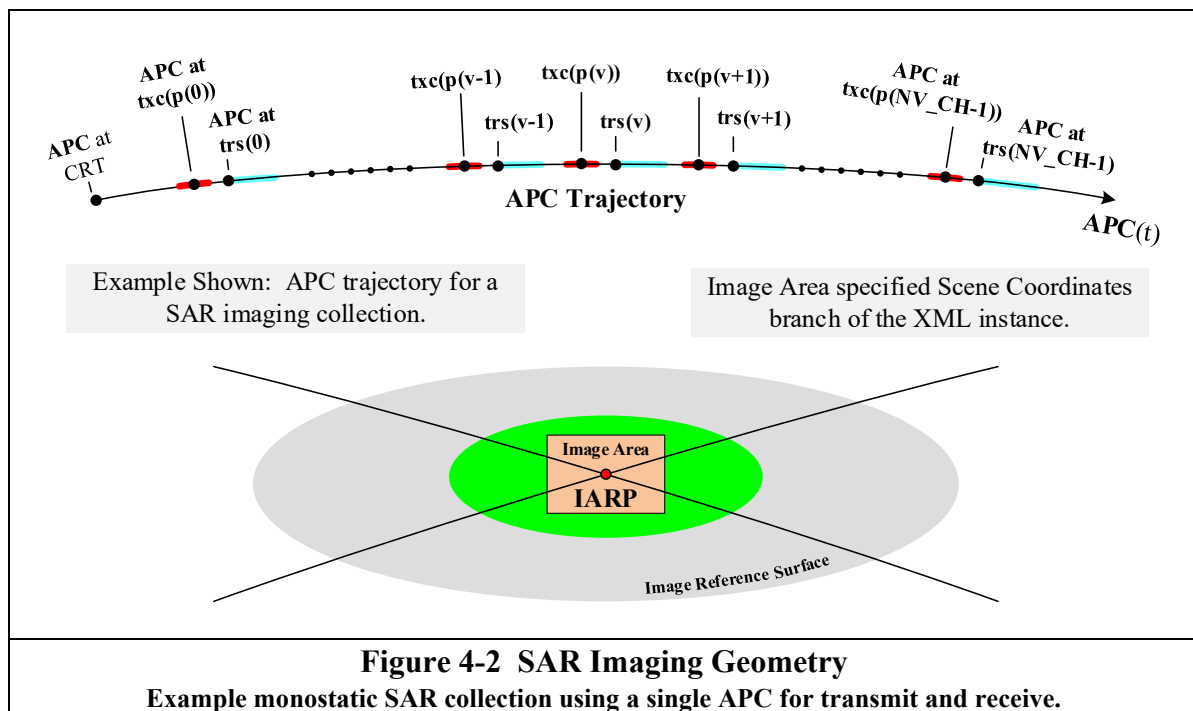
The transmit geometry and receive collection geometry are specified by the sampled APC position and velocity parameters provided in the binary formatted metadata arrays. For a CRSD:SAR or CRSD:TX product, the transmit APC position and velocity are provided in the PPP array for each transmit pulse sequence. For a CRSD:SAR or CRSD:RCV product, the receive APC position and velocity are provided in the PVP array for each receive data channel.

For a SAR imaging product, the parameters linking the receive signal data to the transmit pulse metadata are included in the receive channel metadata. A receive channel's SARImage/TxID identifies the pulse sequence that provided the illumination. For each receive signal vector, the pulse index is specified for use in forming the SAR images. The combined transmit and receive metadata specifies the SAR imaging geometry. Shown in Figure 4-1 is an example receive signal array, its corresponding PVP array, and the PPP array to be used to form the SAR images of the imaged scene. For signal vector v , the corresponding pulse is $p(v)$. For processing the echo signals from the imaged scene, metadata parameters for pulse $p(v)$ are used to, for example, form a CPHD signal vector from the CRSD signal vector.



For SAR imaging collections, the parameters that specify the image area covered by the collection are provided in the XML instance contained in the product. The imaged area is specified in the / CRSDxx / Scene Coordinates branch of the XML structure. See Table 12-3. Figure 4-2 shows an example of a collection geometry for SAR imaging. For the example shown, the initial SAR PHD is collected using a single antenna for both transmit and receive. The initial PHD was processed to form a single receive data channel. The Collection

Reference Time (CRT) is prior to the first transmit pulse. The imaged area is a rectangular area centered on the Image Area Reference Point (IARP). Figure 4-3 shows the collection timeline for the collection shown in Figure 4-2. For the example shown, the SAR echoes that were received and recorded in signal vector v were for the pulse transmitted during the period immediately prior to the receive window. The timeline would be typical of an airborne SAR sensor operating at a short range to the imaged scene.



For a receive only collection, the signal array may be formed from one long sampled signal vector. The signal vector was collected during a single receive time period that may, for example, span multiple seconds. An example receive only collection geometry is shown in

Figure 4-4. The corresponding receive and record collection timeline is shown in Figure 4-5. For such a collection, the formation of the two-dimensional signal array is a design choice that may be based on the properties of the sensor or the data processing system that forms the product. The number of samples per vector, NS_CH , and the receive period per vector, $T_Rcv = NS_CH \cdot T_s$, may be selected based on the rate required for the supporting metadata provided in the PVP array. For example, the variation in APC position vs. time may dictate the vector rate to be formed in order to provide adequately sampled position data versus time.

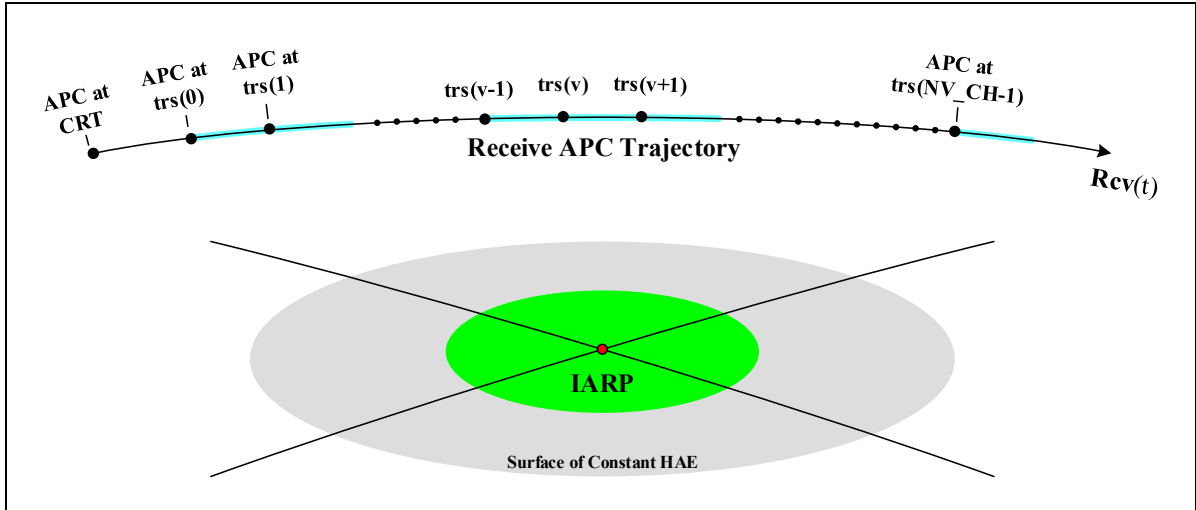


Figure 4-4 Receive Only Geometry
 Example receive only collection geometry using a single receive APC.

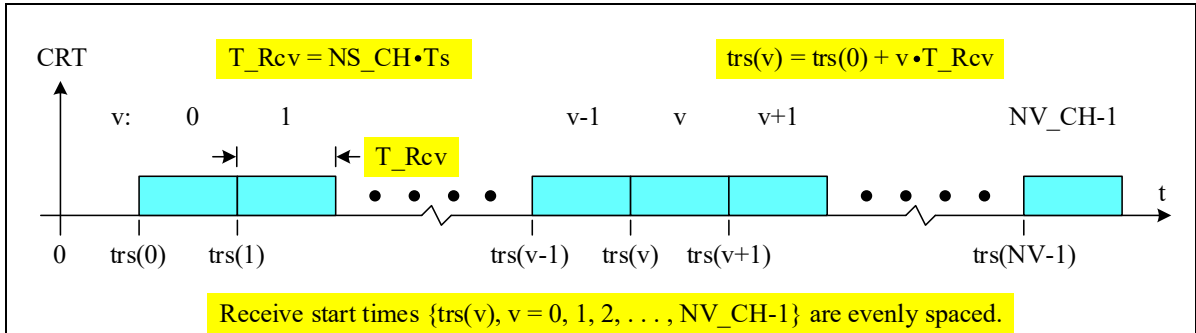


Figure 4-5 Receive Only Timeline
 Example timeline for a receive only collection using one long receive period.

4.3 Signal Complex Envelope

The transmit pulse signals and the received signals observed at the antenna phase center are modeled as real-valued, band-limited time signals. A given received signal, $s_{RCV}(t)$, is expressed in the following form:

$$s_{RCV}(t) = A_{RCV}(t) \cdot \cos(2\pi \cdot f_0 \cdot t + 2\pi \cdot \Delta\Phi_{RCV}(t))$$

The amplitude function $A_{RCV}(t)$ is a non-negative, real-valued function. Frequency f_0 is referred to as the reference frequency. Phase function $\Delta\Phi_{RCV}(t)$ is a real-valued, phase modulation function. Frequency f_0 is in Hz and phase $\Delta\Phi_{RCV}(t)$ is in cycles. Time t is in seconds. The signal has one-sided bandwidth BW_S Hz centered at frequency f_0 . For most systems, the received signals of interest are narrow bandwidth relative to the reference frequency. In general, the ratio of the one-sided bandwidth BW_S to the reference frequency is less than one-half (i.e., $BW_S/f_0 < 0.5$).

The amplitude function $A_{RCV}(t)$ and phase function $\Delta\Phi_{RCV}(t)$ may be combined to form a complex-valued function. The function, $s_{CE}(t)$, is defined to be the complex envelope of the received signal $s_{RCV}(t)$. The complex envelope, $s_{CE}(t)$, is expressed in the following form:

$$s_{CE}(t) = A_{RCV}(t) \cdot \exp\{j \cdot 2\pi \cdot \Delta\Phi_{RCV}(t)\}$$

The complex envelope may also be expressed in terms of its real and imaginary components, $x_{CE}(t)$ and $y_{CE}(t)$. Functions $x_{CE}(t)$ and $y_{CE}(t)$ are real-valued.

$$x_{CE}(t) = A_{RCV}(t) \cdot \cos(2\pi \cdot \Delta\Phi_{RCV}(t)) \quad y_{CE}(t) = A_{RCV}(t) \cdot \sin(2\pi \cdot \Delta\Phi_{RCV}(t))$$

The received signal $s_{RCV}(t)$ may be expressed in terms of the complex envelope signal $s_{CE}(t)$ and reference frequency f_0 by expanding the cosine as the sum of two complex sinusoids (i.e., $\cos(\theta) = \frac{1}{2} \cdot (\exp(j\theta) + \exp(-j\theta))$). Signal $s_{CE}(t)^*$ is the complex conjugate of $s_{CE}(t)$.

$$s_{RCV}(t) = \frac{1}{2} \cdot s_{CE}(t) \cdot \exp\{j \cdot 2\pi \cdot f_0 \cdot t\} + \frac{1}{2} \cdot s_{CE}(t)^* \cdot \exp\{-j \cdot 2\pi \cdot f_0 \cdot t\}$$

The bandwidth of the complex envelope signal $s_{CE}(t)$ is also BW_S and is centered at $f = 0$. The amplitude function $A_{RCV}(t)$ is, in general, slowly varying relative to the signal variation due to the phase modulation function $\Delta\Phi_{RCV}(t)$. For many signals of interest, the bandwidth BW_S is determined almost entirely by the phase modulation. The Linear FM waveforms employed by most SAR sensors are examples of such waveforms.

The relationship between the one-sided bandwidth of the received signal and the two-sided bandwidth of its complex envelope may be seen by comparing the Fourier transforms of the two signals. Let $S_{RCV}(f)$ be the transform of the received signal $s_{RCV}(t)$ and $S_{CE}(f)$ be the transform of the complex envelope signal $s_{CE}(t)$.

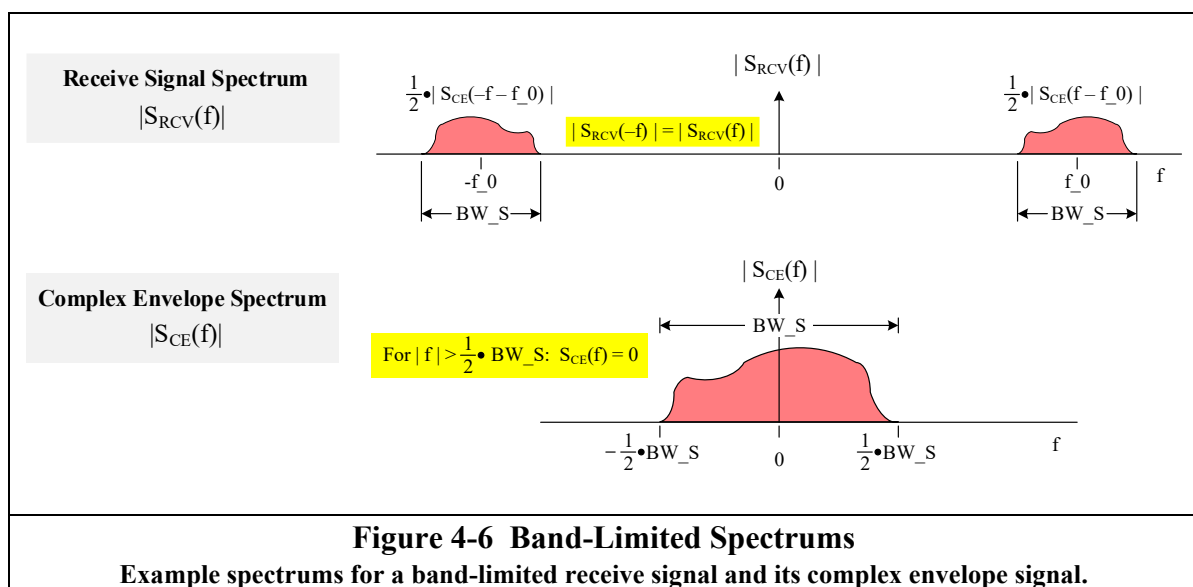
$$S_{RCV}(f) = \int_{-\infty}^{\infty} s_{RCV}(t) \cdot \exp\{-j \cdot 2\pi \cdot f \cdot t\} dt \quad S_{CE}(f) = \int_{-\infty}^{\infty} s_{CE}(t) \cdot \exp\{-j \cdot 2\pi \cdot f \cdot t\} dt$$

Note: The form of the transform shown above is typically referred to as the forward Fourier Transform.

The transform of the received signal, $S_{RCV}(f)$, may be expressed in terms of the transform of the complex envelope signal, $S_{CE}(f)$. The transform $S_{RCV}(f)$, may expressed as shown below.

$$S_{RCV}(f) = \frac{1}{2} \cdot S_{CE}(f - f_0) + \frac{1}{2} \cdot S_{CE}(-f - f_0)^*$$

Figure 4-6 shows the magnitude of the transform of the band-limited receive signal, $|S_{RCV}(f)|$. The magnitude function $|S_{RCV}(f)|$ is referred to as the spectrum of the receive signal. Also shown is the spectrum of the complex envelope function, $|S_{CE}(f)|$. For the example shown in the figure, the ratio BW_S/f_0 is approximately 0.3. The band limited receive signal with one-sided bandwidth BW_S centered on the reference frequency f_0 results in the complex envelope signal with two-sided bandwidth BW_S centered on $f = 0$.



4.4 Transmit Pulse Parameters

For a given transmit sequence, the parameters used to compute the transmit pulse waveforms are summarized in Table 4-1 and Table 4-2. For transmit pulse p , the base transmit pulse waveform function observed at the transmit antenna APC is denoted $s_{XMT}(p, t)$ and is defined as follows.

$$s_{XMT}(p, t) = A_{XMT}(p, t - t_{xc}(p)) \cdot \cos \{ 2\pi \cdot \Phi_{XMT}(p, t - t_{xc}(p)) \}$$

Time $t_{xc}(p)$ is the time the center of the transmit pulse waveform is at the transmit antenna APC. Amplitude function $A_{XMT}(p, t)$ is a real-valued, non-negative function of duration $T_{Xmt}(p)$ centered on time $t = 0$. The phase function $\Phi_{XMT}(p, t)$ is in cycles and is the sum of two phase functions, $\Phi_{XOFF}(p, t)$ and $\Phi_{XMOD}(p, t)$.

$$\Phi_{XMT}(p, t) = \Phi_{XOFF}(p, t) + \Phi_{XMOD}(p, t)$$

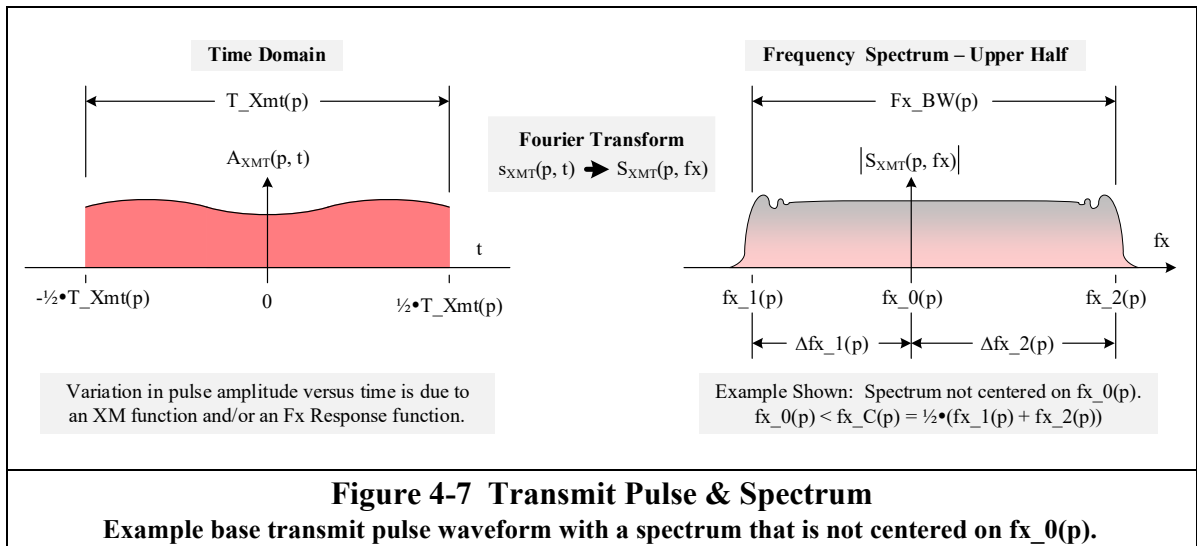
Phase function $\Phi_{XOFF}(p, t)$ provides a frequency offset that places the transmit spectrum at the correct frequency band and is defined as follows.

$$\Phi_{XOFF}(p, t) = \Phi_{X0}(p) + f_{x_0}(p) \cdot t$$

The base transmit pulse modulation is specified by the complex envelope function $sCE_{XMT}(p, t)$ formed from the amplitude function $A_{XMT}(p, t)$ and the phase function $\Phi_{XMOD}(p, t)$.

$$sCE_{XMT}(p, t) = A_{XMT}(p, t) \cdot \exp \{ j \cdot 2\pi \cdot \Phi_{XMOD}(p, t) \}$$

Shown in Figure 4-7 is an example base pulse amplitude function $A_{XMT}(p, t)$ and the upper half of the pulse waveform spectrum, denoted $|S_{XMT}(p, f_x)|$. Also shown is the pulse length, $T_{Xmt}(p)$, and transmit frequency parameters $f_{x_0}(p)$, $f_{x_1}(p)$, and $f_{x_2}(p)$.



The example shown in Figure 4-7 illustrates two important aspects of the transmit signal model and frequency parameters $fx_0(p)$, $fx_1(p)$, and $fx_2(p)$. Frequencies $fx_1(p)$ and $fx_2(p)$ define the band of frequencies intended to support SAR image formation. First, the frequency band from $fx_1(p)$ to $fx_2(p)$ may or may not be centered on $fx_0(p)$. The band may or may not contain $fx_0(p)$. Second, the spectrum may or may not be zero outside of the band from $fx_1(p)$ to $fx_2(p)$. For the base pulse waveform function, the spectrum magnitude at frequencies $fx_1(p)$ and $fx_2(p)$ is not specified or restricted.

For transmit pulse p , define the frequency differences $\Delta fx_1(p)$ and $\Delta fx_2(p)$. Refer to Figure 4-7. The frequency differences are useful in the following discussions and in the methods for computing transmit pulse modulation functions $A_{XMT}(p, t)$ and $\Phi_{XMOD}(p, t)$.

$$\Delta fx_1(p) = fx_1(p) - fx_0(p) \qquad \Delta fx_2(p) = fx_2(p) - fx_0(p)$$

The base transmit pulse waveform $s_{XMT}(p, t)$ is the waveform that would be transmitted when the transmit antenna beam shape pattern has constant $G_{XBS}(f) = 0$ and phase $\Phi_{XBS}(f) = 0$. When the effects of the transmit antenna beam shape are included, the waveform is denoted $s_{XAP}(p, \mathbf{uAP}, t)$. Unit vector $\mathbf{uAP}$ specifies the antenna pointing vector for which the effect of the antenna beam shape pattern has been included. Transmit pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$ is composed of amplitude function $A_{XAP}(p, \mathbf{uAP}, t)$ and phase function $\Phi_{XAP}(p, \mathbf{uAP}, t)$.

$$s_{XAP}(p, \mathbf{uAP}, t) = A_{XAP}(p, \mathbf{uAP}, t - t_{xc}(p)) \cdot \cos\{ 2\pi \cdot \Phi_{XAP}(p, \mathbf{uAP}, t - t_{xc}(p)) \}$$

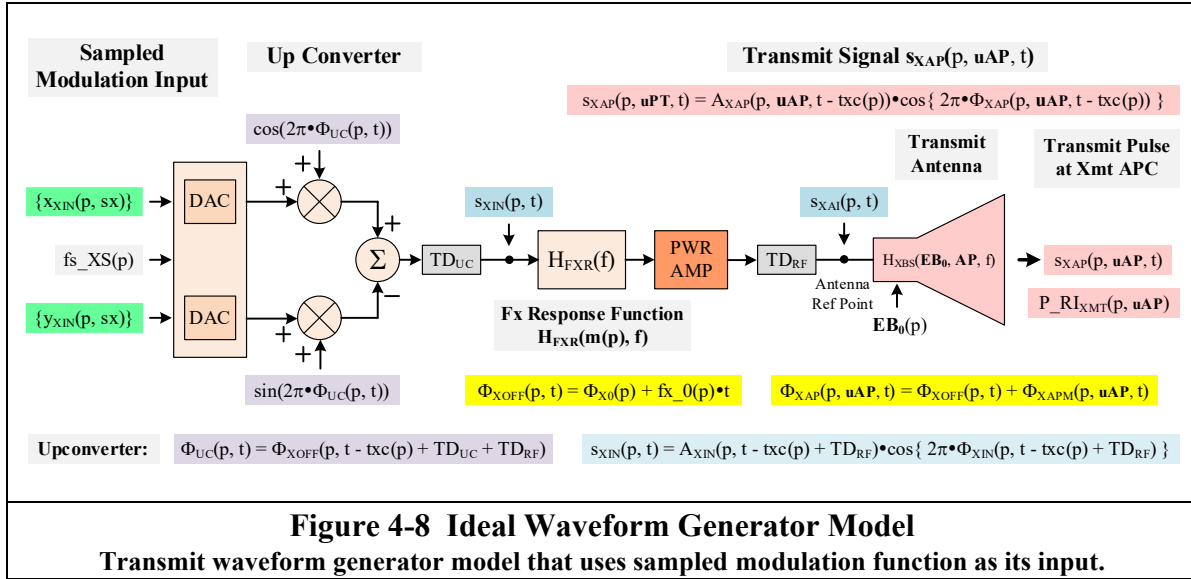
The phase function $\Phi_{XAP}(p, \mathbf{uAP}, t)$ is in cycles and is the sum of two phase functions, $\Phi_{XOFF}(p, t)$ and $\Phi_{XAPM}(p, \mathbf{uAP}, t)$.

$$\Phi_{XAP}(p, \mathbf{uAP}, t) = \Phi_{XOFF}(p, t) + \Phi_{XAPM}(p, \mathbf{uAP}, t).$$

4.5 Ideal Waveform Generator Model

The methods used to compute transmit pulse modulation functions are based upon an ideal SAR waveform generator model. The ideal model supports the generation of both conventional LFM pulse waveforms as well as arbitrary pulse waveforms. The model also includes support for characteristics common to many SAR transmit signal generators and power amplification systems.

The ideal waveform generator model is shown in Figure 4-8. For pulse p , the initial pulse waveform $s_{XIN}(p, t)$ is generated from a sampled input modulation signal vector. A local oscillator generates a reference tone at frequency $f_0(p)$ that is used in the up-conversion from baseband to the desired transmit band. The pulse waveform input at the antenna reference point is denoted $s_{XA1}(p, t)$. The pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$ is the output pulse waveform observed at the APC that propagates along the LOS for unit pointing vector $\mathbf{uAP}$.



The ideal waveform generator model has the following inputs and elements.

- (1) A pair of ideal digital-to-analog converters (DACs) generate a pair of baseband signals from the input real and imaginary vectors. The DACs operate at frequency fs_XS . For pulse p , the DAC timing is controlled to yield the precise signal timing at the APC output.
- (2) The pair of baseband signals are the “in-phase” and “quadrature” inputs to the ideal up-converter. Up conversion provides the $\Phi_{XOFF}(p, t)$ portion of the base pulse phase $\Phi_{XMT}(p, t)$ and output pulse phase $\Phi_{XAP}(p, uAP, t)$. The UC phase is controlled to yield the precise phase at the APC at time $txc(p)$.
- (3) A system frequency response function, $H_{FXR}(f)$, is applied to yield the pulse waveform $s_{XAI}(p, t)$ that is the input to the antenna. The function $H_{FXR}(f)$ models the system frequency response of the signal generator and power system. It may also include a portion of the transmit antenna response that is not included in the antenna beam shape pattern. See Section 6.5.
- (4) The power amplification and transmit antenna are shown as separate elements. This representation is not critical in the model. The model may be accurately applied to a sensor that employs an active array antenna on transmit.
- (5) For each transmit pulse, the base transmit power radiant intensity, denoted $P_RI_0_{XMT}(p)$, is specified (dBW/sr). See Table 4-2. The base radiant intensity is the radiant intensity for the base pulse waveform. The base $P_RI_0_{XMT}(p)$ is used with the transmit antenna beam shape pattern to compute the transmit power in the selected pointing direction, $P_RI_{XMT}(p, uAP)$.

4.5.1 Input Pulse Modulation Function

The sampled input pulse modulation function is the sampled complex envelope of the up-converter output $s_{XIN}(p, t)$ shown in Figure 4-8. For pulse p , the sampled real and imaginary components $\{ xCE_{XIN}(p, sx) \}$ and $\{ yCE_{XIN}(p, sx) \}$ are indexed:

$$sx = -NXS(p), \dots, -1, 0, 1, \dots, NXS(p)$$

The sample rate of the signal is $fs_XS(p)$ (samples/sec). The choice of fs_XS is dependent upon the application but is subject to a minimum rate based on the frequency differences $\Delta fx_1(p)$ and $\Delta fx_2(p)$ and an over-sample ratio $XS_OSR > 1.0$. The minimum rate is computed by:

$$fs_XS_Min(p) = 2 \cdot \text{Max} \{ |\Delta fx_1(p)|, |\Delta fx_2(p)| \} \cdot XS_OSR$$

For the selected value of $fs_XS(p)$ with sample spacing $Ts_XS(p) = 1/fs_XS(p)$, the sample index limit $NXS(p)$ may be computed from the pulse length $T_Xmt(p)$.

$$NXS(p) = \text{CEIL} \{ \frac{1}{2} \cdot T_Xmt(p) / Ts_XS(p) \}$$

4.6 Transmit Pulse Waveform

For transmit pulse p of a given pulse sequence, a method is provided for determining the base transmit pulse modulation function. As defined in Section 4.4, the pulse modulation function is specified by the complex envelope function. For the base pulse waveform $s_{XMT}(p, t)$, the complex envelope is $sCE_{XMT}(p, t)$.

$$sCE_{XMT}(p, t) = A_{XMT}(p, t) \cdot \exp \{ j \cdot 2\pi \cdot \Phi_{XMOD}(p, t) \}$$

The base pulse modulation function cannot, in general, be computed in closed form using the metadata provided in a CRSD product. However, a method is provided to compute a complex-valued signal vector that is the equivalent of the sampled base pulse modulation function. For pulse p , the sampled base pulse modulation vector is $\{ CE_{XMT}(p, sx) \}$. The samples are defined as shown. Sample spacing $Ts_XS(p)$ and sample index limit $NXS(p)$ are as defined in Section 4.5.

For $sx = -NXS(p), \dots, -1, 0, 1, \dots, NXS(p)$:

$$CE_{XMT}(p, sx) = xCE_{XMT}(p, sx) + j \cdot yCE_{XMT}(p, sx) \approx sCE_{XMT}(p, Ts_XS(p) \cdot sx)$$

The method provided for computing $\{ CE_{XMT}(p, sx) \}$ includes the following steps. Each of the steps are specified in descriptions that follow.

- (1) Compute the sample spacing and index limit: $Ts_XS(p)$ and $NXS(p)$.
- (2) Compute the pulse modulation vector $\{ CE_{XIN}(p, sx) \}$ that is the input modulation vector for the ideal waveform generator.

- (3) Compute the Discrete Fourier Transform (DFT) of input pulse modulation vector. The result $\{ S_{XIN}(p, k) \}$ is the spectrum of the input modulation vector.
- (4) Apply the Fx Response function to the spectrum $\{ S_{XIN}(p, k) \}$ by interpolating the Fx Response function provided in the Fx Response array. The result is the spectrum of antenna input signal $\{ S_{XAI}(p, k) \}$.
- (5) Compute the Inverse DFT (IDFT) of the spectrum $\{ S_{XAI}(p, k) \}$. The result is the base pulse modulation vector $\{ CE_{XMT}(p, sx) \}$.

For antenna pointing vector $\mathbf{uAP}$, the output pulse modulation vector is $\{ CE_{XAP}(p, \mathbf{uAP}, sx) \}$ and is computed as summarized below.

- (6) Apply the transmit antenna beam pattern gain and phase for the selected pointing vector $\mathbf{uAP}$ to the spectrum $\{ S_{XAI}(p, k) \}$. The result is the sampled spectrum $\{ S_{XAP}(p, \mathbf{uAP}, k) \}$ of the output transmit pulse $sCE_{XAP}(p, \mathbf{uAP}, t)$.
- (7) Compute the IDFT of the spectrum $\{ S_{XAP}(p, \mathbf{uAP}, k) \}$. The result is the sampled output pulse modulation vector $\{ CE_{XAP}(p, \mathbf{uAP}, sx) \}$.
- (8) The transmit power radiant intensity for output pulse $s_{XAP}(p, \mathbf{uAP}, t)$, $P_{RI_{XMT}}(p, \mathbf{uAP})$, may be computed using the base pulse radiant intensity, $P_{RI_{0XMT}}(p)$, and sampled spectrum vectors $\{ S_{XAI}(p, k) \}$ and $\{ S_{XAP}(p, \mathbf{uAP}, k) \}$.

4.6.1 Select $Ts_XS(p)$ & $NXS(p)$

- (1) Choose the fast time sample spacing for the output modulation vector, $Ts_XS(p)$, making use of the minimum sample rate, $fs_XS_Min(p)$. See Section 4.4. For $TxWFTType = \text{"XM"}$ or "LFM w XM" , also ensure the sample spacing does not exceed the spacing of the XM array, Ts_XMA .

$$Ts_XS_Max(p) = 1/fs_XS_Min(p)$$

For $TxWFTType = \text{"LFM"}$:

$$Ts_XS(p) \leq Ts_XS_Max(p)$$

For $TxWFTType = \text{"XM"}$ or "LFM w XM" :

$$Ts_XS(p) \leq \text{MIN}\{ Ts_XS_Max(p), Ts_XMA \}$$

- (2) Compute sample index offset $NXS(p)$ such that $2 \bullet NXs(p) + 1$ samples spans the pulse length $T_Xmt(p)$.

$$NXS(p) = \text{CEIL}\{ \frac{1}{2} \bullet T_Xmt(p) / Ts_XS(p) \}$$

4.6.2 Compute Input Vector $\{ \text{CE}_{\text{XIN}}(\text{p}, \text{sx}) \}$

The method used to compute the input modulation vector $\{ \text{CE}_{\text{XIN}}(\text{p}, \text{sx}) \}$ is dependent upon the TxWFTType specified for the product.

(1) For TxWFTType = “LFM” or “LFM w XM”:

Compute complex signal vector $\{ \text{CE}_{\text{LFM}}(\text{p}, \text{sx}) \}$ as follows using the FM rate for pulse p, $\text{fx_Rate}(\text{p})$. Phases $\{ \Phi_{\text{LFM}}(\text{p}, \text{sx}) \}$ are in cycles.

For $\text{sx} = -\text{NXS}(\text{p}), \dots, -1, 0, 1, \dots, \text{NXS}(\text{p})$:

$$\Phi_{\text{LFM}}(\text{p}, \text{sx}) = \frac{1}{2} \cdot \text{fx_Rate}(\text{p}) \cdot (\text{Ts_XS}(\text{p}) \cdot \text{sx})^2$$

$$\text{CE}_{\text{LFM}}(\text{p}, \text{sx}) = \exp\{ j \cdot 2\pi \cdot \Phi_{\text{LFM}}(\text{p}, \text{sx}) \}$$

(2) For TxWFTType = “XM” or “LFM w XM”:

Compute complex signal vector $\{ \text{CE}_{\text{XM}}(\text{p}, \text{sx}) \}$ using the XM array vector for pulse p. The XM array vector for pulse p is contained in row w(p). See Table 4-2.

(a) Compute index nCTR and sample index limit NXMA(p) as follows.

$$\text{nCTR} = \text{FLOOR}(\frac{1}{2} \cdot \text{NS_XMA})$$

$$\text{NXMA_Max} = \text{NS_XMA} - 1 - \text{nCTR}$$

$$\text{NXMA}(\text{p}) = \text{MIN}\{ \text{CEIL}(\frac{1}{2} \cdot \text{T_Xmt}(\text{p}) / \text{Ts_XMA}), \text{NXMA_Max} \}$$

(b) Extract complex vector $\{ \text{CE}_{\text{XMA}}(\text{p}, \text{nx}) \}$ from the complex array XM array vector, XMA(w(p), n). See Figure 4-9.

For $\text{nx} = -\text{NXMA}(\text{p}), \dots, -1, 0, 1, \dots, \text{NXMA}(\text{p})$:

$$\text{CE}_{\text{XMA}}(\text{p}, \text{nx}) = \text{XMA}(\text{w}(\text{p}), \text{nCTR} + \text{nx})$$

(c) Compute complex vector $\{ \text{CE}_{\text{XM}}(\text{p}, \text{sx}) \}$ by resampling, if necessary, the extracted vector $\{ \text{CE}_{\text{XMA}}(\text{p}, \text{nx}) \}$. The resampling method accounts for the allowed signal bandwidth for signals in the XM array. See Section 6.6. The resampling yields the output sample spacing $\text{Ts_XS}(\text{p})$.



The output vector is indexed by $\text{sx} = -\text{NXS}(\text{p}), \dots, -1, 0, 1, \dots, \text{NXS}(\text{p})$. The output sample at $\text{sx} = 0$ is aligned with the input sample at $\text{nx} = 0$. See Figure 4-10. Note: For $\text{Ts_XS}(\text{p}) = \text{Ts_XMA}$, resampling is not necessary, and the output vector may be set equal to the input vector.

(3) Assign or compute the input modulation vector $\{CE_{XIN}(p, sx)\}$ as follows based on the TxWFTType. For TxWFTType = “LFM w XM”, compute $\{CE_{XIN}(p, sx)\}$ as the “element by element” product of vectors $\{CE_{LFM}(p, sx)\}$ and $\{CE_{XM}(p, sx)\}$.

For TxWFTType = “LFM”:

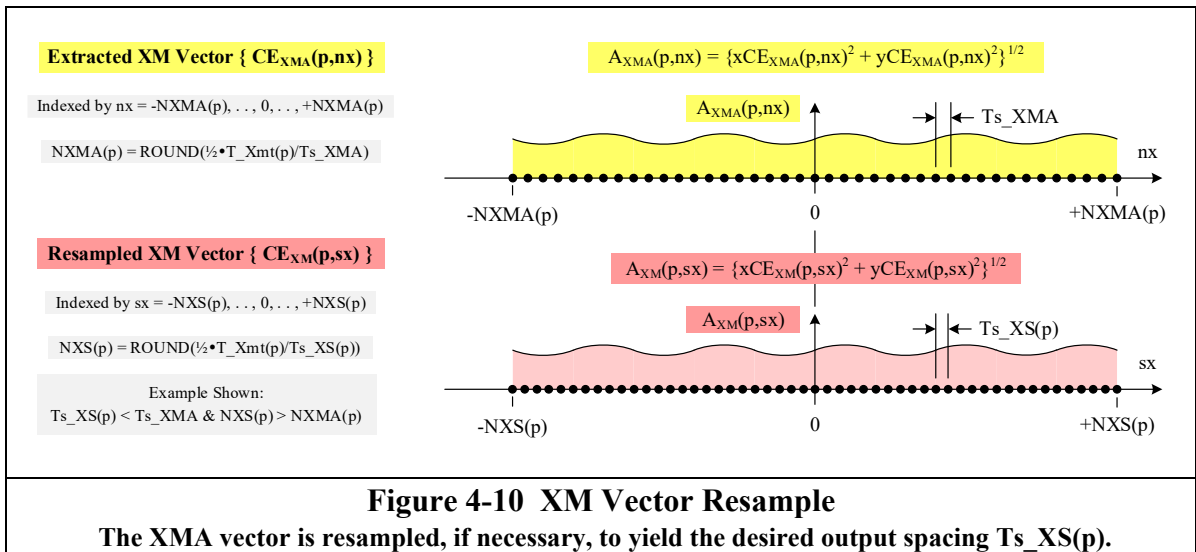
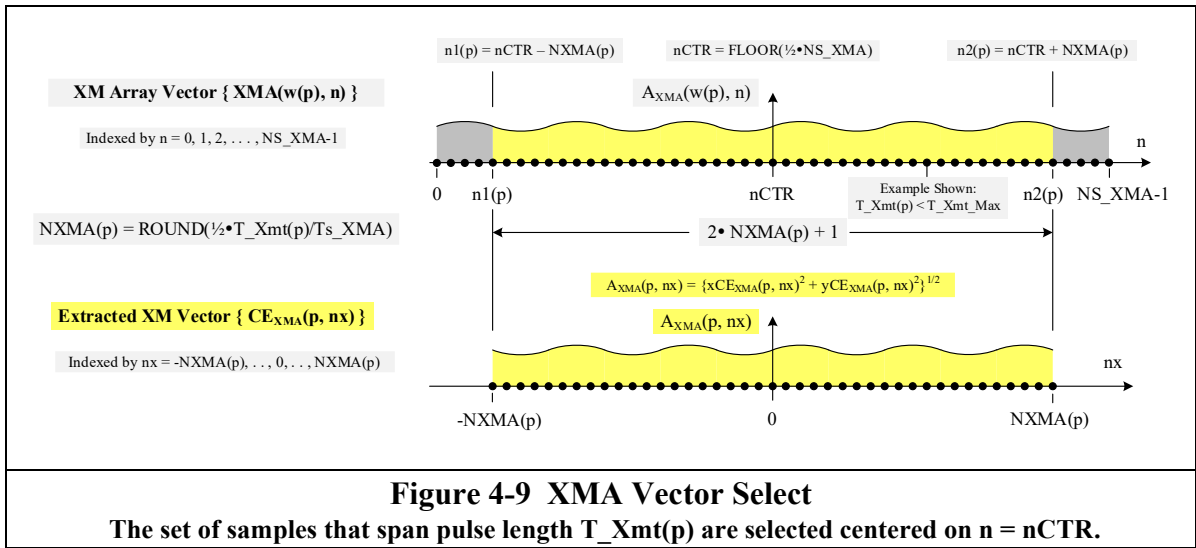
$$\{CE_{XIN}(p, sx)\} = \{CE_{LFM}(p, sx)\}$$

For TxWFTType = “XM”:

$$\{CE_{XIN}(p, sx)\} = \{CE_{XM}(p, sx)\}$$

For TxWFTType = “LFM w XM”:

$$\{CE_{XIN}(p, sx)\} = \{CE_{LFM}(p, sx) \bullet CE_{XM}(p, sx)\}$$



4.6.3 Compute the DFT: $\{ S_{XIN}(p, k) \}$

Compute the Discrete Fourier Transform of the input modulation vector to yield the sampled spectrum $\{ S_{XIN}(p, k) \}$.

(1) Select the integer parameter NF that is typically referred to as the size of the transform as follows. First, compute minimum sizes NF_Min1 and NF_Min2.

(a) Compute NF_Min1 to ensure the output spectrum is adequately sampled.

$$NF_Min1(p) = \text{MAX}\{ 1.10 \cdot (2 \cdot NXS(p)), 2 \cdot NXS(p) + 1000 \}$$

(b) Compute NF_Min2 to ensure sample spacing of the spectrum is less than or equal to sample spacing of the Fx Response array, fx_SS_FXR.

$$NF_Min2(p) = 1/(Ts_XS(p) \cdot fx_SS_FXR)$$

(c) Select NF such that it is an integer greater than or equal to both of the minimums.

$$NF(p) \geq \text{CEIL}\{ \text{MAX}\{ NF_Min1, NF_Min2 \} \}$$

(2) Compute the output sample spacing, fx_SS_XIN(k). Also, compute the scale factor for the DFT as shown.

$$fx_SS_XIN(p) = 1/(Ts_XS(p) \cdot NF(p)) \quad DFT_SF(p) = 1/(2 \cdot NXS(p) + 1)$$

(3) The output samples of the DFT that are to be computed and retained for further processing are indexed by $k = K1(p)$ to $K2(p)$. Indices $K1(p)$ and $K2(p)$ are computed as shown. Frequency differences $\Delta fx_1(p)$ and $\Delta fx_2(p)$ are as shown in Section 4.4.

$$K1(p) = \text{FLOOR}\{ \Delta fx_1(p)/fx_SS_XIN(p) \}$$

$$K2(p) = \text{CEIL}\{ \Delta fx_2(p)/fx_SS_XIN(p) \}$$

(4) Compute the DFT output vector $\{ S_{XIN}(p, k) \}$ as shown or per an equivalent method. Only samples $K1(p)$ through $K2(p)$ need to be computed and used in the subsequent steps.

For $k = K1(p), \dots, K2(p)$:

$$S_{XIN}(p, k) = DFT_SF(p) \cdot \sum_{sx=-NXS(p)}^{NXS(p)} CE_{XIN}(p, sx) \cdot \exp \left\{ -j \cdot 2\pi \cdot \left(\frac{k \cdot sx}{NF(p)} \right) \right\}$$

Note: For the method used to compute $Ts_XS(p)$ and $NF(p)$, index limits $K1(p)$ and $K2(p)$ are constrained to always meet the following condition.

$$-1/2 \cdot NF(p) < K1(p) < K2(p) < 1/2 \cdot NF(p)$$

4.6.4 Apply the Fx Response

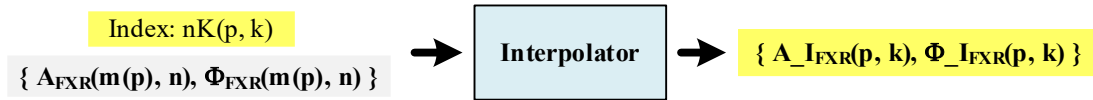
The Fx Response vector for pulse p is contained in row m(p) of the Fx Response array specified for the pulse sequence. Each sample of the Fx Response array is a complex number stored as amplitude and phase. The Fx Response vector is indexed as shown. Phases $\{\Phi_{\text{FXR}}(m(p), n)\}$ are in cycles.

For $n = 0, 1, 2, \dots, \text{NS_FXR} - 1$: $A_{\text{FXR}}(m(p), n)$ & $\Phi_{\text{FXR}}(m(p), n)$

(1) For each sample of the computed spectrum, compute the corresponding index value in the FXR vector. The computed index, $nK(p, k)$, includes both integer and fractional part. Use index $nK(p, k)$ to compute interpolated values of the FXR amplitude and phase response. For sample k, the interpolated amplitude is $A_{\text{IFXR}}(p, k)$ and the interpolated phase is $\Phi_{\text{IFXR}}(p, k)$.

For $k = K1(p), \dots, K2(p)$:

$$nK(p, k) = (\text{fx_0}(p) + \text{fx_SS_XIN}(p) \cdot k - \text{fx_0_FXR}) / \text{fx_SS_FXR}$$



Note: For all FXR arrays, the sample spacing fx_SS_FXR is specified to be fine enough that linear interpolation between adjacent samples provides acceptably accurate values for both amplitude and phase. See Section 6.5.

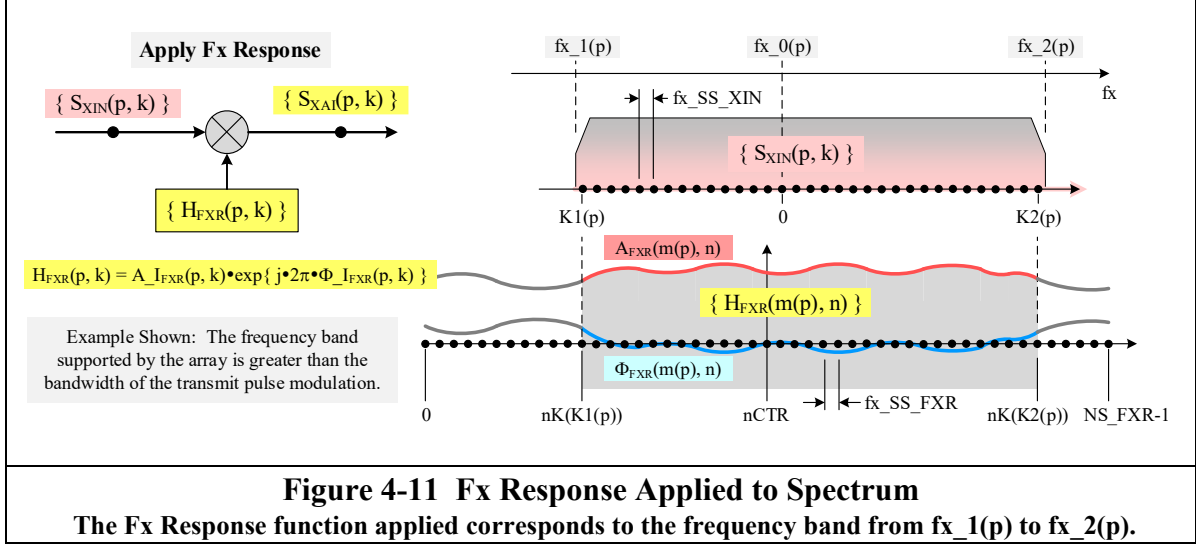
(2) Apply the Fx Response function to the sampled spectrum $\{S_{\text{XIN}}(p, k)\}$ using the interpolated amplitudes and phases. The result is sampled spectrum $\{S_{\text{XAI}}(p, k)\}$. See Figure 4-11.

For $k = K1(p), \dots, K2(p)$:

$$S_{\text{XAI}}(p, k) = S_{\text{XIN}}(p, k) \cdot A_{\text{IFXR}}(p, k) \cdot \exp(j \cdot 2\pi \cdot \Phi_{\text{IFXR}}(p, k))$$

(3) Compute the spectral power $\text{PS_0}(p)$ from the sampled spectrum $\{S_{\text{XAI}}(p, k)\}$. The spectral power.

$$\text{PS_0}(p) = \sum_{k=K1(p)}^{K2(p)} |S_{\text{XAI}}(p, k)|^2$$



4.6.5 Compute the IDFT: $\{ CE_{XMT}(p, sx) \}$

Compute the Inverse DFT of the spectrum with the Fx Response applied to it. Scale the output vector to yield an RMS amplitude equal to 1. The result is the normalized pulse modulation vector of for the base pulse p , $\{ CE_{XMT}(p, sx) \}$.

(1) The size parameter of the IDFT is equal to the size parameter of the DFT, $NF(p)$. The IDFT scale factor is set equal to 1.0.

$$IDFT_SF(p) = 1.0 \text{ (i.e., no scaling)}$$

(2) Compute the IDFT output vector $\{ S_{XMT}(p, sx) \}$ as shown or per an equivalent method. Only samples $-NXS(p)$ through $NXS(p)$ need to be computed and retained.

For $sx = -NXS(p), \dots, NXS(p)$:

$$uCE_{XMT}(p, sx) = IDFT_SF(p) \cdot \sum_{k=K1(p)}^{K2(p)} S_{XAI}(p, k) \cdot \exp \left\{ +j \cdot 2\pi \cdot \left(\frac{k \cdot sx}{NF(p)} \right) \right\}$$

(3) Scale the “un-normalized” pulse modulation vector $\{ uCE_{XMT}(p, sx) \}$ to yield an RMS amplitude equal to 1.0. The result is the “normalized” pulse modulation vector for the base pulse $\{ CE_{XMT}(p, sx) \}$.

$$uMS(p) = \frac{1}{2 \cdot NSX(p) + 1} \cdot \sum_{sx=-NXS(p)}^{NXS(p)} |uCE_{XMT}(p, sx)|^2 \quad uRMS(p) = uMS(p)^{1/2}$$

For $sx = -NXS(p), \dots, NXS(p)$:

$$CE_{XMT}(p, sx) = \frac{1}{uRMS(p)} \cdot uCE_{XMT}(p, sx)$$

A method to compute the pulse modulation vector that includes the effect of the transmit antenna beam shape pattern for a given pointing direction is specified in following steps. For the pointing direction defined by unit antenna pointing vector $\mathbf{uAP}$, the pulse modulation vector is denoted $\{ CE_{XAP}(p, \mathbf{uAP}, s_x) \}$.

4.6.6 Apply the Antenna Gain & Phase Response

The EB SV for pulse p is $\mathbf{EB}_0(p)$. The unit antenna pointing vector $\mathbf{uAP}$ is in antenna coordinates with equivalent 2-element vector $\mathbf{AP}$. The transmit antenna beam shape for pointing vector $\mathbf{AP}$ at frequency f is $H_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, f)$. See Section 9.3.

$$H_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, f) = \{ G_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, f), \Phi_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, f) \}$$

A method for computing antenna gain and phase is specified in Section 9.3.4. The inputs include the transmit APAT parameters and antenna gain/phase support arrays. For frequency fx , the computed gain and phase are G_{XBS} in dB and Φ_{XBS} in cycles.

$$\{ \mathbf{EB}_0(p), \mathbf{AP}, fx \} + \left\{ \begin{array}{c} T_x \\ APAT \\ Params \end{array} \right\} + \left\{ \begin{array}{c} T_x \text{ ARRAY} \\ SA \\ Data \end{array} \right\} + \left\{ \begin{array}{c} T_x \text{ ELEM} \\ SA \\ Data \end{array} \right\} \Rightarrow \boxed{\text{Compute APAT (G}_{BS}, \Phi_{BS})} \Rightarrow \left\{ \begin{array}{c} G_{XBS} \\ \Phi_{XBS} \\ DV \end{array} \right\}$$

(1) For each sample of the spectrum $\{ S_{XIN}(p, k) \}$, compute the frequency value, $fx(p, k)$. Compute the antenna gain value, $G_{XBS}(p, k)$, and phase value, $\Phi_{XBS}(p, k)$. The data valid parameter $DV = \text{"true"}$ indicates the Gain/Phase support arrays cover the selected pointing direction $\mathbf{uAP}$ and the EB SV for pulse p .

For $k = K1(p), \dots, K2(p)$:

$$\begin{aligned} fx(p, k) &= fx_0(p) + fx_SS_XIN(p) \cdot k \\ G_{XBS}(p, k) &= G_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, fx(p, k)) \\ \Phi_{XBS}(p, k) &= \Phi_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, fx(p, k)) \end{aligned}$$

(2) Apply the gain and phase to the sampled spectrum $\{ S_{XIN}(p, k) \}$ by first computing the amplitude value $A_{XBS}(p, k)$ from the gain value $G_{XA}(p, k)$ that is in dB. The result is the sampled spectrum $\{ S_{XAP}(p, \mathbf{uAP}, k) \}$.

For $k = K1(p), \dots, K2(p)$:

$$\begin{aligned} A_{XBS}(p, k) &= 10^{(0.05 \cdot G_{XBS}(p, k))} \\ S_{XAP}(p, \mathbf{uAP}, k) &= S_{XIN}(p, k) \cdot A_{XBS}(p, k) \cdot \exp(j \cdot 2\pi \cdot \Phi_{XBS}(p, k)) \end{aligned}$$

(3) Compute the spectral power $PS(p, \mathbf{uAP})$ from the sampled spectrum $\{ S_{XAP}(p, \mathbf{uAP}, s_x) \}$.

$$PS(p, \mathbf{uAP}) = \sum_{k=K1(p)}^{K2(p)} |S_{XAP}(p, \mathbf{uAP}, k)|^2$$

4.6.7 Compute the IDFT: $\{ \text{CE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) \}$

Compute the Inverse DFT of the spectrum with the antenna beam shape applied to it. Scale the output vector to yield the normalized vector magnitude. The result is the normalized pulse modulation vector for output pulse p along pointing vector $\mathbf{uAP}$, $\{ \text{CE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) \}$.

(1) The size parameter of the IDFT is equal to the size parameter of the DFT, $\text{NF}(\text{p})$. The IDFT scale factor is set equal to 1.0.

$$\text{IDFT_SF}(\text{p}) = 1.0 \text{ (i.e., no scaling)}$$

(2) Compute the IDFT of vector $\{ \text{S}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) \}$ as shown or per an equivalent method. Only samples $-\text{NXS}(\text{p})$ through $\text{NXS}(\text{p})$ need to be computed and retained.

For $\text{sx} = -\text{NXS}(\text{p}), \dots, \text{NXS}(\text{p})$:

$$\text{uCE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) = \text{IDFT_SF}(\text{p}) \cdot \sum_{k=\text{K1}(\text{p})}^{\text{K2}(\text{p})} \text{S}_{\text{XAP}}(\text{p}, \mathbf{uAP}, k) \cdot \exp \left\{ +j \cdot 2\pi \cdot \left(\frac{k \cdot \text{sx}}{\text{NF}(\text{p})} \right) \right\}$$

(3) Compute parameter $\text{RMS}(\text{p}, \mathbf{uAP})$ from the ratio of the spectral power values $\text{PS}_0(\text{p})$ and $\text{PS}(\text{p}, \mathbf{uAP})$.

$$\text{RMS}(\text{p}, \mathbf{uAP}) = \left(\text{PS}(\text{p}, \mathbf{uAP}) / \text{PS}_0(\text{p}) \right)^{1/2}$$

(4) Scale the un-normalized sampled pulse modulation vector $\{ \text{uCE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) \}$ to yield an RMS amplitude equal to $\text{RMS}(\text{p}, \mathbf{uAP})$. The result is the normalized pulse modulation vector $\{ \text{CE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) \}$.

$$\text{uMS}(\text{p}, \mathbf{uAP}) = \frac{1}{2 \cdot \text{NSX}(\text{p}) + 1} \cdot \sum_{\text{sx}=-\text{NXS}(\text{p})}^{\text{NXS}(\text{p})} |\text{uCE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx})|^2$$

$$\text{uRMS}(\text{p}, \mathbf{uAP}) = \text{uMS}(\text{p}, \mathbf{uAP})^{1/2}$$

For $\text{sx} = -\text{NXS}(\text{p}), \dots, \text{NXS}(\text{p})$:

$$\text{CE}_{\text{XAP}}(\text{p}, \mathbf{uAP}, \text{sx}) = \text{RMS}(\text{p}, \mathbf{uAP}) \cdot \frac{1}{\text{uRMS}(\text{p}, \mathbf{uAP})} \cdot \text{uCE}_{\text{XMT}}(\text{p}, \mathbf{uAP}, \text{sx})$$

4.6.8 Compute Transmit Power: $\text{P_RI}_{\text{XAP}}(\text{p}, \mathbf{uAP})$

Compute the transmit power radiant intensity for transmit pulse p in direction of unit pointing vector $\mathbf{uAP}$, $\text{P_RI}_{\text{XAP}}(\text{p}, \mathbf{uAP})$. Use the base pulse radiant intensity for pulse p , $\text{P_RI}_{0\text{XMT}}(\text{p})$, adjusted by the ratio of the computed spectral powers expressed in dB. The computed transmit radiant intensity $\text{P_RI}_{\text{XAP}}(\text{p}, \mathbf{uAP})$ has units of dBW/sr.

$$\text{P_RI}_{\text{XAP}}(\text{p}, \mathbf{uAP}) = \text{P_RI}_{0\text{XMT}}(\text{p}) + 10 \cdot \log_{10} \left(\text{PS}(\text{p}, \mathbf{uAP}) / \text{PS}_0(\text{p}) \right)$$

4.7 Signal Array Size and Sample Timing

Each signal array is a two-dimensional array of complex-valued data samples. The dimensions of the array are referred to as vectors and samples. Each signal array may be a unique size. Shown in Figure 4-12 is the PVP array and the signal array for a given data channel. The size of the signal array is NV_CH vectors by NS_CH samples. The PVP array contains NV_CH sets of parameters.

A CRSD signal array contains a sampled time signal. For the received signal data contained in the array, the sample times are the times the signal was incident at the receive APC. All signal arrays have the following attributes.

- (1) The vectors of the signal array are indexed by $v = 0, 1, 2, \dots, NV_CH - 1$. The samples of the signal array are indexed by $s = 0, 1, 2, \dots, NS_CH - 1$.
- (2) For each signal array, one vector is selected as the reference vector for the channel, denoted v_CH_REF . For a CRSDsar product, the reference vector may be any vector for which the echoes from a transmitted pulse are received from the imaged scene (i.e., pulse index $p(v_CH_REF) \geq 0$).
- (3) The signal array coordinates are referred to as Slow Time (ST) vectors by Fast Time (FT) samples. Increasing vector index corresponds to increasing slow time. Increasing sample index corresponds to increasing fast time.
- (4) The signal array contains signal data sampled at fixed rate $fs(Ch_ID)$ samples per second. The sample period is $Ts(Ch_ID) = 1/fs(Ch_ID)$ seconds.
- (5) Each vector is formed from a unique, continuously sampled time period. Each signal vector spans a time period:

$$T_Rcv(Ch_ID) = NS_CH \cdot Ts(Ch_ID)$$

- (6) The sample time for data sample (v, s) is computed by:

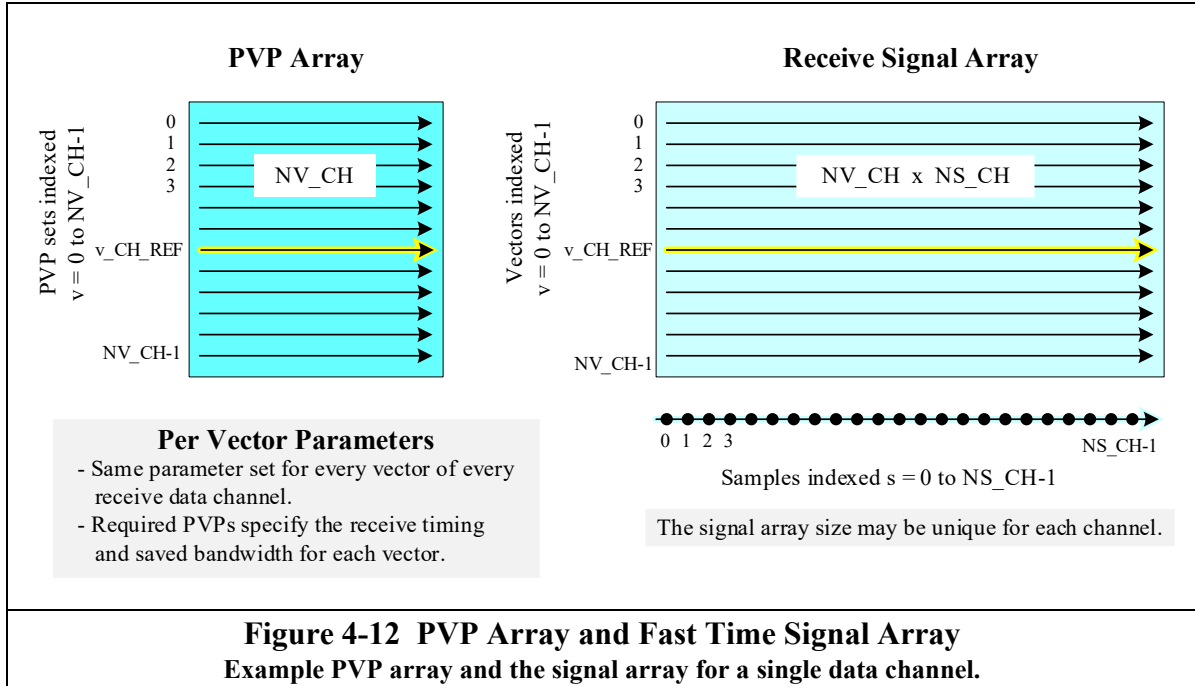
$$t(v, s) = trs(v) + Ts(Ch_ID) \cdot s$$

- (7) For signal arrays with $NV_CH \geq 2$, the times $\{trs(v)\}$ are strictly increasing with index v .
- (8) For each vector, the sample time of the last sample is denoted $trNSm1(v)$ where:

$$trNSm1(v) = trs(v) + Ts(Ch_ID) \cdot (NS_CH - 1)$$

For a signal array with $NV_CH \geq 2$, the sample time of the last sample of one vector is earlier than the sample time of the first sample of the next vector.

$$trNSm1(v) < trs(v+1)$$



- (8) For all vectors in the array, the sample time $trs(v)$ is an integer multiple of the sample period $Ts(Ch_ID)$ relative to $trs(0)$. For all vectors:

$$trs(v) = trs(0) + Ts(Ch_ID) \cdot M(v)$$

where for $v > 1$, $M(v)$ is a positive integer.

- (9) For a given signal array, the vectors may or may not form a continuously sampled signal. For a continuously sampled signal, the vector start times $\{trs(v)\}$ are evenly spaced by the time period spanned by a vector.

$$trs(v) = trs(0) + T_Rcv(Ch_ID) \cdot v$$

For a signal array that is not a continuously sampled signal, the time from the last sample of one vector to the first sample of the next vector may vary and is a period of missing signal data. A signal array formed for a monostatic SAR imaging collection, for example, may have periods of missing signal data during the transmit pulse periods of the collection timeline.

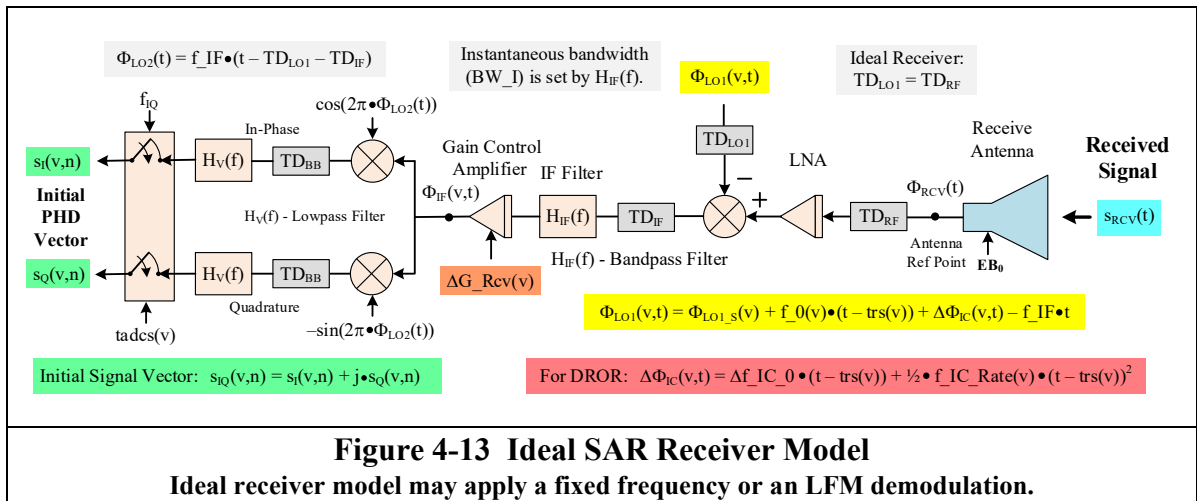
4.8 Ideal Receiver Model

The parameters that specify the receive signal processing applied to each signal vector are described in the following sections. The description makes use of an ideal receiver model that is used to receive, demodulate, and digitize the initial signal array. The ideal receiver is based on a typical SAR sensor receiver and is shown in Figure 4-13. For a collection, the receiver records for N_PHD time intervals that form the initial PHD signal array. Each receive interval, referred to as a receive window, is a fixed duration. For each receive window, the signals that were incident at the receive APC are first demodulated and filtered at an Intermediate Frequency (IF). The signals at IF are then demodulated to form In-Phase and Quadrature (I & Q) baseband signals. The I & Q baseband signals are filtered and digitized using a matched pair of lowpass filters and Analog-to-Digital Converters (ADC).

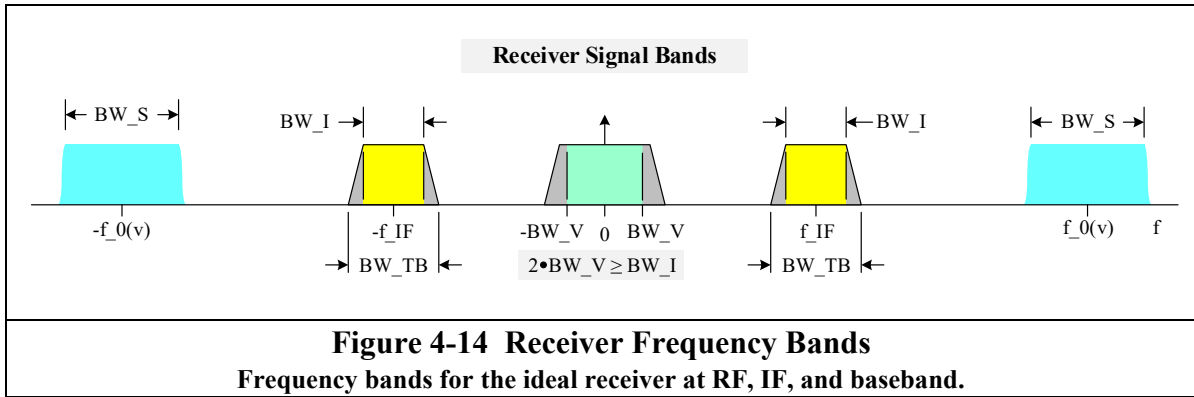
For each receive window, the receiver may use a constant frequency demodulation or an LFM demodulation waveform in the first stage of mixing. The reference waveform for the first mixing is referred to as the first local oscillator (denoted LO1). The LO1 starting frequency and FM rate may vary across receive windows. The IF frequency, denoted f_IF , is fixed for a collection. The bandpass filter at IF and the lowpass filters at baseband are also fixed. The receive signal gain at IF is constant during a receive window but may vary across receive windows. The reference waveform used to form the I & Q baseband components is referred to as the second local oscillator (denoted LO2). The LO2 signal is a constant frequency tone at $f = f_IF$. The I & Q baseband signals are simultaneously digitized and recorded to form the initial PHD signal vector. For each receive window, a set of NS_IQ fast time samples are recorded for both the I & Q signals.

The initial PHD signal array is a two-dimensional array of N_PHD signal vectors and NS_IQ samples per signal vector. The initial PHD vectors are indexed by $v = 0, 1, 2, \dots, N_PHD - 1$ and the samples of each signal vector are indexed by $n = 0, 1, 2, \dots, NS_IQ - 1$. For each receive window, the I & Q signal samples are combined to form a complex-valued initial PHD signal vector. For window v , the initial signal vector is:

$$s_{IQ}(v, n) = s_I(v, n) + j \cdot s_Q(v, n)$$



Shown in Figure 4-14 are the frequency bands for the signals in the ideal receiver for a single receive window. The received signals of interest have bandwidth BW_S that includes frequency $f_0(v)$. The filter at IF, with response $H_{IF}(f)$, sets the instantaneous bandwidth of the receiver, denoted BW_I . The pair of lowpass filters have identical responses, denoted $H_V(f)$. The pair of ADCs sample at a fixed rate, denoted f_IQ . The one-sided bandwidth of the lowpass filters is BW_V and is large enough to pass the bandwidth BW_I at IF. The sample rate f_IQ is greater than BW_I and is high enough to ensure signals in the transition bands of the IF filter and the LPF filter do not alias into the band BW_I centered at $f = 0$. The duration of the receive window is $T_Rcv = (1/f_IQ) \cdot NS_IQ$.



For receive window v , the analog signal processing applied to the received signal $s_{RCV}(t)$ to form the I & Q signals is as follows. The receive signal $s_{RCV}(t)$ is expressed in the following form:

$$s_{RCV}(t) = A_R(t - trc) \cdot \cos\{2\pi \cdot \Phi_R(t - trc)\}$$

Amplitude function $A_R(t)$ is real-valued, rectangular pulse centered at time $t = 0$. The phase function $\Phi_R(t)$ may be a linear phase function (i.e., constant frequency) or it may be an LFM quadratic phase function. Time trc is a time during receive window v . The duration of the received pulse is T_P and is less than the duration of the receive window T_Rcv . In the description below, all phases are in cycles, all frequencies are in Hertz, and all FM rates are in Hertz/sec. Time t is in seconds relative to the t_CRT .

- (1) The receive signal $s_{RCV}(t)$ is incident at the receive APC and output at the Antenna Reference Port. The signal is amplified by a Low Noise Amplifier (LNA) and delayed by T_{DRF} from the APC to the input of the first mixer. The LNA gain and time delay T_{DRF} are constant for the collection.
- (2) The LO1 reference signal determines the band of RF signals that are passed by the IF filter and retained in the I & Q signals. The LO1 reference phase, $\Phi_{LO1}(v, t)$, is of the following form:

$$\Phi_{LO1}(v, t) = \Phi_{LO1_S}(v) + f_0(v) \cdot (t - trs(v)) + \Delta\Phi_{IC}(v, t) - f_IF \cdot t$$

Frequency $f_0(v)$ is referred to as the reference frequency for window v . Phase function $\Delta\Phi_{IC}(v, t)$ may be used to apply an LFM demodulation. The

LO1 reference signal is delayed by TD_{LO1} before input to the mixer. The time delay TD_{LO1} is constant for the collection. For the ideal receiver, $TD_{LO1} = TD_{RF}$.

- (3) The LO1 phase may be a constant frequency signal with starting phase $\Phi_{LO1_S}(v)$ and $f = f_0(v) - f_IF$. Phase function $\Delta\Phi_{IC}(v, t) = 0$. This type of demodulation is referred to as Constant Frequency on Receive (CFOR).
- (4) The LO1 phase function may include $\Delta\Phi_{IC}(v, t)$ to apply an LFM demodulation. The LFM varies the Instantaneous Center (IC) frequency at RF that is passed by the IF filter and retained in the I & Q baseband signals. The phase function $\Delta\Phi_{IC}(v, t)$ is of the following form:

$$\Delta\Phi_{IC}(v, t) = \Delta f_IC_0(v) \cdot (t - trs(v)) + \frac{1}{2} \cdot f_IC_Rate(v) \cdot (t - trs(v))^2$$

The variation in IC frequency is $\Delta f_IC(v, t)$:

$$\Delta f_IC(v, t) = \Delta f_IC_0(v) + f_IC_Rate(v) \cdot (t - trs(v))$$

When the LO1 phase includes an LFM signal, the type of demodulation is referred to as De-Ramp on Receive (DROR).

- (5) For a window that applies DROR, the frequency $\Delta f_IC_0(v)$ and FM rate $f_IC_Rate(v)$ are always selected such that the $\Delta f_IC(v, t)$ passes through 0 within the receive window. Hence, the sign of $\Delta f_IC_0(v)$ is always opposite the sign of $f_IC_Rate(v)$.
- (6) The phase of the signal output from the first mixer and passed by the IF filter has the following form. The total delay at IF is modeled as a single delay TD_{IF} :

$$\Phi_{IF}(v, t) = \Phi_R(t - trc - TD_{RF} - TD_{IF}) - \Phi_{LO1}(v, t - TD_{LO1} - TD_{IF})$$

Expanding the expression for $\Phi_{LO1}(v, t - TD_{LO1} - TD_{IF})$ and replacing TD_{LO1} with TD_{RF} yields the following form:

$$\begin{aligned} \Phi_{IF}(v, t) = & \Phi_R(t - trc - TD_{RF} - TD_{IF}) \\ & - \{ \Phi_{LO1_S}(v) + f_0(v) \cdot (t - trs(v) - TD_{RF} - TD_{IF}) + \Delta\Phi_{IC}(v, t - TD_{RF} - TD_{IF}) \} \\ & + f_IF \cdot (t - TD_{RF} - TD_{IF}) \end{aligned}$$

- (7) The LO2 reference signal is used to form the I & Q baseband signals. The phase of the LO2 reference is $\Phi_{LO2}(t)$ and for the ideal receiver has the following form:

$$\Phi_{LO2}(t) = f_IF \cdot (t - TD_{RF} - TD_{IF})$$

- (8) The I & Q baseband signals, $s_I(v, t)$ and $s_Q(v, t)$, are output by the low pass filters and input to the ADCs. For the ideal receiver, the delay is equal for the I & Q signal paths. The total delay from the output of the gain control amplifier at IF to the input of the ADCs is modeled by a single time delay TD_{BB} . The total receive delay from the APC to the ADC inputs is TD_{RCV} . The total receive delay TD_{RCV} is:

$$TD_{RCV} = TD_{RF} + TD_{IF} + TD_{BB}.$$

- (9) The I & Q signals are of the following form:

$$s_I(v, t) = A_{IQ}(v, t) \cdot \cos\{2\pi \cdot \Phi_{IQ}(v, t)\}$$

$$s_Q(v, t) = A_{IQ}(v, t) \cdot \sin\{2\pi \cdot \Phi_{IQ}(v, t)\}$$

The amplitude $A_{IQ}(v, t)$ is a scaled and delayed version of the receive pulse amplitude $A_R(t)$. Scale factor a_rcv_0 is the scale factor for gain control $\Delta G_Rcv(v) = 0$ dB. Scale factor $gc(v)$ is amplitude scaling due to the gain control amplifier setting for the receive window.

$$A_{IQ}(v, t) = a_rcv_0 \cdot gc(v) \cdot A_R(t - trc - TD_{RCV})$$

- (10) The phase of the baseband I & Q signals $\Phi_{IQ}(v, t)$ is of the following form:

$$\Phi_{IQ}(v, t) = \Phi_{IF}(v, t - TD_{BB}) - \Phi_{LO2}(t - TD_{BB})$$

Expanding phase functions $\Phi_{IF}(v, t)$ and $\Phi_{IF}(v, t)$ and combining terms yields:

$$\Phi_{IQ}(v, t) = \Phi_R(t - trc - TD_{RCV}) -$$

$$\{ \Phi_{LO1_S}(v) + f_0(v) \cdot (t - trs(v) - TD_{RCV}) + \Delta\Phi_{IC}(v, t - TD_{RCV}) \}$$

- (11) For each receive window, the ADCs sample and record NS_IQ samples of the I & Q channel baseband signals. For receive window v , the first sample captures the signals at the ADC inputs at time $t = t_{adcs}(v)$. The sample rate is f_IQ samples per second with sample period $T_IQ = 1/f_IQ$ seconds. The samples times for the digitized signal are:

$$t_IQ(v, n) = t_{adcs}(v) + T_IQ \cdot n$$

The samples of the I & Q signals are combined to form a complex-valued signal vector, $s_{IQ}(v, n)$, of the following form:

$$s_{IQ}(v, n) = s_I(v, n) + j \cdot s_Q(v, n)$$

$$s_{IQ}(v, n) = A_{IQ}(v, t_IQ(v, n)) \cdot \exp\{j \cdot 2\pi \cdot \Phi_{IQ}(v, t_IQ(v, n))\}$$

4.9 CRSD Formation Processing

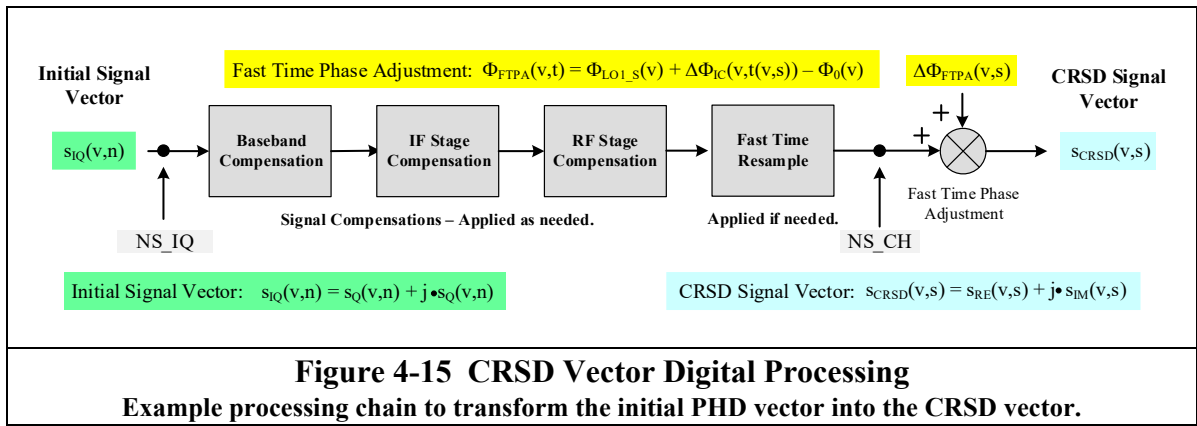
The digital processing that forms the CRSD signal array from the initial PHD signal array is dependent upon the type of demodulation applied. For receivers that apply CFOR demodulation, the processing may only require a conversion of the initial PHD sample format to an allowed CRSD sample format. For receivers that apply DROR demodulation, the processing always includes a phase adjustment that cancels the LFM phase applied in the receiver processing chain. It may also include a resampling to increase the fast time sample rate prior to cancelling the LFM applied in DROR demodulation.

The processing to form the CRSD signal array may also include sensor-specific compensations that are needed to meet the expected signal quality. Figure 4-15 shows an example CRSD formation chain that includes sensor-specific compensations. The processing inputs one vector of the initial PHD array and forms one vector of the compensated signal array. In the example, the initial signal array was recorded by a receiver that is similar to the ideal receiver shown in Figure 4-13. The compensation modules and the order shown in Figure 4-9 are notional. The types of compensations that may be applied include the following:

- (1) Compensation(s) for distortions that may arise when forming and digitizing the baseband signals. These may include ADC bias compensation and compensation for gain and/or phase distortion in forming the I & Q signal components.
- (2) Compensation for variation in receiver gain in slow time (i.e., across receive windows) that is commonly used in SAR receivers. For the example receiver shown in Figure 4-13, the receive gain at IF may vary in slow time. Gain $\Delta G_Rcv(v)$ is the difference in gain for window v relative to the nominal receiver gain. For $\Delta G_Rcv(v) = +2.0$ dB, the signal values for initial vector v are scaled by $gc(v) = 10.0^{**}(+2.0/20.0) = 1.259$.
- (3) Compensation for distortions that arise in the IF stages of the receiver. These may include compensations for variations in filter gain or phase across the instantaneous bandwidth.
- (4) Compensation for distortions and/or gain variation in the RF portion of the receive sensor. The RF compensations may correct, as needed, for known gain variation in the radar receiver signal path. The RF compensation may also correct for gain and/or phase variation vs. frequency in the receive antenna that is not included in the receive antenna beam shape pattern.

For a given receive channel, the signal array is ideally formed such that for in-band signals, the only variation in receive signal gain is specified by the receive antenna beam shape pattern. The antenna beam shape pattern specifies the directional variation in receive gain for a given receive window as well as the variation across receive windows. Provided in Section 7.4 is a method for computing expected signal array power as function of incident power at the receive APC.

The final processing steps shown in Figure 4-15 are a resampling function and a phase adjustment function. The fast time resampling may be needed to align the sample time for the first sample of the CRSD signal vector. Sample $s = 0$ of the CRSD vector contains the signal that was at receive APC at $t = \text{trs}(v)$ and, for the ideal receiver, was at the ADC input at time $t = \text{trs}(v) + \text{TD}_{\text{RCV}}$. The fast time resampling may also adjust the fast time sample rate from the ADC sample rate f_{IQ} to the CRSD sample rate $f_s(\text{Ch_ID})$. The phase adjustment function is referred to as Fast Time Phase Adjustment (FTPA) and may be needed for several reasons. The FTPA may be needed to cancel the LFM phase function applied when DROR demodulation is used to form the initial PHD vector. The FTPA may also be needed to adjust the overall phase of the vector to achieve the desired reference phase function for the vector.



The application of the fast time resampling and the FTPA can be critical in forming the signal vector such that the defined PVPs precisely describe the processing that was applied. The following examples demonstrate application of fast time resampling and the use of the FTPA. For each example, the initial PHD vector was received and digitized by the ideal receiver shown in Figure 4-13. For each example, the analog processing applied to form the initial vector, the resampling (if needed), and the FTPA applied are described. The values for the PVPs are also specified. For vector v , the FTPA phase function that is applied to the NS_CH samples is of the following form:

$$\Delta\Phi_{\text{FTPA}}(v, s) = \Phi_{\text{LOI_S}}(v) + \Delta\Phi_{\text{IC}}(v, t(v, s)) - \Phi_0(v)$$

where the times $t(v, s)$ are the times the received signal was incident at the receive APC. The value $\Phi_0(v)$ applied is a design choice. A logical choice may be to set $\Phi_0(v) = f_{\text{0}}(v) \cdot \text{trs}(v)$. Refer to Section 4.1.3 for guidance computing and storing values for $\text{trs}(v)$ and $\Phi_0(v)$.

4.9.1 Example 1: CFOR Demodulation

The initial PHD signal array is collected using CFOR demodulation for all receive windows. The receiver parameters used to receive and record the initial PHD are as follows.

Initial PHD Channel Parameters:

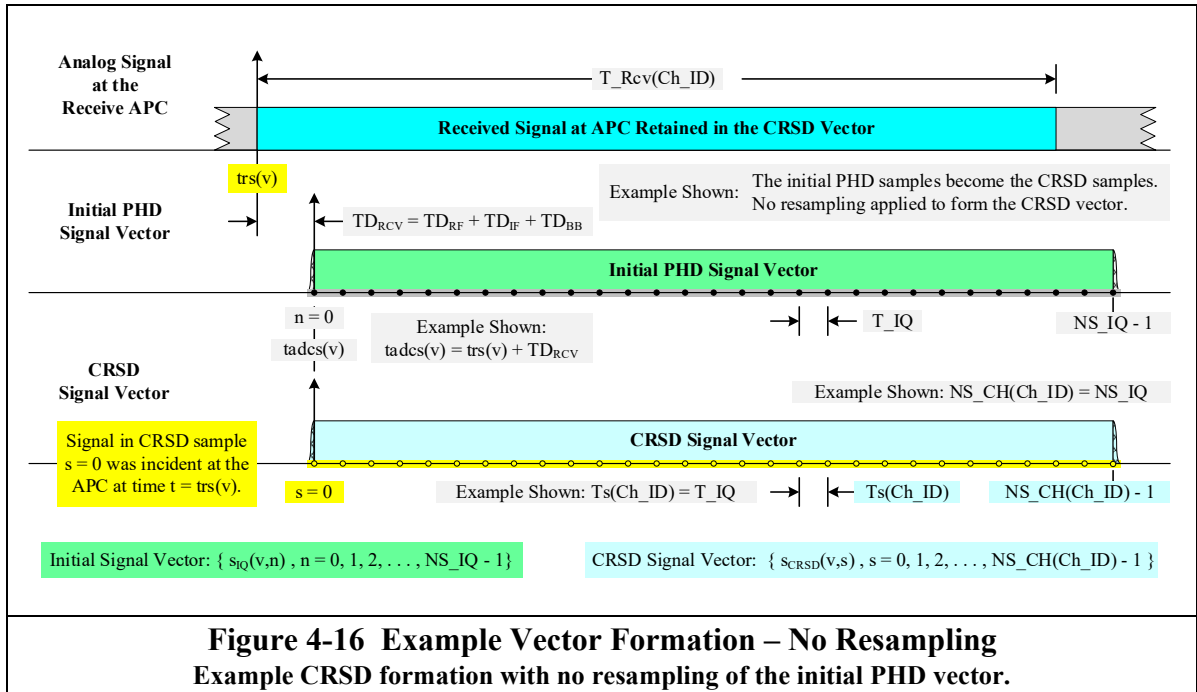
NV_CH: 10,000	BW_I: 200.0×10^6 Hz
NS_IQ: 25,000	f_IQ: 250.0×10^6 samples/sec
	T_IQ: 4.0×10^{-9} sec

The IQ sample rate of $f_{IQ} = 250$ Msamp/sec is an adequate rate for the IQ initial signal array and, per a CRSD product design decision, is the selected sample rate for the CRSD signal array. Also, the sample time of the first sample of each initial PHD signal vector is an integer multiple of the sample period $T_{IQ} = 1/f_{IQ}$ relative to the first sample of vector 0. The sample times of the initial PHD array meet the required sample timing for a CRSD signal array. Hence, the fast time resampling module in Figure 4-15 is not required. The CRSD Channel Parameters are as follows.

CRSD Channel Parameters:

NV_CH: 10,000	BW_Inst: 200.0×10^6 Hz
NS_CH: 25,000	fs: 250.0×10^6 samples/sec
T_Rcv: 100.000×10^{-6} sec	Ts: 4.0×10^{-9} sec

Shown in Figure 4-16 is the receive timing for single vector v . The signal at the receive APC at time $\text{trs}(v)$ is captured in the first sample of the initial PHD vector (sample $n = 0$) at time $\text{tadcs}(v) = \text{trs}(v) + \text{TD}_{RCV}$. The signal is also output in the first sample of the CRSD vector (sample $s = 0$).



For signal vector v , the LO1 reference is a constant frequency signal with the following parameters.

LO1 Phase Parameters for Vector v :

$$\begin{aligned} f_{_0}(v) &= 5000.0 \times 10^6 \text{ Hz} & \Delta f_{_IC_0}(v) &= 0.0 \\ f_{_IC_Rate}(v) &= 0.0 \end{aligned}$$

For the ideal receiver, the receive signal at time $t = \text{trs}(v)$ is mixed with $\Phi_{LO1}(v, \text{trs}(v)) = \Phi_{LO1_S}(v)$. Refer to the description of the ideal receiver in Section 4.8. For CFOR demodulation, the receive signal phase in the vector prior to the FTPA has the following form. Time $t(v, s)$ is the time that the signal in vector v and sample s was incident at the receive APC.

$$\text{Prior to FTPA: } \Phi_{CRSD}(v, s) = \Phi_R(t(v, s) - \text{trc}) - \{\Phi_{LO1_S}(v) + f_{_0}(v) \cdot (t(v, s) - \text{trs}(v))\}$$

The FTPA is used to shift the effective starting phase of the LO1 signal for each vector by a phase $\Phi_0(v) = f_{_0}(v) \cdot \text{trs}(v)$. Refer to Figure 4-15. The phase $\Phi_{FTPA}(v, s)$ is added to the phase of sample (v, s) .

$$\text{FTPA Phase: } \Phi_{FTPA}(v, s) = \Phi_{LO1_S}(v) - f_{_0}(v) \cdot \text{trs}(v)$$

The phase of the receive signal in the CRSD after applying the FTPA has the following form.

$$\text{After FTPA: } \Phi_{CRSD}(v, s) = \Phi_R(t(v, s) - \text{trc}) - \{f_{_0}(v) \cdot \text{trs}(v) + f_{_0}(v) \cdot (t(v, s) - \text{trs}(v))\}$$

The choice of starting phase $\Phi_0(v) = f_{_0}(v) \cdot \text{trs}(v)$ results in a CRSD signal array that was effectively demodulated using a coherent reference tone of the form:

$$\Phi_{DMOD}(v, t) = f_{_0}(v) \cdot t$$

For signal vector v , the instantaneous frequency vs. fast time that is incident at the receive APC and retained in the CRSD signal vector is shown in Figure 4-17. Sample time $\text{trNSm1}(v)$ is the time the signal in sample $s = \text{NS_CH} - 1$ was incident at the receive APC. Frequency $\text{frcv_1}(v)$ and $\text{frcv_2}(v)$ are the minimum and maximum frequencies passed within the instantaneous bandwidth (BW_I). For signal vector v , the demodulation PVPs are assigned as shown.

CRSD Per Vector Demodulation Parameters:

$$\begin{aligned} f_{_0}(v): & 5000.0 \times 10^6 \text{ Hz} & \Delta f_{_IC_0}(v): & 0.0 \text{ Hz} \\ \Phi_0(v): & f_{_0}(v) \cdot \text{trs}(v) & f_{_IC_Rate}(v): & 0.0 \text{ Hz/sec} \end{aligned}$$

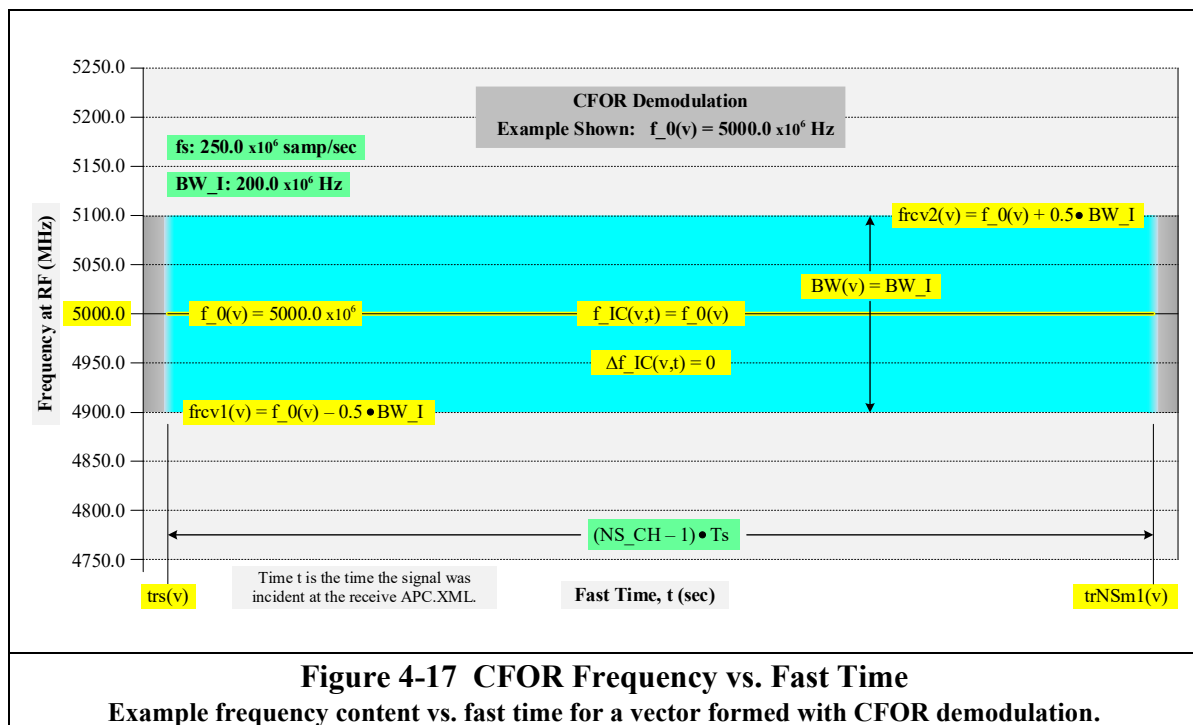
Frequency $\text{frcv_1}(v)$ and $\text{frcv_2}(v)$ are the minimum and maximum frequencies passed within the instantaneous bandwidth (BW_I) between time $\text{trs}(v)$ and $\text{trNSm1}(v)$. Define the total receive bandwidth for the vector, $\text{BW}(v)$, as the difference of $\text{frcv_1}(v)$ and $\text{frcv_2}(v)$. For CFOR, $\text{BW}(v)$ is always equal to BW_I .

CRSD Per Vector Receive Bandwidth Parameters:

$$\text{frcv_1}(v) = f_0(v) - \frac{1}{2} \cdot \text{BW_I} = 4900.0 \times 10^6 \text{ Hz}$$

$$\text{frcv_2}(v) = f_0(v) + \frac{1}{2} \cdot \text{BW_I} = 5100.0 \times 10^6 \text{ Hz}$$

$$\text{BW}(v) = \text{frcv_2}(v) - \text{frcv_1}(v) = 200.0 \times 10^6 \text{ Hz}$$



4.9.2 Example 2: DROR Demodulation

The initial PHD signal array is collected using DROR demodulation for all receive windows. The receiver parameters used to receive and record the initial PHD are as follows.

Initial PHD Channel Parameters:

NV_CH: 10,000

NS_IQ: 25,003

BW_I: 200.0 x 10⁶ Hz

f_IQ: 250.0 x 10⁶ samples/sec

T_IQ: 4.0 x 10⁻⁹ sec

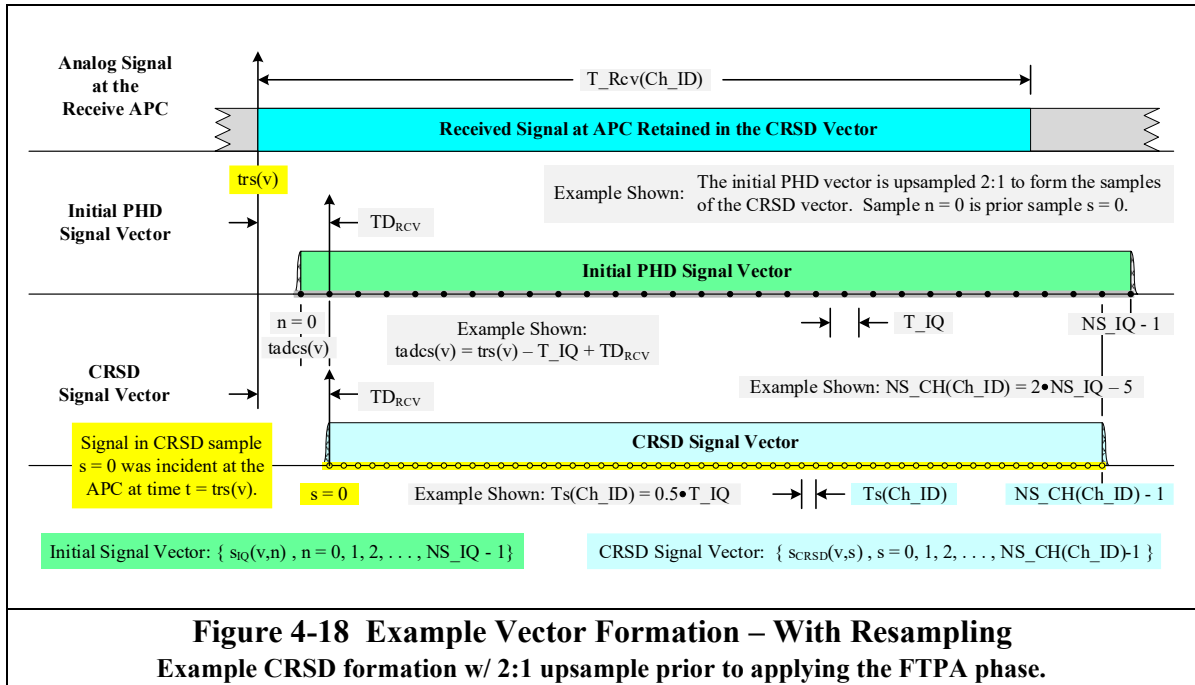
The IQ sample rate of f_IQ = 250 Msamp/sec provides an adequate rate for the IQ initial signal array. However, the total receive bandwidth BW(v) for each signal vector using DROR demodulation is 480 MHz. A CRSD product design decision is made to form the CRSD signal array with a sample rate of 500 Msamp/sec. Hence, the fast time resample module upsamples by a ratio of 2:1 to form the samples of CRSD vectors.

Shown in Figure 4-18 is the receive timing for signal vector v. The signal at the receive APC at time trs(v) is captured in the second sample of the initial PHD vector (sample n = 1) at

time $t_{IQ}(v,1) = t_{adcs}(v) + T_{IQ} = t_{rs}(v) + T_{D_{RCV}}$. Output sample $s = 0$ is resampled coincident with initial PHD sample $n = 1$. Output sample $s = NS_CH - 1$ is resampled coincident with initial PHD sample $n = NS_IQ - 2$. The signal at the receive APC at time $t_{rs}(v)$ is output in the first sample of the CRSD vector (sample $s = 0$). For the example shown, the resampling function outputs $NS_CH = 2 \cdot NS_IQ - 5$ samples. The output samples span slightly less fast time than the initial PHD vector. The CRSD Channel Parameters are as follows.

CRSD Channel Parameters:

NV_CH: 10,000	BW_Inst: 200.0×10^6 Hz
NS_CH: 50,001	fs: 500.0×10^6 samples/sec
T_Rcv: 100.002×10^{-6} sec	Ts: 2.0×10^{-9} sec



For signal vector v , the LO1 reference is a Linear FM signal with the following parameters.

LO1 Phase Parameters for Vector v :

$$f_{0}(v) = 9600.0 \times 10^6 \text{ Hz} \quad \Delta f_{IC_0}(v) = -140.0 \times 10^6 \text{ Hz}$$

$$f_{IC_Rate}(v) = 2.800 \times 10^{12} \text{ Hz/sec}$$

Shown in Figure 4-19 is the received signal bandwidth versus fast time for receive window v . For the example shown, time $t_{rNSm1}(v) = t_{rs}(v) + 100.000 \times 10^{-6}$ seconds. The Instantaneous Center $f_{IC}(v, t)$ sweeps from 9460 MHz to 9740 MHz.

For all collections that apply DROR, the FTPA is applied when forming the CRSD signal array. For each signal vector, the FTPA is applied to cancel the LFM applied by the LO1 reference. This form of FTPA is often referred to as a “re-chirp” of the received signal echoes of the transmit LFM pulse.

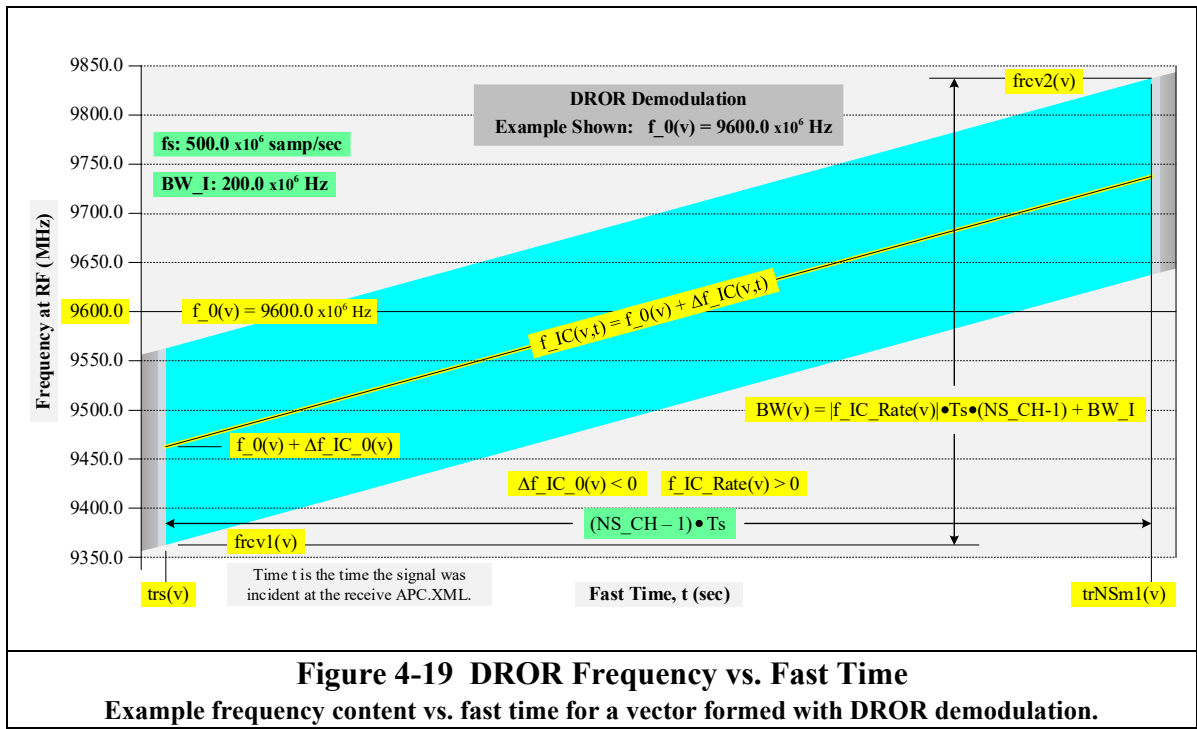
$$\text{Prior to FTPA: } \Phi_{\text{CRSD}}(v, s) = \Phi_R(t(v, s) - \text{trc}) - \{ \Phi_{\text{LOI}_S}(v) + f_0(v) \cdot (t(v, s) - \text{trs}(v)) \} \\ - \{ \Delta f_{\text{IC}_0}(v) \cdot (t(v, s) - \text{trs}(v)) + \frac{1}{2} \cdot f_{\text{IC_Rate}}(v) \cdot (t(v, s) - \text{trs}(v))^2 \}$$

The phase $\Phi_{\text{FTPA}}(v, s)$ that is added to the phase of sample (v, s) has the following form.

$$\text{FTPA Phase: } \Phi_{\text{FTPA}}(v, s) = \Phi_{\text{LOI}_S}(v) - f_0(v) \cdot \text{trs}(v) \\ + \{ \Delta f_{\text{IC}_0}(v) \cdot (t(v, s) - \text{trs}(v)) + \frac{1}{2} \cdot f_{\text{IC_Rate}}(v) \cdot (t(v, s) - \text{trs}(v))^2 \}$$

The phase of the receive signal in the CRSD after applying the FTPA has the following form.

$$\text{After FTPA: } \Phi_{\text{CRSD}}(v, s) = \Phi_R(t(v, s) - \text{trc}) - \{ f_0(v) \cdot \text{trs}(v) + f_0(v) \cdot (t(v, s) - \text{trs}(v)) \}$$



For signal vector v , the demodulation PVPs are set as follows.

CRSD Per Vector Demodulation Parameters:

$$\begin{aligned} f_0(v): & 9600.0 \times 10^6 \text{ Hz} & \Delta f_{\text{IC}_0}(v): & -140.0 \times 10^6 \text{ Hz} \\ \Phi_0(v): & f_0(v) \cdot \text{trs}(v) & f_{\text{IC_Rate}}(v): & 2.800 \times 10^{12} \text{ Hz/sec} \end{aligned}$$

Frequency $\text{frcv}_1(v)$ and $\text{frcv}_2(v)$ are the minimum and maximum frequencies passed within the instantaneous bandwidth (BW_I) between time $\text{trs}(v)$ and $\text{trNSm1}(v)$. For DROR demodulation, the frequency parameters $\text{frcv}_1(v)$ and $\text{frcv}_2(v)$ are computed as follows.

$$\begin{aligned} \Delta f_{\text{IC_NSm1}}(v) &= \Delta f_{\text{IC}_0}(v) + f_{\text{IC_Rate}}(v) \cdot (\text{NS_CH} - 1) \cdot T_s = 280.0 \times 10^6 \text{ Hz} \\ \Delta f_{\text{IC_Min}}(v) &= \text{MIN} \{ \Delta f_{\text{IC}_0}(v), \Delta f_{\text{IC_NSm1}}(v) \} = -140.0 \times 10^6 \text{ Hz} \end{aligned}$$

$$\Delta f_IC_Max(v) = \text{MAX}\{ \Delta f_IC_0(v), \Delta f_IC_NSm1(v) \} = 140.0 \times 10^6 \text{ Hz}$$

CRSD Per Vector Receive Bandwidth Parameters:

$$\text{frcv_1}(v) = f_0(v) - \frac{1}{2} \bullet \text{BW_I} - \Delta f_IC_Min(v) = 9360.0 \times 10^6 \text{ Hz}$$

$$\text{frcv_2}(v) = f_0(v) + \frac{1}{2} \bullet \text{BW_I} + \Delta f_IC_Max(v) = 9840.0 \times 10^6 \text{ Hz}$$

$$\text{BW}(v) = \text{frcv_2}(v) - \text{frcv_1}(v) = 480.0 \times 10^6 \text{ Hz}$$

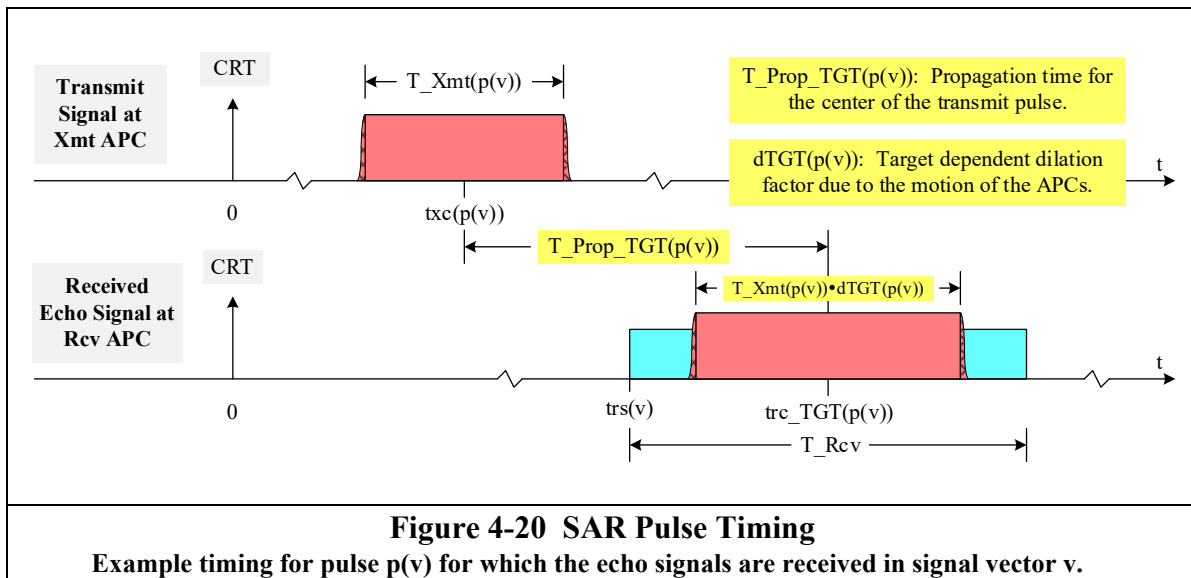
4.9.3 CRSD Sample Rate

The fast time sample rate, $fs(\text{Ch_ID})$, is provided for each data channel and is specified in the CRSD / Channel / Parameters branch of the XML instance. See Table 11-6. As shown in the examples above, the sample rate used is a product design choice. The sample rate requirements for CRSD signal arrays are defined in the Section 7.2.

4.10 SAR Signal Timing

For a SAR imaging collection, signal vector v contains the echo signals from the imaged scene for pulse $p(v)$. See Figure 4-1. Shown in Figure 4-20 is the transmit pulse timing for pulse $p(v)$ and the receive window timing for signal vector v . Shown in the figure is the propagation time for the echo from a point scatterer, denoted T_{GT} , located in the imaged scene. The center of the echo from scatterer T_{GT} arrives at the receive APC at time $trc_TGT(p(v))$. The duration of the received echo is dilated by the factor $dTGT(p(v))$ due to the motion of the APCs relative to the target position.

For the echo signal from point T_{GT} , the propagation time may be computed using the transmit APC position and velocity at time $txc(p(v))$ and the receive APC position and velocity at time $trs(v)$. Parameters that describe the state of troposphere and the state of the ionosphere (if applicable) may be included in XML metadata provided in the product. See Table 12-2. These parameters may be used to estimate the additional propagation time due to the atmosphere in the SAR image formation processing.



5 Scene Coordinates

The parameters that specify the geographic coordinates relevant to the CRSD product are described in this section. The parameters are provided in the / CRSDxx / SceneCoordinates branch of the XML instance in the product. See Table 12-3. The Scene Coordinates data structure includes a set of parameters that are included in all CRSD product types. It also includes additional sets of parameters that may only be included in a CRSD:SAR product.

The scene coordinates parameters that are included in all CRSD products use the following constructs to specify the geographic coordinates and the imaged area. The Scene Coordinates data structure was initially developed for SAR imaging products. Hence, the names of the parameters are very image-centric.

- (1) Image Area Reference Point (IARP): The IARP is a fixed point in the ECEF coordinate frame.
- (2) Reference Surface: The reference surface is a fixed surface relative to the ECEF coordinate frame that contains the IARP. The reference surface specifies a nominal representation of the terrain surface for the imaged scene. In a given product, the reference surface is specified to be one of two types: PLANAR or HAE.
- (3) Image Area Coordinate (IAC) System: The IAC system is used to specify the position of points relative to the IARP. The coordinates are defined to be (IAX, IAY, IAZ). The IARP is the origin of the IAC system. Coordinates IAX and IAY span the reference surface. Coordinate IAZ specifies the displacement off of the reference surface. A point on the reference surface has $IAZ = 0$.
- (4) Image Area: The image area is a region on the reference surface specified by a polygon and a bounding rectangle. For a CRSD:SAR product, the image area specifies a geographic area that bounds the area covered by the SAR images that may be formed from the product. For a CRSD:TX or CRSD:RCV product, the image area specifies a nominal geographic area relevant to the SAR illumination event or the receive-only collection.
- (5) Image Area Corner Points (IACPs): A set of four points located at the corners of the image area bounding rectangle. 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

The / CRSDxx / SceneCoordinates branch is similar to the / CPHD / SceneCoordinates branch of the XML instance contained in all CPHD V1.1.0 products. The parameter names and definitions are identical. The sets of required versus optional elements is similar. The guidance provided in Section 6 of the CPHD V1.1.0 D&I document is directly applicable to all CRSD products. Refer to Table 1-2.

5.1 Guidance for CRSD:SAR

Guidance for specifying the scene coordinates in a CRSD:SAR product is summarized below. All structures and elements that may be included in a CRSD:SAR XML instance may also be included in a CPHD V1.1.0 XML instance.

5.1.1 IARP & Reference Surface

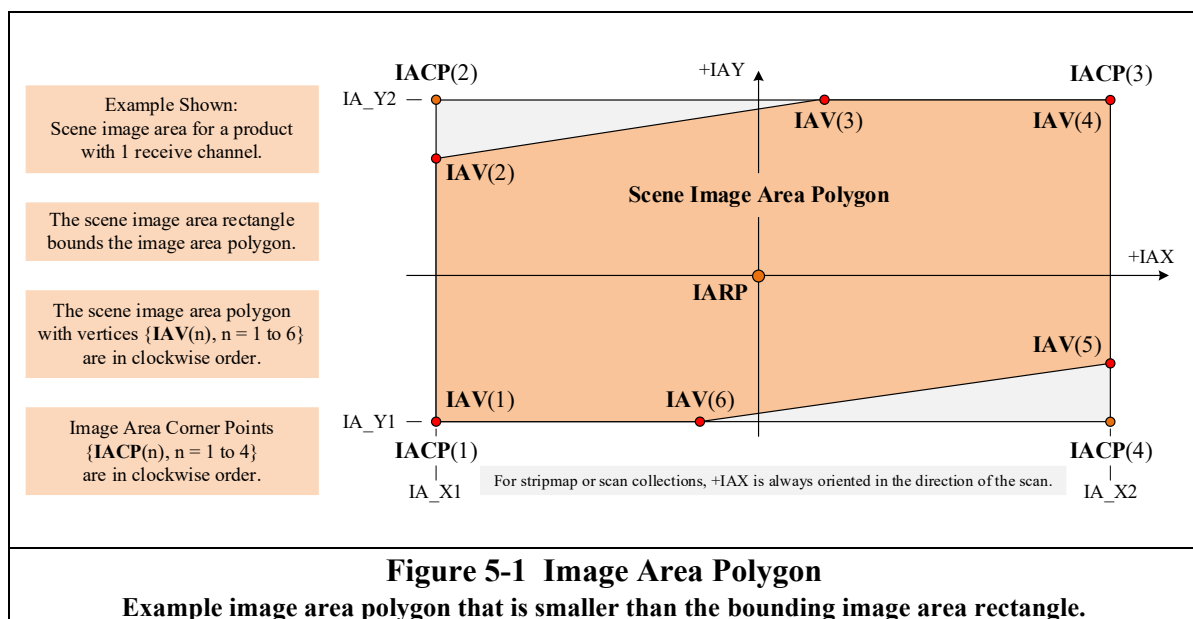
The selection of the IARP position and the type of reference surface is a product design choice. The guidance and restrictions specified for CPHD V1.1.0 products shall apply to all CRSD products. The definition of the Image Area Coordinate system for surface types PLANAR and HAE also applies to all CRSD products. Refer to Section 6.1 and Section 6.2 of the CPHD V1.1.0 D&I document.

5.1.2 Image Area

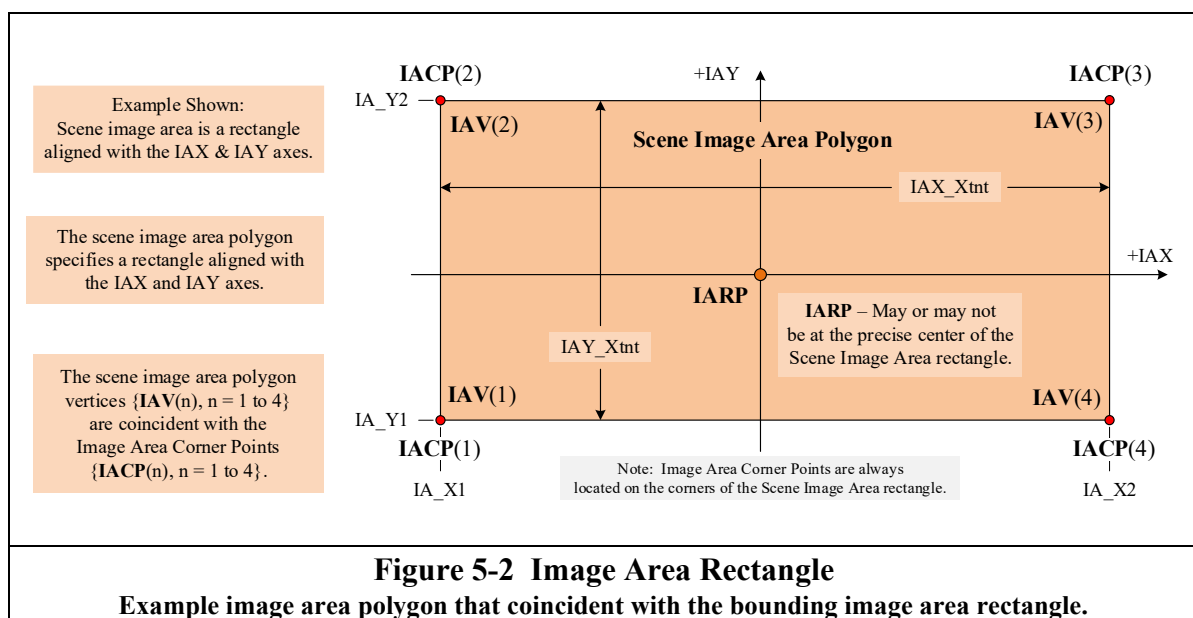
The image area is specified using the parameter set defined in the / CRSDsar / SceneCoordinates / ImageArea structure. The image area is a region on the reference surface specified using a polygon with vertices denoted {IAV(n), n = 1 to NumVertices}. A bounding rectangle is also specified that is aligned with the IAX and IAY axes. The rectangle is specified by the two corner points (IA_X1, IA_Y1) and (IA_X2, IA_Y2). The polygon is referred to as the scene image area polygon. The rectangle is referred to as the scene image area rectangle.

For each receive channel in a CRSD:SAR product, an image area is specified that is the area that may be covered by the SAR images formed from the channel signal array. See Section 7 and Table 12-6. The image area for the channel is also specified using a polygon and bounding rectangle. For a given channel, the polygon is referred to as the channel image area polygon. The rectangle is referred to as the channel image area rectangle. The scene image area parameters are determined from the set of channel-specific image areas specified in the product. The guidance for specifying the scene image area polygon and scene image area rectangle is provided in the examples that follow.

Shown in Figure 5-1 is an example scene image area for a product that contains a single receive channel. For such a product, the scene image area polygon specifies the same area as the channel image area polygon. For the example shown, the scene image area polygon contains 6 vertices. The polygon is closed by the line segment that connects the last vertex to the first vertex. The scene image area rectangle bounds the scene image area polygon. The polygon specifies a smaller area than the rectangle. The IACP positions are denoted {IACP(n), n = 1 to 4} and are located at the corners of the scene bounding rectangle. As shown in Figure 5-1 and specified in Table 12-3, image area polygon vertices and IACPs are listed in CW order when viewed from above the reference surface.

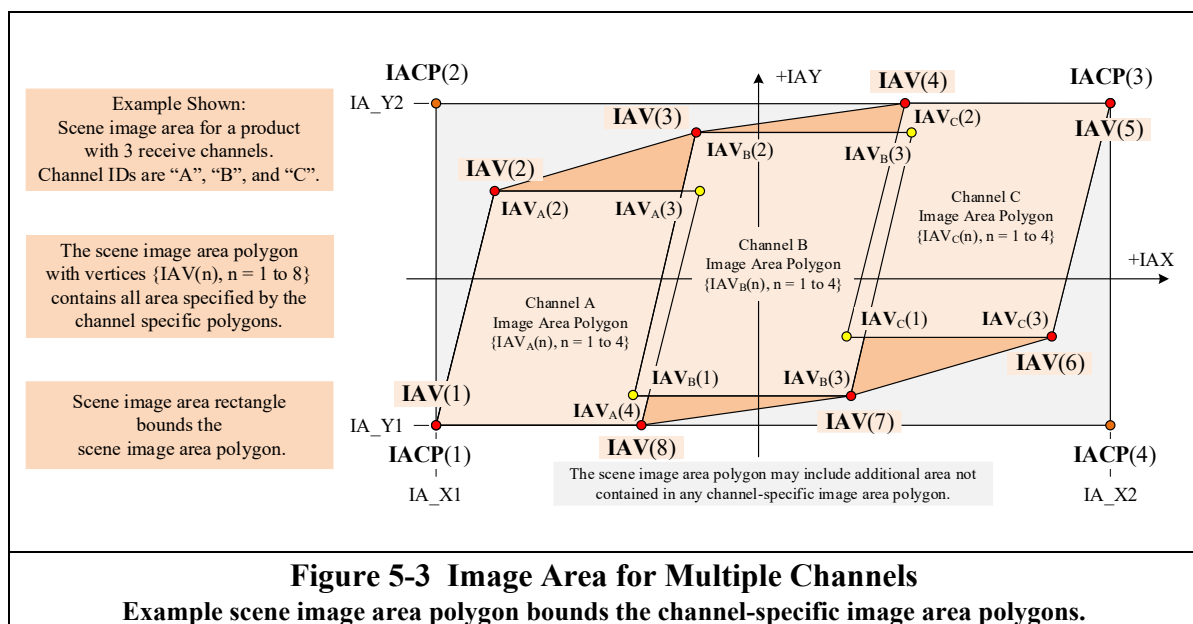


For many products, the image area for each channel is specified as a rectangular area that is aligned with the IAX and IAY axes. An example of such a product is shown in Figure 5-2. For such a product, the scene image area polygon may be specified by a set of four vertices that correspond to the corners of the scene image area rectangle. For the example shown in Figure 5-2, the set of polygon vertices $\{IAV(n)\}$ are coincident with the set of image area corner points $\{IACP(n)\}$.



For a product that contains 2 or more receive channels, the scene image area is determined from the set of channel image area polygons contained in the product. Shown in Figure 5-3 is an example scene image area for a product that contains 3 receive channels. The channel identifiers are “A”, “B”, and “C”. The channel image area polygon is shown for each of the

3 channels. For all CRSD:SAR products, the scene image area polygon is specified such that it includes all of the union of the areas specified by the channel image area polygons. The scene image area polygon may also include additional areas that allow for a more concise set of vertices. For the example shown in Figure 5-3, the scene image area polygon is specified by a set of 8 vertices $\{IAV(n), n = 1 \text{ to } 8\}$ and includes some additional area. For all products that include multiple receive channels, the method for selecting the scene image area polygon is a product design choice.



5.1.3 Image Grid

For any CRSD:SAR product, an optional set of parameters may be included that specifies a geo-referenced image pixel grid. The pixel grid is specified for the image products that may be formed from the receive channel signal arrays contained in the product. The image grid parameters are specified in the / CRSDsar / SceneCoordinates / ImageGrid branch. See Table 12-3. The image grid structure is similar to the image grid structure that may be included in a CPHD product. The guidance for specifying the image grid in a CPHD XML instance is included in Section 6.4 of the CPHD V1.1.0 D&I document. The same guidance and restrictions applies to the image grid structure in a CRSD product.

The CRSD:SAR image grid structure includes an optional segment list structure. A similar optional structure may be included in a CPHD product. The CRSD segment list structure includes only required parameters. This differs from the CPHD segment list structure that includes both required and optional parameters.

5.2 Guidance for CRSD:TX

For a CRSD:TX product, the scene coordinate parameters specify the geographic area that was illuminated by the transmit pulse sequences specified in the product. The image area is a nominal description of the illuminated scene. The following guidance is provided for selecting the IARP, the reference surface, and the image area parameters.

The IARP and reference surface may specify a specific scene surface that was used in the planning of the illumination event. The image area parameters may specify a specific area that was used in the event planning. For all products, the method used to determine the IARP, the reference surface, and image area parameters is a product design choice.

A general approach for determining the scene coordinate parameters for a CRSD:TX product is described below. The approach includes consideration for products that specify multiple transmit pulse sequences.

- (1) For the illumination event, a surface of constant HAE is selected that is at the nominal height of the terrain for the illuminated scene.
- (2) For each transmit pulse sequence, an area of illumination on the constant HAE surface is determined. The area of illumination is determined from the sensor position, the transmit antenna orientation, EB steering vector, and the transmit antenna beam shape pattern.
- (3) For each sequence, the center point of the illuminated area is selected and located on the constant HAE surface.
- (4) The IARP is located on the constant HAE surface at or near the geometric centroid for the set of center points computed for the pulse sequences.
- (5) The type of reference surface is selected. For a planar reference surface, the Earth Tangent Plane (ETP) at the IARP is selected. See Section 8.2 for a method of computing the ETP normal and unit vectors aligned with East and North at a given point.
- (6) The IAX and IAY unit vectors are computed. For an event with the antenna footprint nominally scanning a line on the reference surface, the +IAX axis is oriented in the along scan direction. For other types of events, aligning the IAX and IAY axes is a product design choice. Aligning the +IAX axis with East at the IARP is acceptable default design choice.
- (7) For each transmit pulse sequence, the area of illumination on the reference surface is computed and expressed in image area coordinates. The method for determining the area of illumination for a sequence is a product design choice.
- (8) The image area parameters are determined from the union of the illuminated areas for the sequences included in the product. The scene image area polygon is selected to bound the illuminated areas. The method for selecting the polygon is a product design choice.

5.3 Guidance for CRSD:RCV

For a CRSD:RCV product, the scene coordinate parameters specify the geographic area that was covered by the receive antenna footprint while collecting the receive signal arrays contained in the product. The image area provides a nominal description of the area from which signals were received with the highest receive sensitivity. The guidance for selecting the IARP, the reference surface, and the image area parameters is similar to the guidance provided for CRSD:TX products.

For all CRSD:RCV products, the method used to determine the IARP, the reference surface, and scene image area parameters is a product design choice. The IARP and reference surface may specify a specific scene surface that was used in the planning of the receive-only collection. The general approach described for a CRSD:TX product in Section 5.2 may also be applied for a CRSD:RCV product that includes one or more receive channels.

6 Transmit Sequence Parameters

All CRSD:SAR and CRSD:TX products contain transmit signal metadata. The transmit signal metadata specifies one or more transmit pulse sequences. Each transmit sequence has supporting metadata included in the XML instance, in a PPP array, and in two or more of the support arrays.

Each pulse sequence specifies a set of pulses transmitted with a fixed transmit configuration. For each sequence, all pulses in the sequence are transmitted using a single Antenna Phase Center (APC) and using a single antenna pattern. The transmit polarization relative to the Antenna Coordinate Frame is also fixed as it is specified as part of the antenna pattern. For products that specify two or more transmit sequences, any pair of sequences may specify the same configuration or two unique configurations.

6.1 Tx Pulse Sequences

A given CRSD:SAR or CRSD:TX product may specify one or more transmit pulse sequences. Each pulse sequence in a product is referenced by a text-based identifier. The transmit sequence identifier, denoted Tx_ID, is a string that uniquely identifies the sequence within the product. For each transmit sequence, a PPP array is included in the PPP block. The sequence specific parameters in the XML structure are repeated for each sequence. Refer to Table 12-4 and Table 12-5.

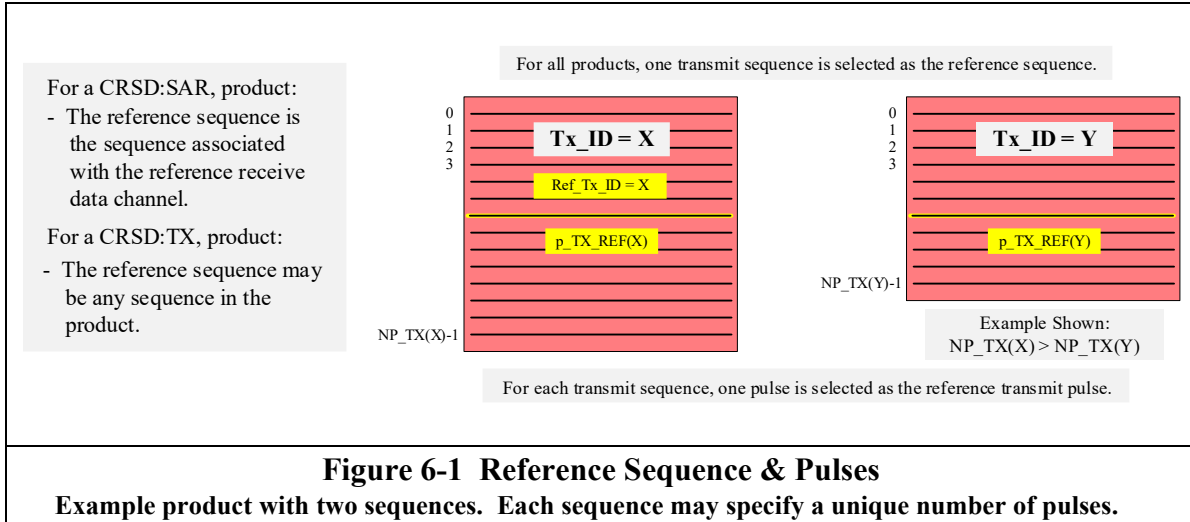
6.1.1 Reference Tx Sequence

For all products, one pulse sequence is specified as the reference sequence. The reference sequence ID is denoted Ref_Tx_ID. For a CRSD:SAR product, the reference sequence is the sequence that provided the SAR illumination for the reference receive channel. See Section 7.1. For a CRSD:TX product, the reference sequence may be any transmit sequence specified in the product. The choice of the reference sequence only impacts the reference geometry parameters that are included in the XML instance. See Section 8. Shown in Figure 6-1 are the PPP arrays for a product that specifies two transmit sequences. For the example shown, the Tx_IDs are X and Y. Sequence X is the reference sequence. Each transmit sequence may specify a unique number of transmit pulses.

6.1.2 Reference Pulse

For each pulse sequence, one pulse is selected as the reference pulse. For a given sequence, the reference pulse index is denoted p_TX_REF. The reference pulse may be any pulse in the sequence. A recommended choice for the reference pulse is the center pulse in the sequence. For a pulse sequence that contains NP_TX pulses, the index of the center pulse, denoted p_TX_CTR, is computed as shown.

$$p_TX_CTR = \text{FLOOR} \{ \frac{1}{2} \cdot NP_TX \}$$



6.2 Transmit Waveform Types

For all products that contain transmit signal metadata, the method used for specifying the transmit pulse waveforms is dependent upon the transmit waveform type. The transmit waveform type is specified by element TxWFTType. For a given product, all pulse waveforms for all transmit pulse sequences are specified using the same waveform type. The waveform type is specified in / CRSDxx / TxSequence branch of the XML instance. There are three defined waveform types.

- (1) TxWFTType = “LFM”: The transmit pulse modulation is specified as an ideal LFM pulse with constant amplitude.
- (2) TxWFTType = “XM”: The transmit pulse modulation is specified using an XM array. The modulation for each pulse is specified by a sampled XM function.
- (3) TxWFTType = “LFM w XM”: The transmit pulse modulation is specified using a combination of an ideal LFM pulse combined with a sampled XM function.

The method for computing transmit pulse waveforms is specified in the Section 4.5 and Section 4.6. The computations that are dependent upon TxWFTType are specified in Section 4.6.2.

6.3 Pulse Sequence Parameters

For each transmit pulse sequence, supporting metadata is specified in the XML instance and in a PPP array. The XML metadata is specified in / CRSDxx / Data / Transmit / TxSequence branch and in the / CRSDxx / TxSequence / Parameters branch. See Table 12-4 and Table 12-5. For a given product, the XML instance specifies the parameters included in the PPP set. See Section 2.5 and Table 12-10.

For each pulse sequence, a subset of the sequence specific XML parameters are computed using values from the PPP array. The methods for computing those parameters are specified in the following sub-sections. The parameters that may be included in a PPP set are defined in Table 4-2.

6.3.1 Waveform Support Arrays

Each pulse sequence references an Fx Response array that is used in computing the transmit pulse waveforms. For waveform types “XM” and “LFM w XM”, each pulse sequence references an XM array that is also used in computing the transmit pulse waveforms. The arrays are referenced by their text-based support array identifier (SA_ID). See Section 2.4.

FxResponse_ID	XML: / CRSDxx / TxSequence / Parameters / FxResponseId
XM_ID	XML: / CRSDxx / TxSequence / Parameters / XMId

The Fx Response arrays are described in Section 6.5. The XM arrays are described in Section 6.6.

6.3.2 Frequency & Timeline Parameters

A set of frequency and timeline parameters shall be computed from the required parameters that are included in every PPP set. The computed parameters summarize the pulse sequence frequency content and timing. The inputs used and the methods for computing the parameters are as follows.

- (1) Use the sets of frequencies {fx_1(p)} and {fx_2(p)} to compute the following parameter.

FxBWFixed	Parameters FxBWFixed = “true” indicates all pulses contain the same bandwidth. Parameter is “true” if for all pulses frequency fx_1(p) is constant and frequency fx_2(p) is constant. Parameter FxBWFixed = “false” otherwise.
-----------	--

- (2) Use the sets of frequencies {fx_1(p)} and {fx_2(p)} to compute the center frequency Fx_C and bandwidth Fx_BW. Frequency Fx_C and bandwidth Fx_BW are in Hz

$fx_1_Min = MIN\{fx_1(p)\}$	$fx_2_Max = MAX\{fx_2(p)\}$
$Fx_C = \frac{1}{2} \cdot (fx_2_Max + fx_1_Min)$	$Fx_BW = fx_2_Max - fx_1_Min$

- (3) Use the set of pulse lengths $\{T_Xmt(p)\}$ to select the pulse lengths T_Xmt_Min and T_Xmt_Max . Pulse lengths T_Xmt_Min and T_Xmt_Max are in seconds.

$$T_Xmt_Min = \text{MIN}\{T_Xmt(p)\} \quad T_Xmt_Max = \text{MAX}\{T_Xmt(p)\}$$

- (4) Use the set of pulse center times $\{txc(p) = txc_INT(p) + txc_FRAC(p)\}$ to assign the following transmit center times. Times txc_1 and txc_2 are in seconds relative to the CRT.

$$txc_1 = txc(0) \quad txc_2 = txc(NP_TX - 1)$$

The parameters of the / CRSDxx / TxSequence / Parameters branch of the XML for the sequence are assigned as shown. The units of the XML parameters are also listed for convenience.

FxBWFixed	➔	XML: FxBWFixed	Boolean
Fx_C	➔	XML: FxC	Hz
Fx_BW	➔	XML: FxBW	Hz
T_Xmt_Min	➔	XML: TXmtMin	sec
T_Xmt_Max	➔	XML: TXmtMax	sec
txc_1	➔	XML: TxTime1	sec
txc_2	➔	XML: TxTime2	sec

6.3.3 Transmit Reference Point

For each transmit pulse sequence, a Transmit Reference Point (TRP) shall be specified that is a fixed point located on the reference surface specified for the product. See Section 5. The TRP position in ECEF coordinates is denoted **TRP**. The TRP position in image area coordinates is denoted **TRP_IAC**. The method for converting between ECEF coordinates and Image Area coordinates is specified in Section 6.2 of the CPHD V1.1.0 D&I document.

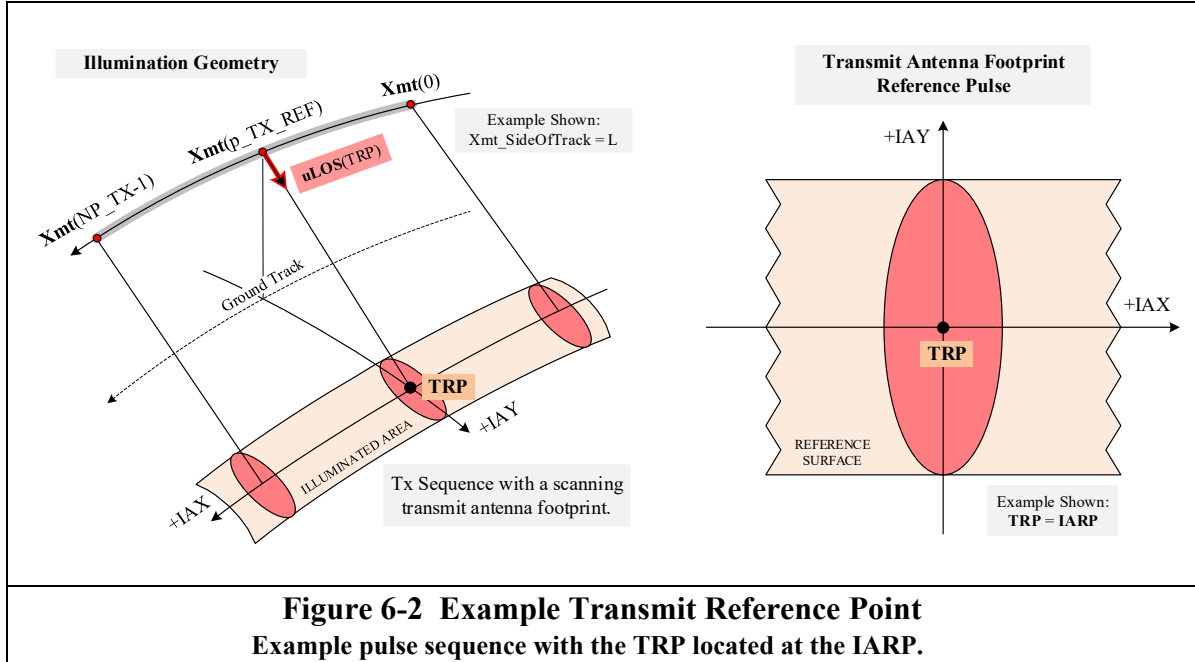
$$\mathbf{TRP} = \begin{bmatrix} \text{TRP_X} \\ \text{TRP_Y} \\ \text{TRP_Z} \end{bmatrix} \quad \mathbf{TRP_IAC} = \begin{bmatrix} \text{TRP_IAX} \\ \text{TRP_IAY} \\ 0 \end{bmatrix}$$

Note: For a point located on the reference surface, the IAZ component is equal to 0.

For each pulse sequence, the TRP may be used to get a general sense of the illumination geometry for the pulse sequence. For all products, the method used for determining the TRP is a product design choice. A recommended choice is to locate the TRP near the center of transmit antenna beam shape footprint for the reference pulse.

Shown in Figure 6-2 is an example illumination geometry for a pulse sequence. The geometry shown is similar to a SAR stripmap mode imaging geometry. The transmit APC position is shown for the first pulse ($p = 0$), the reference pulse ($p = p_TX_REF$), and the last pulse ($p = NP_TX - 1$) of the sequence. For the example shown, the TRP is located at the

center of the transmit antenna beam shape footprint for the reference pulse. For the reference pulse, the Line of Sight (LOS) unit pointing vector, denote $\mathbf{u}_{\text{LOS}}(\text{TRP})$, is aligned with the transmit antenna electrical boresight steering vector. See Section 9.2. For the example shown, the TRP is coincidentally also located at the IARP selected for the product. The +IAX axis is nominally aligned with the along scan direction of the beam shape footprint.



6.3.4 Transmit Polarization

For each pulse sequence, a set of polarization parameters are provided. The polarization parameters describe the orientation of the E-field for the of transmit signals. The parameters include a description of the transmit polarization orientation for the reference pulse. Also provided is a polarization identifier that provides a general description of the polarization orientation for the sequence.

The polarization orientation for the reference pulse incident at the TRP is specified. The orientation is specified relative to the horizontal (H) and vertical (V) directions computed using the LOS from the transmit APC to the TRP. The polarization orientation is specified using a set of four parameters denoted $\{\text{AmpH}, \text{AmpV}, \Phi_H, \Phi_V\}$. The methods for computing the polarization orientation parameters are described in Section 9.4. The inputs to the method include the following.

Parameters for the reference pulse. See Table 4.2.

$\mathbf{Xmt}_{\text{REF}} = \mathbf{Xmt}(\text{p_TX_REF}) =$ Transmit APC position.

$\mathbf{Xmt_uACX}_{\text{REF}} = \mathbf{Xmt_uACX}(\text{p_TX_REF}) =$ Tx ACF X-axis unit vector.

$\mathbf{Xmt_uACY}_{\text{REF}} = \mathbf{Xmt_uACY}(\text{p_TX_REF}) =$ Tx ACF Y-axis unit vector.

Transmit APAT Polarization Parameters – For the APAT specified for the sequence.

$\{\text{AmpX}, \text{AmpY}, \Phi_X, \Phi_Y\} = \text{APAT polarization reference parameters.}$

The TRP polarization parameter set $\{\text{AmpH}, \text{AmpV}, \Phi_H, \Phi_V\}$ shall be computed using the function defined in Section 9.4.4 or an equivalent method. Input parameter $\text{XR} = +1$ to yield the polarization orientation parameters for the transmit pulse.

$$\left\{ \begin{array}{l} \text{Xmt}_{\text{REF}} \\ \text{Xmt_uACX}_{\text{REF}} \\ \text{Xmt_uACY}_{\text{REF}} \end{array} \right\} + \{\text{TRP}\} + \{\text{XR}\} + \left\{ \begin{array}{l} \text{AmpX} \quad \Phi_X \\ \text{AmpY} \quad \Phi_Y \end{array} \right\} \rightarrow \boxed{\text{Compute H,V Pol Parameters}} \rightarrow \left\{ \begin{array}{l} \text{uHOR} \quad \text{AmpH} \quad \Phi_H \\ \text{uVERT} \quad \text{AmpV} \quad \Phi_V \end{array} \right\}$$

The polarization identifier, denoted Pol_ID , is a text-based parameter that provides a general description of the polarization orientation for the pulse sequence. The allowed values for the Pol_ID are listed in Table 9-1. For all products, the criteria used for selecting the Pol_ID is a product design choice. The selection may use the polarization orientation computed for a single pulse and a single point in the scene. The selection may also consider a set of polarization orientations computed for multiple pulses and/or multiple points in the scene.

The parameters of the / CRSDxx / TxSequence / Parameters / TxPolarization branch of the XML for the sequence are assigned as shown. The units of the XML parameters are also listed for convenience.

Pol_ID	→	XML: PolarizationID	ENU
AmpH	→	XML: AmpH	unitless
AmpV	→	XML: AmpV	unitless
Φ_H	→	XML: PhaseH	cycles
Φ_V	→	XML: PhaseV	cycles

6.4 Transmit Power Parameters

For each pulse sequence, parameters are provided that may be used to compute the transmit pulse output power. The transmit pulse power, expressed as a radiant intensity (RI), may be computed for any selected pulse. The computed RI value includes the effects of the transmit antenna beam shape pattern.

6.4.1 Base Pulse Power

For each pulse p , the PPP set includes parameters that are used to compute the base pulse waveform, denoted $s_{XMT}(p, t)$. Also provided is the base pulse mean radiant intensity, denoted $P_RI_0_{XMT}(p)$, with units of dBW/sr. The base pulse waveform is the output pulse waveform for a pointing vector for which the transmit antenna beam shape pattern has constant gain $G_{XBS}(f) = 0$ dB and phase $\Phi_{XBS}(f) = 0$. Refer to Section 4.4 for a description of the base pulse waveform. For pulse p , the parameters that specify the base pulse waveform include the following. Refer to Table 4.2.

$T_Xmt(p)$ = Pulse length (i.e., the pulse duration) (sec).

$txc(p)$ = Time the center of the pulse is output at the transmit APC (sec).

$fx_1(p)$ = Minimum transmit frequency value (Hz).

$fx_2(p)$ = Maximum transmit frequency value (Hz).

$P_RI_0_{XMT}(p)$ = Mean base pulse radiant intensity (dBW/sr).

The base pulse waveform is specified by amplitude function $A_{XMT}(p, t)$, phase function $\Phi_{XMT}(p, t)$, and the pulse center time $txc(p)$. Amplitude function $A_{XMT}(p, t)$ has a duration of $T_Xmt(p)$ seconds centered on $t = 0$. The base pulse amplitude function is defined to have mean squared value equal to 1.

$$MS_{XMT}(p) = \frac{1}{T_Xmt(p)} \cdot \int A_{XMT}(p, t)^2 \cdot dt = 1$$

For the base pulse waveform, the instantaneous radiant intensity is proportional to the square of the base pulse amplitude. Using the scale factor $RI_SF(p)$, the base pulse instantaneous radiant intensity, $P_IRI_{XMT}(p, t)$, may be computed as follows. Scale factor $RI_SF(p)$ and instantaneous radiant intensity $P_IRI_{XMT}(p, t)$ have units of W/sr.

$$P_IRI_{XMT}(p, t) = RI_SF(p) \cdot A_{XMT}(p, t)^2$$

The mean radiant intensity $P_RI_0_{XMT}(p)$ is defined to be the average of the instantaneous radiant intensity for the base pulse waveform. The value is converted from W/sr to dBW/sr.

$$P_RI_0_{XMT}(p) = 10 \cdot \log_{10} \left\{ \frac{1}{T_Xmt(p)} \cdot \int P_IRI_{XMT}(p, t) \cdot dt \right\} = 10 \cdot \log_{10} \{ RI_SF(p) \}$$

6.4.2 Pulse Power w/ Antenna Beam Shape

For a given pulse p , the transmit antenna beam shape pattern may be computed for a selected pointing direction. The selected pointing direction is specified by a unit pointing vector denoted $\mathbf{uAP}$. The base pulse waveform and the beam shape pattern may be used to compute output pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$. Pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$ is the output pulse waveform transmitted in selected pointing direction. The beam shape pattern is computed using the APAT for the pulse sequence as well as a subset of the PPP set. The APAT for the sequence is specified by parameter TxAPAT_ID. For pulse p , the parameters used are the following. Refer to Section 4.6 and Section 9.3.

APC Position & ACF Vectors:

$\mathbf{Xmt}(p)$ = Transmit APC position at time $txc(p)$.

$\mathbf{Xmt_uACX}(p)$ = Tx ACF X-axis unit vector at time $txc(p)$.

$\mathbf{Xmt_uACY}(p)$ = Tx ACF Y-axis unit vector at time $txc(p)$.

$\mathbf{Xmt_EB0}(p)$ = Tx antenna EB steering vector at frequency $f = fa_0$.

Pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$ is specified by amplitude function $A_{XAP}(p, \mathbf{uAP}, t)$, phase function $\Phi_{XAP}(p, \mathbf{uAP}, t)$, and the pulse center time $txc(p)$. Amplitude function $A_{XAP}(p, \mathbf{uAP}, t)$ has duration of $T_Xmt(p)$ seconds centered on $t = 0$. The amplitude function has mean squared value $MS_{XAP}(p, \mathbf{uAP})$.

$$MS_{XAP}(p, \mathbf{uAP}) = \frac{1}{T_Xmt(p)} \cdot \int A_{XAP}(p, \mathbf{uAP}, t)^2 \cdot dt$$

For pulse p and selected unit antenna pointing vector $\mathbf{uAP}$, the instantaneous radiant intensity is proportional to square of the pulse amplitude function. The instantaneous radiant intensity $P_IRI_{XMT}(p, \mathbf{uAP}, t)$, with units of W/sr, is related to the pulse amplitude squared by the scale factor $RI_SF(p)$ defined for the base pulse waveform.

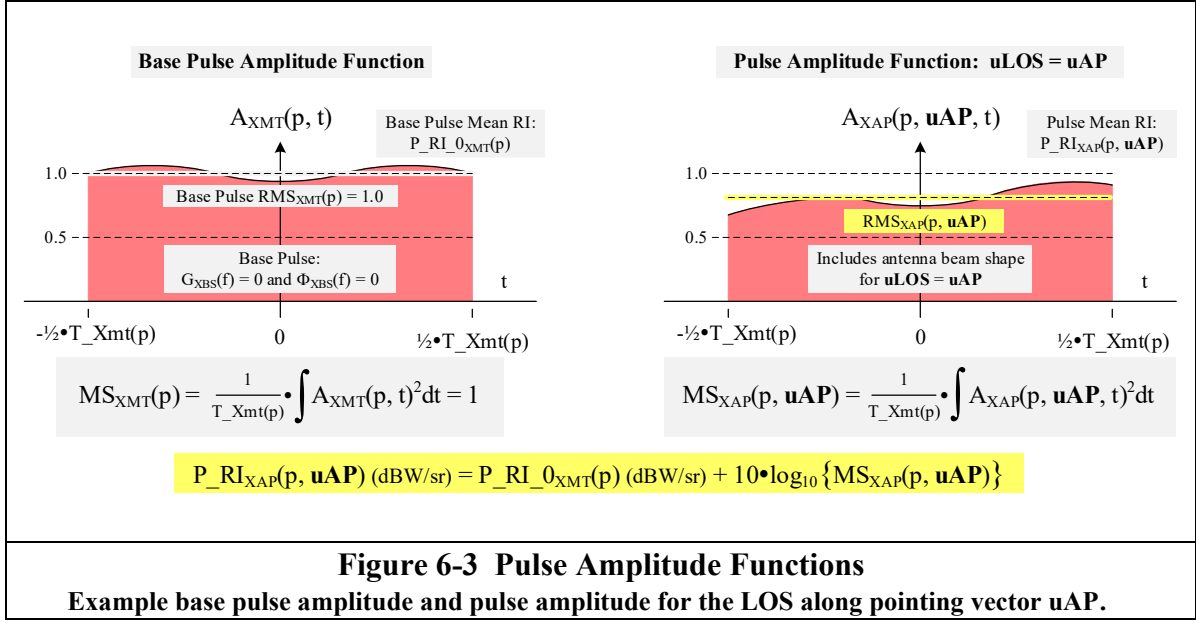
$$P_IRI_{XAP}(p, \mathbf{uAP}, t) = RI_SF(p) \cdot A_{XAP}(p, \mathbf{uAP}, t)^2$$

The mean radiant intensity $P_RI_{XAP}(p, \mathbf{uAP})$ is defined to be the average of the instantaneous radiant intensity for the pulse waveform $s_{XAP}(p, \mathbf{uAP}, t)$. The value is converted from W/sr to dBW/sr.

$$P_RI_{XAP}(p, \mathbf{uAP}) = 10 \cdot \log_{10} \left\{ \frac{1}{T_Xmt(p)} \cdot \int P_IRI_{XAP}(p, \mathbf{uAP}, t) \cdot dt \right\}$$

For pulse p and selected unit antenna pointing vector $\mathbf{uAP}$, mean radiant intensity $P_RI_{XMT}(p, \mathbf{uAP})$ may be computed as follows. See Figure 6-3.

$$P_RI_{XAP}(p, \mathbf{uAP}) = P_RI_0_{XMT}(p) + 10 \cdot \log_{10} \{ MS_{XAP}(p, \mathbf{uAP}) \}$$



For a given pulse p and pointing vector $\mathbf{uAP}$, the mean radiant intensity $P_RI_{XAP}(p, \mathbf{uAP})$ may be estimated using the transmit antenna beam shape gain at center frequency $fx_c(p)$, $G_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, fx_c(p))$. Center frequency $fx_c(p)$ is computed as shown and is in Hz. Refer to Section 9.3.

$$fx_c(p) = \frac{1}{2} \cdot (fx_1(p) + fx_2(p))$$

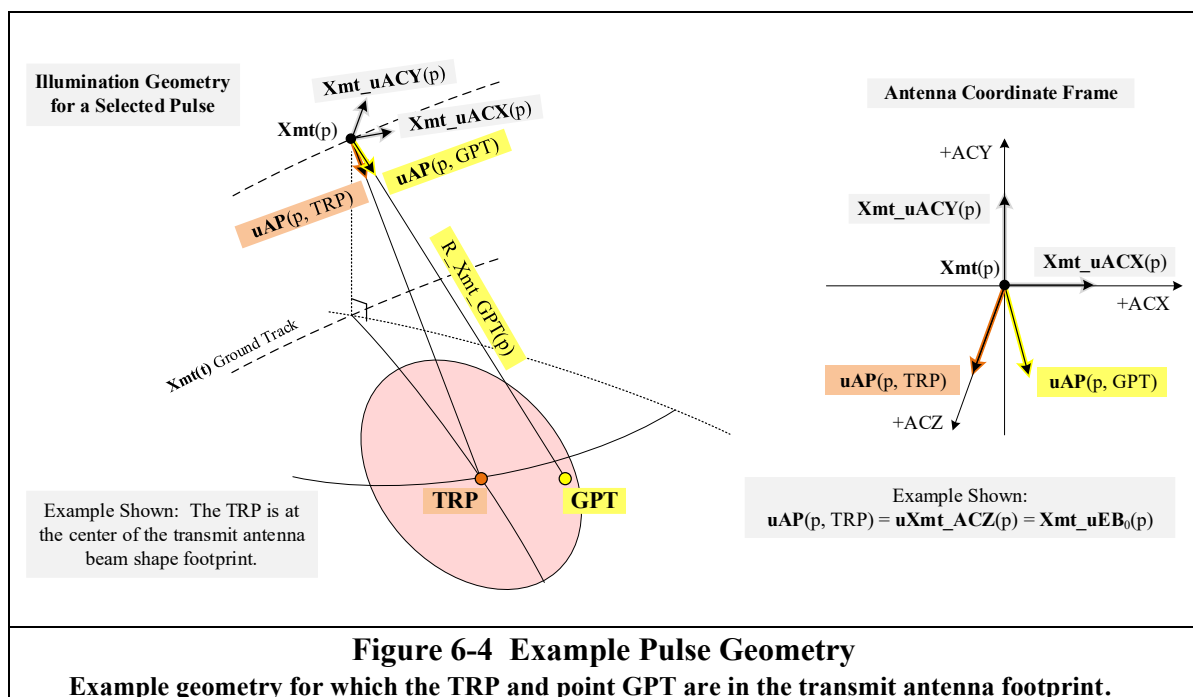
$$P_RI_{XAP}(p, \mathbf{uAP}) \approx P_RI_{0XMT}(p) + G_{XBS}(\mathbf{EB}_0(p), \mathbf{AP}, fx_c(p)) \text{ (dB)}$$

6.4.3 Incident Power at a Scene Point

For scene points illuminated by the transmit antenna mainlobe footprint, the incident power may be computed. Let point GPT be a fixed point located on the reference surface. For a selected pulse p , point GPT is illuminated by the mainlobe of the transmit antenna beam shape pattern. Shown in Figure 6-4 is an example pulse geometry where both the TRP and point GPT are illuminated by the transmit antenna beam shape pattern. The range from the transmit APC at time $txc(p)$ to point GPT is denoted $R_Xmt_GPT(p)$. The unit pointing vector from the transmit APC along the LOS to point GPT is denoted $\mathbf{uAP}(p, \text{GPT})$.

For pulse p , the mean incident power at point GPT is denoted $P_{INCD}(p, \text{GPT})$. The mean incident power is expressed in dBW/m^2 and is computed as shown. The one-way atmospheric loss L_Atm_XNOM is a nominal value provided for each pulse sequence. See Table 12-5. The value is a representative value for the pulse sequence. For precise computations, an application that inputs CRSD products may implement a more precise model for computing atmospheric loss on transmit.

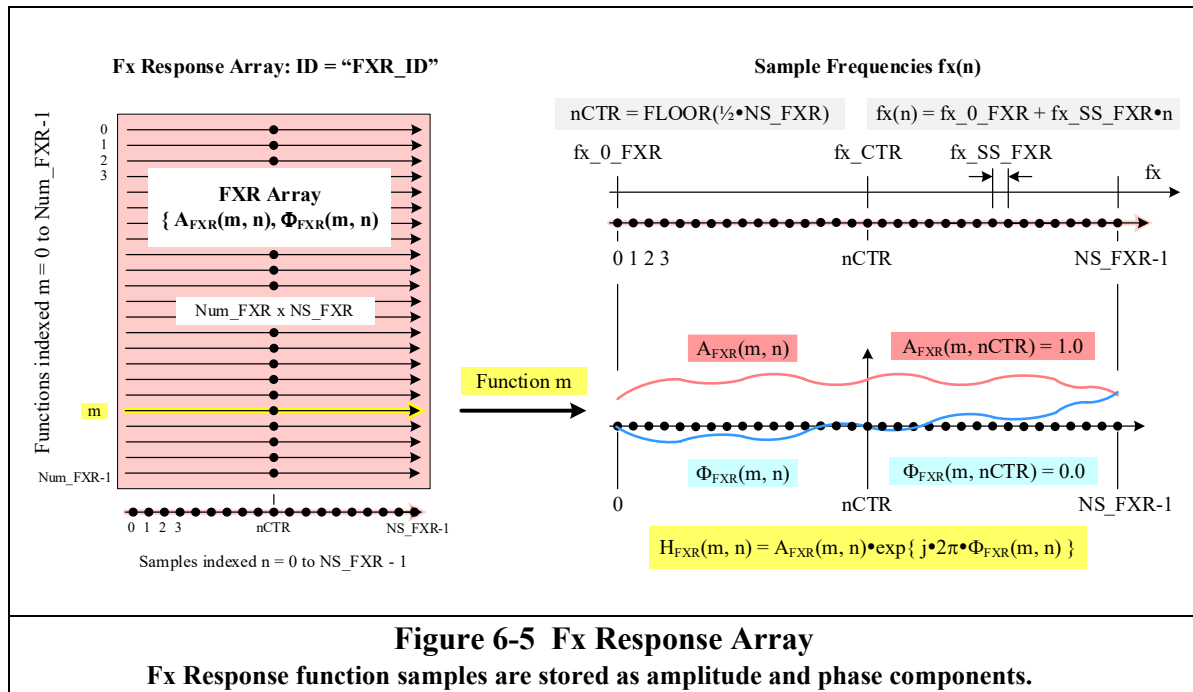
$$P_{INCD}(p, \text{GPT}) = P_RI_{XAP}(p, \mathbf{uAP}(p, \text{GPT})) \\
- 20 \cdot \log_{10} \{R_Xmt_GPT(p)\} - L_Atm_XNOM$$



6.5 Fx Response Arrays

All products that contain transmit signal metadata also include one or more Fx Response arrays. See Table 12-9. Each row of the array contains one sampled Fx Response function. A given array may contain one or more Fx Response functions. An Fx Response function specifies the effective transmit system frequency response for the transmit signal generation and power system for a specified band of frequencies. The response function may also include a portion of the transmit antenna response that is not included in the antenna beam shape pattern. The method for computing transmit pulse waveforms is specified in Section 4.5 and Section 4.6. It includes how a selected Fx Response function is used in computing the transmit pulse waveform.

Each transmit pulse sequence references one Fx Response array. All Fx Responses used by the pulse sequence are included in the referenced array. A given Fx Response function may be used to compute the transmit waveform for zero or more pulses. Shown in Figure 6-5 is an example Fx Response array. The size of the array is Num_FXR rows/functions by NS_FXR elements/samples. For a given support array, the support array ID is used to link the array size information with the other array metadata. See Table 12-4 and Table 12-9. The rows/functions are indexed by $m = 0, 1, 2, \dots, \text{Num_FXR} - 1$. The elements/samples of each function are indexed $n = 0, 1, 2, \dots, \text{NS_FXR} - 1$.



For a product that specifies two or more pulse sequences, the number of Fx Response arrays included and how they are organized is a product design choice. An approach that provides one Fx Response array for all transmit pulse sequences is an acceptable design choice. For

products that specify multiple transmit pulse sequences, an acceptable choice may be to provide one Fx Response array for each transmit pulse sequence.

All Fx Response arrays shall be created and stored per the following the rules and guidance. Refer to Figure 6-5. The array elements/samples are denoted $\text{FXR}(m, n)$.

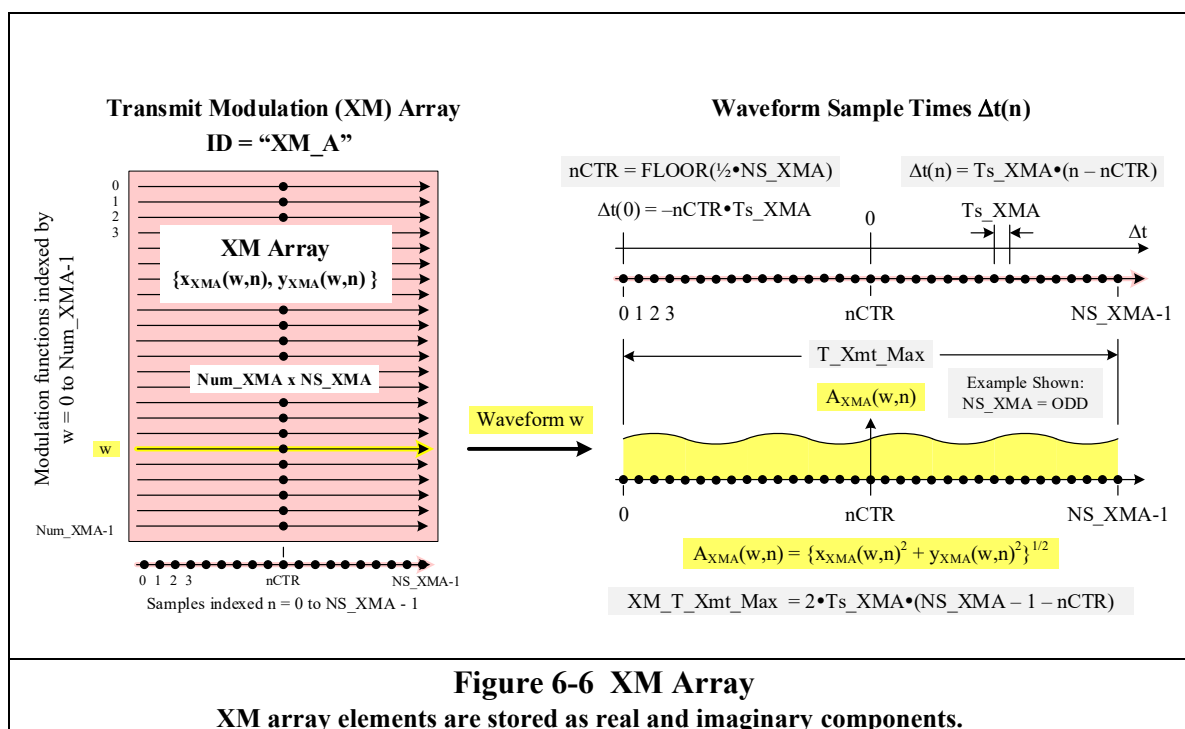
- (1) Parameters fx_0_FXR and fx_SS_FXR specify the frequency values for the NS_FXR samples. For sample n , the response is for frequency $\text{fx}(n) = \text{fx_0_FXR} + \text{fx_SS_FXR} \cdot n$. All frequency parameters are in Hz.
- (2) The center sample index is $n_{\text{CTR}} = \text{FLOOR}(\frac{1}{2} \cdot \text{NS_FXR})$ and corresponds to the frequency value $\text{fx_CTR} = \text{fx_0_FXR} + \text{fx_SS_FXR} \cdot n_{\text{CTR}}$.
- (3) Array element $\text{FXR}(m, n)$ contains two parameters: amplitude $A_{\text{FXR}}(m, n)$ and phase $\Phi_{\text{FXR}}(m, n)$. Each parameter is stored using the F4 binary format. The phase value is in cycles.
- (4) For each row/response function, amplitude $A_{\text{FXR}}(m, n_{\text{CTR}}) = 1.0$ and phase $\Phi_{\text{FXR}}(m, n_{\text{CTR}}) = 0$. For each row/response function, the phase values are samples of a smoothly varying function that is “unwrapped”.
- (5) The minimum number of samples per response function is $\text{NS_FXR_Min} = 3$.
- (6) The frequency band supported for each function is from $\text{fx_0_FXR} \leq \text{fx} \leq \text{fx_NSm1_FXR}$, where:
$$\text{fx_NSm1_FXR} = \text{fx_0_FXR} + \text{fx_SS_FXR} \cdot (\text{NS_FXR} - 1)$$
- (7) Sample spacing fx_SS_FXR is selected to meet the following constraint. For any row/response function, the response at an arbitrary frequency fx may be computed using linear interpolation between a pair of adjacent elements. The amplitude value may be interpolated from the amplitude samples and the phase value may be interpolated using the phase samples.

For a transmit sensor that has a “flat” response across the transmit band, the following guidance is provided. An Fx Response array containing a single “flat” response function may be provided. The array identifier text string may contain the character sequence “FLAT”. The FLAT array may contain $\text{Num_FXR} = 1$ response functions and $\text{NS_FXR} \geq \text{NS_FXR_Min}$ samples. All samples have amplitude $A_{\text{FXR}}(0, n) = 1.0$ and phase $\Phi_{\text{FXR}}(0, n) = 0.0$. Each pulse sequence in the product may reference the FLAT response array. For a transmit sensor for which the frequency response has not been characterized, a FLAT response array may be included and referenced by all pulse sequences specified in the product.

6.6 XM Arrays

All products with TxWFTType = “XM” or “LFM w XM” include one or more XM arrays. See Table 12-9. Each row of the array contains one sampled XM function. A given array may contain one or more XM functions. An XM function specifies all or part of the transmit modulation a pulse. The abbreviation XM is taken from “Xmt Modulation”. For TxWFTType = “XM”, the XM function specifies the modulation for the pulse. For TxWFTType = “LFM w XM”, the XM function is combined with the LFM rate parameter to specify the modulation for the pulse. The method for computing transmit pulse waveforms is specified in Section 4.5 and Section 4.6. It includes how a selected XM function is used in computing the transmit pulse waveform.

Each transmit pulse sequence references one XM array. All XM functions used in the pulse sequence are included in the referenced XM array. A given XM function may be used to compute the transmit modulation for zero or more pulses. Shown in Figure 6-6 is an example XM array. The size of the array is Num_XMA rows/functions by NS_XMA elements/samples. For a given support array, the support array ID is used to link the array size information with the other array metadata. See Table 12-4 and Table 12-9. The rows/functions are indexed by $w = 0, 1, 2, \dots, \text{Num_XMA} - 1$. The samples of each function are indexed $n = 0, 1, 2, \dots, \text{NS_XMA} - 1$.



For any transmit pulse sequence, the pulse length, denoted $T_{Xmt}(p)$, may vary from pulse to pulse. For a given pulse sequence, the minimum and maximum pulse lengths are specified in the XML parameter set provided for each pulse sequence. See Table 12-6. Each XM

array has a minimum and maximum pulse length that it supports. Each XM array shall support the pulse lengths for all pulses of all pulse sequences that reference the XM array.

For a product that specifies two or more pulse sequences, the number of XM arrays included and how they are organized is a product design choice. An approach that provides one XM array for all transmit pulse sequences is an acceptable design choice. An approach that provides one XM array for each pulse sequence is often an acceptable design choice.

All XM arrays shall be created and stored per the following the rules and guidance. Refer to Figure 6-6 and Figure 6-7. The array elements are denoted $XMA(w, n)$.

- (1) The center sample index is $nCTR = \text{FLOOR}(\frac{1}{2} \cdot NS_XMA)$. The sample coordinate is time relative to the center time of the pulse, denoted $\Delta t(n)$. The sample spacing is Ts_XMA . For sample n : $\Delta t(n) = Ts_XMA \cdot (n - nCTR)$.
- (2) Array element $XMA(w, n)$ contains two parameters: real component $x_{XMA}(m, n)$ and imaginary component $y_{XMA}(m, n)$. The two components form a complex-valued sample $s_{XMA}(m, n) = x_{XMA}(m, n) + j \cdot y_{XMA}(m, n)$.
- (3) Each element is stored in the binary format specified by the ElementFormat parameter for the array. The binary format used for a given array is a design choice based on the precision needed to represent the modulation functions.
- (4) Each XM function may be scaled separately to optimize the amplitude values prior to converting to the selected binary format. For each XM function, the signal is specified in the variation in sample values. The amplitude scaling of a given XM function sample values is independent of the transmit power.
- (5) The parameter Max_XMBW specifies the maximum spectral bandwidth (Hz) that may be supported by any XM function in the array. For any XM function, the spectral content is contained within the band $|f| \leq \frac{1}{2} \cdot \text{Max_XMBW}$.
- (6) The sample spacing Ts_XMA and the maximum bandwidth Max_XMBW satisfy the following relationship where $XM_OSR = 1.10$.

$$XM_OSR \cdot \text{Max_XMBW} \leq 1/Ts_XMA$$

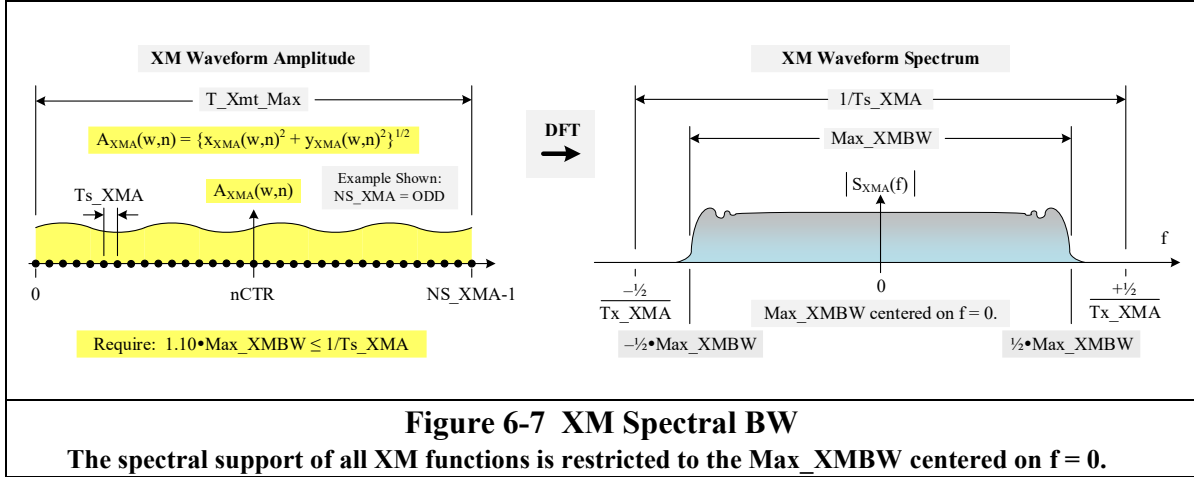
- (7) Each XM function is specified for a specific transmit pulse length, denoted $T_Xmt(w)$. The waveform function is specified by an odd number of samples centered on the sample $nCTR$. The function is specified in samples $n = n1(w)$ through $n2(w)$. Indices $n1(w)$ and $n2(w)$ are computed as follows.

$$NXMA(w) = \text{ROUND}(\frac{1}{2} \cdot T_Xmt(w)/Ts_XMA)$$

$$n1(w) = nCTR - NXMA(w) \quad n2(w) = nCTR + NXMA(w)$$

- (8) The sample spacing Ts_XMA and the minimum pulse length supported $XM_T_Xmt_Min$ are related by the following relationship where $NXMA_Min = 500$. Hence, it follows that $NS_XMA_Min = 1001$.

$$XM_T_Xmt_Min = (2 \cdot NXMA_Min + 1) \cdot Ts_XMA$$



- (9) For a given XM array, the maximum pulse length supported XM_T_Xmt_Max is computed by:

$$\text{XM_T_Xmt_Max} = 2 \cdot (\text{NS_XMA} - 1 - \text{nCTR}) \cdot \text{Ts_XMA}$$

- (10) The number of samples NS_XMA may be an even or odd integer greater than or equal NS_XMA_Min. For NS_XMA even, sample $n_x = 0$ does not contribute to any XM function.

7 Receive Channel Parameters

All CRSD:SAR and CRSD:RCV products contain receive signal data arrays and supporting metadata. The receive signal data and supporting metadata are provided in one or more receive data channels. Each receive channel includes a receive signal array formed from the received SAR PHD or from receive-only signal data. Each channel has supporting metadata included in the XML instance, in a PVP array, and in one or more support arrays.

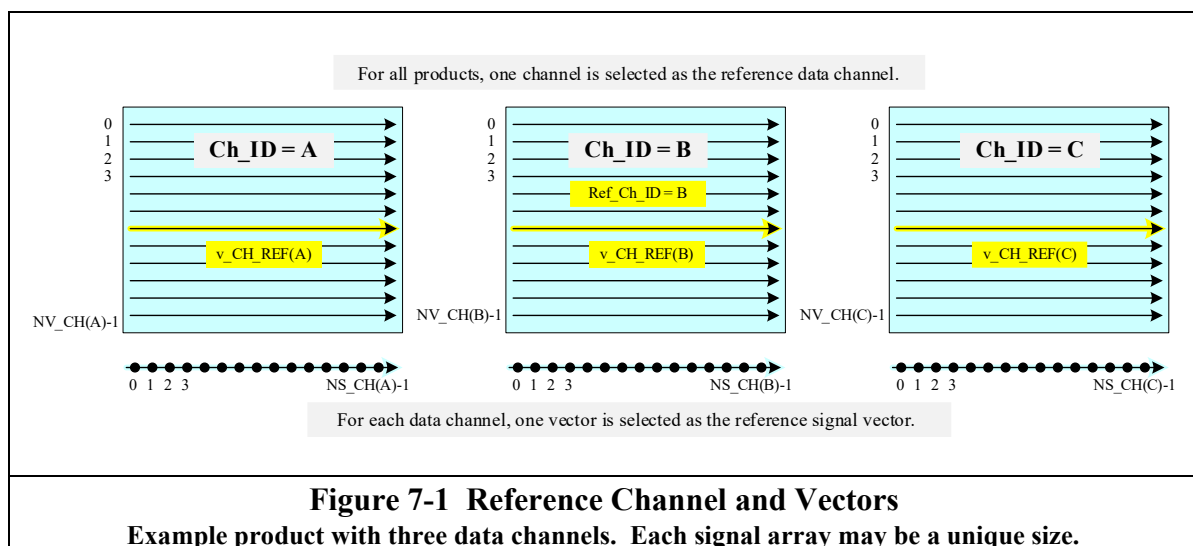
Each data channel contains signal data that was received with a fixed receive configuration. For each channel, all signal data was received using a single Antenna Phase Center (APC) and using a single antenna pattern. The receive polarization is fixed as it is specified as part of the antenna pattern. The instantaneous receive bandwidth, BW_I, is also fixed. For a CRSD:SAR product, each data channel contains the echo signal data received for the transmit pulses of a single transmit pulse sequence. Each pulse sequence was transmitted using a fixed transmit configuration. See Section 6. Hence, the initial PHD that was received and processed to form the signal array is for a fixed transmit configuration and a fixed receive configuration. For products that contain two or more receive channels, any pair of channels may be for signal data collected with the same receive configuration or with two unique configurations.

7.1 Receive Channels

A given CRSD:SAR or CRSD:RCV product may contain one or more receive data channels. Each data channel in a product is referenced by a text-based identifier. The channel identifier, denoted Ch_ID, is a string that uniquely identifies the channel within the product. For each data channel, a signal array is included in the Signal block and a PVP array is included in the PVP block. The channel specific parameters in the XML structure are repeated for each data channel. For a CRSD:SAR product, the channel specific parameters include a set of SAR image parameters. Refer to Table 12-4 and Table 12-6.

7.1.1 Reference Channel

For all products, one channel is selected as the reference channel. The reference channel ID is denoted Ref_Ch_ID. The reference channel may be any channel in the 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 CRSD products. When creating a CRSD product, the choice of the reference channel impacts the reference geometry parameters that are included in the XML instance. See Section 8. For a CRSD:SAR product, the choice of the reference channel may also impact which transmit pulse sequence is selected as the reference sequence. Shown in Figure 7-1 are the signal arrays for a product that contains three receive data channels. For the example shown, the channel identifiers are A, B, and C. Channel B is the reference channel.



7.1.2 Reference Signal Vector

For each data channel, one signal vector is selected as the reference vector. The index of the selected vector is denoted v_CH_REF . The reference vector may be any vector for which the per vector parameters $SIGNAL(v)$ and pulse index $p(v)$ meet the following constraints. See Table 4-4 that describes the set of per vector parameters.

- (1) $SIGNAL(v_CH_REF) = 1$ The reference vector shall contain nominal signal data.
- (2) Pulse Index $p(v_CH_REF) \geq 0$. For a CRSD:SAR product, the TxPulseIndex PVP shall reference a pulse in the sequence (i.e., TxPulseIndex may not be equal to the “no pulse” value).

For many data channels, the center vector of each signal array represents the nominal geometry for the signal array and may be an acceptable 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.

$$v_CH_CTR = FLOOR\{ \frac{1}{2} \cdot NV_CH \}$$

7.2 Required Sample Rate

The fast time sample rate used to form the signal array may be unique for each channel. For each channel, the sample rate is specified in the / CRSDxx / Channel / Parameters / Fs element of the XML instance. For a given channel, the fast time sample rate, denoted $fs(Ch_ID)$, may be any value that meets or exceeds a minimum rate, $fs_Min(Ch_ID)$. In addition to the minimum rate, a second sample rate, $fs_BWR(Ch_ID)$, is defined. Sample rate $fs_BWR(Ch_ID)$ is a rate that will enable simplification in the applications that input the CRSD signal array and form the derived products. The method for computing both sample rates is based on the receive frequency content of the signal array.

For a given channel, the method for computing $fs_Min(Ch_ID)$ and $fs_BWR(Ch_ID)$ is as follows. The parameters are computed based on two channel-dependent bandwidths.

BW_I(Ch_ID): Instantaneous bandwidth (Hz) for the receiver and digital processing that forms the initial PHD signal array. Parameter $BW_I(Ch_ID)$ is specified in the / CRSDxx / Channel / Parameters / BWInst element of the XML instance.

BW_R(Ch_ID): Maximum receive BW retained in any one signal vector. The $BW_R(Ch_ID)$ is computed from the PVPs. For each vector, $BW(v) = frcv_2(v) - frcv_1(v)$. $BW_R(Ch_ID)$ is the maximum value for any vector in the array: $BW_R(Ch_ID) = \text{Max}\{ BW(v) \}$.

The minimum sample rate, $fs_Min(Ch_ID)$, and sample rate $fs_BWR(Ch_ID)$, are computed as shown below. The computed values are in samples/second.

$$fs_Min(Ch_ID) = 1.10 \times BW_I(Ch_ID)$$

$$fs_BWR(Ch_ID) = BW_R(Ch_ID) + 0.10 \times BW_I(Ch_ID)$$

For all products and all data channels, the selected sample rate shall meet the following condition:

$$fs(Ch_ID) \geq fs_Min(Ch_ID).$$

Sample rate $fs_Min(Ch_ID)$ ensures that the signal array is adequately sampled relative to the instantaneous bandwidth of the channel. Sample rate $fs_BWR(Ch_ID)$ ensures the signal array is sampled such that the Discrete Fourier Transform (DFT) of any signal vector will yield a frequency domain vector with unambiguous mapping between frequency domain samples and RF frequency received at the APC. For collections that use CFOR demodulation, rate $fs_BWR(Ch_ID)$ is equal to $fs_Min(Ch_ID)$. For collections that use DROR demodulation, $fs_BWR(Ch_ID)$ is greater than $fs_Min(Ch_ID)$. Refer to Section 4.9.1 and Section 4.9.2 for examples of each type of collection.

7.3 Channel Parameters

For each receive data channel, supporting metadata is specified in the XML instance and in a PVP array. The XML metadata is specified in / CRSDxx / Data / Receive / Channel branch and in the / CRSDxx / Channel / Parameters branch. See Table 12-4 and Table 12-6. For given product, the XML instance specifies the set of parameters included in the PVP set. See Section 2-7 and Table 12-11.

For each channel, a subset of the channel specific XML parameters are computed using values from the PVP array. The methods for computing those parameters are specified in the following sub-sections. The parameters that may be included in a PVP set are defined in Table 4-4.

7.3.1 Frequency & Timeline Parameters

The CRSD data structure provides support for signal arrays that are formed with varying timing, frequency content, and sample rates. The signal processing applied to form the signal arrays may vary across channels and across the signal vectors within a given channel. The flexibility provided in the data structure enables the signal data from many sensors to be accurately described. The allowed flexibility, however, can provide challenges for the applications that input the CRSD products and form the derived data products. For many sensors, the signal arrays are collected and processed using the same receive demodulation and filtering to form each signal vector in the array. For such a collection, many of the per vector parameters will be constant.

A set of frequency and timeline parameters shall be computed from the required parameters that are included in every PVP array. The computed parameters summarize the receive channel frequency content and timing. The inputs used and the methods for computing the parameters are as follows.

(1) Use the sets of frequencies $\{f_0(v)\}$, $\{frcv_1(v)\}$, and $\{frcv_2(v)\}$, and the set of signal content parameters $\{SIGNAL(v)\}$ to compute the following parameters.

RefFreqFixed	Parameter RefFreqFixed = “true” indicates the signal array is formed with a fixed reference frequency. Parameter is “true” if for all vectors the reference frequency $f_0(v)$ is constant. Parameter RefFreqFixed = “false” otherwise.
FrcvFixed	Parameter FrcvFixed = “true” indicates the signal array is formed with a fixed receive band. Parameter is “true” if for all vectors frequency $frcv_1(v)$ is constant and frequency $frcv_2(v)$ is constant. Parameter FrcvFixed = “false” otherwise.
SignalNormal	Parameter SignalNormal = “true” indicates all signal vectors contain “normal” signal data. Parameter is set true when for all vectors parameter $SIGNAL(v) = 1$. Parameter SignalNormal = “false” otherwise.

- (2) Use the set of reference frequencies $\{f_0(v)\}$ to assign frequency f_{0_REF} . Frequency f_{0_REF} is in Hz.

$$f_{0_REF} = f_0(v_{CH_REF})$$

- (3) Use the sets of frequencies $\{frcv_1(v)\}$ and $\{frcv_2(v)\}$ to select frequency $frcv_Min$ and $frcv_Max$. Frequencies $frcv_Min$ and $frcv_Max$ are in Hz.

$$frcv_Min = \text{MIN}\{frcv_1(v)\} \quad frcv_Max = \text{MAX}\{frcv_2(v)\}$$

- (4) Use the set of receive start times $\{trs(v) = trs_INT(v) + trs_FRAC(v)\}$ to assign the following receive start times. Times trs_1 and trs_2 are in seconds relative to the CRT.

$$trs_1 = trs(0) \quad trs_2 = trs(NV_CH - 1)$$

The parameters of the / CRSDxx / Channel / Parameters branch of the XML for the channel are assigned as shown. The units of the XML parameters are also listed for convenience.

RefFreqFixed	➔	XML: RefFreqFixed	Boolean
FrcvFixed	➔	XML: FrcvFixed	Boolean
SignalNormal	➔	XML: SignalNormal	Boolean
f_{0_REF}	➔	XML: F0Ref	Hz
$frcv_Min$	➔	XML: FrcvMin	Hz
$frcv_Max$	➔	XML: FrcvMax	Hz
trs_1	➔	XML: RcvStartTime1	sec
trs_2	➔	XML: RcvStartTime2	sec

7.3.2 Receive Reference Point

For each receive data channel, a Receive Reference Point (RRP) shall be specified that is a fixed point located on the reference surface specified for the product. See Section 5. The RRP position in ECEF coordinates is denoted **RRP**. The RRP position in image area coordinates is denoted **RRP_IAC**. The method for converting between ECEF coordinates and Image Area coordinates is specified in Section 6.2 of the CPHD V1.1.0 D&I document.

$$\mathbf{RRP} = \begin{bmatrix} RRP_X \\ RRP_Y \\ RRP_Z \end{bmatrix} \quad \mathbf{RRP_IAC} = \begin{bmatrix} RRP_IAX \\ RRP_IAY \\ 0 \end{bmatrix}$$

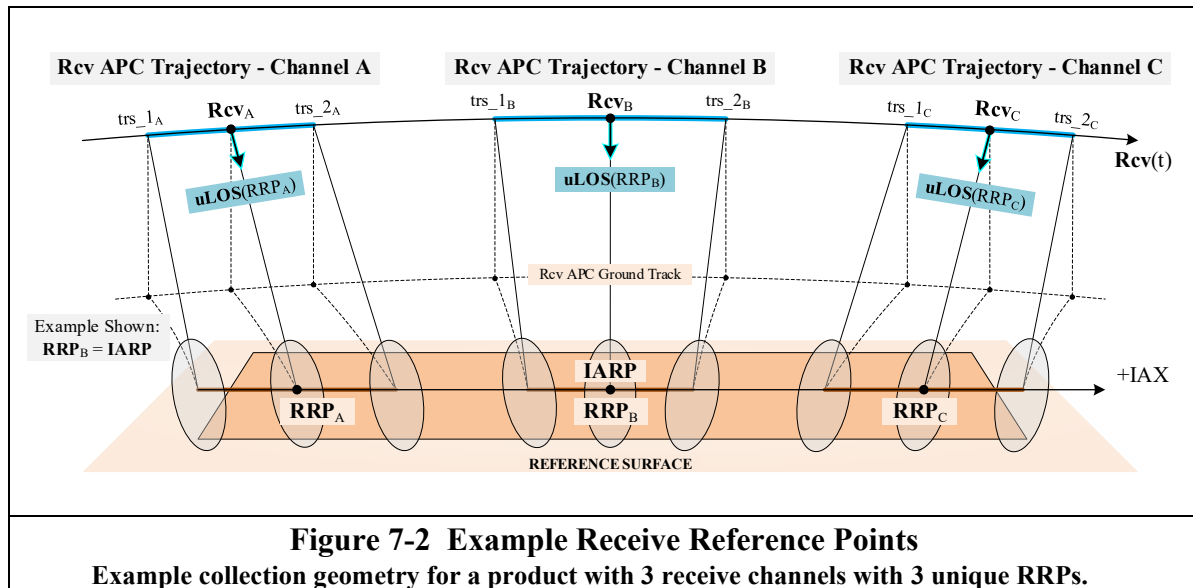
Note: For a point located on the reference surface, the IAZ component is equal to 0.

For each receive channel, the RRP may be used to get a general sense of the collection geometry for the receive channel. For all products, the method used for determining the RRP is a product design choice. A recommended choice is to locate the RRP near the center of

receive antenna beam shape footprint for the reference signal vector. For a CRSD:SAR product, a second recommended choice is to locate the RRP near the center of the image area covered by the channel. Refer to Section 7.5.2.

Shown in Figure 7-2 is an example receive collection geometry for a product that contains 3 receive channels. The channel identifiers are A, B, and C. All 3 channels were collected using the same receive configuration. The geometry shown is similar to a right-looking SAR stripmap mode imaging geometry. For the example shown, the initial receive signal data for each channel was collected during a unique period of time. For each receive channel, the receive antenna beam shape footprint scans a unique portion of the reference surface. The initial signal data for channel A was collected first. The initial signal data for channel B was collected second. The initial signal data for channel C was collected last.

The receive APC trajectory and the antenna beam shape pattern footprint are highlighted for each of the three receive channels. For receive channel A, the receive APC trajectory is highlighted from the APC position at $t = \text{trs_1}_A$ to the receive APC position at time trs_2_A . The RRP position is denoted RRP_A . The receive APC position at the receive start time for the reference vector is denoted Rcv_A . Also, shown is the LOS unit pointing vector from Rcv_A to the RRP_A , denoted $\mathbf{uLOS}(\text{RRP}_A)$. For channels B and C, the same set of parameters shown. For receive channel B, the receive APC trajectory is highlighted from the APC position $t = \text{trs_1}_B$ to the APC position at time trs_2_B . For receive channel C, the receive APC trajectory is highlighted from the APC position at $t = \text{trs_1}_C$ to the APC position at time trs_2_C . For each channel, the RRP is located near the peak of the receive beam shape pattern for the reference signal vector. For the example shown, the RRP for channel B, RRP_B , is coincidentally located at the IARP selected for the product.



7.3.3 Receive Polarization

For each receive channel, a set of polarization parameters are provided. The polarization parameters describe the orientation of the E-field for signals that were received with maximum receive sensitivity. The parameters include a description of the receive polarization orientation for the reference vector. Also provided is a polarization identifier that provides a general description of the polarization orientation for the receive channel.

The polarization orientation for the signal received from the RRP with maximum receive sensitivity is specified for the reference signal vector. The orientation is specified relative to the horizontal (H) and vertical (V) directions computed using the LOS from the receive APC to the RRP. The polarization orientation is specified using a set of four parameters denoted $\{\text{AmpH}, \text{AmpV}, \Phi_H, \Phi_V\}$. The methods for computing the polarization orientation parameters are described in Section 9.4. The inputs to the method include the following.

Parameters for the reference signal vector. See Table 4.4.

$\mathbf{Rcv}_{REF} = \mathbf{Rcv}(\mathbf{v_CH_REF}) =$ Receive APC position.

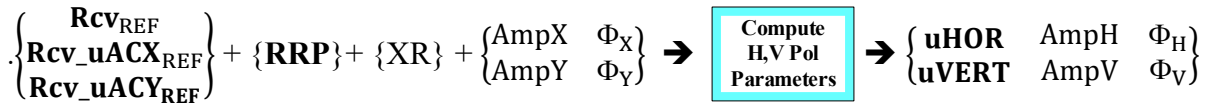
$\mathbf{Rcv_uACX}_{REF} = \mathbf{Rcv_uACX}(\mathbf{v_CH_REF}) =$ Rcv ACF X-axis unit vector.

$\mathbf{Rcv_uACY}_{REF} = \mathbf{Rcv_uACY}(\mathbf{v_CH_REF}) =$ Rcv ACF Y-axis unit vector.

Receive APAT Polarization Parameters – For the APAT specified for the channel.

$\{\text{AmpX}, \text{AmpY}, \Phi_X, \Phi_Y\} =$ APAT polarization reference parameters.

The RRP polarization parameter set $\{\text{AmpH}, \text{AmpV}, \Phi_H, \Phi_V\}$ shall be computed using the function defined in Section 9.4.4 or an equivalent method. Input parameter $\text{XR} = -1$ to yield the polarization orientation parameters for the receive signal with maximum receive sensitivity.



The polarization identifier, denoted Pol_ID , is a text-based parameter that provides a general description of the polarization orientation with peak receive sensitivity for the receive channel. The allowed values for the Pol_ID are listed in Table 9-1. For all products, the criteria used for selecting the Pol_ID is a product design choice. The selection may use the polarization orientation computed for a single signal vector and a single point in the scene. The selection may also consider a set of polarization orientations computed for multiple vectors and/or multiple points in the scene.

The parameters of the / CRSDxx / Channel / Parameters / RcvPolarization branch of the XML for the sequence are assigned as shown. The units of the XML parameters are also listed for convenience.

Pol_ID	$\rightarrow$	XML: PolarizationID	ENU
AmpH	$\rightarrow$	XML: AmpH	unitless

AmpV	➔	XML: AmpV	unitless
Φ_H	➔	XML: PhaseH	cycles
Φ_V	➔	XML: PhaseV	cycles

7.4 Receive Power Parameters

For a given receive channel, let $s_{FILE}(v, s)$ denote the channel signal array that is stored in standard format in the CRSD product file. For vector v , the PVP $Amp_SF(v)$ is the scale factor to be applied to yield the correct amplitude values. Let $s_{CRSD}(v, s)$ denote the signal array after the scale factor is applied to each signal vector.

$$s_{CRSD}(v, s) = Amp_SF(v) \bullet s_{FILE}(v, s)$$

The signal power array, denoted $P_{CRSD}(v, s)$, is computed shown.

$$P_{CRSD}(v, s) = |s_{CRSD}(v, s)|^2$$

For a given channel, the signal array contains a sum of receive signals that were incident at the receive antenna and thermal noise. The thermal noise may be from sources both internal and external to the radar sensor. For each receive channel, parameters are provided to relate signal power incident at the receive APC and observed or predicted signal power array values. Also provided is an estimate of the thermal noise power from sources internal to radar sensor. The parameters provided for each receive channel include the following.

$P_Irr_0_{RCV}$	Reference receive irradiance for the channel (dBW/m ²). Reference signal power level incident at the receive APC that results in signal array power $P_{CRSD} = 1.0$ for receive antenna beam shape gain $G_{RBS} = 0$ dB. XML: RcvRefIrradiance
$P_Irr_SD_{RCV}$	Estimated error standard deviation for the reference receive irradiance for the channel (dBW/m ²). XML: RcvIrradianceErrorStdDev
PN_{CRSD}	Nominal thermal noise power level in the channel signal array. Equal to the expected thermal noise power in a given sample due to sources internal to the radar sensor. XML: PNCRSD
BN_{CRSD}	Noise equivalent bandwidth for the thermal noise in the signal array. Expressed as a fraction of the fast time sample rate for the channel. XML: BNCRSD

The method for computing signal array power as function of signal power incident at the receive APC is described below. Used in the description are the following parameters.

$P_Irr_{RCV}(\mathbf{uAP}, t)$	Receive signal irradiance (dBW/m ²) incident at the receive APC from the LOS specified by unit antenna pointing vector $\mathbf{uAP}$. The signal is incident at the APC at time t .
---------------------------------	---

$PS_{CRSD}(\mathbf{uAP}, v, s)$ Signal array power for the signal incident at the receive APC from the LOS specified by unit antenna pointing vector $\mathbf{uAP}$. The signal is contained in signal array sample (v, s) . May also be expressed in dB: $PS_dB_{CRSD}(\mathbf{uAP}, v, s) = 10 \cdot \log_{10}(PS_{CRSD}(\mathbf{uAP}, v, s))$

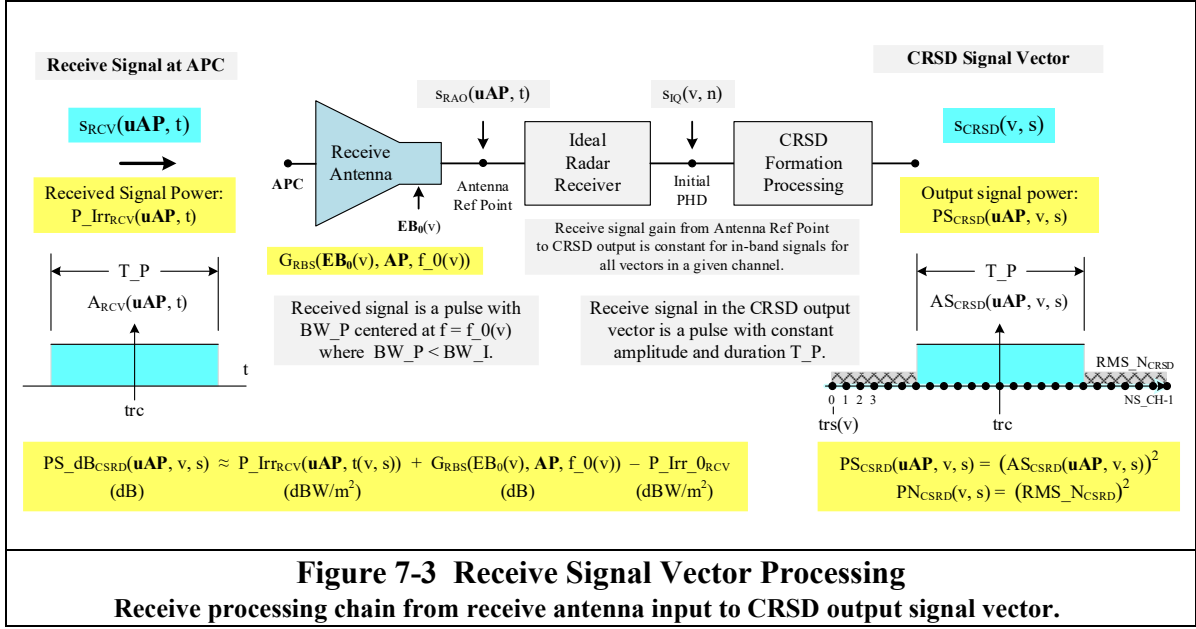
7.4.1 Receive Signal Power

For each receive channel, the signal array is formed by a combination of analog and digital signal processing. For a signal incident at the receive antenna, the analog processing includes the directional selectivity of the receive antenna. It also includes the processing applied in the radar receiver that outputs the initial PHD signal array. The digital processing includes the CRSD formation processing that inputs the initial PHD and forms the receive channel signal array. The CRSD formation processing may apply one of more types of compensation and/or resampling. Refer to Section 4.8 and Section 4.9. For a given receive channel, the signal array is ideally formed such that for in-band signals, the only variation in signal gain is due to the receive antenna beam shape pattern. The beam shape pattern varies with receive direction for a given receive window and across receive windows as the APC position and ACF orientation vary with time.

For any given receive channel, the receive processing gain is controlled. For a receive signal with incident irradiance P_Irr_0RCV (dBW/m²), the output signal array power $PS_{CRSD}(v, s) = 1.0$ ($PS_dB_{CRSD}(v, s) = 0.0$ dB) for the following conditions.

- (1) The received signal is incident at the receive APC during the receive window processed to form signal vector v at time $tr(v, s) = trs(v) + Ts \cdot s$.
- (2) The receive signal is in-band for signal vector v .
- (3) The receive signal polarization orientation is matched to the receive polarization orientation with maximum receive sensitivity for the incident LOS pointing direction.
- (4) The receive antenna beam shape gain for the incident LOS pointing direction $GRBS(f) = 0$ dB for all values of frequency f .

Shown in Figure 7-3 is an example receive signal processing chain that inputs a signal at the receive APC and outputs a CRSD signal vector. The chain includes the receive antenna, an ideal radar receiver, and CRSD formation processing. The input receive signal, denoted $srcv(\mathbf{uAP}, t)$, is incident from the LOS specified by the unit pointing vector $\mathbf{uAP}$. The incident signal is a pulse waveform centered at time $t = trc$ that corresponds to center of the receive window for signal vector v . The incident signal power is $P_IrrRCV(\mathbf{uAP}, t)$ (dBW/m²) and is constant across the pulse. The receive pulse duration is T_P and is equal to half the duration of the receive window for the channel (i.e., $T_P = \frac{1}{2} \cdot T_Rcv$). The receive pulse has bandwidth BW_P centered at $f = f_0(v)$ where $BW_P < BW_I$. The pulse signal is in-band for vector v . The receive antenna beam shape gain, denoted $GRBS(\mathbf{EB}_0(v), \mathbf{AP}, f_0(v))$ (dB), is the beam shape gain for signal vector v and for unit pointing vector $\mathbf{uAP}$ evaluated at frequency $f_0(v)$. Refer to Section 9 for the methods used to compute antenna beam shape gain.



Shown in the right-hand portion of Figure 7-3 is the output CRSD signal vector, $s_{CRSD}(v, s)$. The vector contains a sampled pulse signal of duration T_P that is centered in the vector. The pulse has amplitude $AS_{CRSD}(\mathbf{uAP}, v, s)$ and signal array power $PS_{CRSD}(\mathbf{uAP}, v, s)$. The power $PS_dB_{CRSD}(\mathbf{uAP}, v, s)$ may be estimated from the incident irradiance, $P_{IrrRCV}(\mathbf{uAP}, t(v, s))$, using the reference irradiance for the channel, P_{Irr_0RCV} .

$$PS_dB_{CRSD}(\mathbf{uAP}, v, s) \approx P_{IrrRCV}(\mathbf{uAP}, t(v, s)) + G_{RBS}(EB_0(v), \mathbf{AP}, f_0(v)) - P_{Irr_0RCV}$$

(dB) (dBW/m²) (dB) (dBW/m²)

Note: Signal in sample (v, s) was incident at the receive APC at $t(v, s) = trs(v) + Ts \cdot s$.

For each channel, the error statistic P_{Irr_SDRCV} provides the expected error in the reference irradiance for the channel. The error in reference irradiance contributes to the error in the above expression for signal array power as function of incident power. An additional source of error is the variation in antenna beam shape gain $G_{RBS}(EB_0(v), \mathbf{AP}, f)$ with frequency across the signal bandwidth. For a given signal vector and LOS pointing vector $\mathbf{uAP}$, the beam shape gain across the signal bandwidth may be computed. For the variation in beam shape gain, an improved estimate in expected error may be computed.

7.4.2 Noise Power

For each receive channel, an estimate of the thermal noise power is provided. The provided parameter, denoted PN_{CRSD} , is an estimate for the thermal noise in the signal array from sources internal to radar sensor. For all products, the method for computing the noise power in the signal array is a product design choice. For a given radar sensor, gain compensation applied to yield a constant signal gain (i.e., to yield a constant reference irradiance for the array) may result in a variation in thermal noise power across the signal array. For all products, compensation to yield constant signal gain is to be prioritized ahead of achieving constant thermal noise power in the signal array.

7.5 SAR Image Parameters

For all CRSD:SAR products, parameters are provided for each receive data channel for use in SAR image formation processing. The parameters are used by applications that input the channel signal array and form images of the illuminated scene. The SAR parameters are specified in the / CRSD / Channel / Parameters / SARImage branch of the XML instance for each receive channel. See Table 12-6. The SAR parameters provided are described below.

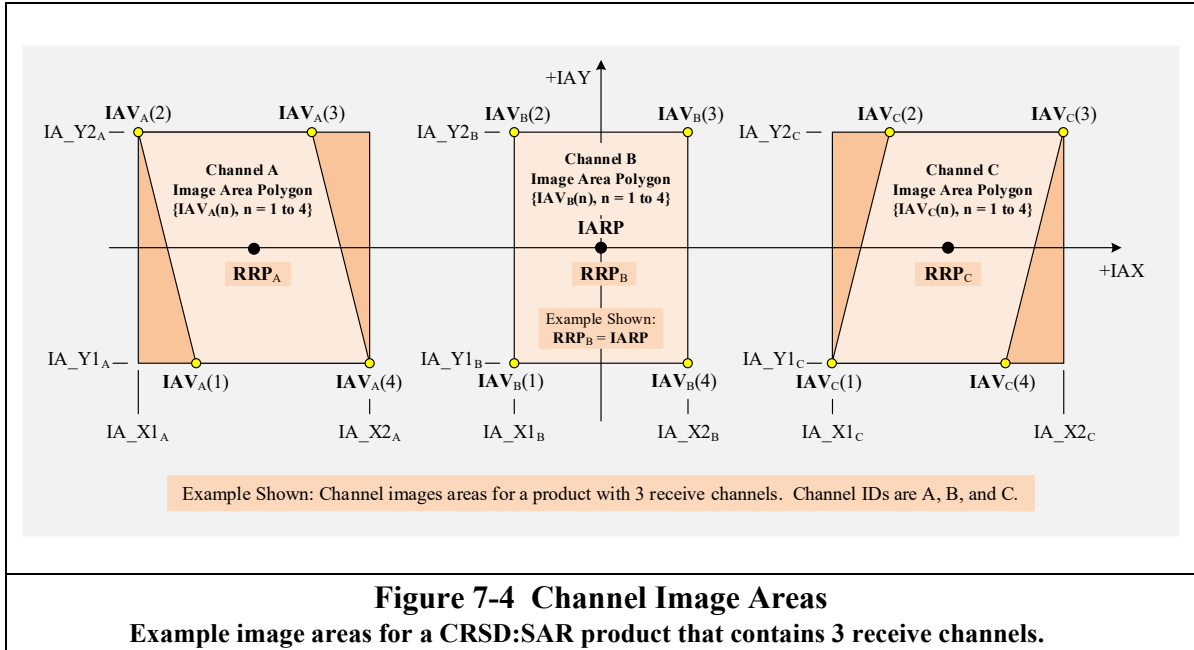
7.5.1 Transmit Sequence

For each receive channel, the Tx_ID specifies the transmit pulse sequence associated with the channel. The referenced pulse sequence provided the illumination for which the echoes from the imaged scene are contained in the channel signal array. For each signal vector v , the pulse index $p(v)$ is specified in the PVP set. Refer to Figure 4-1. The echo signals from the imaged scene of pulse $p(v)$ are contained in signal vector v . For the reference signal vector, the echoes of pulse $p_CH_REF = p(v_CH_REF)$ are contained in the signal vector. Pulse p_CH_REF is referred to as the reference vector pulse.

7.5.2 Image Area

For each receive channel, an image area shall be specified that is located on the reference surface specified in the product. The image area is the area that may be covered by the SAR images that may be formed from the channel signal array. For a given channel, the image area is specified by a polygon and bounding rectangle. The polygon is referred to as the channel image area polygon. The bounding rectangle is referred to as the channel image area rectangle. The vertices of the polygon are specified in image area coordinates. For a given polygon with vertices indexed from $n = 1, 2, \dots, N$, the line segment from the vertex $n = N$ to the vertex $n = 1$ closes the polygon. The bounding rectangle is aligned with the IAX and IAY axes. The image area for the channel includes all points located in the interior or on the boundary of the channel image area polygon.

Shown in Figure 7-4 are the channel image areas for an example CRSD:SAR product that contains 3 receive channels. The channel IDs are A, B, and C. For each channel, the image area polygon is specified by a set of 4 vertices. For channels A and C, the channel image area rectangle covers more area than the image area polygon. For the example shown, the RRP for each channel is located in the center of the channel image area.



7.5.3 COD Time & Dwell Time

For each channel, parameters shall be provided that map a point in the image area to the portion of channel signal array that may be used for SAR image formation processing. For a selected scene point located in the channel image area, the parameters provided are used to compute a center of dwell (COD) time and a dwell time. The COD time and the dwell time are used to compute the portion of the signal array that may be used to form a SAR image pixel that is centered at the selected scene point.

For a scene point located within the channel image area, the COD time and the dwell time are computed from the scene point position in image area coordinates. For the scene point at (IAX, IAY, 0), the computed parameters are denoted as follows. Coordinates IAX and IAY are in meters.

$t_COD(IAX, IAY)$ Center of Dwell time (sec) for the scene point relative to the Collection Reference Time (t_CRT).

$T_Dwell(IAX, IAY)$ Dwell time (sec) for which the channel signal array contains the echo signals from scene point of the transmit pulses.

For a given CRSD:SAR product, the parameters provided to compute COD times and dwell times are specified using one of two types of defined metadata structures. A given product may use (1) COD time polynomials and dwell time polynomials, or (2) dwell time arrays. The same choice of metadata structure shall be used for all receive channels in the product.

COD Time & Dwell Time Polynomials

For a product that uses COD time and dwell time polynomials, the polynomials to be used for each receive channel and the set of coefficients for each polynomial are specified in the XML instance. The / SARImage / DwellTimes / Polynomials structure is included in the structure for each channel. The COD_ID and Dwell_ID specify the COD time polynomial and the dwell time polynomial to be used for the channel. Also included in the XML is the / CRSDsar / DwellPolynomials structure that specifies the set of coefficients for each polynomial. Specified in the structure are one or more COD time polynomials and one or more dwell time polynomials. Each polynomial is identified by its text-based identifier. A given polynomial may be used by 0, 1, or more channels within a product.

Each polynomial is a function of coordinates IAX and IAY. For scene point GPT located at (GPT_IAX, GPT_IAY, 0), the COD time, denoted t_COD_GPT , and the dwell time, denoted T_Dwell_GPT , are computed using the polynomials specified for the channel. Coordinates GPT_IAX and GPT_IAY are in meters.

$$t_COD_GPT = \sum_{m=0}^{Ord1} \sum_{n=0}^{Ord2} cCOD(m,n) \cdot (GPT_IAX)^m \cdot (GPT_IAY)^n$$

$$T_Dwell_GPT = \sum_{m=0}^{Ord1} \sum_{n=0}^{Ord2} cDwell(m,n) \cdot (GPT_IAX)^m \cdot (GPT_IAY)^n$$

Dwell Time Arrays

For a product that uses dwell time arrays, the dwell time array to be used for each receive channel is specified in the XML instance. The / SARImage / DwellTimes / Array structure is included in the structure for each channel. The DTA_ID specifies the dwell time array to be used for the channel. Also included in the product is one or more dwell time array support arrays. Each dwell time array in a product is specified by parameters included in the XML instance and by a two-dimension array included in the support block of the product. Each dwell time array specifies COD times and dwell times over an area located on the reference surface. A given dwell time array may be used by 0, 1, or more channels within a given product. For each channel that uses a given dwell time array, the dwell time array shall yield valid COD times and dwell times for the entire image area specified for the channel.

A dwell time array is a two-dimensional array of data elements. Each array element, denoted $DT_{SA}(m, n)$, contains the COD time and dwell time for input position (IAX(m), IAY(n)). The COD time is denoted $t_COD_{SA}(m, n)$. The dwell time is denoted $T_Dwell_{SA}(m, n)$. All dwell time arrays shall be created and stored per the following rules and guidance. See Table 12-4 and Table 12-9.

- (1) The array size is NumRows x NumCols. Require $NumRows \geq 2$ and $NumCols \geq 2$.
- (2) The row coordinate is IAX and is computed by: $IAX(m) = IAX_0 + m \cdot IAX_SS$.
- (3) The column coordinate is IAY and is computed by: $IAY(n) = IAY_0 + n \cdot IAY_SS$.

- (4) For an array with elements containing invalid data, the NODATA parameter is included in the XML branch that specifies the support array. See Table 12-9: / DwellTimeArray / NODATA. An element with invalid data is assigned the NODATA byte sequence.
- (5) For a given array, the array size and grid spacings in IAX and IAY are a design choice. The grid spacing shall be fine enough to support accurate bilinear interpolation over the image areas for all channels that reference the array.
- (6) For an input position (IAX, IAY) that falls between grid locations that contain valid data, the COD time and dwell time values, $t_COD(IAX, IAY)$ and $T_Dwell(IAX, IAY)$, may be computed using bilinear interpolation of the COD time values and dwell time values of the four “surrounding” elements.

A method for computing COD times and dwell time values from a dwell time array is provided. For input position (IAX, IAY), the COD time $t_COD(IAX, IAY)$ and $T_Dwell(IAX, IAY)$ are computed. The method assumes that the dwell time array included in the CRSD product file, $\{DT_{SA}(m, n)\}$, has been separated into a COD time array, $\{t_COD_{SA}(m, n)\}$, and a dwell time array, $\{T_Dwell(m, n)\}$. The method also makes use of a data valid array, $\{DV_{SA}(m, n)\}$, that is an array of Boolean parameters. For element (m, n), $DV_{SA}(m, n) = \text{“true”}$ indicates that element $DT_{SA}(m, n)$ contains valid COD time and dwell time values. The data valid array may be formed as a one-time preprocessing step.

The method for computing COD times and dwell times may be implemented as the function shown below. For input scene point position (IAX, IAY), the output is a COD time $t_COD = t_COD(IAX, IAY)$, dwell time value $T_Dwell = T_Dwell(IAX, IAY)$, and a data valid Boolean, DV.

$$\begin{Bmatrix} IAX \\ IAY \end{Bmatrix} + \begin{Bmatrix} \{t_COD_{SA}(m, n)\} \\ \{T_Dwell_{SA}(m, n)\} \\ \{DV_{SA}(m, n)\} \end{Bmatrix} + \begin{Bmatrix} \text{NumRows} & \text{NumCols} \\ iax_0 & iay_0 \\ iax_SS & iay_SS \end{Bmatrix} \rightarrow \boxed{\text{Interpolate Dwell Time Supp Array}} \rightarrow \begin{Bmatrix} t_COD \\ T_Dwell \\ DV \end{Bmatrix}$$

The method used to interpolate dwell time array values is the same method used to interpolate antenna gain/phase arrays. Refer to Section 9.3.2.

COD Time & Dwell Time to Signal Array Vector Set

For scene point GPT with COD time t_COD_GPT and dwell time T_Dwell_COD , the method for computing the portion of the channel signal array that may be used to form a SAR image pixel centered at point GPT is as follows. The portion of the signal array that may be used is the set of vectors indexed by $v = v1_GPT, \dots, v2_GPT$.

$$0 \leq v1_GPT \leq v2_GPT \leq NV_CH - 1.$$

- (1) For each signal vector in the array, assign Boolean parameter SAR(v) = “true” if the vector supports SAR image formation. Assign SAR(v) as shown. For each vector that supports image formation, compute the reference time txr(v) as shown.

For $v = 0, 1, 2, \dots, NV-CH - 1$:

$$SAR(v) = \begin{cases} \text{"true"}, & \text{if } p(v) \geq 0 \\ \text{"false"}, & \text{otherwise} \end{cases}$$

$$txr(v) = \begin{cases} \frac{1}{2} \cdot (trs(v) + txc(p(v))), & \text{if } SAR(v) = \text{"true"} \\ \text{NAN}, & \text{otherwise} \end{cases}$$

- (2) For scene point GPT, compute the start and end of the dwell time supported by the signal array. Times t_SOD_GPT and t_EOD_GPT are in seconds relative to CRT.

$$t_SOD_GPT = t_COD_GPT - \frac{1}{2} \cdot T_Dwell_GPT$$

$$t_EOD_GPT = t_COD_GPT + \frac{1}{2} \cdot T_Dwell_GPT$$

- (3) Select vector indices v1_GPT and v2_GPT as follows.

$$v1_GPT = \text{Minimum value of } v \text{ for which } t_SOD_GPT \leq txr(v)$$

$$v2_GPT = \text{Maximum value of } v \text{ for which } txr(v) \leq t_EOD_GPT$$

7.5.4 Transmit Polarization

For each receive channel, a set of transmit polarization parameters are provided. The parameters describe the orientation of the E-field of the transmit pulses that illuminated the channel image area. The parameters provided include a description of the transmit polarization orientation for the reference vector pulse. Also provided is a polarization identifier that provides a general description of the transmit polarization orientation for the channel.

The polarization orientation for the reference vector pulse incident at the RRP for the channel is specified. The orientation is specified relative to the horizontal (H) and vertical (V) directions computed using the LOS from the transmit APC to the RRP. The methods for computing the polarization orientation parameters are described in Section 9.4. The inputs to the method include the following PPPs for the reference vector pulse. (i.e., for pulse $p = p_CH_REF$).

Parameters for the reference vector pulse. See Table 4.2.

$$\mathbf{Xmt}_{RVP} = \mathbf{Xmt}(p_CH_REF) = \text{Transmit APC position.}$$

$$\mathbf{Xmt_uACX}_{RVP} = \mathbf{Xmt_uACX}(p_CH_REF) = \text{Tx ACF X-axis unit vector.}$$

$$\mathbf{Xmt_uACY}_{RVP} = \mathbf{Xmt_uACY}(p_CH_REF) = \text{Tx ACF Y-axis unit vector.}$$

Transmit APAT Polarization Parameters – For the APAT specified for the sequence.

$\{\text{AmpX}, \text{AmpY}, \Phi_X, \Phi_Y\} = \text{APAT polarization reference parameters.}$

The RRP polarization parameter set $\{\text{AmpH}, \text{AmpV}, \Phi_H, \Phi_V\}$ shall be computed using the function defined in Section 9.4.4 or an equivalent method. Input parameter $\text{XR} = +1$ to yield the polarization orientation parameters for the transmit pulse.

$$\begin{Bmatrix} \text{Xmt}_{\text{RVP}} \\ \text{Xmt_uACX}_{\text{RVP}} \\ \text{Xmt_uACY}_{\text{RVP}} \end{Bmatrix} + \{\text{RRP}\} + \{\text{XR}\} + \begin{Bmatrix} \text{AmpX} & \Phi_X \\ \text{AmpY} & \Phi_Y \end{Bmatrix} \rightarrow \boxed{\text{Compute H,V Pol Parameters}} \rightarrow \begin{Bmatrix} \text{uHOR} & \text{AmpH} & \Phi_H \\ \text{uVERT} & \text{AmpV} & \Phi_V \end{Bmatrix}$$

The transmit polarization identifier, denoted Pol_ID , is a text-based parameter that provides a general description of the polarization orientation pulses that illuminated the channel image area. The allowed values for the Pol_ID are listed in Table 9-1. For all products, the criteria used for selecting the Pol_ID is a product design choice.

The parameters of the / CRSDsar / Channel / Parameters / SARImage / TxPolarization branch of the XML for the channel are assigned as shown. The units of the XML parameters are also listed for convenience.

Pol_ID	$\rightarrow$	XML: PolarizationID	ENU
AmpH	$\rightarrow$	XML: AmpH	unitless
AmpV	$\rightarrow$	XML: AmpV	unitless
Φ_H	$\rightarrow$	XML: PhaseH	cycles
Φ_V	$\rightarrow$	XML: PhaseV	cycles

8 Reference Geometry Parameters

For all products, a set of reference geometry parameters is provided that describes the relevant geometry for the collection or illumination event specified in the product. The parameters are provided to support search and discovery of CRSD products based upon geometry parameters via a query of the XML instance. The parameters are included in the ReferenceGeometry branch of the XML structure. See Table 12-7. The set of parameters provided is dependent upon the CRSD product type. The inputs and the methods used to compute the reference geometry parameters are specified in the following sections.

8.1 Reference Point & APC Parameters

For all products, the reference geometry inputs include a reference point, denoted RPT. The inputs also include transmit APC parameters for one transmit pulse and/or receive APC parameters for one receive signal vector. The set of inputs is dependent upon the CRSD product type. The inputs for each product type are as follows. All times are in seconds relative to the CRT. All position coordinates are in meters and all velocity coordinates are in meters/second.

The RPT is selected from the set of transmit reference points or the set of receive reference points included in the product. The RPT position in ECEF coordinates, **RPT**, shall be selected as follows. The RPT position in image area coordinates IAX and IAY is also selected.

For CRSD:TX:

$$\mathbf{RPT} = \begin{bmatrix} \text{RPT_X} \\ \text{RPT_Y} \\ \text{RPT_Z} \end{bmatrix} = \mathbf{TRP}(\text{Ref_Tx_ID}) \quad \text{See Table 12-5: TxRefPoint}$$

$$\text{RPT_IAX} = \text{TRP_IAX}(\text{Ref_Tx_ID})$$

$$\text{RPT_IAY} = \text{TRP_IAY}(\text{Ref_Tx_ID})$$

For CRSD:SAR or CRSD:RCV:

$$\mathbf{RPT} = \begin{bmatrix} \text{RPT_X} \\ \text{RPT_Y} \\ \text{RPT_Z} \end{bmatrix} = \mathbf{RRP}(\text{Ref_Ch_ID}) \quad \text{See Table 12-6: RcvRefPoint}$$

$$\text{RPT_IAX} = \text{RRP_IAX}(\text{Ref_Ch_ID})$$

$$\text{RPT_IAY} = \text{RRP_IAY}(\text{Ref_Ch_ID})$$

For a CRSD:SAR or CRSD:TX product, the transmit APC parameters shall be selected from the PPP array for one pulse of the reference transmit sequence. The selected parameters are the transmit center time, tx_{REF} , the APC position, $\mathbf{X}_{\text{mt}_{\text{REF}}}$, and the APC velocity, $\mathbf{V}_{\text{Xmt}_{\text{REF}}}$. The time is computed from the PPP integer and fractional parts and may be stored in a single F8 formatted parameter. See Table 4-2. The selected transmit APC position and velocity are in ECEF coordinates. The reference pulse index, p_{REF} , is selected based on the product type.

For CRSD:TX:

$$p_{\text{REF}} = p_{\text{TX_REF}}(\text{Ref_Tx_ID}) \quad \text{See Table 12-5: RefPulseIndex}$$

For CRSD:SAR:

$$p_{\text{REF}} = p_{\text{CH_REF}}(\text{Ref_Ch_ID}) \quad \text{See Table 12-6: SARImage/RefVectorPulseIndex}$$

For CRSD:SAR or CRSD:TX:

$$tx_{\text{CREF}} = tx_{\text{INT}}(\text{Ref_Tx_ID}, p_{\text{REF}}) + tx_{\text{FRAC}}(\text{Ref_Tx_ID}, p_{\text{REF}})$$

$$\mathbf{Xmt}_{\text{REF}} = \begin{bmatrix} Xmt_X_{\text{REF}} \\ Xmt_Y_{\text{REF}} \\ Xmt_Z_{\text{REF}} \end{bmatrix} = \mathbf{Xmt}(\text{Ref_Tx_ID}, p_{\text{REF}})$$

$$\mathbf{VXmt}_{\text{REF}} = \begin{bmatrix} VXmt_X_{\text{REF}} \\ VXmt_Y_{\text{REF}} \\ VXmt_Z_{\text{REF}} \end{bmatrix} = \mathbf{VXmt}(\text{Ref_Tx_ID}, p_{\text{REF}})$$

For a CRSD:SAR or CRSD:RCV product, the receive APC parameters shall be selected from the PVP array for the reference signal vector of the reference receive channel. The selected parameters are the receive start time, trs_{REF} , the APC position, $\mathbf{Rcv}_{\text{REF}}$, and the APC velocity, $\mathbf{VRcv}_{\text{REF}}$. The time is computed from the PVP integer and fractional parts and may be stored in a single F8 formatted parameter. See Table 4-4. The selected receive APC position and velocity are in ECEF coordinates.

For CRSD:SAR or CRSD:RCV:

$$v_{\text{REF}} = v_{\text{CH_REF}}(\text{Ref_Ch_ID}) \quad \text{See Table 12-6: RefVectorIndex}$$

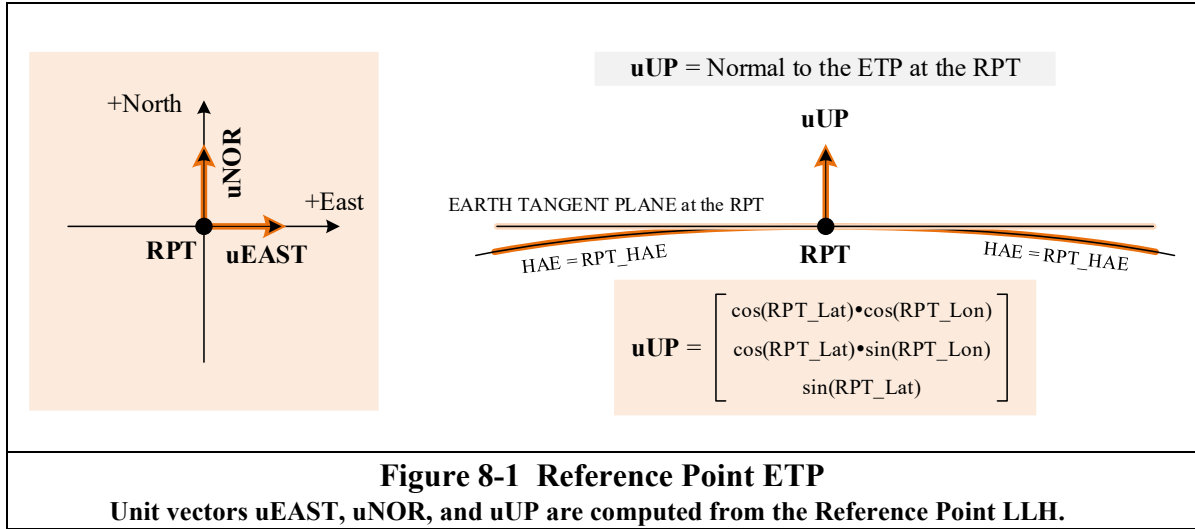
$$trs_{\text{REF}} = trs_{\text{INT}}(\text{Ref_Ch_ID}, v_{\text{REF}}) + trs_{\text{FRAC}}(\text{Ref_Ch_ID}, v_{\text{REF}})$$

$$\mathbf{Rcv}_{\text{REF}} = \begin{bmatrix} Rcv_X_{\text{REF}} \\ Rcv_Y_{\text{REF}} \\ Rcv_Z_{\text{REF}} \end{bmatrix} = \mathbf{Rcv}(\text{Ref_Ch_ID}, v_{\text{REF}})$$

$$\mathbf{VRcv}_{\text{REF}} = \begin{bmatrix} VRcv_X_{\text{REF}} \\ VRcv_Y_{\text{REF}} \\ VRcv_Z_{\text{REF}} \end{bmatrix} = \mathbf{VXmt}(\text{Ref_Ch_ID}, v_{\text{REF}})$$

8.2 Reference Point Parameters

Compute the following parameters for the reference point using its position in ECEF coordinates, **RPT**. The parameters computed are the position in WGS 84 geodetic LLH and the unit basis vectors for the East, North, Up (ENU) coordinate frame with origin at the reference point. See Figure 8-1.



Compute Reference Point Parameters

The reference point parameters computations may be implemented as the function shown below. The input is the reference point position in ECEF coordinates. The basis vectors are in ECEF coordinates.

$$\left\{ \mathbf{RPT} = \begin{bmatrix} \text{RPT_X} \\ \text{RPT_Y} \\ \text{RPT_Z} \end{bmatrix} \right\} \rightarrow \boxed{\text{Compute Ref Point Parameters}} \rightarrow \left\{ \begin{bmatrix} \text{RPT_Lat} \\ \text{RPT_Lon} \\ \text{RPT_HAE} \end{bmatrix} \begin{Bmatrix} \mathbf{uEAST} \\ \mathbf{uNOR} \\ \mathbf{uUP} \end{Bmatrix} \right\}$$

- (1) Compute the reference point position in WGS 84 geodetic LLH. The geodetic latitude and longitude are in decimal degrees. The HAE is in meters.

$$\mathbf{RPT} = \begin{bmatrix} \text{RPT_X} \\ \text{RPT_Y} \\ \text{RPT_Z} \end{bmatrix} \rightarrow \boxed{\text{Convert ECEF to LLH}} \rightarrow \mathbf{RPT_LLH} = \begin{bmatrix} \text{RPT_Lat} \\ \text{RPT_Lon} \\ \text{RPT_HAE} \end{bmatrix}$$

- (2) Compute the unit basis vectors for the East, North, Up (ENU) coordinate frame with origin at the reference point. Vector **uUP** is normal to the surface of constant HAE at the RPT. The plane formed by the **uEAST** and **uNOR** vectors is referred to as the Earth Tangent Plane (ETP) at the RPT. The ETP is tangent to the surface of constant HAE at the RPT. See Figure 8-1.

Compute unit vectors **uEAST**, **uNOR**, and **uUP** in ECEF coordinates as shown.

$$\mathbf{uEAST} = \begin{bmatrix} -\sin(\text{RPT_Lon}) \\ \cos(\text{RPT_Lon}) \\ 0 \end{bmatrix} \quad \mathbf{uNOR} = \begin{bmatrix} -\sin(\text{RPT_Lat}) \cdot \cos(\text{RPT_Lon}) \\ -\sin(\text{RPT_Lat}) \cdot \sin(\text{RPT_Lon}) \\ \cos(\text{RPT_Lat}) \end{bmatrix}$$

$$\mathbf{uUP} = \begin{bmatrix} \cos(\text{RPT_Lat}) \cdot \cos(\text{RPT_Lon}) \\ \cos(\text{RPT_Lat}) \cdot \sin(\text{RPT_Lon}) \\ \sin(\text{RPT_Lat}) \end{bmatrix}$$

For all products, the parameters of the ReferenceGeometry branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

RPT	➔	XML: RefPoint/ECF	meters
(RPT_IAX, RPT_IAY)	➔	XML: RefPoint/IAC	meters

8.3 APC Geometry Parameters

For each APC selected, a set of parameters that specify the geometry for the APC relative to the reference point are computed. The set of parameters are computed from the APC position, APC velocity, and the reference point position. The parameters computed include the common SAR geometry parameters slant range, ground range, side of track, and grazing angle.

8.3.1 APC to PT Geometry Parameters

For a given APC with position and velocity, **APC_{REF}** and **VAPC_{REF}**, the geometry parameters relative to a fixed scene point position, **PT**, are computed as specified below. For point PT, the ENU unit basis vectors are computed as specified in Section 8.2.

Compute APC to PT Parameters

The APC to PT geometry parameter computations may be implemented as a function as shown below. All input positions and vectors are in ECEF coordinates.

$$\left\{ \begin{matrix} \mathbf{APC}_{\text{REF}} \\ \mathbf{VAPC}_{\text{REF}} \end{matrix} \right\} + \left\{ \begin{matrix} \mathbf{PT} \\ \mathbf{uEAST} \\ \mathbf{uNOR} \\ \mathbf{uUP} \end{matrix} \right\} \Rightarrow \boxed{\text{APC to PT Geometry Parameters}} \Rightarrow \left\{ \begin{matrix} \text{R_APC_PT} \\ \text{Rdot_APC_PT} \\ \text{Rg_PT} \\ \text{SideOfTrack} \end{matrix} \quad \begin{matrix} \mathbf{uAPC} \\ \mathbf{uAPCDot} \\ \text{DCA} \end{matrix} \quad \begin{matrix} \text{SQNT} \\ \text{AZIM} \\ \text{GRAZ} \\ \text{INCD} \end{matrix} \right\}$$

The output parameters to be computed are as listed. The methods to compute them are as follows.

(1) Compute the range from the APC to the PT, R_APC_PT . Compute the unit vector that points from PT to the APC, $\mathbf{u}APC$. Compute the range rate of the APC relative to the PT, $Rdot_APC_PT$. The range is in meters and the range rate is in meters/sec.

$$R_APC_PT = | \mathbf{APC}_{REF} - \mathbf{PT} | \quad \mathbf{u}APC = \frac{1}{R_APC_PT} \bullet (\mathbf{APC}_{REF} - \mathbf{PT})$$

$$Rdot_APC_PT = \mathbf{V}APC_{REF} \bullet \mathbf{u}APC$$

Also compute the derivative with respect to time of the unit vector $\mathbf{u}APC$, $\mathbf{u}APCDot$.

$$\mathbf{u}APCDot = \frac{d}{dt}(\mathbf{u}APC) = \frac{1}{R_APC_PT} \bullet (\mathbf{V}APC_{REF} - Rdot_APC_PT \bullet \mathbf{u}APC)$$

(2) Compute the distance from the WGS 84 Earth Center (EC) to the PT, PT_DEC . Also, compute the unit vector pointing from the EC to the PT, $\mathbf{u}EC_PT$. The distance from the earth center is in meters.

$$PT_DEC = | \mathbf{PT} | \quad \mathbf{u}EC_PT = \frac{1}{PT_DEC} \bullet \mathbf{PT}$$

(3) Compute the distance from the Earth Center (EC) to the APC, APC_DEC . Also, compute the unit vector pointing from the EC to the APC, $\mathbf{u}EC_APC$. The distance from the earth center is in meters. See Figure 8-2.

$$APC_DEC = | \mathbf{APC}_{REF} | \quad \mathbf{u}EC_APC = \frac{1}{APC_DEC} \bullet \mathbf{APC}_{REF}$$

Point $\mathbf{A}G_{REF}$ shown in Figure 8-2 is located on the spherical earth model of radius PT_DEC that contains the scene point. Compute the position $\mathbf{A}G_{REF}$ in ECEF coordinates.

$$\mathbf{A}G_{REF} = PT_DEC \bullet \mathbf{u}EC_APC$$

(4) The ground range to the scene point is the distance measured on the spherical earth model from $\mathbf{A}G_{REF}$ to $\mathbf{PT}$. Compute the angle between unit vectors $\mathbf{u}EC_APC$ and $\mathbf{u}EC_PT$, EA_APC . Compute the ground range to the PT, Rg_PT . See Figure 8-2. The angle EA_APC is in radians and the ground range is in meters.

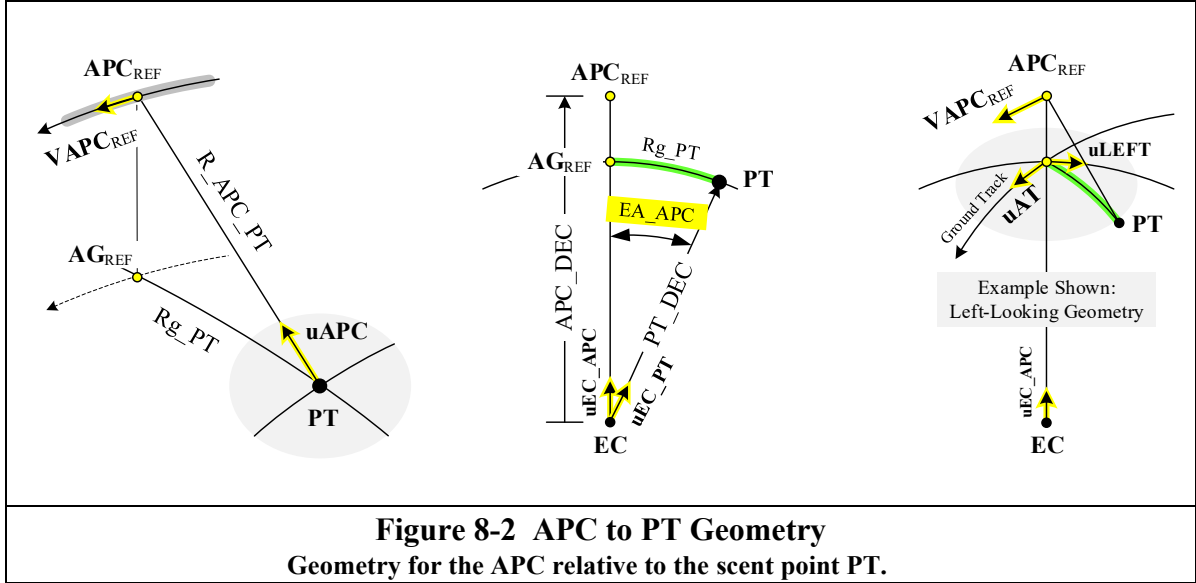
$$EA_APC = \arccos(\mathbf{u}EC_APC \bullet \mathbf{u}EC_PT)$$

$$Rg_PT = PT_DEC \bullet EA_APC$$

(5) The APC ground track at the reference time is defined by the APC velocity vector projected onto spherical earth model of radius PT_DEC . See Figure 8-2. Compute the along track component of the velocity vector, $\mathbf{V}AT_{REF}$. Also compute the magnitude, VAT_M .

$$\mathbf{V}AT_{REF} = \mathbf{V}APC_{REF} - \{ \mathbf{V}APC_{REF} \bullet \mathbf{u}EC_APC \} \bullet \mathbf{u}EC_APC$$

$$VAT_M = | \mathbf{V}AT_{REF} |$$



(6) Determine the Side of Track for the scene point relative to the APC ground track. Unit vector **uLEFT** points to the left side of the APC ground track. Note: For $VAT_M = 0$ or $Rg_PT = 0$, the along track direction is undefined.

If { $VAT_M = 0$ or $Rg_PT = 0$ } : Side of Track is undefined – set to a default.

SideOfTrack = “L”

Else:

Determine the Side of Track.

$$\mathbf{uAT} = \frac{1}{VAT_M} \cdot \mathbf{VAT_REF}$$

$$\mathbf{uLEFT} = \mathbf{uEC_APC} \times \mathbf{uAT}$$

$$\text{SideOfTrack} = \begin{cases} \text{"L"}, & \mathbf{uLEFT} \bullet \mathbf{uAPC} < 0 \\ \text{"R"}, & \text{otherwise} \end{cases}$$

(7) Compute the Doppler Cone Angle (DCA) between the APC velocity vector and the line-of-sight (LOS) to the scene point. First, compute the magnitude of the velocity vector, $VAPC_M$. Parameter $VAPC_M$ is in meters/sec. The DCA is in degrees on the range $[0, 180]$.

$$VAPC_M = |\mathbf{VAPC_REF}|$$

If { $VAPC_M = 0$ }:

APC is fixed – set DCA to a default value.

$$DCA = 90.0$$

Else:

Compute the DCA to the scene point.

$$DCA = \arccos\left\{\frac{-\mathbf{Rdot_APC_PT}}{VAPC_M}\right\} \quad 0 \leq DCA \leq 180$$

(8) The ground squint angle, like the ground range, is measured on the spherical earth model that contains the scene point. Compute the ground squint angle to the reference point based on the angle off the normal to the APC ground track. See Figure 8-3. The squint angle, SQNT, is defined to be zero when the arc from AG_{REF} to the scene point is normal to the ground track. The squint angle is in degrees on the range $[-90, 90]$.

If { VAT M=0 or Rg PT=0 }:

Ground squint angle is undefined.

$$\text{SQNT} = 0$$

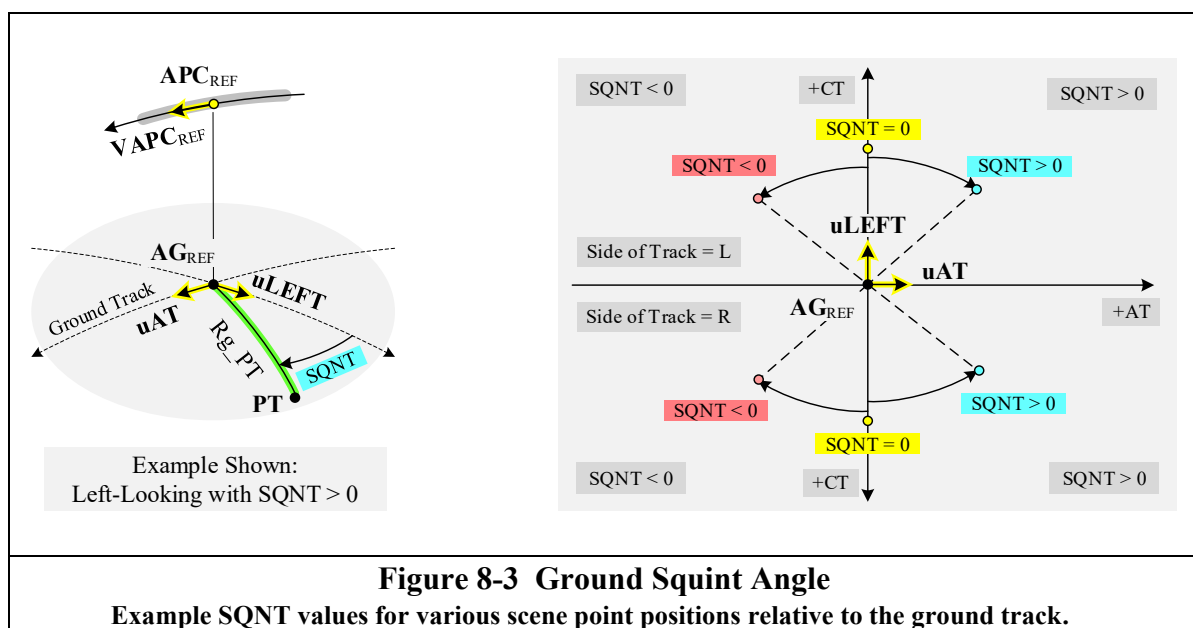
Else: Compute the ground squint angle.

$$\mathbf{P_T - A_T} = \mathbf{uAT} \bullet (\mathbf{P_T - A G_{REF}})$$

$$\text{PT} - \text{CT} = | \mathbf{u}_{\text{LEFT}} \bullet (\mathbf{PT} - \mathbf{AG}_{\text{REF}}) | \quad \text{Note: } \text{PT} - \text{CT} \geq 0$$

$$\text{SQNT} = \text{atan}\left\{\text{PT_AT}/\text{PT_CT}\right\} \quad -90 \leq \text{SQNT} \leq 90$$

Note: For broadside, “non-squinted” geometry ($PT_AT = 0$), the $SQNT = 0$. For “forward-looking” geometry, the $SQNT > 0$. For “aft-looking” geometry, the $SQNT < 0$.



(9) Compute ENU components of the unit vector $\mathbf{u}_{\text{APC}}$.

$$\mathbf{u}_{\text{APC}} \mathbf{E} = \mathbf{u}_{\text{EAST}} \bullet \mathbf{u}_{\text{APC}}$$

$$\mathbf{uAPC} \text{ N} = \mathbf{uNOR} \bullet \mathbf{uAPC}$$

$$\mathbf{uAPC} \quad \mathbf{UP} = \mathbf{uUP} \bullet \mathbf{uAPC}$$

(10) Compute the azimuth angle to the APC position projected into the ETP. The point in the ETP is denoted **AETP_{REF}**. See Figure 8-4. The azimuth angle, **AZIM**, is measured CW from North toward East and is in degrees. For the APC directly above or below the ETP (**Rg_PT** = 0), set **AZIM** equal to 0.

If { **Rg_PT** = 0 } : **AZIM** is undefined - set equal to 0.

$$\mathbf{AZIM} = 0.0$$

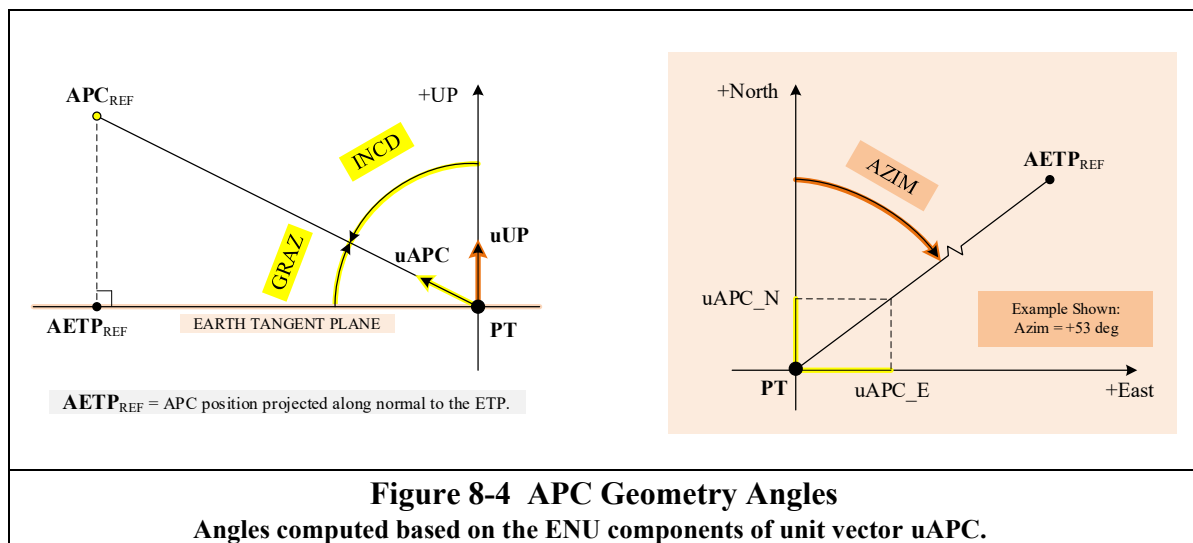
Else: **AZIM** is defined – compute as shown.

$$\mathbf{AZIM} = \text{atan2}\left\{\mathbf{uAPC_E} / \mathbf{uAPC_N}\right\} \quad 0 \text{ deg} \leq \mathbf{AZIM} < 360 \text{ deg}$$

(11) Compute the incidence angle, **INCD**, and the grazing angle, **GRAZ**, for the LOS from the APC to the scene point. The incidence angle is in degrees on the range [0,180]. The grazing angle is in degrees on the range [-90, 90]. See Figure 8-3.

$$\mathbf{INCD} = \text{acos}\{\mathbf{uAPC_UP}\} \quad 0 \leq \mathbf{INCD} \leq 180$$

$$\mathbf{GRAZ} = 90 - \mathbf{INCD} \quad -90 \leq \mathbf{GRAZ} \leq 90$$

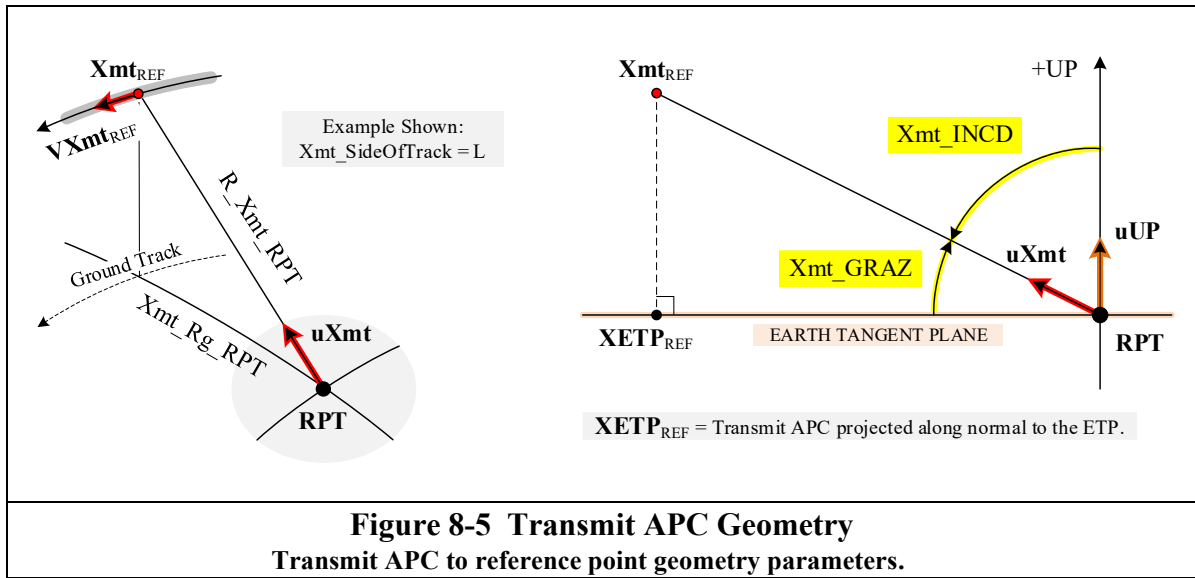


8.3.2 Transmit APC Parameters

For a CRSD:SAR or CRSD:TX product, compute the geometry parameters for the Transmit APC relative to the reference point RPT. The parameters are computed from the Transmit APC position and velocity, $\mathbf{Xmt}_{REF}$ and $\mathbf{VXmt}_{REF}$, and the reference point position, $\mathbf{RPT}$. The parameters shall be computed using the function defined in Section 8.3.1 or an equivalent method. The ENU unit basis vectors are computed using the reference point position $\mathbf{RPT}$ as specified in Section 8.2.

$$\left\{ \begin{matrix} \mathbf{Xmt}_{REF} \\ \mathbf{VXmt}_{REF} \end{matrix} \right\} + \left\{ \begin{matrix} \mathbf{RPT} \\ \mathbf{uEAST} \\ \mathbf{uNOR} \\ \mathbf{uUP} \end{matrix} \right\} \rightarrow \boxed{\text{APC to PT Geometry Parameters}} \rightarrow \left\{ \begin{matrix} R_Xmt_RPT \\ Rdot_Xmt_RPT \\ Xmt_Rg_RPT \\ Xmt_SideOfTrack \end{matrix} \right\} \left\{ \begin{matrix} \mathbf{uXmt} \\ \mathbf{uXmtDot} \\ Xmt_DCA \end{matrix} \right\} \left\{ \begin{matrix} Xmt_SQNT \\ Xmt_AZIM \\ Xmt_GRAZ \\ Xmt_INCD \end{matrix} \right\}$$

Shown in Figure 8-5 is an example transmit APC to RPT geometry for a left-looking collection. The unit vector $\mathbf{uXmt}$ points from the reference point toward the transmit APC position.



The parameters of the / CRSD / ReferenceGeometry / TxParameters branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

tx_{REF}	➔	XML: Time	seconds
$\mathbf{Xmt}_{REF}$	➔	XML: APCPos	meters
$\mathbf{VXmt}_{REF}$	➔	XML: APCVel	meters/sec
$Xmt_SideOfTrack$	➔	XML: SideOfTrack	
R_Xmt_RPT	➔	XML: SlantRange	meters

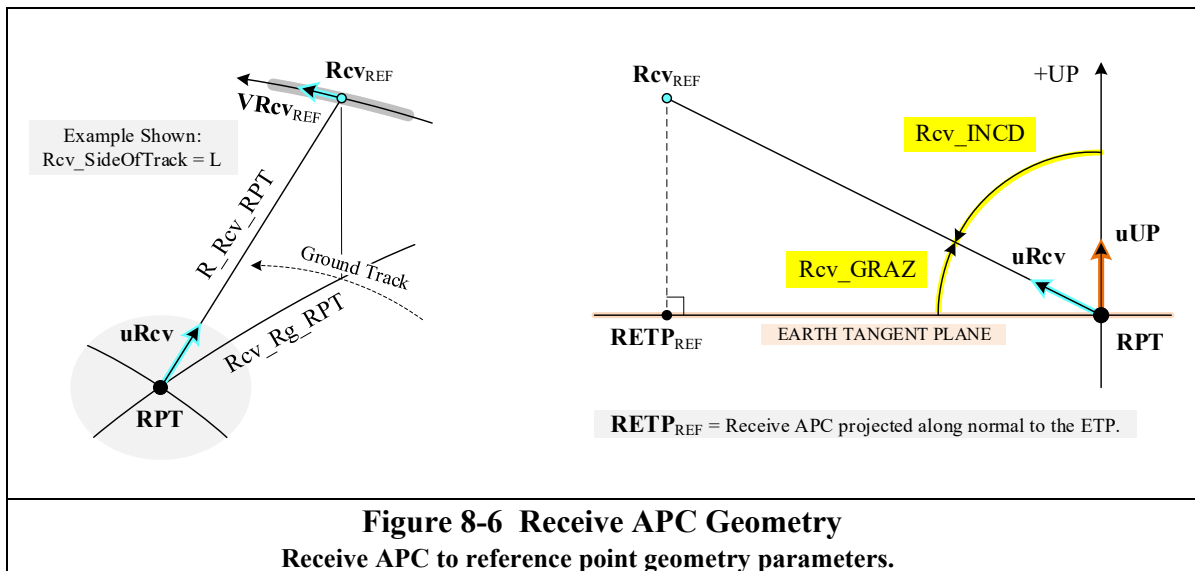
Xmt_Rg_RPT	➔	XML: GroundRange	meters
Xmt_DCA	➔	XML: DopplerConeAngle	degrees
Xmt_SQNT	➔	XML: SquintAngle	degrees
Xmt_AZIM	➔	XML: AzimuthAngle	degrees
Xmt_GRAZ	➔	XML: GrazeAngle	degrees
Xmt_INCD	➔	XML: IncidenceAngle	degrees

8.3.3 Receive APC Parameters

For a CRSD:SAR or CRSD:RCV product, compute the geometry parameters for the Receive APC relative to the reference point RPT. The parameters are computed from the Receive APC position and velocity, $\mathbf{Rcv}_{REF}$ and $\mathbf{VRcv}_{REF}$, and the reference point position, $\mathbf{RPT}$. The parameters shall be computed using the function defined in Section 8.3.1 or an equivalent method. The ENU unit basis vectors are computed using the reference point position $\mathbf{RPT}$ as specified in Section 8.2.

$$\left\{ \begin{matrix} \mathbf{Rcv}_{REF} \\ \mathbf{VRcv}_{REF} \end{matrix} \right\} + \left\{ \begin{matrix} \mathbf{RPT} \\ \mathbf{uEAST} \\ \mathbf{uNOR} \\ \mathbf{uUP} \end{matrix} \right\} \rightarrow \boxed{\text{APC to PT Geometry Parameters}} \rightarrow \left\{ \begin{matrix} R_Rcv_RPT \\ Rdot_Rcv_RPT \\ Rcv_Rg_RPT \\ Rcv_SideOfTrack \end{matrix} \right\} \begin{matrix} \mathbf{uRcv} \\ \mathbf{uRcvDot} \\ Rcv_DCA \end{matrix} \left\{ \begin{matrix} Rcv_SQNT \\ Rcv_AZIM \\ Rcv_GRAZ \\ Rcv_INCD \end{matrix} \right\}$$

Shown in Figure 8-6 is an example receive APC to RPT geometry for a left-looking collection. The unit vector $\mathbf{uRcv}$ points from the reference point toward the receive APC position.



The parameters of the / CRSD / ReferenceGeometry / RcvParameters branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

t_{SREF}	➔	XML: Time	seconds
$\mathbf{Rcv}_{\text{REF}}$	➔	XML: APCPos	meters
$\mathbf{VRcv}_{\text{REF}}$	➔	XML: APCVel	meters/sec
Rcv_SideOfTrack	➔	XML: SideOfTrack	
R_Rcv_RPT	➔	XML: SlantRange	meters
Rcv_Rg_RPT	➔	XML: GroundRange	meters
Rcv_DCA	➔	XML: DopplerConeAngle	degrees
Rcv_AZIM	➔	XML: AzimuthAngle	degrees
Rcv_GRAZ	➔	XML: GrazeAngle	degrees
Rcv_INCD	➔	XML: IncidenceAngle	degrees
Rcv_SQNT	➔	XML: SquintAngle	degrees

8.4 SAR Image Parameters

For a CRSD:SAR product, the parameters that specify the imaging geometry for the reference point are computed. The SAR image parameters are computed using parameters for the two APCs and the reference point position. The transmit APC parameters used are a subset of those computed in Section 8.3.2. The receive APC parameters used are a subset of those computed in Section 8.3.3.

8.4.1 Reference Time

The reference time, denoted t_{REF} , is the slow time that will be associated with the selected signal vector for image formation processing. The reference time is the approximate time the center of the selected transmit pulse was incident at the reference point.

(1) The reference time, t_{REF} , shall be computed as shown. The reference time in seconds relative to the CRT.

$$t_{\text{REF}} = t_{\text{XCREF}} + \left(\frac{R_{\text{Xmt_RPT}}}{R_{\text{Xmt_RPT}} + R_{\text{Rcv_RPT}}} \right) \cdot (t_{\text{SREF}} - t_{\text{XCREF}})$$

(2) Use the reference point position in image area coordinates, (RPT_IAX, RPT_IAY), to compute the COD time, t_COD_RPT , and the dwell time, T_Dwell_RPT . The COD time is in seconds relative to the CRT. The dwell time is in seconds. The COD time and dwell time shall be computed using the metadata specified for the reference receive channel. See Section 7.5.3. See Table 12-6.

$$t_COD_RPT = COD_Time(Ref_Ch_ID, RPT_IAX, RPT_IAY)$$

$$T_Dwell_RPT = Dwell_Time(Ref_Ch_ID, RPT_IAX, RPT_IAY)$$

Note: The value of t_COD_RPT may or may not be equal to the value of t_{REF} .

8.4.2 ARP to RPT Geometry

The SAR parameters are computed assuming the APC positions and velocities are for the Center of Aperture (COA) for an image pixel centered on the reference point. The pixel would have COA time equal to t_{REF} . The methods used account for the precise bistatic imaging geometry defined by the two APC positions and the reference point position. The ARP to RPT geometry parameters shall be computed as specified below or using an equivalent method.

(1) Compute the bistatic pointing vector, $\mathbf{bP}_{REF}$, and its derivative with respect to time, $\mathbf{bPDot}_{REF}$.

$$\mathbf{bP}_{REF} = \frac{1}{2} \cdot (\mathbf{uXmt}_{REF} + \mathbf{uRcv}_{REF})$$

$$\mathbf{bPDot}_{REF} = \frac{1}{2} \cdot (\mathbf{uXmtDot}_{REF} + \mathbf{uRcvDot}_{REF})$$

(2) Compute the magnitude of the pointing vector, bP_Mag , and the bistatic angle, $Bistat_Ang$. The bistatic angle is in radians and is on the interval $[0, \pi]$. See Figure 8-7.

$$bP_Mag = |\mathbf{bP}_{REF}| \quad Bistat_Ang = 2 \cdot \arccos(bP_Mag)$$

(3) Compute the bistatic angle rate, $Bistat_Ang_Rate$, equal to the derivative w.r.t. time of the bistatic angle. For the magnitude of the pointing vector equal to 0 or equal to 1, set the rate equal to zero. The bistatic angle rate is in radians/sec.

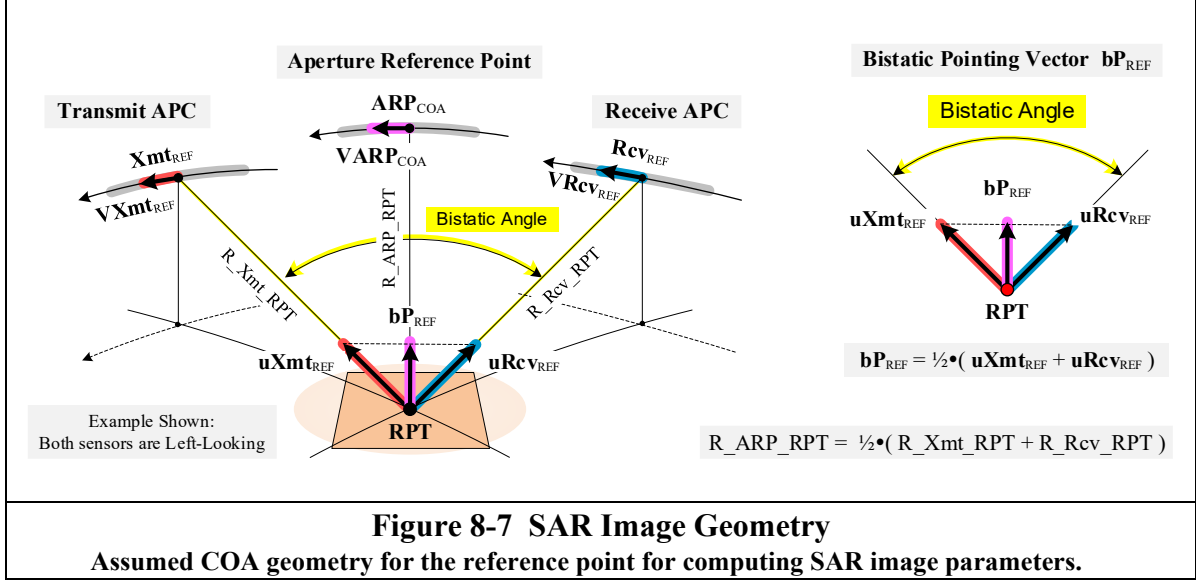
For $0 < bP_Mag < 1.0$:

$$Bistat_Ang_Rate = \left(\frac{-4}{\sin(Bistat_Ang)} \right) \cdot (\mathbf{bP}_{REF} \bullet \mathbf{bPDot}_{REF})$$

Else:

$$Bistat_Ang_Rate = 0$$

Note: In general, the derivative of the bistatic angle is undefined as the angle transitions through a value of 0 ($bP_Mag = 1.0$) or a value of π . ($bP_Mag = 0$).



(4) Compute Aperture Reference Point (ARP) position and velocity, $\mathbf{ARP}_{COA}$ and $\mathbf{VARP}_{COA}$, for the assumed COA geometry for the reference point. Refer to Figure 8-7. First compute the unit vector $\mathbf{uARP}$ and its derivative, $\mathbf{uARPDot}$.

For $bP_Mag > 0$:

$$\mathbf{uARP} = \frac{1}{bP_Mag} \cdot \mathbf{bP}_{REF}$$

$$\mathbf{uARPDot} = \frac{1}{bP_Mag} \cdot \{ \mathbf{bPDot}_{REF} - (\mathbf{bPDot}_{REF} \cdot \mathbf{uARP}) \cdot \mathbf{uARP} \}$$

$$R_ARP_RPT = \frac{1}{2} \cdot (R_Xmt_RPT + R_Rcv_RPT)$$

$$Rdot_Avg_RPT = \frac{1}{2} \cdot (Rdot_Xmt_RPT + Rdot_Rcv_RPT)$$

$$\mathbf{ARP}_{COA} = \mathbf{RPT} + R_ARP_RPT \cdot \mathbf{uARP}$$

$$\mathbf{VARP}_{COA} = Rdot_Avg_RPT \cdot \mathbf{uARP} + R_ARP_RPT \cdot \mathbf{uARPDot}$$

Else: $bP_Mag = 0$:

$$R_ARP_RPT = 0$$

$$Rdot_Avg_RPT = 0$$

$$\mathbf{ARP}_{COA} = \mathbf{RPT}$$

$$\mathbf{VARP}_{COA} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

For the $bP_Mag = 0$, the geometry does not support a SAR image of the ETP centered on the reference point. For such a condition, an ARP position is undefined.

- (5) Compute the unit vectors $\mathbf{uEC_ARP}$ and $\mathbf{uEC_RPT}$. Compute the position of point $\mathbf{AG_{COA}}$ located on the spherical earth model that contains the reference point. Position $\mathbf{AG_{COA}}$ is in ECEF coordinates with components in meters. See Figure 8-8.

$$\mathbf{RPT_DEC} = |\mathbf{RPT}| \quad \mathbf{uEC_RPT} = \frac{1}{\mathbf{RPT_DEC}} \cdot \mathbf{RPT}$$

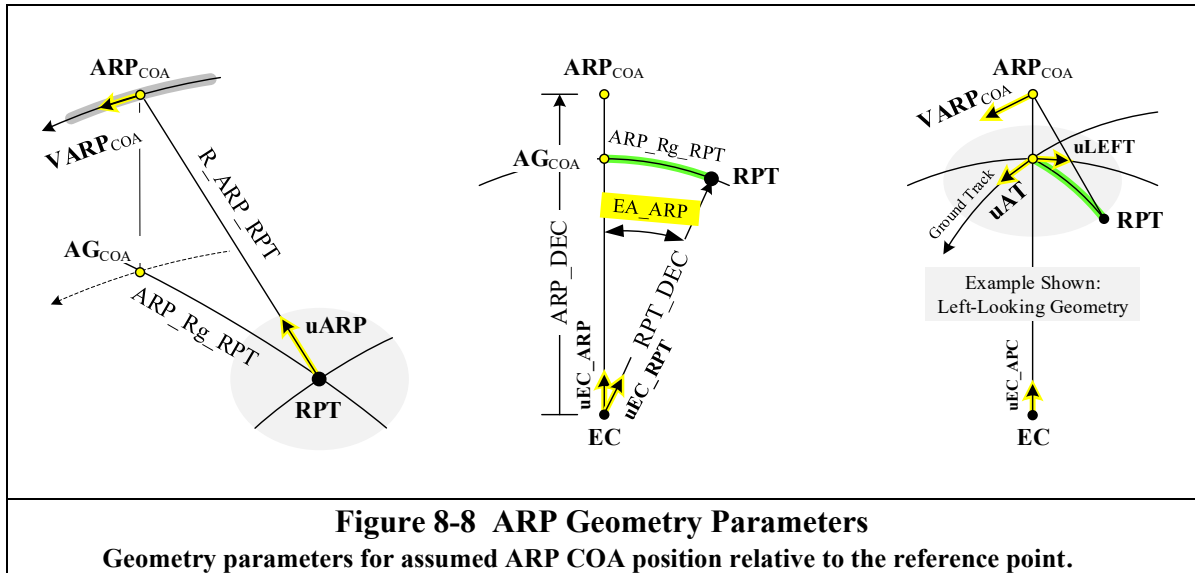
$$\mathbf{ARP_DEC} = |\mathbf{ARP_{REF}}| \quad \mathbf{uEC_ARP} = \frac{1}{\mathbf{ARP_DEC}} \cdot \mathbf{ARP}$$

$$\mathbf{AG_{COA}} = \mathbf{RPT_DEC} \cdot \mathbf{uEC_ARP}$$

- (6) The ground range to the reference point is the distance measured on the spherical earth model from $\mathbf{AG_{COA}}$ to $\mathbf{RPT}$. Compute the angle $\mathbf{EA_ARP}$ and the ground range $\mathbf{ARP_Rg_RPT}$. The angle $\mathbf{EA_ARP}$ is in radians and the ground range is in meters.

$$\mathbf{EA_ARP} = \text{acos}(\mathbf{uEC_ARP} \cdot \mathbf{uEC_RPT})$$

$$\mathbf{ARP_Rg_RPT} = \mathbf{RPT_DEC} \cdot \mathbf{EA_ARP}$$



- (7) The ARP ground track is defined by the ARP velocity vector projected onto the spherical earth model of radius $\mathbf{RPT_DEC}$. See Figure 8-8. Compute the along track component of the velocity vector, $\mathbf{VAT_{COA}}$. Also compute the magnitude, $\mathbf{VAT_M_{COA}}$.

$$\mathbf{VAT_{COA}} = \mathbf{VARP_{COA}} - \{ \mathbf{VARP_{COA}} \cdot \mathbf{uEC_ARP} \} \cdot \mathbf{uEC_ARP}$$

$$\mathbf{VAT_M_{COA}} = |\mathbf{VAT_{COA}}|$$

(8) Determine the Side of Track for the reference point relative to the ARP ground track. Unit vector **uLEFT** points to the left side of the ARP ground track. Note: For VAT_MCOA = 0 or for ARP_Rg_RPT = 0, the Side of Track is undefined.

If { VAT_MCOA = 0 or ARP_Rg_RPT = 0 } : Side of Track is undefined.

ARP_SideOfTrack = "L" Set to a default value.

Else: Determine the Side of Track.

$$\mathbf{uAT} = \frac{1}{\text{VAT_MCOA}} \bullet \mathbf{VAT_COA} \quad \mathbf{uLEFT} = \mathbf{uEC_ARP} \times \mathbf{uAT}$$

$$\text{ARP_SideOfTrack} = \begin{cases} \text{"L"}, & \mathbf{uLEFT} \bullet \mathbf{uARP} < 0 \\ \text{"R"}, & \text{otherwise} \end{cases}$$

(9) Compute the Doppler Cone Angle (DCA) between the ARP velocity vector and the line-of-sight (LOS) to the reference point. First, compute the magnitude of the velocity vector, VARP_M. Parameter VARP_M is in meters/sec. The ARP_DCA is in degrees on the range [0, 180].

$$\text{VARP_M} = | \mathbf{VAPC_REF} |$$

If { VARP_M = 0 } : ARP is fixed – set DCA to a default value.

$$\text{ARP_DCA} = 90.0$$

Else: Compute the DCA to the reference point.

$$\text{ARP_DCA} = \text{acos} \left\{ \frac{-\text{Rdot_Avg_RPT}}{\text{VARP_M}} \right\} \quad 0 \leq \text{ARP_DCA} \leq 180$$

(10) The ground squint angle, like the ground range, is measured on the spherical earth model that contains the reference point. Compute the ground squint angle to the reference point based on the angle off the normal to the ARP ground track. Refer to Figure 8-9. The squint angle, ARP_SQNT, is defined to be zero when the arc from AGCOA to the reference point is normal to the ground track. The squint angle is in degrees on the range [-90, 90].

If { VAT_MCOA = 0 or ARP_Rg_RPT = 0 } : Squint angle is undefined.

ARP_SQNT = 0 Set to a default value.

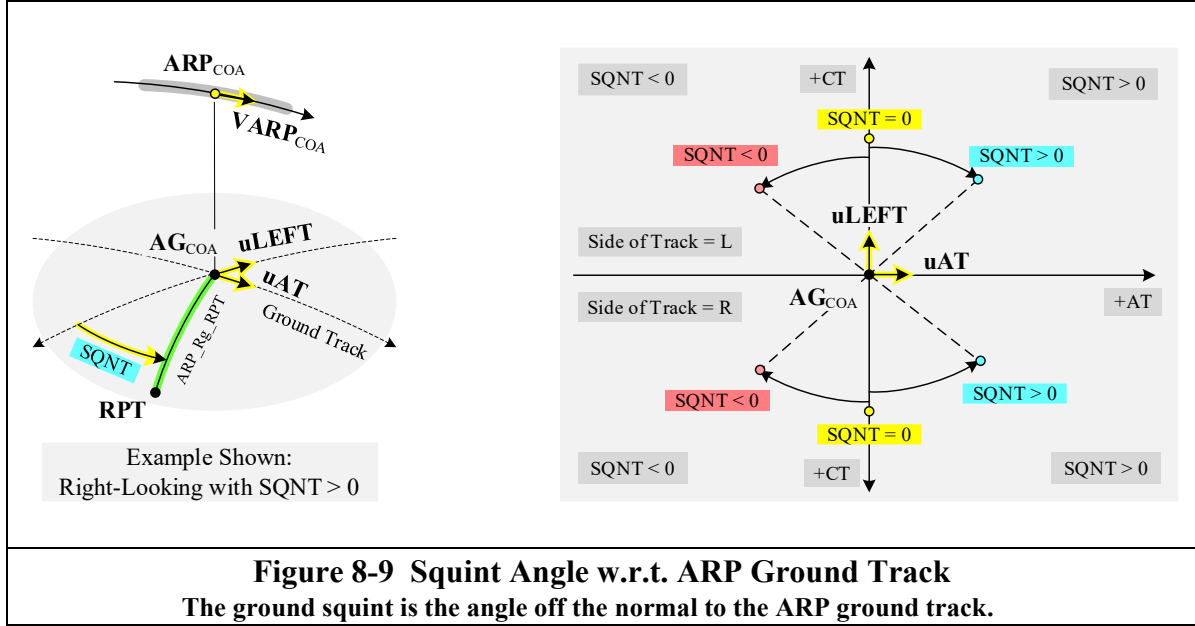
Else: Compute the squint angle.

$$\text{RPT_AT} = \mathbf{uAT} \bullet (\text{RPT} - \mathbf{AGCOA})$$

$$\text{RPT_CT} = | \mathbf{uLEFT} \bullet (\text{RPT} - \mathbf{AGCOA}) | \quad \text{Note: RPT_CT} \geq 0$$

$$\text{ARP_SQNT} = \text{atan} \left\{ \frac{\text{RPT_AT}}{\text{RPT_CT}} \right\} \quad -90 \leq \text{ARP_SQNT} \leq 90$$

Note: For a broadside, “non-squinted” geometry ($RPT_AT = 0$), the $ARP_SQNT = 0$. For “forward-looking” geometry, the $ARP_SQNT > 0$. For “aft-looking” geometry, the $ARP_SQNT < 0$.



(11) Use the bistatic pointing vector to define a Ground Plane Coordinate (GPC) system with origin at the reference point. The GPC system has components (GPX, GPY, GPZ). The GPX and GPY axes lie in the ETP at the reference point. The +GPZ axis is normal to the ETP. The +GPX axis is aligned with projection of the pointing vector $\mathbf{bP}_{REF}$ into the ETP.

$$\mathbf{uGPZ} = \mathbf{uUP}$$

$$\mathbf{bP_GPZ} = \mathbf{bP}_{REF} \bullet \mathbf{uGPZ}$$

$$\mathbf{bP_ETP} = \mathbf{bP}_{REF} - \mathbf{bP_GPZ} \bullet \mathbf{uGPZ}$$

$$\mathbf{bP_GPX} = |\mathbf{bP_ETP}|$$

For $\mathbf{bP_GPX} = 0$, the geometry does not support a SAR image of the ETP centered on the reference point. For such a condition, set the following angles equal to zero.

For $\mathbf{bP_GPX} = 0$:

$$ARP_AZIM = 0$$

$$ARP_TWST = 0$$

$$ARP_GRAZ = 90$$

$$ARP_SLOPE = 0$$

$$ARP_INCD = 0$$

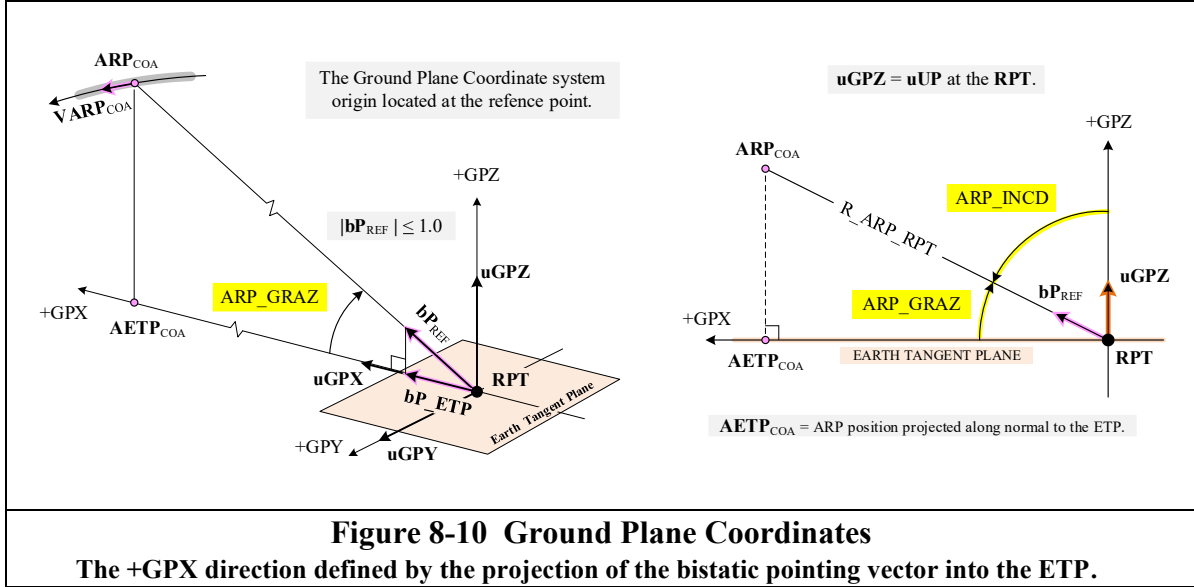
$$ARP_LO_DIR = 0$$

For $\mathbf{bP_GPX} > 0$, compute the angles as specified in the steps (12) through (20) below.

- (12) Compute unit vectors $\mathbf{uGPX}$ and $\mathbf{uGPY}$ that lie in the ETP. The unit vectors are in ECEF coordinates. Refer Figure 8-10.

$$\mathbf{uGPX} = \frac{1}{bP_GPX} \bullet bP_ETP$$

$$\mathbf{uGPY} = \mathbf{uGPZ} \times \mathbf{uGPX}$$



- (13) Compute the ENU components of the of the unit vector $\mathbf{uARP}$ that points from reference point to the ARP.

$$uARP_E = \mathbf{uEAST} \bullet \mathbf{uARP}$$

$$uARP_N = \mathbf{uNOR} \bullet \mathbf{uARP}$$

$$uARP_U = \mathbf{uUP} \bullet \mathbf{uARP}$$

- (14) Compute the azimuth angle to the ARP position projected into the ETP. The point in the ETP is denoted $\mathbf{AETP}_{COA}$. The azimuth angle, ARP_AZIM , is measured CW from North toward East and is in degrees.

$$ARP_AZIM = \text{atan2}\{uARP_E / uARP_N\} \quad 0 \leq ARP_AZIM < 360 \text{ deg}$$

- (15) Compute the incidence angle, ARP_INCD , and the grazing angle, ARP_GRAZ , for the LOS from the ARP to the reference point. The incidence angle is in degrees on the range [0,180]. The grazing angle is in degrees on the range [-90, 90]. See Figure 8-9.

$$ARP_INCD = \text{acos}\{uARP_U\}$$

$$0 \leq ARP_INCD \leq 180$$

$$ARP_GRAZ = 90 - ARP_INCD$$

$$-90 \leq ARP_GRAZ \leq 90$$

(16) Compute the projection of the derivative of the pointing vector, $\mathbf{bPDotREF}$, onto the +GPY direction, $\mathbf{bPDot_GPY}$.

$$\mathbf{bPDot_GPY} = \mathbf{bPDotREF} \bullet \mathbf{uGPY}$$

For $\mathbf{bPDot_GPY} = 0$, the collection geometry does not support a SAR image of the ETP centered on the reference point. For such a condition, set the following angles equal to zero.

For $\mathbf{bPDot_GPY} = 0$:

$$\text{ARP_TWST} = 0 \quad \text{ARP_SLOPE} = 0 \quad \text{ARP_LO_DIR} = 0$$

For $\mathbf{bPDot_GPY} \neq 0$, compute the angles as specified in the steps (17) through (20) below.

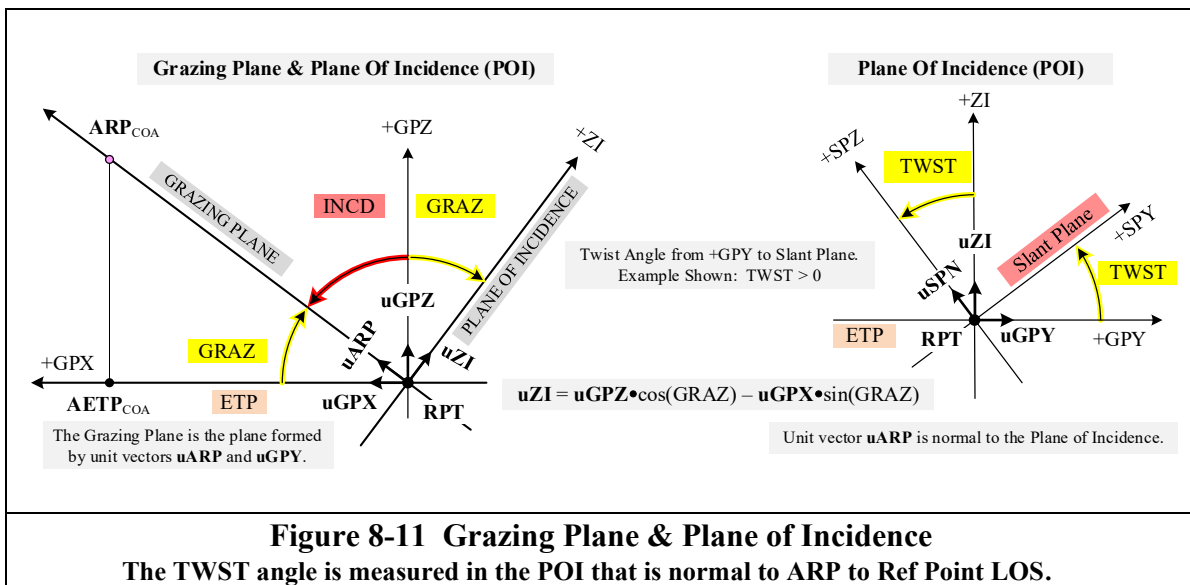
(17) Compute the bistatic slant plane unit normal, denoted $\mathbf{uSPN}$. The bistatic slant plane is the plane formed by the bistatic pointing vector and its derivative. Choose the SGN parameter to ensure the $\mathbf{uSPN}$ points “upward”.

$$\text{SGN} = \begin{cases} +1, & \text{if } \mathbf{bPDot_GPY} > 0 \\ -1, & \text{otherwise} \end{cases} \quad \mathbf{SPN} = \text{SGN} \bullet \{ \mathbf{bPREF} \times \mathbf{bPDotREF} \}$$

$$\mathbf{uSPN} = \frac{1}{|\mathbf{SPN}|} \bullet \mathbf{SPN}$$

(18) The twist angle is the measured in the Plane of Incidence (POI) at the reference point. See Figure 8-11. The twist angle is the angle between the ETP and the bistatic slant plane. Compute the twist angle, ARP_TWST , as shown. The angle is in degrees and on the range $(-90, 90)$.

$$\text{ARP_TWST} = -\arcsin\{ \mathbf{uSPN} \bullet \mathbf{uGPY} \} \quad -90 < \text{ARP_TWST} < 90$$



(19) The slope angle is the angle between the bistatic slant plane and the ETP. Compute the slope angle, ARP_SLOPE, as shown. The angle is in degrees on the range [0, 90).

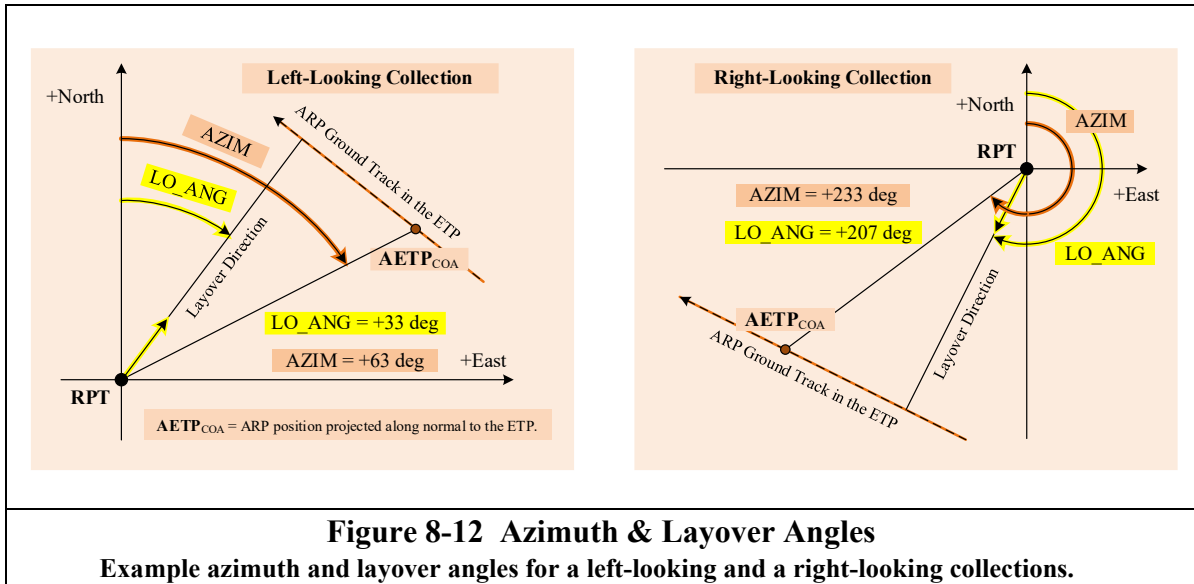
$$\text{ARP_SLOPE} = \arccos\{ \mathbf{uSPN} \bullet \mathbf{uGPZ} \} \quad 0 \leq \text{ARP_SLOPE} < 90$$

(20) The layover direction is the direction elevated targets will be displaced (or “laid over”) in the ETP. The layover angle is the angle from north at the reference point to the layover direction. Compute the layover angle, ARP_LO_ANG, as shown. The layover angle is in degrees and is on the interval [0, 360). See Figure 8-12.

$$\text{LO_E} = -\mathbf{uEAST} \bullet \mathbf{uSPN}$$

$$\text{LO_N} = -\mathbf{uNOR} \bullet \mathbf{uSPN}$$

$$\text{ARP_LO_ANG} = \text{atan2}\left\{ \frac{\text{LO_E}}{\text{LO_N}} \right\} \quad 0 \leq \text{ARP_LO_ANG} < 360 \text{ deg}$$



8.4.3 SAR XML Parameters

The parameters of the / CRSDsar / ReferenceGeometry / SARImage branch of the XML are assigned as shown. The units of the XML parameters are also listed for convenience.

$t_{\text{COD_RPT}}$	➔	XML: CODTime	seconds
$T_{\text{Dwell_RPT}}$	➔	XML: DwellTime	seconds
t_{REF}	➔	XML: ReferenceTime	seconds
ARP_{COA}	➔	XML: ARPPos	meters
VARP_{COA}	➔	XML: ARPVel	meters/sec

Bistat_Ang•(180/π)	➔	XML: BistaticAngle	degrees
Bistat_Ang_Rate•(180/π)	➔	XML: BistaticAngleRate	deg/sec
ARP_SideOfTrack	➔	XML: SideOfTrack	
R_ARP_RPT	➔	XML: SlantRange	meters
ARP_Rg_RPT	➔	XML: GroundRange	meters
ARP_DCA	➔	XML: DopplerConeAngle	degrees
ARP_SQNT	➔	XML: SquintAngle	degrees
ARP_AZIM	➔	XML: AzimuthAngle	degrees
ARP_GRAZ	➔	XML: GrazeAngle	degrees
ARP_INCD	➔	XML: IncidenceAngle	degrees
ARP_TWST	➔	XML: TwistAngle	degrees
ARP_SLOPE	➔	XML: SlopeAngle	degrees
ARP_LO_ANG	➔	XML: LayoverAngle	degrees

9 Antenna Parameters

For all CRSD products, parameters that specify the antenna(s) used on transmit and/or on receive are provided. The antenna parameters are provided to support the subsequent processing and analysis by the applications that input the CRSD product. For a given transmit sequence, the transmit antenna parameters may be used to compute the relative power levels of the transmit signals incident at the illuminated scene. For a given receive channel, the receive antenna parameters may be used to compute the relative power levels received as function of pointing direction. The computed receive signal levels are used in both SAR image formation processing and in characterizing signals received from active emitters located in or near the imaged scene.

The antenna beam shape pattern may be used to compute absolute power levels as well as relative power levels. For each transmit pulse, the transmit radiant intensity (dBW/sr) is provided for a beam shape gain $G_{XBS} = 0$ dB. The transmit beam shape pattern may then be used to compute the transmit radiant intensity for a selected pointing direction. For each receive data channel, a scale factor is provided that relates digital signal power to received irradiance (dBW/m²) for a beam shape gain $G_{RBS} = 0$ dB. The receive beam shape pattern may then be used to compute the scale factor that relates digital signal power to received irradiance for a selected pointing direction.

For an antenna used on transmit and/or receive, the CRSD metadata structure uses the following constructs to specify the antenna pointing and beam shape versus time during the event.

- (1) Antenna Coordinate Frame (ACF): An ACF is defined for each antenna and is used to specify its orientation vs. time. The ACF is fixed with respect to the physical structure of the antenna. The ACF is a right-handed coordinate frame with coordinates (ACX, ACY, ACZ). The +ACZ axis is referred to as the mechanical boresight of the antenna.
- (2) Antenna Phase Center (APC): An APC is a single point that is the effective point source for transmitted pulses and/or the effective point of reception for received signals. Each APC is specified at a fixed position in the ACF of one antenna.
- (3) Electrical Boresight (EB) Steering Vector: An EB steering vector (SV) specifies the mainlobe pointing direction of the antenna beam shape pattern. The EB SV is specified relative to the ACF. For a mechanically steered antenna, the EB SV is specified to be aligned with the +ACZ axis.
- (4) Antenna Pattern (APAT): An APAT specifies a one-way beam shape gain pattern and phase pattern as a function of selected pointing direction and EB SV. The pointing direction is specified relative to the ACF. Each APAT also specifies a set of polarization parameters that may be used to compute the polarization orientation on transmit and receive.

For all CRSD products, the antennas used during the event are described in the XML instance. The ACFs, APCs, and APATs are specified in the / CRSDxx /Antenna branch. See

Table 12-12. For each transmit pulse sequence, the APC and APAT used are specified. See Table 12-5. For each receive channel, the APC and APAT used are specified. See Table 12-6. The parameters that vary with time are provided in the PPP array for each transmit pulse sequence and the PVP array for each receive data channel. See Table 4-2 and Table 4-4.

9.1 Antenna Orientation, Position, & Velocity

The parameters that vary with time are provided for each transmit pulse and for each receive signal vector. The parameters provided are the ACF orientation, APC position and velocity, and EB SV.

9.1.1 ACF Orientation Parameters

For many antennas, the ACF may be aligned to the mechanical frame that was used to build and characterize the antenna. The ACX and ACY axes are in the “plane” of the antenna. For a mechanically steered antenna, the +ACZ axis is nominally aligned with the peak of the mainlobe of the antenna pattern. For an electronically steered antenna, the +ACZ axis is nominally aligned with the center of the field of regard that may be scanned by the EB SV.

The following guidance is provided for populating and using the ACF orientation parameters included in all products.

- (1) The ACF orientation relative to the ECEF coordinate frame at a given time t is specified by the unit vectors $\mathbf{uACX}(t)$ and $\mathbf{uACY}(t)$. The unit vector $\mathbf{uACZ}(t)$ is computed from the cross product:

$$\mathbf{uACZ}(t) = \mathbf{uACX}(t) \times \mathbf{uACY}(t)$$

- (2) At time t , the transformation matrix from the ACF to the ECEF frame, $T_{ACF}^{ECEF}(t)$, is formed from the unit basis vectors.

$$T_{ACF}^{ECEF}(t) = [\mathbf{uACX}(t) \quad \mathbf{uACY}(t) \quad \mathbf{uACZ}(t)]$$

The transformation matrix from the ECEF frame to the ACF, $T_{ECEF}^{ACF}(t)$, is formed by the transpose of matrix T_{ACF}^{ECEF} .

$$T_{ECEF}^{ACF}(t) = [T_{ACF}^{ECEF}(t)]^T$$

- (3) For each transmit pulse p , the transmit ACF basis vectors at the transmit pulse center time $txc(p)$, $\mathbf{uACX}(txc(p))$ and $\mathbf{uACY}(txc(p))$, are specified in the PPP array.
- (4) For each receive signal vector v , the receive ACF basis vectors at the receive start time $trs(v)$, $\mathbf{uACX}(trs(v))$ and $\mathbf{uACY}(trs(v))$, are provided in the PVP array.
- (5) For any pulse or signal vector, the pair of vectors $\mathbf{uACX}(t)$ and $\mathbf{uACY}(t)$ are to meet the following conditions subject to the finite precision of the binary format used:

$$|\mathbf{uACX}(t)| = 1 \quad |\mathbf{uACY}(t)| = 1 \quad \mathbf{uACX}(t) \bullet \mathbf{uACY}(t) = 0$$

Applications that input a CRSD product are not expected to orthonormalize the pair of vectors prior to computing $\mathbf{uACZ}(t)$.

9.1.2 APC Parameters

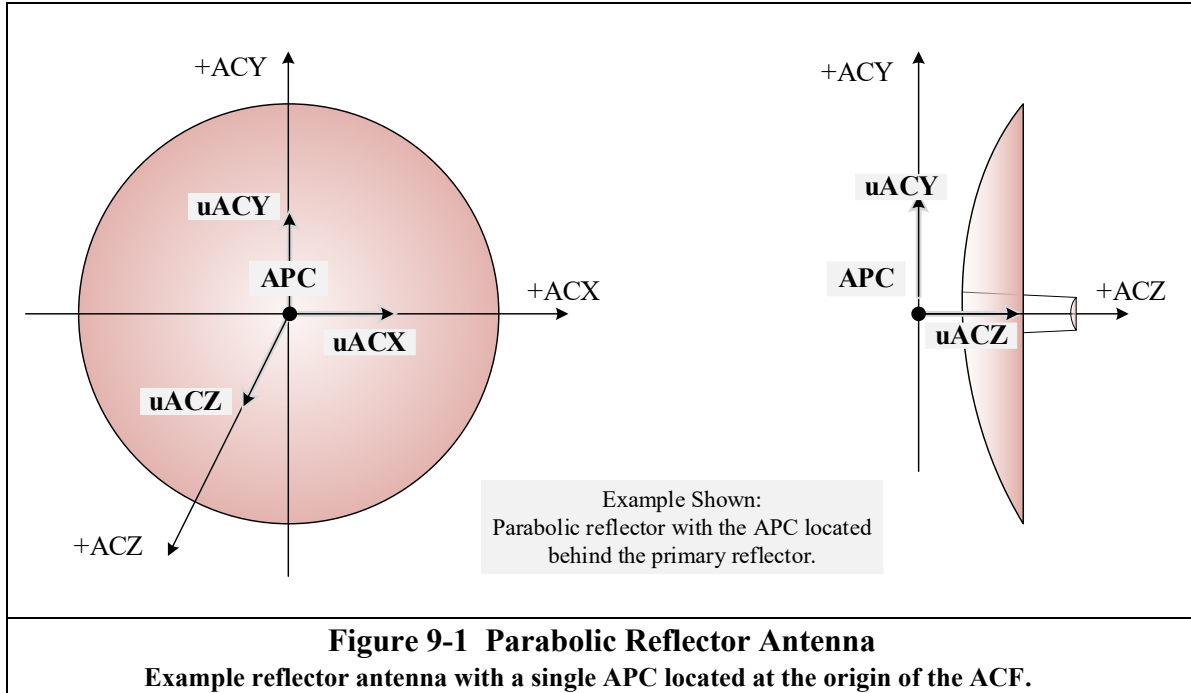
For each physical antenna used during an event, one or more APCs are defined and assigned to the antenna. Each APC is assigned a unique APC identifier (APC_ID). For a given transmit pulse sequence, all pulses are transmitted using a single APC. For a given receive data channel, all signal data is received using a single APC.

- (1) Each APC is assigned to one antenna via the ACF_ID value. The APC is specified to be located at a fixed point in the ACF of the assigned antenna. See Table 12-9, /AntPhaseCenter/APCXYZ.
- (2) For antennas with multiple APCs, the APC positions in the ACF provide a simple method for specifying the precise baseline between any pair of APCs.
- (3) For an antenna with only a single APC assigned to it, the APC position may be set to any point relative to the ACF origin. A design choice to set the position equal to the ACF origin is the recommended choice.
- (4) For a given transmit pulse sequence, the TxAPC_ID identifies the APC used. See Table 12-5. For each transmit pulse p , the transmit APC position and velocity at the transmit pulse center time $txc(p)$ are specified in the PPP array.
- (5) For a given receive channel, the RcvAPC_ID identifies the APC used. See Table 12-6. For each receive signal vector v , the receive APC position and velocity at the receive start time $trs(v)$ are specified in the PVP array.

9.1.3 Example ACF & APC Configurations

The following examples demonstrate use of the ACF and APC parameters for various antenna types and collection configurations.

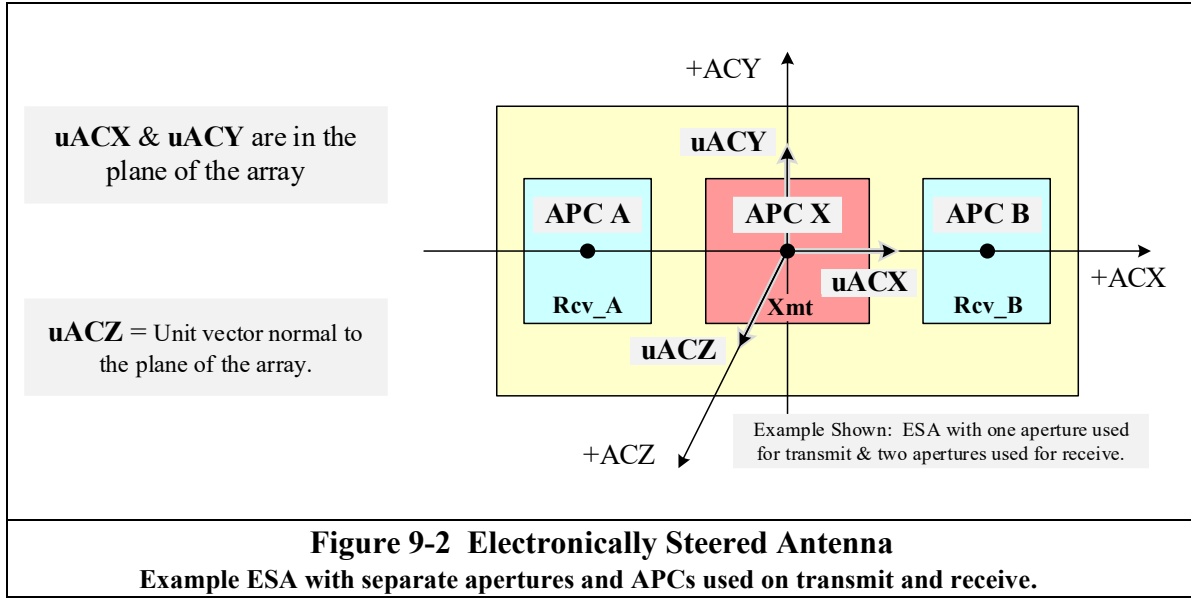
Consider a SAR imaging collection that uses a single antenna and a single APC for both transmit and receive. Shown in Figure 9-1 is an example parabolic reflector antenna with a single APC located slightly behind the primary reflector. For the example shown, the APC is located at the origin of the ACF. The antenna beam shape pattern is fixed relative to the ACF with the mainlobe nominally centered on the +ACZ axis. The antenna beam shape pointing is controlled via the ACF orientation to point the +ACZ axis toward the imaged scene. This type of antenna is referred to as a “mechanically steered” antenna.



The CRSD:SAR product XML metadata instance includes the following parameters. All transmit sequences and all receive channels reference the one APC and, indirectly, the one ACF. In the example shown, the product was formed with one transmit sequence and one receive data channel.

Antenna	TxSequence/Parameters
NumACFs = 1	Identifier = "TxSeq_1"
NumAPCs = 1	TxAPCId = "APC_0"
AntCoordFrame	•
Identifier = "RFLR"	•
AntPhaseCenter	Channel/Parameters
Identifier = "APC_0"	Identifier = "RcvCh_1"
ACFId = "RFLR"	RcvAPCId = "APC_0"
APCXYZ = [0 0 0] ^T	•

Consider a SAR imaging collection that uses a single antenna with separate APCs for transmit and for receive. Shown in Figure 9-2 is an example of an electronically steered antenna (ESA) with a single transmit APC and two separate receive APCs. For an ESA, the antenna beam shape pointing is controlled via the combination of the ACF orientation and an electrical steering vector for each aperture. For the example shown, the transmit APC is located at the ACF origin and the two receive APCs are located on the ACX axis at equal distances from the origin.. Also shown is the transmit aperture (in red) and the two receive apertures (in blue).

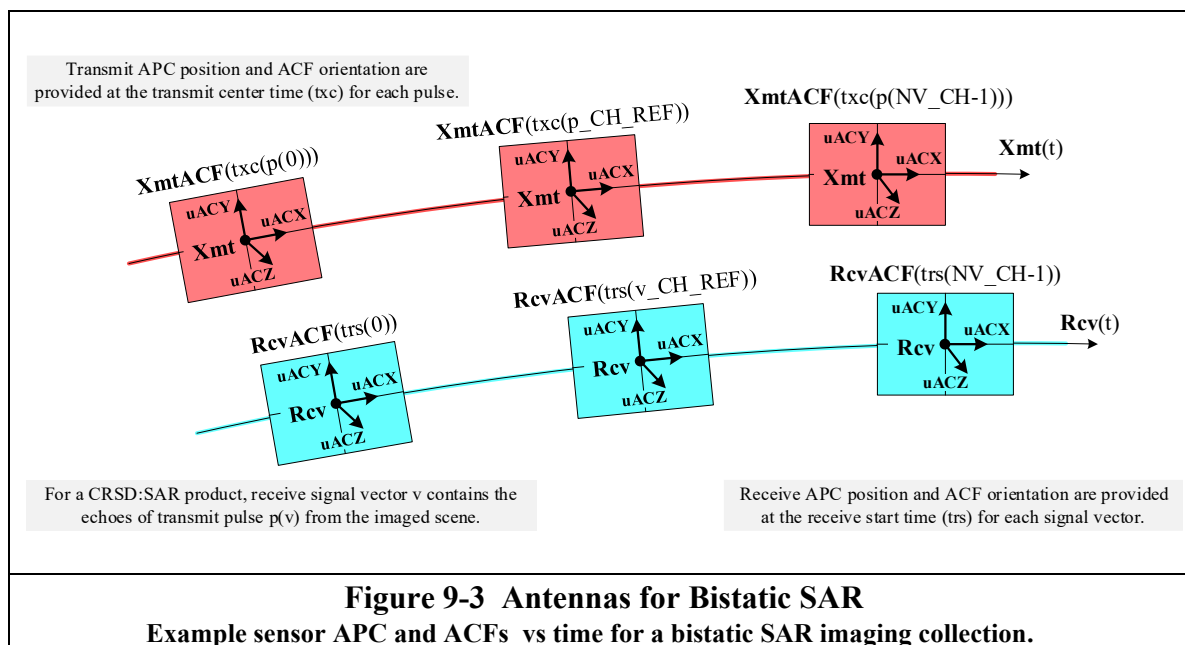


The CRSD:SAR product XML metadata instance includes the following parameters. Refer to Figure 9-2. In the example shown, the product was formed with one transmit sequence and contains two receive channels. The transmit APC ID is “X” and the receive APC IDs are “A” and “B”. For the example shown, the APC spacing along the ACX axis is 2.0 meters.

Antenna	TxSequence/Parameters
NumACFs = 1	Identifier = “TxSeq_1”
NumAPCs = 3	TxAPCId = “X”
AntCoordFrame	•
Identifier = “ESA”	•
AntPhaseCenter	Channel/Parameters
Identifier = “X”	Identifier = “RcvCh_A”
ACFId = “ESA”	RcvAPCId = “A”
APCXYZ = [0 0 0] ^T	•
AntPhaseCenter	Channel/Parameters
Identifier = “A”	Identifier = “RcvCh_B”
ACFId = “ESA”	RcvAPCId = “B”
APCXYZ = [-2.0 0 0] ^T	•
AntPhaseCenter	
Identifier = “B”	
ACFId = “ESA”	
APCXYZ = [2.0 0 0] ^T	

Consider a bistatic SAR imaging collection using two similar radar sensors flying along approximately parallel trajectories. The transmit sensor illuminates the imaged scene with a single transmit pulse sequence using a single transmit APC. The receive sensor uses a single APC to receive the echoes of the transmit pulses from the imaged scene. Shown in Figure 9-3 is an example of such a collection. The transmit sensor antenna is shown in red. The receive sensor antenna is shown in blue. The transmit APC position vs. time is denoted

$\mathbf{Xmt}(t)$ and the receive APC position vs. time is denoted $\mathbf{Rcv}(t)$. See Section 4.1, Table 4-2, and Table 4-4. The receive antenna is shown at time $\text{trs}(v)$ for three signal vectors. The transmit antenna is shown at time $\text{txc}(p)$ for the three pulses associated with the three signal vectors. Refer to Figure 4-1.



For the example shown in Figure 9-3, a CRSD:SAR product is formed that specifies a single transmit sequence and contains a single receive data channel. The XML metadata instance includes the following parameters. The /CRSDsar/Antenna branch specifies two ACFs and two APCs. The transmit sequence references the transmit APC and indirectly the transmit ACF. The receive channel references the receive APC and indirectly the receive ACF

Antenna	TxSequence/Parameters
NumACFs = 2	Identifier = "TxSeq_0"
NumAPCs = 2	TxAPCId = "XmtAPC"
AntCoordFrame	•
Identifier = "XmtACF"	•
AntCoordFrame	•
Identifier = "RcvACF"	•
AntPhaseCenter	Channel/Parameters
Identifier = "XmtAPC"	Identifier = "RcvCh_0"
ACFId = "XmtACF"	RcvAPCId = "RcvAPC"
APCXYZ = [0 0 0] ^T	•
AntPhaseCenter	•
Identifier = "RcvAPC"	•
ACFId = "RcvACF"	•
APCXYZ = [0 0 0] ^T	•

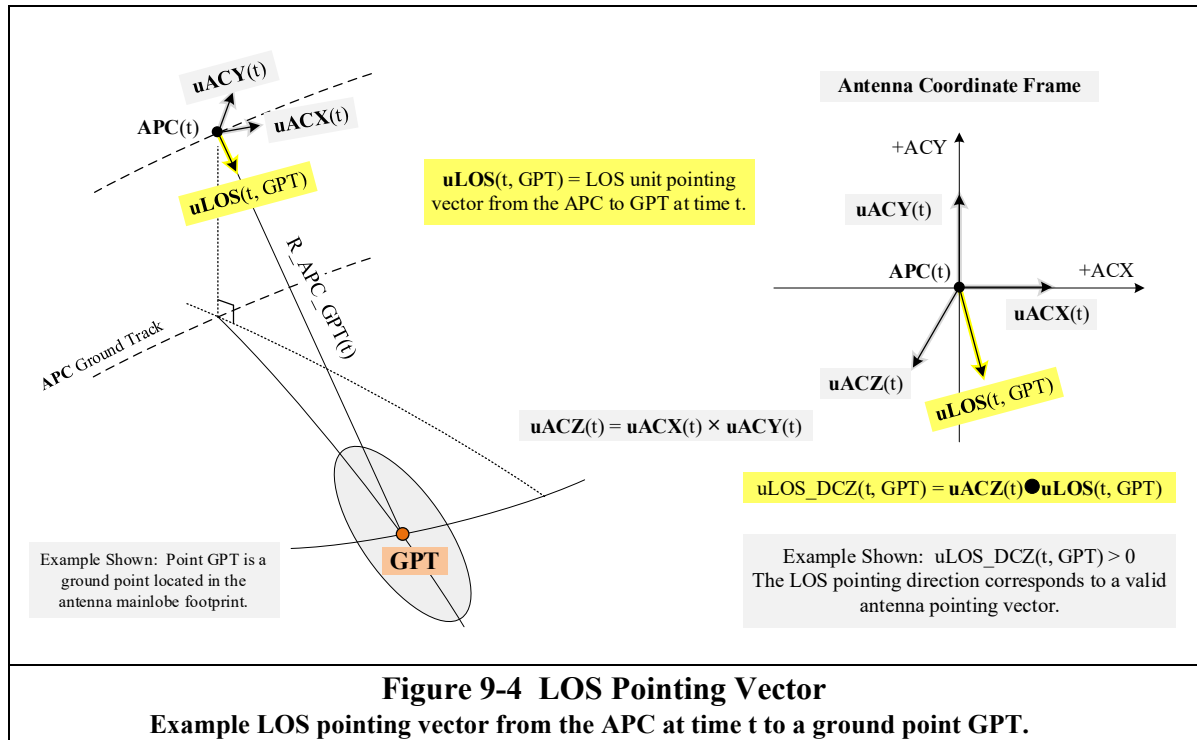
9.2 Pointing Vectors

The methods for computing antenna beam shape and polarization parameters make use of the APC position and ACF orientation. They also make use of several types of pointing vectors. A pointing vector is a unit vector that points from the APC in given direction. The types of pointing vectors are defined below. At a given time t , the APC position is $\mathbf{APC}(t)$ and the ACF unit vectors are $\mathbf{uACX}(t)$, $\mathbf{uACY}(t)$, and $\mathbf{uACZ}(t)$.

9.2.1 LOS Pointing Vectors

A line-of-sight (LOS) pointing vector is a unit vector that points from the APC in any arbitrary direction. An LOS pointing vector in ECEF coordinates is denoted $\mathbf{uLOS}$. For the APC at time t , the LOS direction may be computed for an arbitrary point GPT displaced from the APC. The LOS vector from the APC at time t to point GPT is denoted $\mathbf{uLOS}(t, \text{GPT})$. The LOS pointing vector is computed as follows. Let $\mathbf{GPT}$ denote the position of point GPT. See Figure 9-4. All vectors are in ECEF coordinates. Components of $\mathbf{APC}(t)$ and $\mathbf{GPT}$ are in meters.

$$R_APC_GPT(t) = |\mathbf{GPT} - \mathbf{APC}(t)| \quad \mathbf{uLOS}(t, \text{GPT}) = \frac{1}{R_APC_GPT(t)} \cdot (\mathbf{GPT} - \mathbf{APC}(t))$$



The LOS pointing vector expressed in the antenna coordinates, denoted $\mathbf{uLOS_ACF}(t, \text{GPT})$, may be computed using the ACF basis vectors or the matrix $T_{ECEF}^{ACF}(t)$ defined in terms of them. See Section 9.1.1 above.

$$\mathbf{uLOS_ACF}(t, \text{GPT}) = \begin{bmatrix} \text{uLOS_DCX}(t, \text{GPT}) \\ \text{uLOS_DCY}(t, \text{GPT}) \\ \text{uLOS_DCZ}(t, \text{GPT}) \end{bmatrix} = \mathbf{T}_{\text{ECEF}}^{\text{ACF}}(t) \bullet \mathbf{uLOS}(t, \text{GPT})$$

For unit vectors in antenna coordinates, the components are denoted using DCX, DCY, and DCZ. The components are the “direction cosines” of the LOS pointing vector relative to the axes of the ACF.

9.2.2 Antenna Pointing Vectors

An antenna pointing vector is a unit vector that, when expressed in antenna coordinates, has a positive DCZ component. An antenna pointing vector points from the APC to the “front side” of the ACX x ACY plane. For any antenna pointing vector, the DCZ component may be computed from the DCX and DCY components. For an antenna pointing vector expressed in antenna coordinates, denoted $\mathbf{uAP}$, the DCZ component may be computed as shown.

$$\mathbf{uAP} = \begin{bmatrix} \text{AP_DCX} \\ \text{AP_DCY} \\ \text{AP_DCZ} \end{bmatrix} \quad \text{AP_DCZ} = +\{1 - \text{AP_DCX}^2 - \text{AP_DCY}^2\}^{1/2}$$

In the methods used to compute antenna beam shape gain and phase, an antenna pointing vector may be denoted $\mathbf{AP}$ and will only include the DCX and DCY components.

$$\mathbf{uAP} = \begin{bmatrix} \text{AP_DCX} \\ \text{AP_DCY} \\ \text{AP_DCZ} \end{bmatrix} \Leftrightarrow \mathbf{AP} = \begin{bmatrix} \text{AP_DCX} \\ \text{AP_DCY} \end{bmatrix}$$

For the example LOS pointing vector shown in Figure 9-4, with positive DCZ component ($\text{uLOS_DCZ}(t, \text{GPT}) > 0$), the corresponding antenna pointing vector may be formed from the DCX and DCY components.

$$\mathbf{AP}(t, \text{GPT}) = \begin{bmatrix} \text{AP_DCX}(t, \text{GPT}) \\ \text{AP_DCY}(t, \text{GPT}) \end{bmatrix} = \begin{bmatrix} \text{uLOS_DCX}(t, \text{GPT}) \\ \text{uLOS_DCY}(t, \text{GPT}) \end{bmatrix}$$

9.2.3 EB Steering Vectors

An EB steering vector is an antenna pointing vector that specifies the mainlobe pointing direction of the antenna beam shape pattern. The EB SV may vary for each transmit pulse and/or for each receive signal vector. The EB SV parameters provided in a CRSD product have the following attributes.

- (1) An EB SV is specified in ACF coordinates using a pair of direction cosines EB_DCX and EB_DCY. An EB SV may be denoted as an antenna pointing vector with two components or as a unit vector in ACF coordinates.

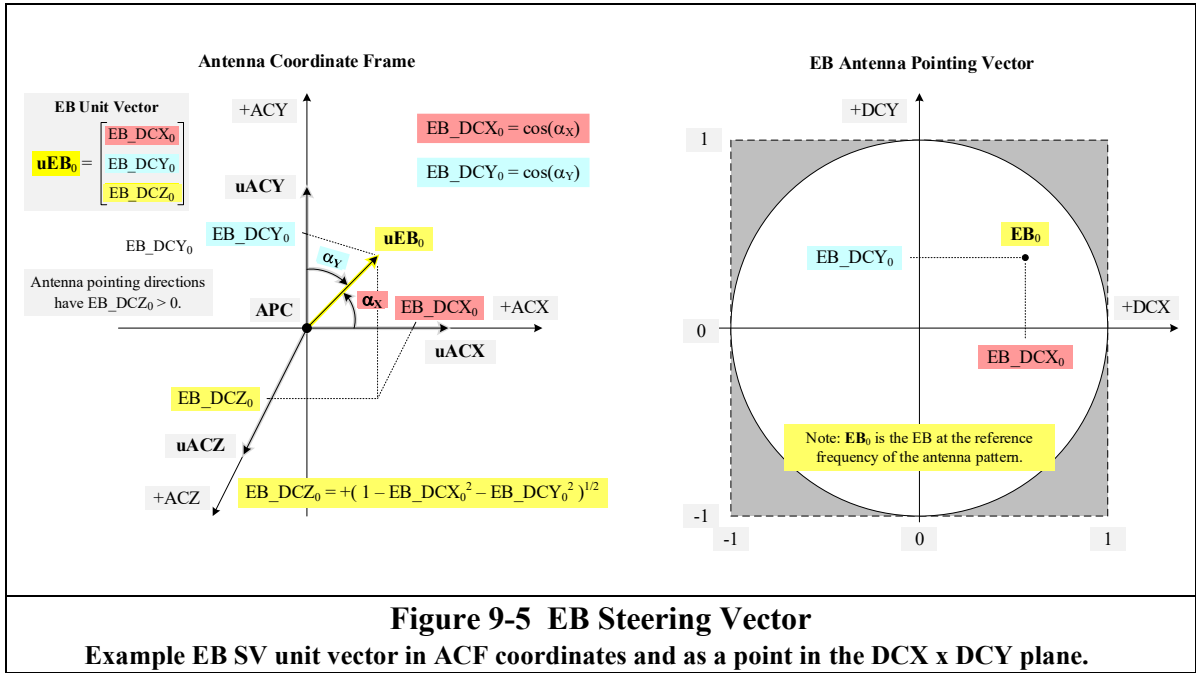
$$\mathbf{EB} = \begin{bmatrix} \mathbf{EB_DCX} \\ \mathbf{EB_DCY} \end{bmatrix} \Leftrightarrow \mathbf{uEB} = \begin{bmatrix} \mathbf{EB_DCX} \\ \mathbf{EB_DCY} \\ \mathbf{EB_DCZ} \end{bmatrix}$$

- (2) For an ESA, the EB SV may vary with both time and frequency. At a given time t and frequency f , the EB SV is denoted as follows.

$$\mathbf{EB}(t, f) = \begin{bmatrix} \mathbf{EB_DCX}(t, f) \\ \mathbf{EB_DCY}(t, f) \end{bmatrix}$$

- (3) The EB SV value specified in a PPP array or a PVP array is the value at the reference frequency specified in the APAT parameter set. The EB value at the reference frequency, denoted f_{a_0} , is denoted $\mathbf{EB}_0(t) = \mathbf{EB}(t, f_{a_0})$. See Figure 9-5.
- (4) The EB SV at a given time may “shift” as a function of frequency. The shift as a function of frequency is computed using the EB Frequency Shift parameters specified in the APAT parameter set. See Section 9.2.4.
- (5) For each transmit pulse, the EB SV specified in the PPP array is the value at the $f = f_{a_0}$ for the antenna pattern specified for the transmit pulse sequence (TxAPAT_ID). For pulse p , the EB SV is at time $t = t_{xc}(p)$ and is denoted as shown.

$$\mathbf{Xmt_EB}_0(p) = \begin{bmatrix} \mathbf{Xmt_EB_DCX}_0(p) \\ \mathbf{Xmt_EB_DCY}_0(p) \end{bmatrix}$$



- (6) For each receive signal vector, the EB SV specified in the PVP array is the value at the $f = fa_0$ for the antenna pattern specified for the receive data channel (RcvAPAT_ID). For signal vector v , the EB SV is at time $t = trs(v)$ and is denoted as shown.

$$\mathbf{Rcv_EB}_0(v) = \begin{bmatrix} \text{Rcv_EB_DCX}_0(v) \\ \text{Rcv_EB_DCY}_0(v) \end{bmatrix}$$

- (7) For a mechanically steered antenna, the $\mathbf{EB}_0(t) = [0 \ 0]^T$ for all transmit pulses in a transmit pulse sequence and/or all signal vectors in a receive data channel that use the antenna. The $\mathbf{EB}(t, f)$ is aligned with the +ACZ axis and it does not vary with time or frequency.

9.2.4 EB Shift vs. Frequency

The EB SV at an arbitrary frequency, $\mathbf{EB}(f)$, may be shifted relative to the EB SV at the antenna reference frequency $\mathbf{EB}_0$. The value of $\mathbf{EB}(f)$ may be computed from $\mathbf{EB}_0$ using the EB frequency shift parameters specified in the antenna pattern. Refer to Table 12-12: Antenna/AntPattern/EBFreqShift. The antenna pattern parameters used are as follows.

fa_0 : Antenna pattern reference frequency (Hz).

EBFS_DCXSF: EB frequency shift scale factor for DCX (dimensionless).

EBFS_DCYSF: EB frequency shift scale factor for DCY (dimensionless).

Compute $\mathbf{EB}(f)$

The method for computing the EB SV at frequency f , $\mathbf{EB}(f)$, may be implemented as the function shown below. The input $\mathbf{EB}_0$ is the EB SV specified in the PPP array for a selected pulse or in the PVP array for a selected receive signal vector. Input frequency f is in Hz.

$$\{ \mathbf{EB}_0 \} + \left\{ \begin{matrix} f \\ fa_0 \end{matrix} \right\} + \left\{ \begin{matrix} \text{EBFS_DCXSF} \\ \text{EBFS_DCYSF} \end{matrix} \right\} \rightarrow \boxed{\text{Compute } \mathbf{EB}(f)} \rightarrow \{ \mathbf{EB}(f) \}$$

- (1) Compute the frequency difference expressed as a fraction of the reference frequency fa_0 , $\Delta f_Frac(f)$.

$$\Delta f_Frac(f) = (f - fa_0)/fa_0$$

- (2) Compute components $\text{EB_DCX}(f)$ and $\text{EB_DCY}(f)$ as shown.

$$\text{EB_DCX}(f) = \text{EB_DCX}_0 \cdot \left(\frac{1}{1 + \text{EBFS_DCXSF} \cdot \Delta f_Frac(f)} \right)$$

$$\text{EB_DCY}(f) = \text{EB_DCY}_0 \cdot \left(\frac{1}{1 + \text{EBFS_DCYSF} \cdot \Delta f_Frac(f)} \right)$$

Note 1: For an EBFS scale factor equal to 1.0, the component at fa_0 is scaled by (fa_0/f) .

Note 2: For an EBFS scale factor equal to 0.0, the component does not vary with frequency.

9.3 Antenna Beam Shape Patterns

Each APAT in a CRSD product specifies a one-way antenna beam shape pattern. The antenna beam shape pattern specifies the relative antenna gain and phase vs. frequency for a selected pointing direction. The beam shape pattern is a function of the EB SV at fa_0 , $\mathbf{EB}_0$, the antenna pointing vector for the selected pointing direction, $\mathbf{AP}$, and the frequency, f , in Hz. The antenna beam shape pattern, denoted $H_{BS}(\mathbf{EB}_0, \mathbf{AP}, f)$, includes a gain pattern and a phase pattern.

$$H_{BS}(\mathbf{EB}_0, \mathbf{AP}, f) = \{ G_{BS}(\mathbf{EB}_0, \mathbf{AP}, f), \Phi_{BS}(\mathbf{EB}_0, \mathbf{AP}, f) \}$$

The beam shape gain pattern $G_{BS}(\mathbf{EB}_0, \mathbf{AP}, f)$ specifies a one-way gain in dB. The beam shape phase pattern $\Phi_{BS}(\mathbf{EB}_0, \mathbf{AP}, f)$ specifies a one-way phase in cycles. The beam shape gain and phase are relative to the absolute antenna gain and phase for the following values of EB SV, antenna pointing vector, and frequency.

- (1) The EB SV at fa_0 aligned with the +ACZ axis: $\mathbf{EB}_0 = [0 \ 0]^T$.
- (2) The pointing direction aligned with the +ACZ axis: $\mathbf{AP} = [0 \ 0]^T$.
- (3) Frequency equal the reference frequency: $f = fa_0$.

Hence, for all APATs specified in a CRSD product:

$$G_{BS}([0 \ 0]^T, [0 \ 0]^T, fa_0) = 0 \text{ dB} \quad \Phi_{BS}([0 \ 0]^T, [0 \ 0]^T, fa_0) = 0 \text{ cycles}$$

The parameters that specify an APAT are included in the XML instance and in two antenna gain/phase support arrays. Refer to Table 12-12. Each APAT is referenced by a text-based identifier. The identifier, denoted APAT_ID, uniquely identifies the antenna beam shape pattern within the product.

The antenna beam shape pattern at frequency fa_0 is computed by the combination of two antenna gain/phase functions: an array gain/phase function and an element gain/phase function. Each function is specified in an antenna gain/phase support array. For each APAT, the ArrayGP_ID specifies the support array containing the sampled array gain/phase function. The ElemGP_ID specifies the support array containing the sampled element gain/phase function.

The variation in antenna beam shape pattern with frequency, if any, is computed using three sets of parameters. Each set of parameters is used to compute a type of variation with frequency that is common across many antenna types. Setting all parameters equal to zero will result in a beam shape pattern that is invariant with frequency.

- (1) EB Frequency Shift Parameters: A pair of parameters used to compute the EB SV shift vs. frequency. See Section 9.2.4.
- (2) Mainlobe (ML) Frequency Dilation Parameters: A pair of parameters used to compute the variation in the width of the array gain/phase function vs.

frequency. For SAR imaging, the primary effect is variation in the ML width vs. frequency. See Section 9.3.4.

- (3) Boresight Gain Variation Polynomial: A one-dimension polynomial that specifies the variation in array pattern gain vs. frequency independent of pointing direction. See Section 9.3.4.

For each APAT, a set of polarization parameters are provided that may be used to compute the polarization orientation as a function of antenna pointing vector. The parameters provided may be used to compute the polarization orientation on transmit and receive for any selected pointing vector. See Section 9.4.

9.3.1 Antenna Gain/Phase Support Arrays

An antenna gain/phase function maps an input antenna pointing vector, $\mathbf{AP} = [\text{dcx } \text{dcy}]^T$, to a gain value and phase value, denoted $G(\text{dcx}, \text{dcy})$ and $\Phi(\text{dcx}, \text{dcy})$. Gain values are in dB and phase values are in cycles. All antenna gain/phase functions have the following properties.

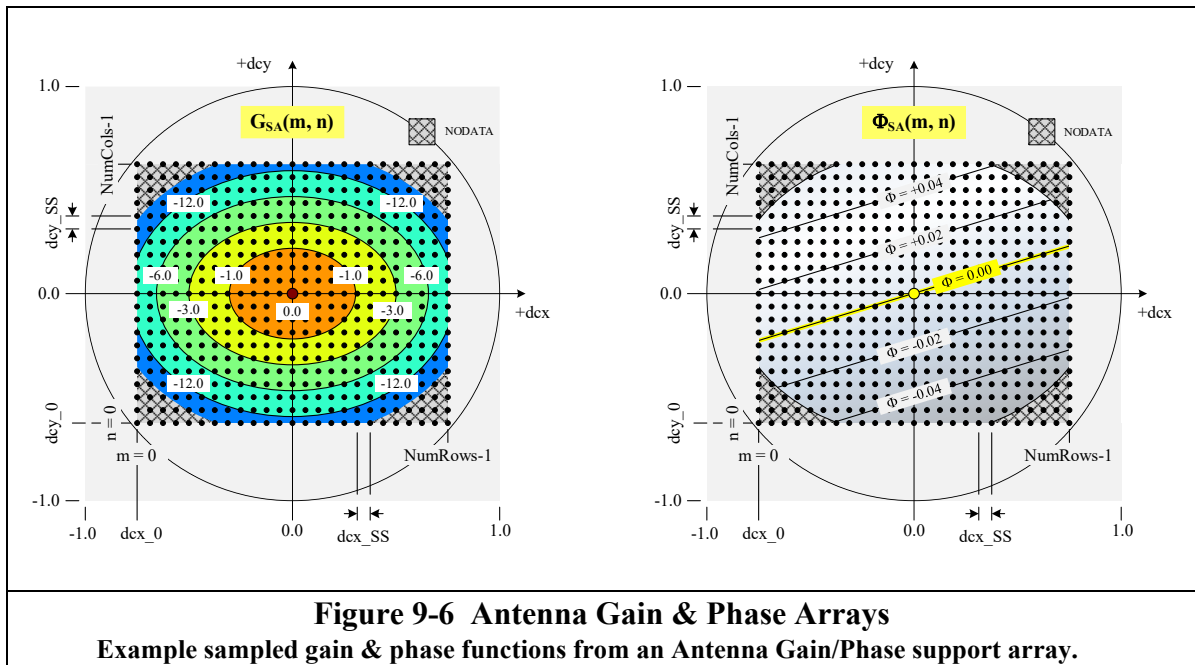
- (1) The input is restricted to be a valid pointing vector, hence: $\text{dcx}^2 + \text{dcy}^2 < 1$.
- (2) For input $\mathbf{AP} = [0 \ 0]^T$, $G(0, 0) = 0$ and $\Phi(0, 0) = 0$.

An antenna gain/phase support array contains a sampled antenna gain/phase function. Each support array element, denoted $\text{GP}_{\text{SA}}(m, n)$, contains the gain and phase for input $[\text{dcx}(m) \ \text{dcy}(n)]^T$. The gain value is denoted $G_{\text{SA}}(m, n)$. The phase value is denoted $\Phi_{\text{SA}}(m, n)$. All antenna gain/phase support arrays shall be created and stored per the following the rules and guidance. See Table 12-4 and Table 12-9.

- (1) The array size is NumRows x NumCols. Require $\text{NumRows} \geq 2$ and $\text{NumCols} \geq 2$.
- (2) Rows are indexed by $m = 0, 1, 2, \dots, \text{NumRows} - 1$. The row coordinate is dcx and is computed by: $\text{dcx}(m) = \text{dcx_0} + m \cdot \text{dcx_SS}$.
- (3) Require for all rows: $-1.0 \leq \text{dcx}(m) \leq 1.0$. For a given array, the set of row coordinate values $\{\text{dcx}(m)\}$ may span any portion of the interval $[-1.0, 1.0]$.
- (4) Columns are indexed by $n = 0, 1, 2, \dots, \text{NumCols} - 1$. The column coordinate is dcy and is computed by: $\text{dcy}(n) = \text{dcy_0} + n \cdot \text{dcy_SS}$.
- (5) Require for all columns: $-1.0 \leq \text{dcy}(n) \leq 1.0$. For a given array, the set of column coordinate values $\{\text{dcy}(n)\}$ may span any portion of the interval $[-1.0, 1.0]$.
- (6) For an element with array coordinates $(\text{dcx}(m), \text{dcy}(n)) = (0, 0)$, require $G_{\text{SA}}(m, n) = 0$ and $\Phi_{\text{SA}}(m, n) = 0$.
- (7) For an array with elements containing invalid data, the NODATA parameter is included in the XML branch that specifies the support array. See Table 12-9: / GainPhaseArray / NODATA. An element with invalid data is assigned the NODATA byte sequence.

- (8) For an input pointing vector $[dcx \ dcy]^T$ that falls between grid locations that contain valid data, the gain and phase values, $G(dcx, dcy)$ and $\Phi(dcx, dcy)$, may be computed using bilinear interpolation of the gain values and phase values of the four “surrounding” elements. See Section 9.3.2.
- (9) For a given array, the array size and grid spacings in dcx and dcy are a design choice. The grid spacing shall be fine enough to support accurate bilinear interpolation over the mainlobe portion of the pattern. For an array that includes both mainlobe and sidelobes, accurate interpolation near the nulls of the pattern is not guaranteed.
- (10) The portion of the (dcx, dcy) plane spanned by the array is referred to as the array extent. For a given gain/phase array, the array extent is a design choice. The portion of the array containing valid data is also a design choice. For a CRSD:SAR product, the valid data is to include the portion of the (dcx, dcy) input space corresponding to the pointing directions used to illuminate and/or receive signals from the imaged scene.

Shown in Figure 9-6 are plots generated from the sampled gain and phase functions contained in an antenna gain/phase support array. Shown in the left portion is a contour plot of the gain array values $\{G_{SA}(m, n)\}$. Shown in right portion is a contour plot of the phase array values $\{\Phi_{SA}(m, n)\}$. For the example shown, the array extent spans a significant portion of the unit circle. The gain plot shows a large portion of a mainlobe with peak value at input $[0 \ 0]^T$. The phase plot shows a linear variation in phase across the mainlobe. For the example shown, portions of the array are filled with the NODATA byte sequence.



9.3.2 Computing Gain/Phase from a Support Array

A method for computing gain and phase values from an antenna gain/phase support array is provided. For input pointing vector $[dcx \ dcy]^T$, the gain $G(dcx, dcy)$ and phase $\Phi(dcx, dcy)$ are computed. The method assumes that the antenna gain/phase array included in the CRSD product file, $\{GP_{SA}(m, n)\}$, has been separated into a gain array, $\{G_{SA}(m, n)\}$, and a phase array, $\{\Phi_{SA}(m, n)\}$. The method also makes use of a data valid array, $\{DV_{SA}(m, n)\}$, that is an array of Boolean parameters. For element (m, n) , $DV_{SA}(m, n) = \text{“true”}$ indicates that element $GP_{SA}(m, n)$ contains valid gain and phase values. The data valid array may be formed as a one-time preprocessing step.

The method for computing antenna gain/phase values may be implemented as the function shown below. For input antenna pointing vector $[dcx \ dcy]^T$, the output is a gain value $G = G(dcx, dcy)$ in dB, phase value $\Phi = \Phi(dcx, dcy)$ in cycles, and a data valid Boolean, DV.

$$\begin{Bmatrix} dcx \\ dcy \end{Bmatrix} + \begin{Bmatrix} \{G_{SA}(m, n)\} \\ \{\Phi_{SA}(m, n)\} \\ \{DV_{SA}(m, n)\} \end{Bmatrix} + \begin{Bmatrix} \text{NumRows} & \text{NumCols} \\ dcx_0 & dcy_0 \\ dcx_SS & dcy_SS \end{Bmatrix} \Rightarrow \boxed{\text{Interpolate Ant (G, } \Phi \text{ Supp Array)}} \Rightarrow \begin{Bmatrix} G \\ \Phi \\ DV \end{Bmatrix}$$

(1) For input dcx , compute the row index value m_dcx that includes both an integer and fractional part. Compute integer-valued indices $m0$ and $m1$.

$$m_dcx = \frac{1}{dcx_SS} \cdot (dcx - dcx_0) \quad m0 = \text{FLOOR}(m_dcx) \quad m1 = m0 + 1$$

Test for input dcx contained in the extent of the array. If dcx is contained, continue with Step 2. If dcx is not contained in the extent, assign outputs as shown and exit the function.

If $\{ m0 < 0 \text{ or } m1 > \text{NumRows} - 1 \}$ then: Input dcx is NOT contained.

$G = \text{NaN}$ Assign output G and Φ to invalid values.

$\Phi = \text{NaN}$ Invalid values are user-defined.

$DV = \text{“false”}$ Set DV to indicate data is invalid. Exit the function.

Else: Input dcx is contained in the extent.

Continue with Step 2.

(2) For input dcy , compute the column index values n_dcy , $n0$, and $n1$.

$$n_dcy = \frac{1}{dcy_SS} \cdot (dcy - dcy_0) \quad n0 = \text{FLOOR}(n_dcy) \quad n1 = n0 + 1$$

Test for input dcy contained in the extent of the array. If dcy is contained, continue with Step 3. If dcy is not contained in the extent, assign outputs as shown and exit the function.

If $\{ n0 < 0 \text{ or } n1 > \text{NumCols} - 1 \}$ then: Input dcy is NOT contained in the span.

$G = \text{NaN}$ $\Phi = \text{NaN}$ $DV = \text{“false”}$

Else: Input dcy is contained in the span.

Continue with Step 3.

(3) Elements (m0, n0), (m0, n1), (m1, n0), and (m1, n1) are referred to as the surrounding elements for input $[dcx \ dcy]^T$. Compute or assign the outputs G, Φ , and DV per the following algorithm.

- (a) If all surrounding elements contain valid data, compute outputs G and Φ using bilinear interpolation of the surrounding gain and phase values. Set output DV = “true” to indicate outputs G and Φ contain valid data.
- (b) If one or more of the surrounding elements contains invalid data, assign outputs to the default values: G = NAN and Φ = NAN. Set output DV = “false” to indicate G and Φ contain invalid data.

The method specified includes the key aspects of working with the antenna gain/phase support arrays. For applications that inputs CRSD products, the method used is a design choice.

9.3.3 Antenna Gain/Phase Function Pairs

A given APAT specifies two antenna gain/phase functions. The functions are referred to as the array gain/phase function and the element gain/phase function. The names “array” and “element” are taken from terminology commonly associated with an ESA. The array gain and phase functions are denoted $G_ARR(dcx, dcy)$ and $\Phi_ARR(dcx, dcy)$. The element gain and phase functions are denoted $G_ELEM(dcx, dcy)$ and $\Phi_ELEM(dcx, dcy)$. For $f = fa_0$, the APAT beam shape gain and phase pattern is computed from the sum of the two functions as shown. The gain values are expressed in dB and the phase values are in cycles.

For $\mathbf{EB}_0 = \begin{bmatrix} EB_DCX_0 \\ EB_DCY_0 \end{bmatrix}$ and $\mathbf{AP} = \begin{bmatrix} AP_DCX \\ AP_DCY \end{bmatrix}$:

$$\Delta AP_DCX_0 = AP_DCX - EB_DCX_0 \quad \Delta AP_DCY_0 = AP_DCY - EB_DCY_0$$

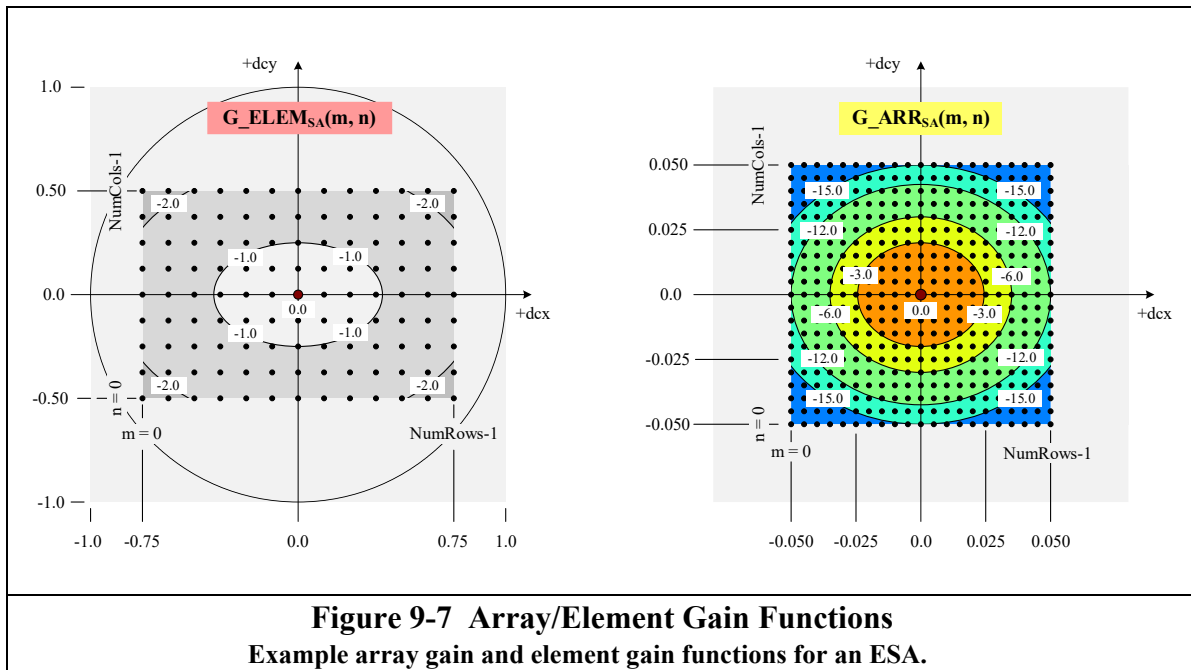
$$G_{BS}(\mathbf{EB}_0, \mathbf{AP}, f = fa_0) = G_ARR(\Delta AP_DCX_0, \Delta AP_DCY_0) \\ + G_ELEM(AP_DCX, AP_DCY)$$

$$\Phi_{BS}(\mathbf{EB}_0, \mathbf{AP}, f = fa_0) = \Phi_ARR(\Delta AP_DCX_0, \Delta AP_DCY_0) \\ + \Phi_ELEM(AP_DCX, AP_DCY)$$

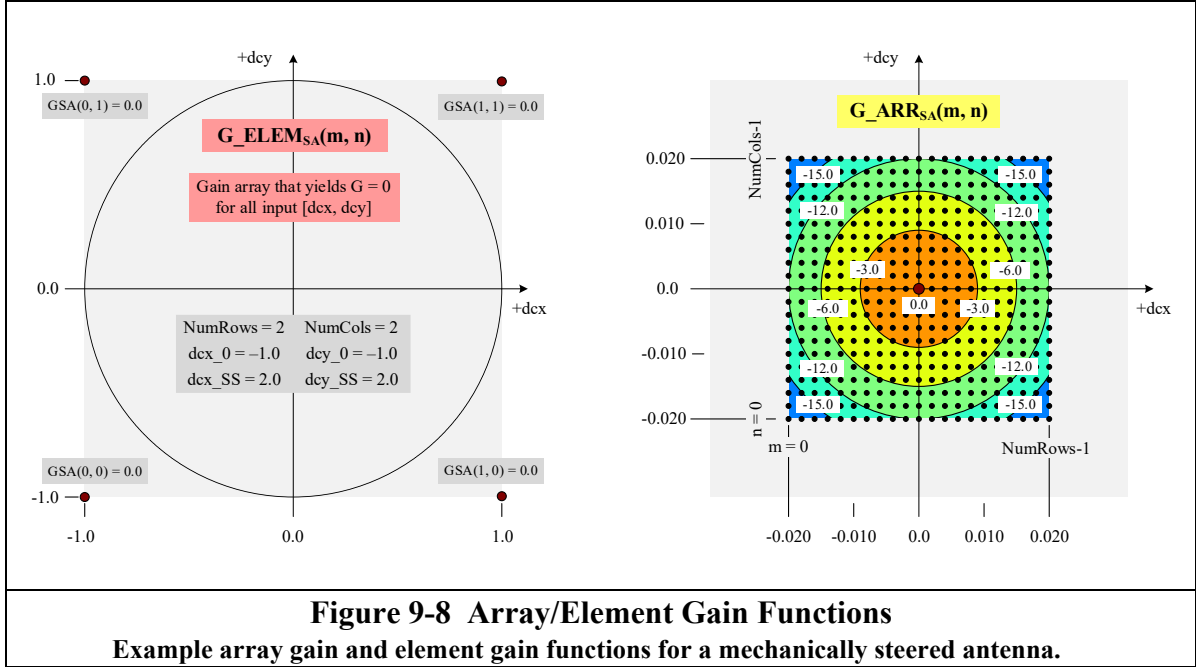
For an ESA, the two functions combine to model the beam shape gain and phase as a function of the EB SV. The array gain/phase function specifies the mainlobe and sidelobe shape (if included) for the APAT. The mainlobe peak is nominally centered at $\Delta \mathbf{AP} = [0 \ 0]^T$. The array function mainlobe is steered to the pointing direction specified by the EB SV. The element gain/phase function models the reduction in element gain that occurs for pointing

directions off of mechanical boresight. For a mechanically steered antenna, the beam shape gain and phase for $f = f_{a_0}$ is completely specified by the array gain/phase function. The element gain/phase function is specified such that it yields $G_ELEM = 0$ and $\Phi_ELEM = 0$ for all input pointing directions. Additional guidance is provided below.

Shown in Figure 9-7 are a pair of gain plots made from the antenna gain/phase support arrays of an APAT for an ESA. The gain plot on the left was generated from the element gain/phase SA gain array, $G_ELEM_{SA}(m, n)$. The gain plot on the right was generated from the array gain/phase SA gain array, $G_ARR_{SA}(m, n)$. The element gain/phase array extent covers EB SVs with a range of cone angle α_X of approximately $45 \text{ deg} < \alpha_X < 135 \text{ deg}$ and a range of cone angle α_Y of approximately $60 \text{ deg} < \alpha_Y < 120 \text{ deg}$. Refer to Figure 9-5. The array gain/phase array extent covers pointing angles off the EB SV of approximately 3 degrees for $\mathbf{EB} = [0 \ 0]^T$. The gain array extent covers a portion of the mainlobe that includes the -12 dB gain contour but does not include any portion of the sidelobes of the pattern. Producers of CRSD products are encouraged to include as much of the array gain/phase pattern as possible. For a well characterized antenna, this may include the near-in sidelobes of the gain function.



Shown in Figure 9-8 are a pair of gain plots made from the antenna gain/phase support arrays of an APAT for a mechanically steered antenna. For a mechanically steered antenna, the antenna beam shape pattern at $f = f_{a_0}$ is specified in the array gain/phase support array. The element gain/phase support array is specified to yield $G_ELEM(dcx, dcy) = 0$ and $\Phi_ELEM(dcx, dcy) = 0$. For the example shown, the element gain/phase support array is a 2×2 array with $G_{SA}(m, n) = 0$ and $\Phi_{SA}(m, n) = 0$ for all elements. The element array grid locations do not correspond to valid pointing directions but will yield the desired result for any valid pointing direction using the interpolation method specified in Section 9.3.2.



9.3.4 Computing Antenna Beam Shape Gain/Phase

A method is defined for computing the antenna beam shape pattern for a selected antenna pointing vector, $\mathbf{AP}$, and frequency, f . The method computes the gain value, $G_{\text{ANT}}(\mathbf{EB}_0, \mathbf{AP}, f)$, and the phase value, $\Phi_{\text{ANT}}(\mathbf{EB}_0, \mathbf{AP}, f)$.

$$H_{\text{BS}}(\mathbf{EB}_0, \mathbf{AP}, f) = \{ G_{\text{BS}}(\mathbf{EB}_0, \mathbf{AP}, f), \Phi_{\text{BS}}(\mathbf{EB}_0, \mathbf{AP}, f) \}$$

The inputs to the method include the pointing vectors $\mathbf{EB}_0$ and $\mathbf{AP}$, and the frequency f . The inputs also include a subset of the APAT parameters. See Table 12-12. The input set of APAT parameters is as follows.

$$\left\{ \begin{array}{l} \text{APAT} \\ \text{Params} \end{array} \right\} = \left\{ \begin{array}{lll} \text{fa_0} & \text{EBFS_DCXSF} & \text{MLFD_DCXSF} \\ \text{cG_BS(:)} & \text{EBFS_DCYSF} & \text{MLFD_DCYSF} \end{array} \right\}$$

fa_0	Antenna pattern reference frequency (Hz).
cG_BS(0:ORDER)	Coefficients of the boresight gain vs. frequency polynomial.
EBFS_DCXSF	EB frequency shift scale factor for DCX.
EBFS_DCYSF	EB frequency shift scale factor for DCY.
MLFD_DCXSF	Mainlobe frequency dilation scale factor for DCX.
MLFD_DCYSF	Mainlobe frequency dilation scale factor for DCY.

The inputs to the method include the APAT array gain/phase support array specified by the ArrayGP_ID. The array gain/phase array and metadata are denoted as shown. See Table 12-9.

$$\begin{Bmatrix} \text{ARRAY} \\ \text{SA} \\ \text{Data} \end{Bmatrix} = \begin{Bmatrix} \{G_ARR_{SA}(m,n)\} \\ \{\Phi_ARR_{SA}(m,n)\} \\ \{DV_ARR_{SA}(m,n)\} \end{Bmatrix} + \text{ARR} \begin{Bmatrix} \text{NumRows} & \text{NumCols} \\ \text{dcx}_0 & \text{dcy}_0 \\ \text{dcx}_{SS} & \text{dcy}_{SS} \end{Bmatrix}$$

The inputs to the method include the APAT element gain/phase support array specified by the ElemGP_ID. The element gain/phase array and metadata are denoted as shown.

$$\begin{Bmatrix} \text{ELEM} \\ \text{SA} \\ \text{Data} \end{Bmatrix} = \begin{Bmatrix} \{G_ELEM_{SA}(m,n)\} \\ \{\Phi_ELEM_{SA}(m,n)\} \\ \{DV_ELEM_{SA}(m,n)\} \end{Bmatrix} + \text{ELEM} \begin{Bmatrix} \text{NumRows} & \text{NumCols} \\ \text{dcx}_0 & \text{dcy}_0 \\ \text{dcx}_{SS} & \text{dcy}_{SS} \end{Bmatrix}$$

The method for computing APAT beam shape gain/phase values may be implemented as the function shown below. For inputs $\mathbf{EB}_0$, $\mathbf{AP}$, and f , the outputs are the gain $G_{BS} = G_{BS}(\mathbf{EB}_0, \mathbf{AP}, f)$ in dB, the phase $\Phi_{BS} = \Phi_{BS}(\mathbf{EB}_0, \mathbf{AP}, f)$ in cycles, and a data valid Boolean, DV. For DV = “true”, the output gain and phase are valid. For DV = “false”, the output gain and phase are not valid.

$$\{ \mathbf{EB}_0, \mathbf{AP}, f \} + \{ \text{APAT} \}_{\text{Params}} + \begin{Bmatrix} \text{ARRAY} \\ \text{SA} \\ \text{Data} \end{Bmatrix} + \begin{Bmatrix} \text{ELEM} \\ \text{SA} \\ \text{Data} \end{Bmatrix} \Rightarrow \boxed{\text{Compute APAT } (G_{BS}, \Phi_{BS})} \Rightarrow \begin{Bmatrix} G_{BS} \\ \Phi_{BS} \\ \text{DV} \end{Bmatrix}$$

(1) For input frequency f , compute the electrical boresight pointing vector, $\mathbf{EB}(f)$. See the method defined in Section 9.2.4.

$$\{ \mathbf{EB}_0 \} + \left\{ \begin{matrix} f \\ f_{a_0} \end{matrix} \right\} + \begin{Bmatrix} \text{EBFS_DCXSF} \\ \text{EBFS_DCYSF} \end{Bmatrix} \Rightarrow \boxed{\text{Compute EB}(f)} \Rightarrow \{ \mathbf{EB}(f) = \begin{bmatrix} \text{EB_DCX} \\ \text{EB_DCY} \end{bmatrix} \}$$

(2) For input frequency f , compute the array pattern boresight gain adjustment, ΔG_{BS} . First, compute the frequency difference expressed as a fraction of the reference frequency f_{a_0} , Δf_{Frac} . Boresight gain ΔG_{BS} is in dB.

$$\Delta f_{\text{Frac}} = (f - f_{a_0})/f_{a_0} \quad \Delta G_{BS} = \sum_{k=0}^{\text{ORDER}} c_{GBS}(k) \cdot (\Delta f_{\text{Frac}})^k$$

(3) For input frequency f , compute the array pattern frequency dilation scale factors for DCX and DCY, ARR_SF_DCX and ARR_SF_DCY .

$$\text{ARR_SF_DCX} = 1 + \text{MLFD_DCXSF} \cdot \Delta f_{\text{Frac}}$$

$$\text{ARR_SF_DCY} = 1 + \text{MLFD_DCYSF} \cdot \Delta f_{\text{Frac}}$$

(4) Compute the pointing vector difference, $\Delta \mathbf{AP}$, by computing the two components as shown. Each component is scaled to account for the frequency dilation of the array pattern mainlobe in the given dimension.

$$\Delta AP_DCX = (AP_DCX - EB_DCX) \cdot ARR_SF_DCX$$

$$\Delta AP_DCY = (AP_DCY - EB_DCY) \cdot ARR_SF_DCY$$

(5) Compute array function gain and phase for input vector $\Delta \mathbf{AP}$ by interpolating the array gain/phase support array. The method specified in Section 9.3.2 may be used.

$$\{ \Delta \mathbf{AP} = \begin{bmatrix} \Delta AP_DCX \\ \Delta AP_DCY \end{bmatrix} \} + \begin{Bmatrix} \text{ARRAY} \\ \text{SA} \\ \text{Data} \end{Bmatrix} \rightarrow \boxed{\text{Interpolate Ant (G, } \Phi \text{) Supp Array}} \rightarrow \begin{Bmatrix} G_ARR \\ \Phi_ARR \\ DV_ARR \end{Bmatrix}$$

Check that the computed gain and phase are valid as indicated by $DV_ARR = \text{"true"}$. For $DV_ARR = \text{"false"}$, the input set $\{ \mathbf{EB}_0, \mathbf{AP}, f \}$ is not supported. Set output $DV = \text{"false"}$ and exit the function. For $DV_ARR = \text{"true"}$, continue with Step 6.

If $\{ DV_ARR = \text{"false"} \}$ then: Input set $\{ \mathbf{EB}_0, \mathbf{AP}, f \}$ is NOT supported.

$$G_{ANT} = \text{NAN} \quad \Phi_{ANT} = \text{NAN} \quad DV = \text{"false"}$$

Exit the function.

Else:

Continue with Step 6.

(6) Compute element function gain and phase for input vector $\mathbf{AP}$ by interpolating the element gain/phase support array. The method specified in Section 9.3.2 may be used.

$$\{ \mathbf{AP} = \begin{bmatrix} AP_DCX \\ AP_DCY \end{bmatrix} \} + \begin{Bmatrix} \text{ELEM} \\ \text{SA} \\ \text{Data} \end{Bmatrix} \rightarrow \boxed{\text{Interpolate Ant (G, } \Phi \text{) Supp Array}} \rightarrow \begin{Bmatrix} G_ELEM \\ \Phi_ELEM \\ DV_ELEM \end{Bmatrix}$$

Check that the computed gain and phase are valid as indicated by $DV_ELEM = \text{"true"}$. For $DV_ELEM = \text{"false"}$, the input $\mathbf{AP}$ is not supported by element gain/phase array. Set output $DV = \text{"false"}$ and exit the function. For $DV_ELEM = \text{"true"}$, continue with Step 7.

If $\{ DV_ELEM = \text{"false"} \}$ then: Input $\mathbf{AP}$ is NOT supported.

$$G_{BS} = \text{NAN} \quad \Phi_{BS} = \text{NAN} \quad DV = \text{"false"}$$

Exit the function.

Else:

Continue with Step 7.

(7) Compute the output gain and phase, G_{BS} and Φ_{BS} , as shown. Set output DV equal to "true" and exit the function.

$$G_{BS} = \Delta G_{BS} + G_ARR + G_ELEM$$

$$\Phi_{BS} = \Phi_ARR + \Phi_ELEM$$

$$DV = \text{"true"}$$

9.4 Polarization Parameters

For each APAT, a set of four polarization parameters are provided that may be used to compute the polarization orientation on transmit and on receive. The polarization orientation refers to the orientation of the E-field of the propagating wavefront. The polarization parameters provided are AmpX, AmpY, PhaseX, and PhaseY (phases denoted Φ_X and Φ_Y). See Table 12-12. Amplitudes AmpX and AmpY are dimensionless. Phases Φ_X and Φ_Y are in cycles. For a given APAT, the parameters are subject to the following constraints.

$$\text{AmpX}^2 + \text{AmpY}^2 = 1 \quad -0.5 \leq \Phi_X \leq 0.5 \quad -0.5 \leq \Phi_Y \leq 0.5$$

9.4.1 Polarization Orientation: LOS = +ACZ

The APAT polarization parameters specify the polarization orientation for signals that propagate along the +ACZ axis (i.e., for LOS unit vector $\mathbf{u}_{\text{LOS}} = \mathbf{u}_{\text{ACZ}}$). On transmit, the parameters specify the E-field orientation for the transmit pulse propagating in the +ACZ direction. The E-field orientation is denoted $\mathbf{E}_{\text{ACZ_Xmt}}(t)$. For a CW signal at $f = f_{a_0}$, the E-field orientation is expressed as follows. For unit vectors $\mathbf{u}_{\text{ACX}}$ and $\mathbf{u}_{\text{ACY}}$ in ECEF coordinates, then vector $\mathbf{E}_{\text{ACZ_Xmt}}(t)$ is also in ECEF coordinates.

$$\begin{aligned} \mathbf{E}_{\text{ACZ_Xmt}}(t) = & \text{AmpX} \cdot \cos(2\pi \cdot f_{a_0} \cdot t + 2\pi \cdot \Phi_X) \cdot \mathbf{u}_{\text{ACX}} \\ & + \text{AmpY} \cdot \cos(2\pi \cdot f_{a_0} \cdot t + 2\pi \cdot \Phi_Y) \cdot \mathbf{u}_{\text{ACY}} \end{aligned}$$

On receive, the parameters specify the E-field orientation for the signal propagating in the –ACZ direction that is received with maximum receive sensitivity. The E-field orientation is denoted $\mathbf{E}_{\text{ACZ_Rcv}}(t)$. For a CW signal at $f = f_{a_0}$, the E-field orientation with maximum sensitivity for $\mathbf{u}_{\text{LOS}} = \mathbf{u}_{\text{ACZ}}$ is expressed as follows. Note: Phases Φ_X and Φ_Y are included with negative signs on receive.

$$\begin{aligned} \mathbf{E}_{\text{ACZ_Rcv}}(t) = & \text{AmpX} \cdot \cos(2\pi \cdot f_{a_0} \cdot t - 2\pi \cdot \Phi_X) \cdot \mathbf{u}_{\text{ACX}} \\ & + \text{AmpY} \cdot \cos(2\pi \cdot f_{a_0} \cdot t - 2\pi \cdot \Phi_Y) \cdot \mathbf{u}_{\text{ACY}} \end{aligned}$$

For both transmit and receive, parameters AmpX and AmpY specify the relative amplitudes of the E-field components in the ACX and ACY directions. The AmpX and AmpY values do not specify the true amplitude values that are a function of the power density of the propagating wavefront.

9.4.2 Polarization Orientation: Arbitrary LOS

The polarization orientation for signals transmitted or received along an arbitrary antenna pointing vector may be computed. For unit vector $\mathbf{u}_{\text{LOS}}$ corresponding to a valid antenna pointing vector, a transmit signal propagates in the $+\mathbf{u}_{\text{LOS}}$ direction and a receive signal propagates in the $-\mathbf{u}_{\text{LOS}}$ direction. The E-field orientation on transmit is denoted $\mathbf{E}_{\text{Xmt}}(t, \mathbf{u}_{\text{LOS}})$ and on receive is denoted $\mathbf{E}_{\text{Rcv}}(t, \mathbf{u}_{\text{LOS}})$. For both transmit and receive, the E-field is oriented normal to the direction of propagation (i.e., normal to $\mathbf{u}_{\text{LOS}}$).

The polarization orientation may be computed by first computing vectors **ACXN(uLOS)** and **ACYN(uLOS)**. Vector **ACXN(uLOS)** is the component of **uACX** that is normal to **uLOS**. Vector **ACYN(uLOS)** is the component of **uACY** that is normal to **uLOS**.

$$\mathbf{ACXN}(\mathbf{uLOS}) = \mathbf{uACX} - \{\mathbf{uACX} \bullet \mathbf{uLOS}\} \bullet \mathbf{uLOS}$$

$$\mathbf{ACYN}(\mathbf{uLOS}) = \mathbf{uACY} - \{\mathbf{uACY} \bullet \mathbf{uLOS}\} \bullet \mathbf{uLOS}$$

For a CW signal at $f = f_{a_0}$, the E-field orientation on transmit **E_Xmt(t, uLOS)** may be expressed as follows.

$$\begin{aligned} \mathbf{E_Xmt}(t, \mathbf{uLOS}) = & \text{AmpX} \bullet \cos(2\pi \bullet f_{a_0} \bullet t + 2\pi \bullet \Phi_X) \bullet \mathbf{ACXN}(\mathbf{uLOS}) \\ & + \text{AmpY} \bullet \cos(2\pi \bullet f_{a_0} \bullet t + 2\pi \bullet \Phi_Y) \bullet \mathbf{ACYN}(\mathbf{uLOS}) \end{aligned}$$

For a CW signal at $f = f_{a_0}$, the E-field orientation with maximum sensitivity on receive **E_Rcv(t, uLOS)** may be expressed as follows. Note: Phases Φ_X and Φ_Y are included with negative signs on receive.

$$\begin{aligned} \mathbf{E_Rcv}(t, \mathbf{uLOS}) = & \text{AmpX} \bullet \cos(2\pi \bullet f_{a_0} \bullet t - 2\pi \bullet \Phi_X) \bullet \mathbf{ACXN}(\mathbf{uLOS}) \\ & + \text{AmpY} \bullet \cos(2\pi \bullet f_{a_0} \bullet t - 2\pi \bullet \Phi_Y) \bullet \mathbf{ACYN}(\mathbf{uLOS}) \end{aligned}$$

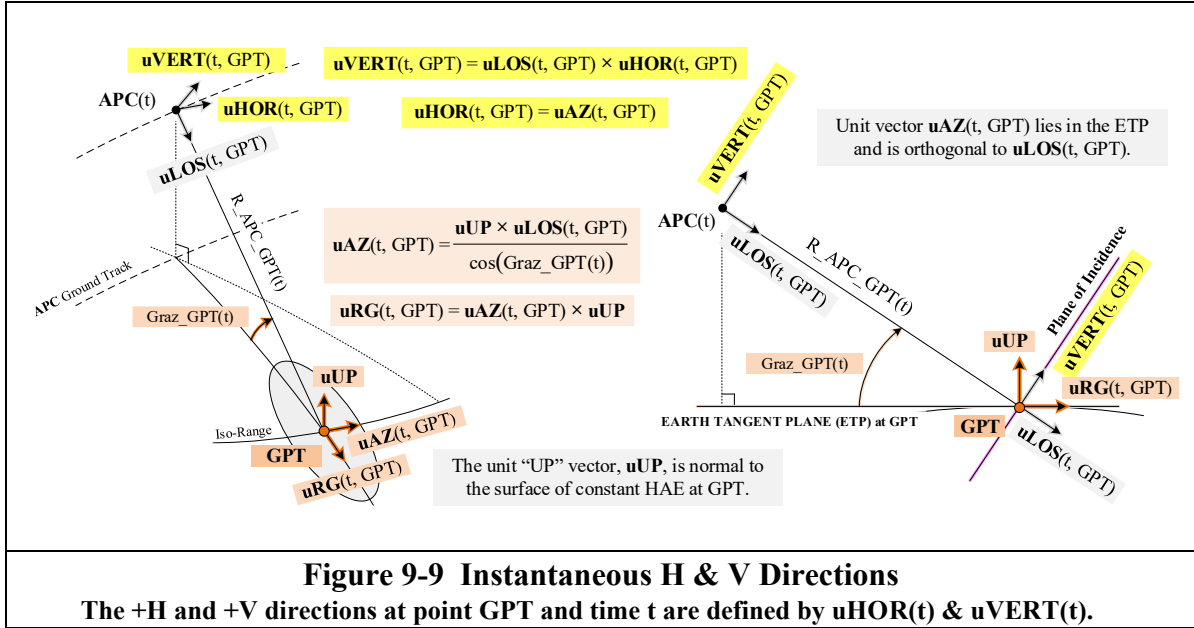
Note: The vectors **E_Xmt(t, uLOS)** and **E_Rcv(t, uLOS)** specify the relative magnitudes and phases of the E-field components in the **ACXN(uLOS)** and **ACYN(uLOS)** directions. The variation in the magnitude of **E_Xmt(t, uLOS)** with LOS pointing vector is, in general, unrelated to the variation in transmit power density. The variation in the magnitude of **E_Rcv(t, uLOS)** with LOS pointing vector is, in general, unrelated to the variation in receive sensitivity.

9.4.3 Polarization (H, V) Directions

For SAR imaging collections, of interest is the polarization orientation for signals incident at and scattered from points in the imaged scene. The polarization orientation is typically expressed relative to the horizontal (H) and vertical (V) directions at a given scene point. The H and V directions are based on the APC position and the selected scene point. During a collection, the H and V directions at the scene point will vary with time as the APC position varies.

For use in computing and interpreting CRSD polarization parameters, the instantaneous H and V polarization directions are defined as follows. Refer to Figure 9-9. At time t , the APC position is **APC(t)**, and the selected scene point is GPT at position **GPT**. The unit vector **uUP** is normal to the ETP at point GPT. Refer to Figure 8-1. Unit vector **uLOS(t, GPT)** is the LOS pointing vector that points from the APC to the scene point. Unit vectors **uRG(t, GPT)** and **uAZ(t, GPT)** lie in the ETP and are computed as shown. Unit vector **uAZ(t, GPT)** is normal to the LOS and defines the instantaneous +H polarization direction. Unit vector **uRG(t, GPT)** is in the increasing range direction. Polarization unit vector **uHOR(t, GPT)** is

equal to $\mathbf{uAZ}(t, \text{GPT})$. The +V polarization direction is also normal to the LOS and lies in the plane formed by the APC, the scene point GPT, and the unit UP vector. The unit vectors $\mathbf{uHOR}(t, \text{GPT})$ and $\mathbf{uVERT}(t, \text{GPT})$ define the Plane of Incidence (POI) at point GPT for a transmitted signal.



A method for computing the instantaneous H & V directions is defined. The method may be implemented as the function shown below. The APC and scene point GPT positions are in ECEF coordinates. The output unit vectors are also in ECEF coordinates.

$$\{ \text{APC} \} + \{ \text{GPT} \} \rightarrow \boxed{\text{Compute (H, V, LOS) Unit Vectors}} \rightarrow \begin{Bmatrix} \mathbf{uHOR} \\ \mathbf{uVERT} \\ \mathbf{uLOS} \end{Bmatrix}$$

(1) Compute the unit UP vector at point GPT, $\mathbf{uUP}$. Use the method for computing reference point parameters specified in Section 8.2 or an equivalent method. Only the output $\mathbf{uUP}$ is needed.

$$\{ \text{GPT} = \begin{Bmatrix} \text{GPT_X} \\ \text{GPT_Y} \\ \text{GPT_Z} \end{Bmatrix} \} \rightarrow \boxed{\text{Compute Ref Point Parameters}} \rightarrow \left\{ \begin{Bmatrix} \text{GPT_Lat} \\ \text{GPT_Lon} \\ \text{GPT_HAE} \end{Bmatrix} \begin{Bmatrix} \mathbf{uEAST} \\ \mathbf{uNOR} \\ \mathbf{uUP} \end{Bmatrix} \right\}$$

(2) Compute the range from the APC to point GPT, $R_{\text{APC_GPT}}$. Compute the unit LOS vector that points from the APC to the point GPT, $\mathbf{uLOS}$.

$$R_{\text{APC_GPT}} = |\mathbf{GPT} - \mathbf{APC}| \quad \mathbf{uLOS} = \frac{1}{R_{\text{APC_GPT}}} \cdot (\mathbf{GPT} - \mathbf{APC})$$

- (3) Compute unit vector **uHOR** that points in the +H direction.

$$\mathbf{HOR} = \mathbf{uUP} \times \mathbf{uLOS} \quad \mathbf{uHOR} = \frac{1}{|\mathbf{HOR}|} \bullet \mathbf{HOR}$$

- (4) Compute the unit vector **uVERT** that points in the +V direction.

$$\mathbf{uVERT} = \mathbf{uLOS} \times \mathbf{uHOR}$$

9.4.4 Polarization Relative to (H, V) Directions

The polarization orientation on transmit and/or receive may be expressed relative to the instantaneous H & V directions at a selected scene point. The orientation is expressed using a set of four parameters: AmpH, AmpV, Phase H, and PhaseV (phases denoted Φ_H and Φ_V). For scene point GPT, the E-field orientation at time t for a CW signal at $f = f_{a_0}$ is denoted **E_HV(t, GPT)**.

$$\begin{aligned} \mathbf{E_HV}(t, \text{GPT}) = & \text{AmpH} \bullet \cos(2\pi \bullet f_{a_0} \bullet t + 2\pi \bullet \Phi_H) \bullet \mathbf{uHOR}(t, \text{GPT}) \\ & + \text{AmpV} \bullet \cos(2\pi \bullet f_{a_0} \bullet t + 2\pi \bullet \Phi_V) \bullet \mathbf{uVERT}(t, \text{GPT}) \end{aligned}$$

Amplitudes AmpH and AmpV are dimensionless and specify the relative amplitudes of the E-field components in the H and V directions. Phases Φ_H and Φ_V are in cycles. The parameters are subject to the same constraints that apply to the APAT polarization parameter set.

$$\text{AmpH}^2 + \text{AmpV}^2 = 1 \quad -0.5 \leq \Phi_H \leq 0.5 \quad -0.5 \leq \Phi_V \leq 0.5$$

On transmit, **E_HV(t, GPT)** is the polarization orientation for the transmit signal incident at point GPT. It is computed using the transmit APC position, the transmit ACF unit vectors, and the transmit APAT polarization parameters. The parameters associated with polarization orientation vector **E_Xmt(t, uLOS)** are used to compute the H & V parameter set.

On receive, **E_HV(t, GPT)** is the polarization orientation with maximum receive sensitivity for a signal received from point GPT. It is computed using the receive APC position, the receive ACF unit vectors, and the receive APAT polarization parameters. The parameters associated with polarization orientation vector **E_Rcv(t, uLOS)** are used to compute the H & V parameter set.

A method for computing **E_HV(t, GPT)** is specified as follows. The method may be implemented as the function shown below. The method may be used to compute the polarization orientation on transmit or on receive. Integer input parameter XR indicates the polarization orientation parameters to be computed are for a transmit signal (XR = +1) or for a receive signal (XR = -1).

$$\begin{Bmatrix} \text{APC} \\ \mathbf{uACX} \\ \mathbf{uACY} \end{Bmatrix} + \{ \text{GPT} \} + \{ \text{XR} \} + \begin{Bmatrix} \text{AmpX} & \Phi_X \\ \text{AmpY} & \Phi_Y \end{Bmatrix} \rightarrow \boxed{\text{Compute H,V Pol Parameters}} \rightarrow \begin{Bmatrix} \mathbf{uHOR} & \text{AmpH} & \Phi_H \\ \mathbf{uVERT} & \text{AmpV} & \Phi_V \end{Bmatrix}$$

- (1) Use the APC position and scene point position to compute the unit vectors for the H, V, and LOS directions. Use the method defined in Section 9.4.3.

$$\{ \text{APC} \} + \{ \text{GPT} \} \rightarrow \boxed{\text{Compute (H, V, LOS) Unit Vectors}} \rightarrow \begin{Bmatrix} \mathbf{uHOR} \\ \mathbf{uVERT} \\ \mathbf{uLOS} \end{Bmatrix}$$

- (2) Compute vectors **ACXN** and **ACYN** that are the components of **uACX** and **uACY** that are normal to the LOS. See Figure 9-10.

$$\mathbf{ACXN} = \mathbf{uACX} - \{ \mathbf{uACX} \bullet \mathbf{uLOS} \} \bullet \mathbf{uLOS}$$

$$\mathbf{ACYN} = \mathbf{uACY} - \{ \mathbf{uACY} \bullet \mathbf{uLOS} \} \bullet \mathbf{uLOS}$$

Note: The polarization parameters relative to the H & V directions are only valid for the LOS corresponding to a valid antenna pointing vector.

For the LOS a valid antenna pointing vector: $\mathbf{uLOS} \bullet \{ \mathbf{uACX} \times \mathbf{uACY} \} > 0$.

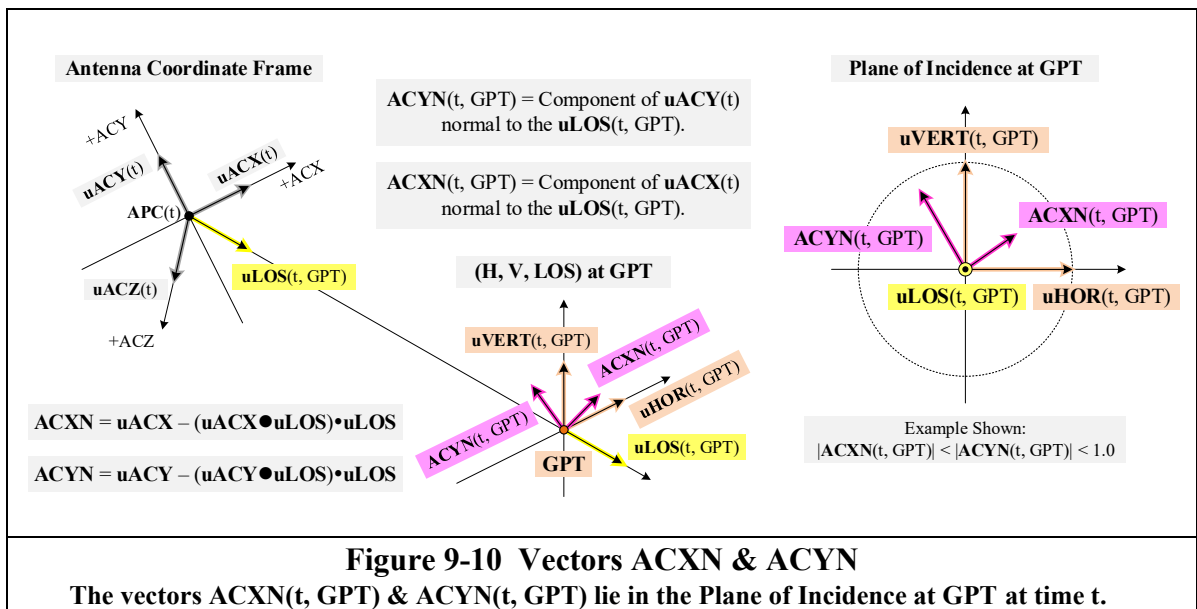
- (3) Compute parameters aXH, and aYH by projecting the E-field components in the ACXN and ACYN directions onto the +H direction. Compute parameters aXV and aYV by projecting the E-field components in the ACXN and ACYN directions onto the +V direction.

$$aXH = \text{AmpX} \bullet \{ \mathbf{ACXN} \bullet \mathbf{uHOR} \}$$

$$aYH = \text{AmpY} \bullet \{ \mathbf{ACYN} \bullet \mathbf{uHOR} \}$$

$$aXV = \text{AmpX} \bullet \{ \mathbf{ACXN} \bullet \mathbf{uVERT} \}$$

$$aYV = \text{AmpY} \bullet \{ \mathbf{ACYN} \bullet \mathbf{uVERT} \}$$



- (4) Compute amplitude a_H and phase Φ_H that are the amplitude and phase of the E-field component in the H direction. First compute complex-valued parameter c_H . Amplitude a_H is dimensionless. Phase Φ_H is in cycles.

$$\text{For } \mathbf{E_H}(t, \text{GPT}) = a_H \cdot \cos(2\pi \cdot f_{a_0} \cdot t + 2\pi \cdot \Phi_H) \cdot \mathbf{u_{HOR}}$$

$$c_H = a_{XH} \cdot \exp(XR \cdot j \cdot 2\pi \cdot \Phi_X) + a_{YH} \cdot \exp(XR \cdot j \cdot 2\pi \cdot \Phi_Y)$$

$$a_H = |c_H| \quad \Phi_H = \begin{cases} \frac{1}{2\pi} \cdot \text{Arg}(c_H), & \text{if } a_H > 0 \\ 0, & \text{Otherwise} \end{cases}$$

- (5) Compute amplitude a_V and phase Φ_V that are the amplitude and phase of the E-field component in the V direction. First compute complex-valued parameter c_V . Amplitude a_V is dimensionless. Phase Φ_V is in cycles.

$$\text{For } \mathbf{E_V}(t, \text{GPT}) = a_V \cdot \cos(2\pi \cdot f_{a_0} \cdot t + 2\pi \cdot \Phi_V) \cdot \mathbf{u_{VERT}}$$

$$c_V = a_{XV} \cdot \exp(XR \cdot j \cdot 2\pi \cdot \Phi_X) + a_{YV} \cdot \exp(XR \cdot j \cdot 2\pi \cdot \Phi_Y)$$

$$a_V = |c_V| \quad \Phi_V = \begin{cases} \frac{1}{2\pi} \cdot \text{Arg}(c_V), & \text{if } a_V > 0 \\ 0, & \text{Otherwise} \end{cases}$$

- (6) Compute the normalized amplitudes AmpH and AmpV from amplitudes a_H and a_V .

$$\text{AmpH} = a_H / (a_H^2 + a_V^2)^{1/2} \quad \text{AmpV} = a_V / (a_H^2 + a_V^2)^{1/2}$$

9.4.5 Polarization ID

The polarization orientation may be assigned a text-based identifier. A polarization ID value is assigned for each transmit pulse sequence and for each receive data channel. See Table 12-5 and Table 12-6. The text-based identifier provides a general sense of the polarization orientation. The allowed ID values are listed in Table 9-1. For each ID value, a description is provided as well as an example set of polarization orientation parameter values.

Table 9-1 Polarization ID Values		
ID Value	Polarization Description	Example Polarization Parameter Set
H	Horizontal Polarization: E-field is linearly polarized and is nominally aligned with the H direction in the imaged scene.	Ideal H&V parameter values: $\text{AmpH} = 1.0$ $\text{AmpV} = 0.0$ $-0.5 \leq \text{PhaseH} \leq 0.5$ $\text{PhaseV} = 0.0$
V	Vertical Polarization: E-field is linearly polarized and is nominally aligned with the V direction in the imaged scene.	Ideal H&V parameter values: $\text{AmpH} = 0.0$ $\text{AmpV} = 1.0$ $\text{PhaseH} = 0.0$ $-0.5 \leq \text{PhaseV} \leq 0.5$
X	ACF X-Axis Polarization: E-field is linearly polarized and is aligned with the Antenna Coordinate Frame X-axis.	Ideal APAT polarization parameters: $\text{AmpX} = 1.0$ $\text{AmpY} = 0.0$ $-0.5 \leq \text{PhaseX} \leq 0.5$ $\text{PhaseY} = 0.0$
Y	ACF Y-Axis Polarization: E-field is linearly polarized and is aligned with the Antenna Coordinate Frame Y-axis.	Ideal APAT polarization parameters: $\text{AmpX} = 0.0$ $\text{AmpY} = 1.0$ $\text{PhaseX} = 0.0$ $-0.5 \leq \text{PhaseY} \leq 0.5$
S	Slant Polarization: E-field is linearly polarized and is not nominally aligned with either the H or V directions.	Ideal H&V phase values: $\text{AmpH} > 0$ & $\text{AmpV} > 0$ $\text{PhaseV} - \text{PhaseH} = 0.5 \cdot n$, where n is an integer $n = -2, -1, 0, 1$, or 2 .
E	Elliptical Polarization: E-field is not linearly polarized and has components in both H and V directions. General ID value that may be used when criteria for all other ID values are not met.	Ideal H&V phase values: $\text{AmpH} > 0$ & $\text{AmpV} > 0$ $\text{PhaseV} - \text{PhaseH} \neq 0.5 \cdot n$, where n is an integer $n = -2, -1, 0, 1$, or 2
RHC	Right-Hand Circular Polarization: E-field H and V components are nominally equal amplitude and are nominally ± 90 degrees out-of-phase. On transmit: H leads V. On receive: V leads H.	Ideal H&V parameter values: $\text{AmpH} = 0.707$ $\text{AmpV} = 0.707$ On Transmit: $\text{PhaseV} - \text{PhaseH} = -0.25$ or 0.75 On Receive: $\text{PhaseV} - \text{PhaseH} = 0.25$ or -0.75

Table 9-1 Polarization ID Values		
ID Value	Polarization Description	Example Polarization Parameter Set
LHC	Left-Hand Circular Polarization: : E-field H and V components are nominally equal amplitude and are nominally ± 90 degrees out-of-phase. On transmit: V leads H. On receive: H leads V.	Ideal H&V parameter values: $\text{AmpH} = 0.707$ $\text{AmpV} = 0.707$ On Transmit: $\text{PhaseV} - \text{PhaseH} = 0.25$ or -0.75 On Receive: $\text{PhaseV} - \text{PhaseH} = -0.25$ or 0.75

10 Error Parameters

For any CRSD product an optional set of error parameters may be included. The parameters that may be included are estimated error statistics for a subset of the metadata included in the product. When included in a product, the set of error parameters is specified in the XML instance and is dependent upon the CRSD product type.

The optional error statistics that may be included are for the parameters that contribute to geolocation error in the SAR images that may be formed from the product. The types of parameters for which error statistics may be included are summarized as follows.

- (1) Position & Velocity: Estimated statistics for the errors in the APC position and velocity metadata included in the product. See Table 12-13.
- (2) Timing & Frequency: Estimated statistics for the errors in radar sensor control timing and frequency. The control timing and frequency errors result in errors in the transmit and/or receive timing and frequency metadata. See Table 12-13.
- (3) Atmospheric Propagation: Estimated statistics for the errors in the troposphere refractivity parameter and/or the ionosphere TECV parameter included in the product. See Table 12-2.

For all CRSD products, the following convention is used for defining parameter error values. Let parameter X be the true value of a parameter that is estimated or measured. Let X_0 be the estimated or measured value. Define ΔX to be the error in the estimated value X_0 where ΔX is computed as shown.

$$\Delta X = X - X_0 \quad \Leftrightarrow \quad \text{Error} = \text{True Value} - \text{Estimated Value}$$

For all parameters for which error statistics are provided, the errors are assumed to be zero mean. The statistics provided specify standard deviations, variances, and covariances. Hence, for estimated parameter X_0 with error ΔX :

$$E(\Delta X) = E(X - X_0) = 0$$

10.1 Position & Velocity Error Parameters

For all products, sensor position and velocity metadata are provided for each sensor specified in the product. For a given sensor, let $\mathbf{P}(t)$ and $\mathbf{V}(t)$ be the true position and velocity vectors at time t . Let $\mathbf{P}_0(t)$ and $\mathbf{V}_0(t)$ be the estimated position and velocity vectors at time t specified in or derived from the product metadata. Define position error vector $\Delta \mathbf{P}(t)$ to be the error in the estimated position $\mathbf{P}_0(t)$. Define velocity error vector $\Delta \mathbf{V}(t)$ to be the error in the estimated velocity metadata $\mathbf{V}_0(t)$. Position error $\Delta \mathbf{P}(t)$ and velocity error $\Delta \mathbf{V}(t)$ are computed as shown per the stated convention.

$$\Delta \mathbf{P}(t) = \begin{bmatrix} \Delta P1(t) \\ \Delta P2(t) \\ \Delta P3(t) \end{bmatrix} = \mathbf{P}(t) - \mathbf{P_0}(t) \quad \Delta \mathbf{V}(t) = \begin{bmatrix} \Delta V1(t) \\ \Delta V2(t) \\ \Delta V3(t) \end{bmatrix} = \mathbf{V}(t) - \mathbf{V_0}(t)$$

For a product that includes error parameters, estimated position and velocity error statistics are provided for each sensor specified in the product. Provided for each sensor is a 6 x 6 position/velocity error covariance matrix. For error vector $\Delta \mathbf{PV}(t)$ formed from the position and velocity error vectors at time t , covariance matrix $\mathbf{C_PV}(t)$ is defined as shown. The definition for $\mathbf{C_PV}(t)$ makes use of the stated assumption that for all products, $E(\Delta \mathbf{P}(t)) = E(\Delta \mathbf{V}(t)) = [0 \ 0 \ 0]^T$.

For $\Delta \mathbf{PV}(t) = [\Delta P1(t), \Delta P2(t), \Delta P3(t), \Delta V1(t), \Delta V2(t), \Delta V3(t)]^T$:

$$\mathbf{C_PV}(t) = E(\Delta \mathbf{PV}(t) \bullet \Delta \mathbf{PV}(t)^T)$$

10.1.1 PV Error Coordinate Frames

For all products, all position and velocity metadata parameters are specified in ECEF coordinates. For a given sensor, the position/velocity error statistics may be specified using any one of three allowed coordinate frames. The allowed coordinate frames are as follows.

ECEF	Earth Centered Earth Fixed: Coordinates are (X, Y, Z). Specified in an XML instance by parameter Frame = “ECF”.
RICF	Radial, In-Track, Cross-Track, Fixed (RICF): Coordinates are (R, I, C). The RICF frame is defined by the sensor position and the ECEF velocity vector at a specified time. The frame is specified in an XML instance by parameter Frame = “RIC_ECF”.
RICI	Radial, In-Track, Cross-Track, Inertial (RICI): Coordinates are (R, I, C). The RICI frame is defined by the sensor position and the ECI velocity vector at a specified time. The frame is specified in an XML instance by parameter Frame = “RIC_ECI”.

The RICF and RICI coordinate frames both have their origin defined at an estimated sensor position. The orientation of the frame relative to the ECEF frame is computed using the estimated sensor position and the estimated velocity vector. For the discussion that follows, define the following parameters.

P_0	Estimated sensor position vector specified in or derived from the product metadata at time $t = t_{RIC}$. Vector components are in meters.
V_0	Estimated sensor velocity vector specified in or derived from the product metadata at time $t = t_{RIC}$. All velocity vectors specified in a product metadata are for the sensor relative to the ECEF coordinate frame. Vector components are in meters/sec.
V_ECI_0	Estimated sensor velocity vector relative to the ECI coordinate frame at time $t = t_{RIC}$. Vector components are in meters/sec.

The velocity vector $\mathbf{V_ECI_0}$ is computed as follows. Parameter ω_3 is the nominal rotation rate of the ECEF frame relative to the ECI frame.

$$\mathbf{V_ECI_0} = \mathbf{V_0} + \begin{bmatrix} 0 \\ 0 \\ \omega_3 \end{bmatrix} \times \mathbf{P_0} \quad \omega_3 = 0.000,072,921 \text{ rad/sec}$$

The method for computing the orientation of the RICF and RIC I frames relative to the ECEF frame is specified as follows.

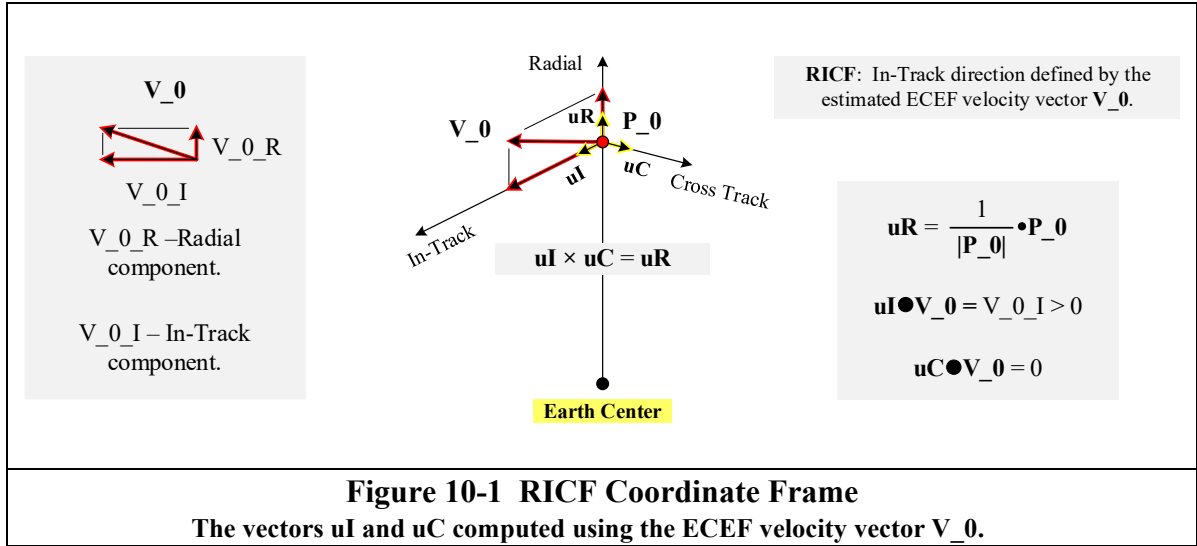
Radial, In-Track, Cross-Track Basis Vectors

The RIC unit basis vectors in ECEF coordinates, denoted $\mathbf{uR}$, $\mathbf{uI}$, and $\mathbf{uC}$, are computed as follows. For the RICF frame, velocity vector $\mathbf{V_0}$ is used to compute $\mathbf{uI}$ and $\mathbf{uC}$ vectors. See Figure 10-1. For the RIC I frame, the velocity vector $\mathbf{V_ECI_0}$ is used to compute $\mathbf{uI}$ and $\mathbf{uC}$ vectors.

$$\mathbf{uR} = \frac{1}{|\mathbf{P_0}|} \cdot \mathbf{P_0}$$

$$\mathbf{C} = \begin{cases} \mathbf{uR} \times \mathbf{V_0}, & \text{for RICF frame} \\ \mathbf{uR} \times \mathbf{V_ECI_0}, & \text{for RIC I frame} \end{cases} \quad \mathbf{uC} = \frac{1}{|\mathbf{C}|} \cdot \mathbf{C}$$

$$\mathbf{uI} = \mathbf{uC} \times \mathbf{uR}$$



10.1.2 Position & Velocity Error Statistics

The position and velocity error statistics included in a given product are dependent upon the product type. For a CRSD:SAR product, the statistics included are dependent on the collect type. The statistics that are included are summarized as follows.

CRSD:SAR – Collect Type = Monostatic

For a product formed for a monostatic SAR imaging collection, a single position/velocity error covariance matrix at time $t = t_{REF}$ is specified. The error vector is denoted $\Delta \mathbf{PV}(t_{REF})$ and the error covariance matrix is $\mathbf{C_PV}(t_{REF})$. Time t_{REF} is specified in the SAR image reference geometry parameters. See Section 8.4 and Table 12-7.

$$\mathbf{C_PV}(t_{REF}) = E(\Delta \mathbf{PV}(t_{REF}) \bullet \Delta \mathbf{PV}(t_{REF})^T)$$

For error statistics specified in an RIC frame, the position and velocity vectors used to compute the RIC frame basis vectors are the ARP position and velocity specified in the SAR image reference geometry parameters.

$$t_{RIC} = t_{REF} \qquad \mathbf{P_0} = \mathbf{ARP}_{COA} \qquad \mathbf{V_0} = \mathbf{VARP}_{COA}$$

CRSD:SAR – Collect Type = Bistatic

For a product formed for a bistatic SAR imaging collection, a position/velocity error covariance matrix at time $t = t_{REF}$ is specified for each sensor. For the transmit sensor, the error vector is denoted $\Delta \mathbf{XPV}(t_{REF})$ and the error covariance matrix is $\mathbf{C_XPV}(t_{REF})$. For the receive sensor, the error vector is denoted $\Delta \mathbf{RPV}(t_{REF})$ and the error covariance matrix is $\mathbf{C_RPV}(t_{REF})$. Also provided is the joint covariance matrix denoted $\mathbf{C_XRPV}(t_{REF})$. The reference frame used for error vectors $\Delta \mathbf{XPV}(t_{REF})$ and $\Delta \mathbf{RPV}(t_{REF})$ may or may not be the same.

For the transmit sensor:

$$\begin{aligned} \Delta \mathbf{XPV}(t_{REF}) &= [\Delta \mathbf{XP1}(t_{REF}), \Delta \mathbf{XP2}(t_{REF}), \Delta \mathbf{XP3}(t_{REF}), \\ &\quad \Delta \mathbf{XV1}(t_{REF}), \Delta \mathbf{XV2}(t_{REF}), \Delta \mathbf{XV3}(t_{REF})]^T: \\ \mathbf{C_XPV}(t_{REF}) &= E(\Delta \mathbf{XPV}(t_{REF}) \bullet \Delta \mathbf{XPV}(t_{REF})^T) \end{aligned}$$

For the receive sensor:

$$\begin{aligned} \Delta \mathbf{RPV}(t_{REF}) &= [\Delta \mathbf{RP1}(t_{REF}), \Delta \mathbf{RP2}(t_{REF}), \Delta \mathbf{RP3}(t_{REF}), \\ &\quad \Delta \mathbf{RV1}(t_{REF}), \Delta \mathbf{RV2}(t_{REF}), \Delta \mathbf{RV3}(t_{REF})]^T: \\ \mathbf{C_RPV}(t_{REF}) &= E(\Delta \mathbf{RPV}(t_{REF}) \bullet \Delta \mathbf{RPV}(t_{REF})^T) \end{aligned}$$

The joint error covariance matrix:

$$\mathbf{C_XRPV}(t_{REF}) = E(\Delta \mathbf{XPV}(t_{REF}) \bullet \Delta \mathbf{RPV}(t_{REF})^T)$$

For error statistics specified in an RIC frame, the position and velocity vectors used to compute the RIC frame basis vectors are as follows. For the transmit sensor, use the transmit sensor reference geometry position and velocity as shown. For the receive sensor, use the receive sensor reference geometry position and velocity as shown.

For the transmit sensor:

$$t_{RIC} = t_{REF} \quad \mathbf{P_0} = \mathbf{Xmt}_{REF} + \mathbf{VXmt}_{REF} \bullet (t_{REF} - t_{xCREF}) \quad \mathbf{V_0} = \mathbf{VXmt}_{REF}$$

For the receive sensor:

$$t_{RIC} = t_{REF} \quad \mathbf{P_0} = \mathbf{Rcv}_{REF} + \mathbf{VRcv}_{REF} \bullet (t_{REF} - t_{rSREF}) \quad \mathbf{V_0} = \mathbf{VRcv}_{REF}$$

CRSD:TX

For a CRSD:TX product, a single position/velocity error covariance matrix at time $t = t_{xCREF}$ is specified. The error vector is denoted $\Delta\mathbf{XPV}(t_{xCREF})$ and the error covariance matrix is $\mathbf{C_XPV}(t_{xCREF})$. Time t_{xCREF} is specified in the transmit sensor reference geometry parameters.

$$\mathbf{C_XPV}(t_{xCREF}) = E(\Delta\mathbf{XPV}(t_{xCREF}) \bullet \Delta\mathbf{XPV}(t_{xCREF})^T)$$

For error statistics specified in an RIC frame, the position and velocity used to compute the RIC frame basis vectors are the transmit APC position and velocity specified in the transmit reference geometry parameters. See Section 8.1 and Table 12-7.

$$t_{RIC} = t_{xCREF} \quad \mathbf{P_0} = \mathbf{Xmt}_{REF} \quad \mathbf{V_0} = \mathbf{VXmt}_{REF}$$

CRSD:RCV

For a CRSD:RCV product, a single position/velocity error covariance matrix at time $t = t_{rSREF}$ is specified. The error vector is denoted $\Delta\mathbf{RPV}(t_{rSREF})$ and the error covariance matrix is $\mathbf{C_RPV}(t_{rSREF})$. Time t_{rSREF} is specified in the receive sensor reference geometry parameters.

$$\mathbf{C_RPV}(t_{rSREF}) = E(\Delta\mathbf{RPV}(t_{rSREF}) \bullet \Delta\mathbf{RPV}(t_{rSREF})^T)$$

For error statistics specified in an RIC frame, the position and velocity used to compute the RIC frame basis vectors are the receive APC position and velocity specified in the receive reference geometry parameters.

$$t_{RIC} = t_{rSREF} \quad \mathbf{P_0} = \mathbf{Rcv}_{REF} \quad \mathbf{V_0} = \mathbf{VRcv}_{REF}$$

10.1.3 Error Decorrelation Parameters

For each sensor position/velocity error covariance matrix specified in a product, an optional error decorrelation function may be included. The inclusion of the decorrelation functions is a product design choice. Guidance for the use of the decorrelation functions is also a product design choice and is specified per the PDD.

10.2 Timing & Frequency Error Parameters

For all products, timing and frequency metadata are provided for each sensor specified in the product. For each transmit pulse, the transmit center time, pulse length, and phase modulation function are specified. For each receive signal vector, the receive start time, receive window sample timing, and phase demodulation function are specified.

For a given sensor, timing and frequency metadata are derived and/or measured from a combination of sensor-specific timing and control components and functions. The timing and control components may include one or more control clocks and/or reference oscillators in the radar sensor payload. Timing and/or frequency signals from other sensor subsystems (e.g., a GPS receiver) may be recorded and input to the data processing functions that compute the sensor timing and frequency metadata provided in the CRSD product.

For a product that includes error parameters, a set of timing and control clock frequency error statistics are provided. The statistics provided may be used to compute the expected statistics for the errors in the transmit and/or receive metadata. The statistics provided are used with an ideal sensor timing and control model. For a given transmit pulse, the expected statistics for errors in transmit timing and frequency may be computed. For a given receive signal vector, the expected statistics for errors in receive timing and frequency may be computed.

10.2.1 SAR Timing & Control Model

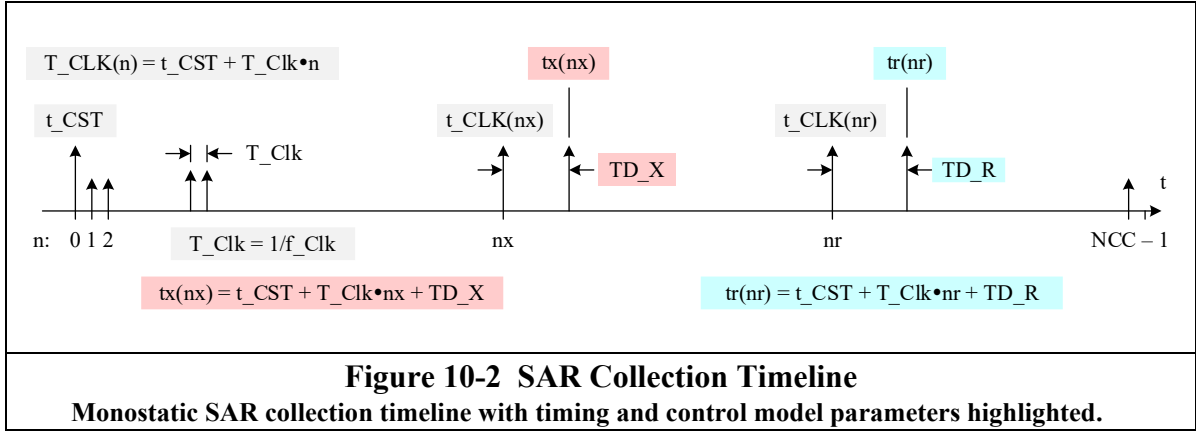
The inputs and methods used to compute the expected statistics for errors in transmit and receive metadata are based on an ideal SAR sensor timing and control model. The model includes a single control clock that generates both transmit pulse events and receive window events. The control clock is derived from a single reference oscillator that is also used to generate the transmit pulse waveforms, the receive window demodulation signals, and control the receive signal sampling.

The SAR sensor timing and control model specifies the following parameters and methods to generate an imaging collection timeline. Refer to Figure 10-2.

- (1) The collection starts at time t_CST and consists of an integer number of control clock periods. The control clock frequency is f_CLK with control clock period $T_Clk = 1/f_CLK$. Frequency f_CLK is generated from a single reference oscillator and is constant for the collection.
- (2) Control clock periods are indexed by $n = 0, 1, 2, \dots, NCC - 1$. Time t_CST corresponds to the leading edge of clock period 0. The time of the leading edge of clock period n is $t_CLK(n) = t_CST + T_CLK \cdot n$.
- (3) Transmit signal generation is initiated on a control clock count. For a transmit signal initiated on clock count n_x , the signal is output at the transmit APC at time $tx(n_x) = t_CLK(n_x) + TD_X$. Time TD_X is a transmit delay that is fixed for the collection.
- (4) Receive signal demodulation and sampling is initiated on a control clock count. For a receive signal sampling initiated on clock count n_r , the time the

sampled signal is incident at the receive APC is $tr(nr) = t_CLK(nr) + TD_R$. Time TD_R is a receive “delay” that is fixed for the collection. The value of TD_R may be positive or negative.

- (5) Transmit pulse waveforms are generated from the same reference oscillator that generates the control clock frequency f_CLK .
- (6) Receive demodulation waveforms and ADC sample times are generated from the same reference oscillator that generates the control clock frequency f_CLK .



10.2.2 Timing & Frequency Errors

The errors in the CRSD timing and frequency metadata are assumed to be of same form that arise for a sensor controlled by the equivalent of the ideal timing and control model. For any sensor, the errors in timing and frequency metadata are assumed to be equal to those that would result for metadata values computed using the ideal model with incorrect model parameter values. For a given sensor, the ideal model parameters that may be in error are described in the following.

Control Clock Frequency Error

For a given collection, the true control clock frequency is f_Clk . The estimated or measured control clock frequency used to compute metadata times and frequencies is f_Clk_0 . The error in estimated frequency f_Clk_0 is Δf_Clk . The frequency error may be also expressed as a scale factor, denoted f_Clk_SF , that is the ratio of the error divided by the estimated value. The true clock frequency may be expressed in terms of f_Clk_0 and f_Clk_SF as shown.

$$\Delta f_Clk = f_Clk - f_Clk_0 \quad f_Clk_SF = \Delta f_Clk / f_Clk_0$$

$$f_Clk = f_Clk_0 \cdot (1 + f_Clk_SF)$$

The true control clock period is $T_Clk = 1/f_Clk$. The estimated control clock period is $T_Clk_0 = 1/f_Clk_0$. The error in estimated clock period T_Clk_0 is ΔT_Clk . The clock

period error may also be expressed as a scale factor, denoted T_Clk_SF . The parameters associated with the clock period are as shown. The clock period error scale factor may be expressed in terms of the clock frequency error scale factor.

$$\begin{aligned}\Delta T_Clk &= T_Clk - T_Clk_0 & T_Clk_SF &= \Delta T_Clk / T_Clk_0 \\ T_Clk &= T_Clk_0 \cdot (1 + T_Clk_SF) & T_Clk_SF &= -f_Clk_SF \cdot \frac{1}{1 + f_Clk_SF}\end{aligned}$$

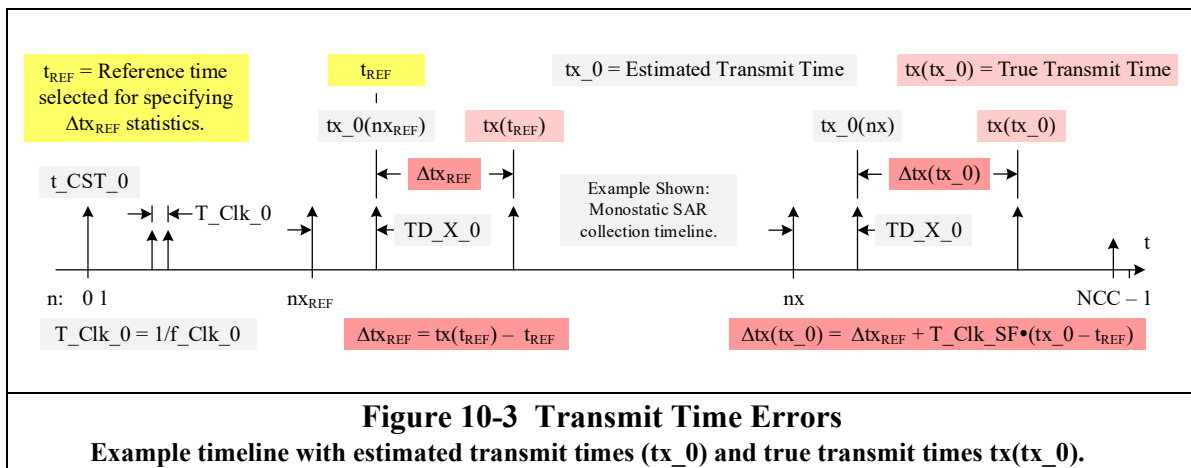
For a given sensor, the statistics for the control clock frequency error scale factor, f_Clk_SF , are specified. For a CRSD:SAR product formed for a bistatic SAR imaging collection, the statistics are specified for the transmit sensor frequency error scale factor, denoted $f_Clk_X_SF$, and the receive sensor frequency error scale factor, denoted $f_Clk_R_SF$.

Transmit Time Error at the Reference Time

For a given collection, transmit times are computed using the ideal timing and control model based upon estimated or measured values for multiple parameters. The net effect is that for an estimated transmit time tx_0 , the transmit time error $\Delta tx(tx_0)$, and the true transmit time $tx(tx_0)$ are linear functions of tx_0 . For a given sensor, a reference time is defined for specifying timing errors. For a specified reference time t_{REF} , the transmit time error may be written as shown.

$$\Delta tx(tx_0) = \Delta tx_{REF} + T_Clk_SF \cdot (tx_0 - t_{REF}) \quad tx(tx_0) = tx_0 + \Delta tx(tx_0)$$

Transmit time error Δtx_{REF} is the transmit time error for $tx_0 = t_{REF}$. Shown in Figure 10-3 is an example collection timeline for a monostatic SAR collection. For a transmit time initiated at clock count nx_{REF} , the estimated transmit time tx_0 is equal to t_{REF} . The resulting error Δtx_{REF} is a combination of the errors in estimated values for timing and control model parameters t_CST , T_Clk , and TD_X .



For specifying transmit time error statistics, the statistics for transmit time error Δtx_{REF} are specified. For all CRSD:SAR products, the reference time is defined to be equal to the

reference time specified for the SAR image reference geometry. For all CRSD:TX products, the reference time is defined to be equal to the transmit APC reference geometry time, denoted t_{xREF} . See Table 12-7. Parameter / SARImage / ReferenceTime and parameter / TxParameters / Time.

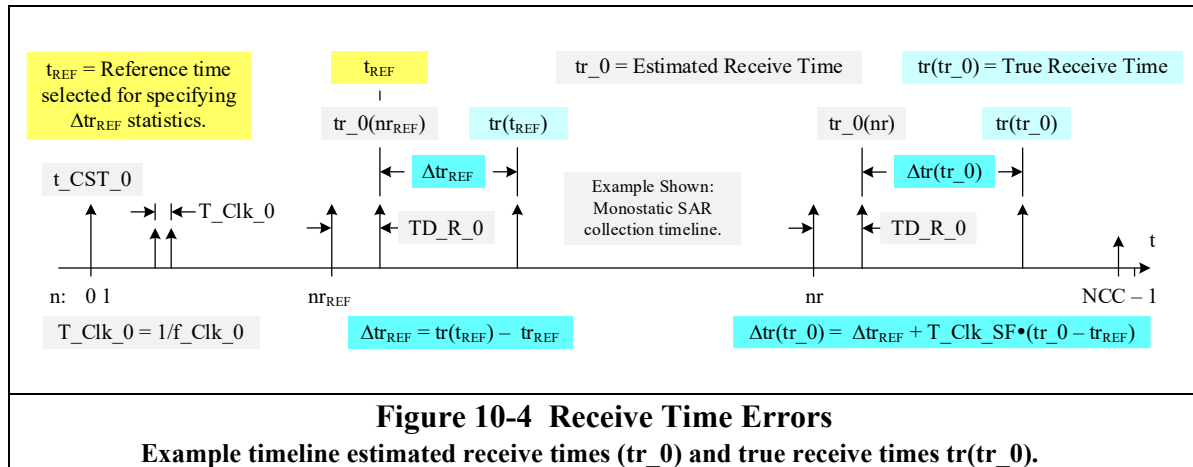
Receive Time Error at the Reference Time

For a given collection, receive times are computed using the ideal timing and control model based upon estimated or measured values for multiple parameters. The net effect is that for an estimated receive time tr_0 , the receive time error $\Delta tr(tr_0)$, and the true receive time $tr(tr_0)$ are linear functions of tr_0 . For a specified reference time t_{REF} , the receive time error may be written as shown.

$$\Delta tr(tr_0) = \Delta tr_{REF} + T_Clk_SF \cdot (tr_0 - t_{REF}) \quad tr(tr_0) = tr_0 + \Delta tr(tr_0)$$

Receive time error Δtr_{REF} is the receive time error for $tr_0 = t_{REF}$. Shown in Figure 10-4 is an example collection timeline for a monostatic SAR collection. For a receive time initiated at clock count nr_{REF} , the estimated receive time tr_0 is equal to t_{REF} . The resulting error Δtr_{REF} is a combination of the errors in estimated values for timing and control model parameters t_CST_0 , T_Clk_0 , and TD_R_0 .

For specifying receive time error statistics, the statistics for receive time error Δtr_{REF} are specified. For all CRSD:SAR products, the reference time is defined to be equal to the reference time specified for the SAR image reference geometry. For all CRSD:RCV products, the reference time is defined to be equal to the receive APC reference geometry time, denoted tr_{sREF} . See Table 12-7. Parameter / SARImage / ReferenceTime and parameter / RcvParameters / Time.



10.2.3 Time & Frequency Error Statistics

The timing and frequency statistics included in a given product are dependent upon the product type. For a CRSD:SAR product, the statistics included are dependent on the collect type. The statistics that are included are summarized as follows.

CRSD:SAR – Collect Type = Monostatic

For a product formed for a monostatic SAR imaging collection, error statistics are specified for the transmit time error, $\Delta t_{x_{REF}}$, the receive time error, $\Delta t_{r_{REF}}$, and the sensor control clock error scale factor, f_{Clk_SF} . The transmit time error and receive time error are specified at reference time t_{REF} . Time t_{REF} is specified in the SAR image reference geometry parameters. The 3-component error vector is denoted $\Delta \mathbf{XRTF}$ and the error covariance matrix is $\mathbf{C_XRTF}$. See Section 8.4 and Table 12-7.

$$\Delta \mathbf{XRTF} = [\Delta t_{x_{REF}}, \Delta t_{r_{REF}}, f_{Clk_SF}]^T \quad \mathbf{C_XRTF} = E(\Delta \mathbf{XRTF} \bullet \Delta \mathbf{XRTF}^T)$$

CRSD:SAR – Collect Type = Bistatic

For a product formed for a bistatic SAR imaging collection, error statistics are included for both the transmit sensor and the receive sensor. For the transmit sensor, error statistics are specified for the transmit time error, $\Delta t_{x_{REF}}$, and the sensor control clock error scale factor, $f_{Clk_X_SF}$. For the receive sensor, the error statistics are specified for the receive time error, $\Delta t_{r_{REF}}$, and the sensor control clock error scale factor, $f_{Clk_R_SF}$. The transmit time error and receive time errors are specified at reference time t_{REF} . Time t_{REF} is specified in the SAR image reference geometry parameters. The 4-component error vector is denoted $\Delta \mathbf{XRTF}$ and the error covariance matrix is $\mathbf{C_XRTF}$.

$$\Delta \mathbf{XRTF} = [\Delta t_{x_{REF}}, f_{Clk_X_SF}, \Delta t_{r_{REF}}, f_{Clk_R_SF}]^T$$

$$\mathbf{C_XRTF} = E(\Delta \mathbf{XRTF} \bullet \Delta \mathbf{XRTF}^T)$$

CRSD:TX

For a CRSD:TX product, error statistics are specified for the transmit time error, $\Delta t_{x_{REF}}$, and the sensor control clock error scale factor, $f_{Clk_X_SF}$. The transmit time error is specified at reference time $t_{x_{REF}}$. Time $t_{x_{REF}}$ is specified in the transmit sensor reference geometry parameters. The 2-component error vector is denoted $\Delta \mathbf{XTF}$ and the error covariance matrix is $\mathbf{C_XTF}$. See Section 8.1.

$$\Delta \mathbf{XTF} = [\Delta t_{x_{REF}}, f_{Clk_X_SF}]^T \quad \mathbf{C_XTF} = E(\Delta \mathbf{XTF} \bullet \Delta \mathbf{XTF}^T)$$

CRSD:RCV

For a CRSD:RCV product, error statistics are specified for the receive time error, Δt_{REF} , and the sensor control clock error scale factor, $f_{\text{Clk_R_SF}}$. The receive time error is specified at reference time t_{SREF} . Time t_{SREF} is specified in the receive sensor reference geometry parameters. The 2-component error vector is denoted $\Delta \mathbf{RTF}$ and the error covariance matrix is $\mathbf{C_RTF}$.

$$\Delta \mathbf{RTF} = [\Delta t_{\text{REF}}, f_{\text{Clk_R_SF}}]^T \quad \mathbf{C_RTF} = E(\Delta \mathbf{RTF} \bullet \Delta \mathbf{RTF}^T)$$

10.2.4 Error Decorrelation Parameters

For each sensor timing and frequency error covariance matrix specified in a product, an optional set of error decorrelation functions may be included. The inclusion of the decorrelation functions is a product design choice. Guidance for the use of the decorrelation functions is also a product design choice and is specified per the PDD.

10.3 Atmospheric Error Parameters

For many applications that input CRSD products, information about atmospheric conditions are used in the subsequent processing. For example, SAR image formation applications commonly use estimates of the additional propagation delay due to the troposphere and the ionosphere. For any CRSD product, optional parameters may be included in the XML instance that describe the troposphere and the ionosphere (if applicable). The parameters provided may also include estimated error statistics. See Table 12-2.

11 CRSD XML Description

The CRSD 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 CRSD 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 PDD. See Section 3.

11.1 XML Parameter Types

The XML structure includes the complex types listed in Table 11-1. These complex types are formally defined in the CRSD XML schema. The parameter types are listed in Table 11-1 for convenience.

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

Table 11-1 XML Parameter Types		
Type	Description	Guidance
TXT	Value is a string of text characters. See XML datatype xs: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 and false for clarity. Discourage the use of 1 and 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 CRSD date and time parameters are specified in UTC (Coordinated Universal Time). The trailing “Z” indicates the value is in UTC. The decimal point and 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 may be specified per PDD.
INT	Value is an integer in decimal format. Values may be positive, negative or zero. See XML datatype xs:integer.	Integer values for some parameters in some products will exceed the range supported by a 32-bit binary integer format.

Table 11-1 XML Parameter Types

Type	Description	Guidance
DBL	Value is real-valued decimal number. See XML datatype xs:double. Values may be accurately stored in an IEEE Binary64 floating point variable.	
HEX	Value is a hexadecimal representation of an integral number of bytes. See XML datatype 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 Sample.
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., location of a point on the image reference surface).
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 parameter (e.g., positions in ECEF 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 CRSD, 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 CRSD, 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 $M = \text{order1}$ and $c(m) = \text{Coef w/ exponent1} = m$. The input variable is Var1. The output parameter is $Z(\text{Var1})$: $Z(\text{Var1}) = \sum_{m=0}^M c(m) \lfloor (\text{Var1})^m$
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 $M = \text{order1}$, $N = \text{order2}$ and coefficient $c(m,n) = \text{Coef w/ exponent1} = m$ and $\text{exponent2} = n$. The input variables are Var1 and Var2. The output parameter is $Z(\text{Var1}, \text{Var2})$: $Z(\text{Var1}, \text{Var2}) = \sum_{m=0}^M \sum_{n=0}^N c(m,n) \lfloor (\text{Var1})^m \lfloor (\text{Var2})^n$

Table 11-1 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 ECEF coordinates vs. time). Example: Let $MX = X \text{ order1}$, $MY = Y \text{ order1}$ and $MZ = Z \text{ order1}$. 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 $V(\text{Var1})$: $V(\text{Var1}) = \begin{bmatrix} X(\text{Var1}) \\ Y(\text{Var1}) \\ Z(\text{Var1}) \end{bmatrix}$ $V(\text{Var1}) = \begin{bmatrix} \sum_{mx=0}^{MX} c(mx) [(\text{Var1})^{mx}] \\ \sum_{my=0}^{MY} c(my) [(\text{Var1})^{my}] \\ \sum_{mz=0}^{MZ} c(mz) [(\text{Var1})^{mz}] \end{bmatrix}$
PxP	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 11-2. Used for specifying defined PPPs and defined PVPs.	Size and Offset specify the size and placement of the binary parameter in the set of PVPs provided for each vector. Format specifies the binary format of the components of the parameter.
APxP	Identifies a parent tag with children Name, Offset, Size and Format. Size and Offset are type INT. Name and Format are type TXT. Binary formats are specified per the guidance in Table 11-2. Used for specifying AddedPPPs and AddedPVPs	The value of Name identifies the Added PPP or the Added PVP parameter. Use of Size, Offset and Format are the same as for type PxP.
MTX	Identifies a parent tag that consists of a set of entries for a two-dimensional matrix. The values of each child tag are floating point type, “DBL”. “Entry” represents an entry in the matrix The parent tag will have attributes “size1” and “size2”. Total number entries less than or equal to $\text{NumEntries} = \text{size1} \times \text{size2}$. Each entry “Entry” will have attributes “index1” and “index2”. The value of index1 may be from 1 to size1. The value of index2 maybe from 1 to size2. Matrix entries equal to zero may be omitted.	Used for including error covariance matrices. Ex: Parent attribute: size1=“6” and size2=“6” indicates complex type contains the entries of a 6 x 6 square matrix. Ex: Entry attributes: index1=“1” index2=“2” indicates the entry is the (1,2) entry of the matrix.

Table 11-1 XML Parameter Types		
Type	Description	Guidance
EDF	Identifies a parent tag with children: CorrCoefZero and DecorrRate. Children are of type “DBL”. Correlation Coefficient (CC) is a function of the time difference Δt . $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \cdot \Delta t))$	Value of CorrCoefZero (CC0) restricted to (0.0, 1.0]. Value of DecorrRate (DCR) > 0.

11.2 Binary Parameter Formats

The allowed binary formats are listed in Table 11-2. For CRSD product files, all binary parameters shall be formatted with the Most Significant Byte (MSB) stored first (i.e., binary data is in Big Endian format).

Table 11-2 Allowed Binary Formats	
Format Strings	Description and Guidance
Unsigned Integer “U1”, “U2”, “U4”, “U8”	Unsigned integer (UINT) of size n bytes. Allowed 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. Allowed 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.
Named Parameters	Used to specify data elements that are formed from 1 or more parameters. Individual parameters may be of any allowed format. Each element is described by “<name>=<format_string>;” The named parameter format string comprises one or more of these concatenated together. For example: “A=U2;B=I2;C=F4;D=CF8;E=S32;”

11.3 XML Enumeration List

The enumerations used in the XML structure and the allowed values are listed in Table 11-3. The allowed values are specified in the CRSD XML schema.

Table 11-3 XML Enumerations	
Enumeration	Allowed Values
CollectType	“MONOSTATIC” and “BISTATIC”
ModeType	“SPOTLIGHT”, “STRIPMAP”, and “DYNAMIC STRIPMAP”
RefHeight	“IARP” and “ZERO”
EarthModel	“WGS_84” All CRSD products use the WGS 84 reference ellipsoid.
SignalArrayFormat	“CI2”, “CI4”, and “CF8”
Polarization ID	“X”, “Y”, “V”, “H”, “S”, “E”, “RHC”, “LHC”
Tx Waveform Type	“LFM”, “XM”, and “LFM w XM”
SideOfTrack	“L” and “R”
Frame	“ECF”, “RIC_ECF”, and “RIC_ECI”

12 CRSD XML Structure

The CRSD XML metadata specifies how the data in a given product was collected and processed. The XML metadata also specifies the content of the other data blocks in the product. The XML structure is described in this section and is formally defined by the CRSD XML schema. The XML instance included in a given product is dependent upon the CRSD product type. The root node element of the instance and the required branches are unique for each product type. The XML metadata instance for each product type is summarized as follows.

12.1 XML: SAR Imaging

For a CRSD:SAR product, the root node element of the XML instance is “CRSDsar”. The structure contains 14 primary branches that are required and included in all XML instances. The structure contains 3 optional branches that may also be included.

CRSD SAR Imaging: <CRSDsar . . . > . . . </CRSDsar>

Required SAR Branches

CRSDsar / ProductInfo
 CRSDsar / SARInfo
 CRSDsar / TransmitInfo
 CRSDsar / ReceiveInfo
 CRSDsar / Global
 CRSDsar / SceneCoordinates
 CRSDsar / Data
 CRSDsar / TxSequence
 CRSDsar / Channel
 CRSDsar / ReferenceGeometry
 CRSDsar / SupportArray
 CRSDsar / PPP
 CRSDsar / PVP
 CRSDsar / Antenna

Optional SAR Branches

CRSDsar / DwellPolynomials
 CRSDsar / ErrorParameters
 CRSDsar / GeoInfo**

** The CRSD / GeoInfo branch may be repeated in a given instance. Use of the GeoInfo branch is defined per the product design process.

12.2 XML: Transmit Only

For a CRSD:TX product, the root node element of the XML instance is “CRSDtx”. The structure contains 10 primary branches that are required and included in all XML instances. The structure contains 2 optional branches that may also be included.

CRSD Transmit Only: <CRSDtx . . . > . . . </CRSDtx>

Required TX Branches

CRSDtx / ProductInfo
 CRSDtx / TransmitInfo
 CRSDtx / Global
 CRSDtx / SceneCoordinates
 CRSDtx / Data
 CRSDtx / TxSequence
 CRSDtx / ReferenceGeometry
 CRSDtx / SupportArray
 CRSDtx / PPP
 CRSDtx / Antenna

Optional TX Branches

CRSDtx / ErrorParameters
 CRSDtx / GeoInfo**

** The CRSD / GeoInfo branch may be repeated in a given instance. Use of the GeoInfo branch is defined per the product design process.

12.3 XML: Receive Only

For a CRSD:RCV product, the root node element of the XML instance is “CRSDrcv”. The structure contains 10 primary branches that are required and included in all XML instances. The structure contains 2 optional branches that may also be included.

CRSD Receive Only: <CRSDrcv . . . > . . . </CRSDrcv>

Required RCV Branches

CRSDsar / ProductInfo
 CRSDsar / ReceiveInfo
 CRSDsar / Global
 CRSDsar / SceneCoordinates
 CRSDsar / Data
 CRSDsar / Channel
 CRSDsar / ReferenceGeometry
 CRSDsar / SupportArray
 CRSDsar / PVP
 CRSDsar / Antenna

Optional RCV Branches

CRSDsar / ErrorParameters
 CRSDsar / GeoInfo**

** The CRSD / GeoInfo branch may be repeated in a given instance. Use of the GeoInfo branch is defined per the product design process.

12.4 Color Scheme for XML Tables

The XML structure is described in Tables 12-1(a) through 12-14 below. Each table describes one of the primary branches. Some branches or structures are included based on the CRSD product type. The description for each branch includes the guidance for when the branch is included in an instance. For a given instance, a particular branch may be required to be included, may be optional to include, or may be required to be omitted. In the following tables, each branch is also highlighted by color to indicate when the branch is included in an XML instance. The highlight colors used and the implication for the branch are as follows.

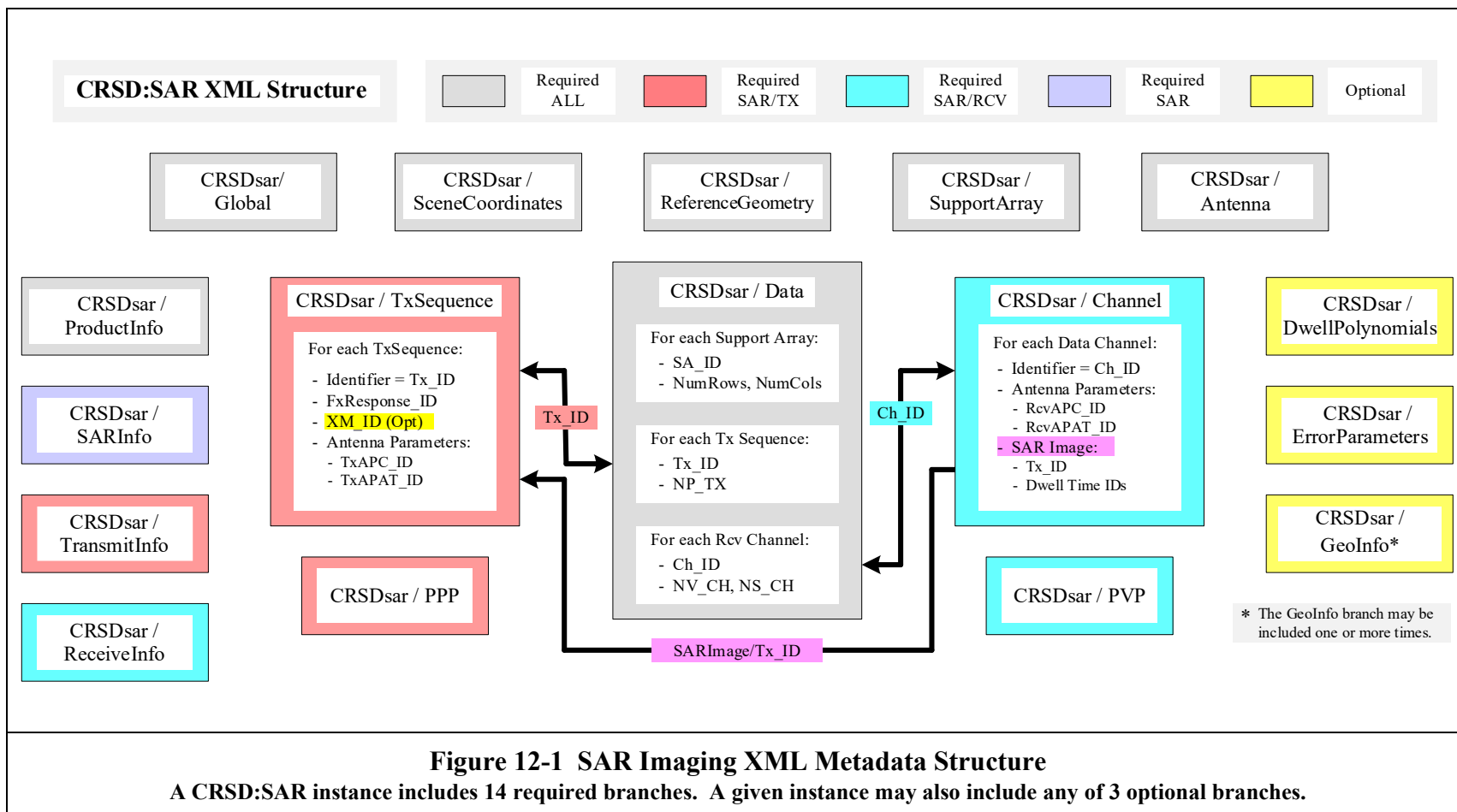
GRAY	Required to be included in all instances that also include the parent node of the branch. Examples include: Table 12-1(a) /CRSDxx/ProductInfo Table 12-3 /CRSDxx/SceneCoordinates/IARP Table 12-4 /CRSDxx/Data/Transmit/TxSequence Table 12-4 /CRSDxx/Data/Receive/Channel
VIOLET	Required to be included in all SAR Imaging instances that also include the parent node of the branch. Omitted for all Transmit Only and all Receive Only instances. Examples include: Table 12-1(b) /CRSDsar/SARInfo Table 12-6 /CRSDsar/Channel/Parameters/SARImage Table 12-13 /CRSDsar/ErrorParameters/SARImage
RED	Required to be included in all Transmit Only instances and in SAR Imaging instances (except where noted) that also include the parent node of the branch. Omitted for all Receive Only instances. Examples include: Table 12-1(c) /CRSDxx/TransmitInfo Table 12-4 /CRSDxx/Data/Transmit Table 12-13 /CRSDtx/ErrorParameters/TxSensor (TX only)
BLUE	Required to be included in all Receive Only instances and in SAR Imaging instances (except where noted) that also include the parent node of the branch. Omitted for all Transmit Only instances. Examples include: Table 12-1(d) /CRSDxx/ReceiveInfo Table 12-4 /CRSDxx/Data/Receive Table 12-13 /CRSDrcv/ErrorParameters/RcvSensor (RCV only)
YELLOW	Optional branch that may be included in an instance that includes the parent node of the branch. For some optional branches, they may only be included for some product types. Examples include: Table 12-1(a) /CRSDxx/ProductInfo/CreationInfo Table 12-3 /CRSDxx/SupportArray/XMArray (SAR or TX only)

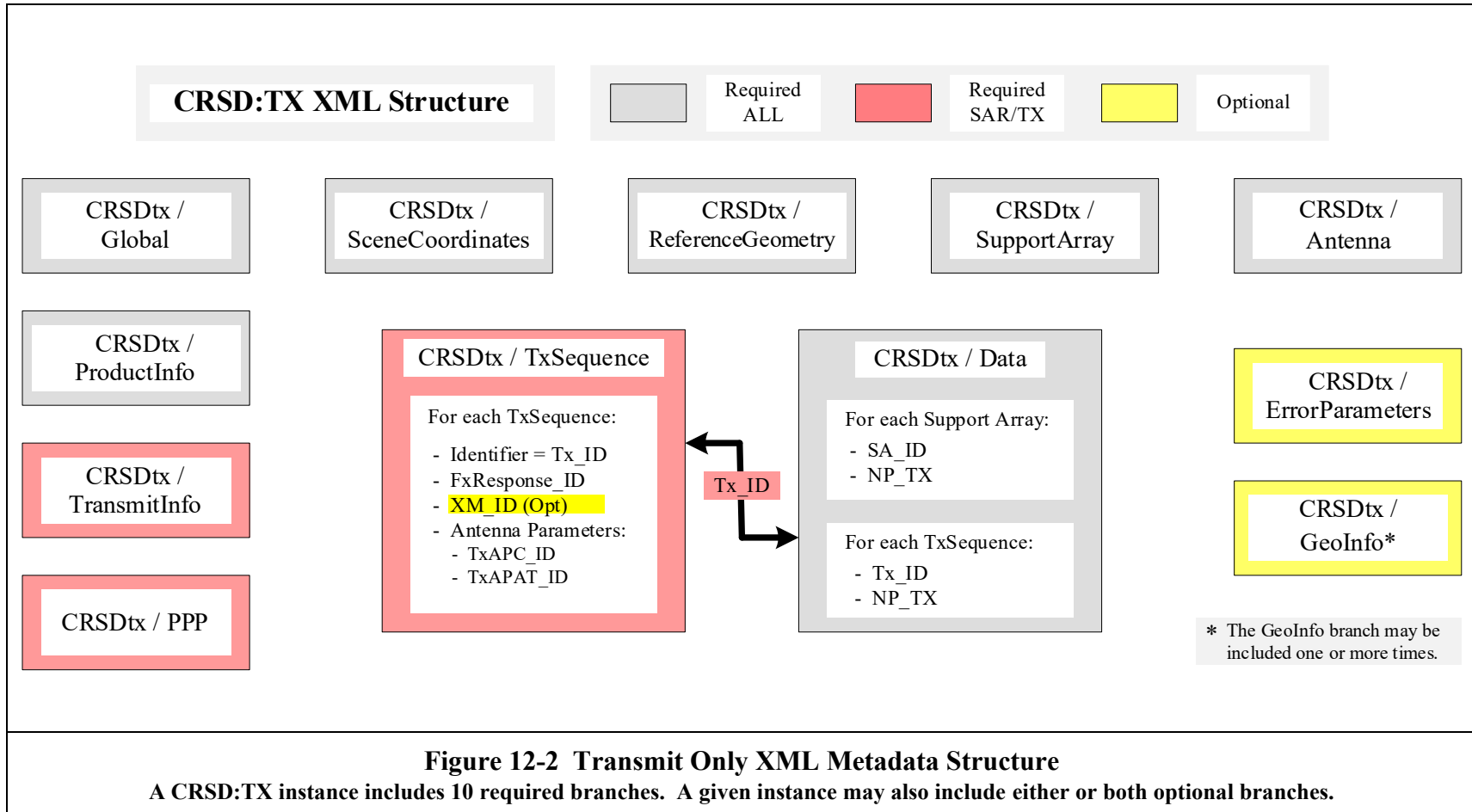
ORANGE

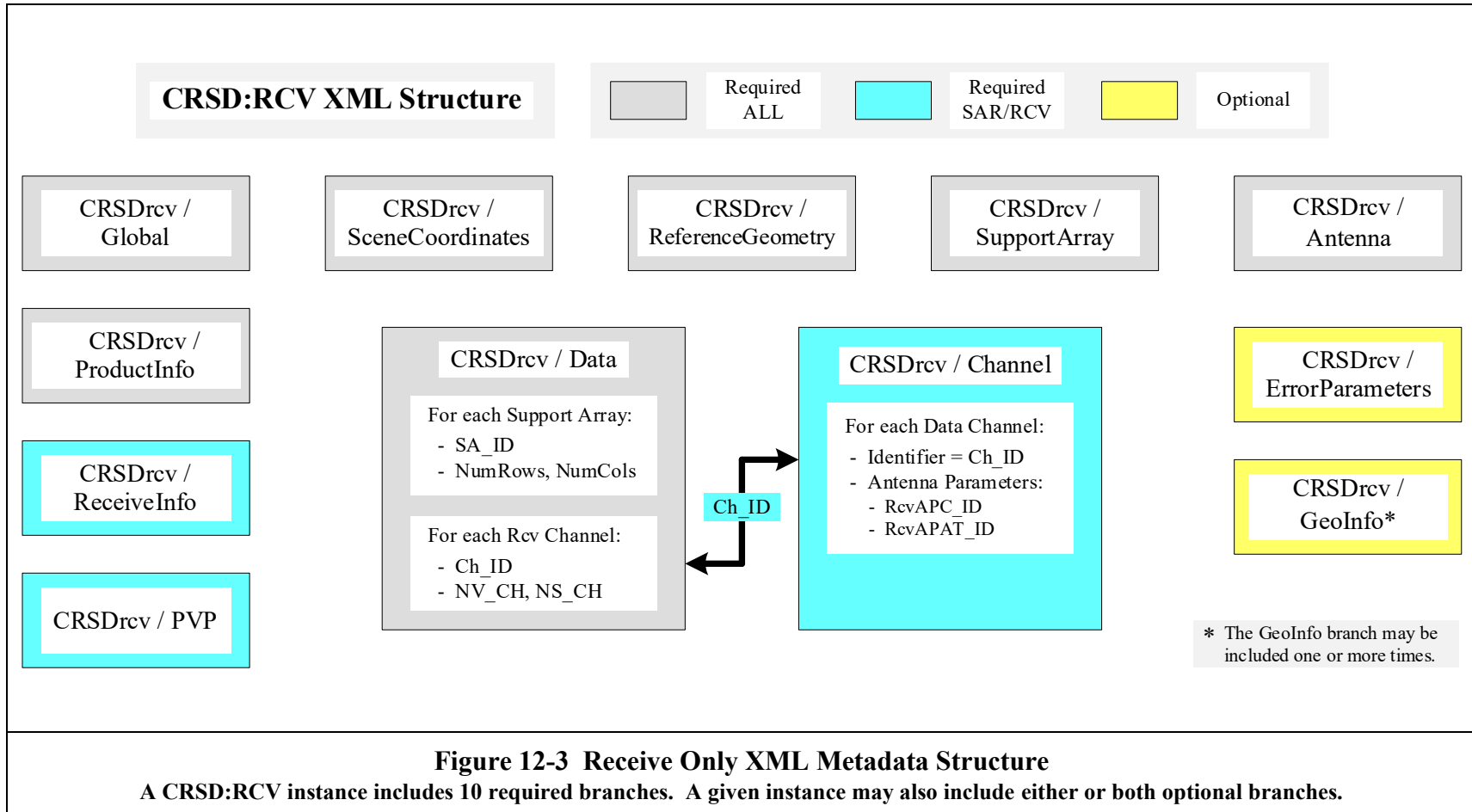
Branch is included by a choice from two or more branches. One of the allowed choice branches is included in all instances that contain the parent node for the branch. Examples include:

Table 12-3	/CRSDxx/SceneCoordinates/ReferenceSurface/Planar /ReferenceSurface/HAE
Table 12-13	/CRSDsar/ErrorParameters/SARImage/Monostatic /SARImage/Bistatic

The CRSD XML structures are graphically illustrated in Figure 12-1, Figure 12-2, and Figure 12-3. The color highlighting scheme used in Tables 12-1(a) through 12-14 is also used in the figures. Shown in Figure 12-1 is the XML structure for a SAR imaging product. All of the primary branches are shown. Also shown are some of the key identifier elements that are used in the CRSDsar data structure (e.g., Tx_ID, Ch_ID, etc.). Shown in Figure 12-2 is the XML structure for a Transmit Only product. Shown in Figure 12-3 is the XML structure for a Receive Only product.







12.5 CRSD XML Tables

12.5.1 XML: ProductInfo / SARInfo / TxInfo / RevInfo

Table 12-1(a) Product Information								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / ProductInfo			R		1	Information about the product. May include the time it was created, and the application(s) used.		
	ProductName		R	TXT	1	Identifies the CRSD product. May include the sensor names, the event names, and the product type.		Allowed values specified per Product Design Document (PDD).
	Classification		R	TXT	1	Text field containing human-readable banner. Classification, file control and handling, including proprietary markings. Value also included in product file header. See Table 2-1.		Allowed values specified per PDD. 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 PDD. Default value: “UNRESTRICTED”
	CountryCode		O	TXT	1	List of country codes for the region covered by the collection.		Method for specifying Country Codes per PDD.
	Profile		O	TXT	1	Specifies the product profile used to create the product. A profile specifies the contents to be included in a given product. See Sect 3.		Allowed values specified per PDD.
	CreationInfo		O		1+	Information about the application(s) used and the time(s) the product was created.		Multiple instances may be included (as needed).
		Application	R	TXT	1	Name and version identifier of the application used to create the product.		Allowed values specified per PDD.
		DateTime	R	XDT	1	Date and Time the application was used in creating the product.		Allowed values specified per PDD.
		Site	O	TXT	1	Identifies the site where the application was used to create the product.		Allowed values specified per PDD.

Table 12-1(a) Product Information								
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.
		Parameter	O	TXT	1+	Text field that may be included per Product Design Document.		Attribute: name = “xxx” identifies the parameter.

Table 12-1(b) SAR Imaging Information								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar / SARInfo			SAR		1	Information about the SAR imaging collection.		
	CollectType		R	ENU	1	Specifies the SAR Collect Type. 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 11-3.
	RadarMode		R		1	Parameters that specify the radar mode used to collect the initial PHD data.		
		ModeType	R	ENU	1	SAR imaging Mode Type used for the imaging operation. For bistatic collection, specifies the Mode Type used by the Receive sensor.		Allowed values: “SPOTLIGHT”, “STRIPMAP” and “DYNAMIC STRIPMAP” See Table 11-3.
		ModeID	O	TXT	1	SAR system specific mode identifier or mode name.		Allowed values specified per PDD.
	Parameter		O	TXT	1+	Text field that may be included per a Product Design Document.		Attribute: name = “xxx” identifies the parameter name.

Table 12-1(c) Transmit Sensor Information						
Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDtx / TransmitInfo	SAR TX		1	Information about the Transmit Sensor and the transmit signal event. See Sect 3.		
SensorName	R	TXT	1	Identifies the Transmit sensor that provided the transmitted signals specified in the product and, for SAR imaging, were received and recorded.		Allowed values specified per PDD.
EventName	R	TXT	1	Identifies the Transmit sensor imaging or transmit-only event.		Allowed values specified per PDD.
Parameter	O	TXT	1+	Text field that may be included per a Product Design Document.		Attribute: name = “xxx” identifies the parameter name.

Table 12-1(d) Receive Sensor Information						
Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrcv / ReceiveInfo	SAR RCV		1	Information about the Receive Sensor and the collection event when the radar signal data was received and recorded. See Sect 3.		
SensorName	R	TXT	1	Identifies the Receive sensor that collected the initial PHD or receive only data used to form the receive signal arrays.		Allowed values per PDD. For monostatic SAR, value shall be equal to the Transmit sensor name.
EventName	R	TXT	1	Identifies the Receive sensor imaging event or receive only event when the initial signal data was collected.		Allowed values per PDD. For monostatic SAR, value shall be equal to the Transmit event name.
Parameter	O	TXT	1+	Text field that may be included per a Product Design Document.		Attribute: name = “xxx” identifies the parameter name.

12.5.2 XML: Global

Table 12-2 Global Parameters						
Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / Global	R		1	Global parameters that apply to all receive channels and/or transmit pulse sequences.		
CollectionRefTime	R	XDT	1	Collection Reference Time (t _{CRT}). Time reference used for all other times in the product. All transmit times and all receive times are specified in seconds relative to t _{CRT} .	UTC	The choice of CRT is a product design choice. The start time of the event is an acceptable choice.
TropoParameters	O			Parameters used to compute the propagation delay due to the troposphere.		May be included in any product.
N0	R	DBL	1	Estimated troposphere refractivity (N0) value of the for the imaged scene (dimensionless).		Value provided for the IARP (LatLon).
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 11-3.
N0ErrorStdDev	O	DBL	1	Estimated standard deviation for the error in the estimated troposphere refractivity value.		Require error standard deviation to be ≥ 0.0
IonoParameters	O		1	Parameters used to compute propagation effects due to the ionosphere.		May be included in any product for spaceborne sensors.
TECV	R	DBL	1	Estimated Total Electron Content (TEC) integrated along the Vertical (V) 1 TECU = 10 ¹⁶ e ⁻ /m ²	TECU	
F2Height	R	DBL	1	The nominal F2 height of the ionosphere.	m	
TECErrorStdDev	O	DBL	1	Estimated standard deviation for the error in the estimated TECV value.	TECU	Require error standard deviation to be ≥ 0.0

Table 12-2 Global Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	Transmit	SAR TX		1	Parameters derived from the transmit pulse PPP included in the product.		
	TxTime1	R	DBL	1	Earliest transmit center time, txc_1, for any transmit pulse in the product. Value computed by the sum of the PPP Integer + Fraction	sec	Value may be negative, zero, or positive.
	TxTime2	R	DBL	1	Latest transmit center time, txc_2, for any transmit pulse in the product.	sec	
	FxMin	R	DBL	1	Minimum fx_1 PPP value for any transmit pulse in the product.	Hz	
	FxMax	R	DBL	1	Maximum fx_2 PPP value for any transmit pulse in the product.	Hz	
	Receive	SAR RCV		1	Parameters derived from the receive signal PVP metadata included in the product.		
	RcvStartTime1	R	DBL	1	Earliest Receive Start Time, trs_1, for any signal vector in the product. Value computed by the sum of the PVP Integer + Fraction	sec	Value may be negative, zero, or positive.
	RcvStartTime2	R	DBL	1	Latest Receive Start Time, trs_2, for any signal vector in the product.	sec	
	FrcvMin	R	DBL	1	Minimum frcv_1 PVP value for any signal vector in the product.	Hz	
	FrcvMax	R	DBL	1	Maximum frcv_2 PVP value for any signal vector in the product.	Hz	

12.5.3 XML: SceneCoordinates

Table 12-3 Scene Geographic Coordinates								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / SceneCoordinates			R		1	Parameters that define geographic coordinates of the imaged scene. See the Sect 5.		
	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: “WGS_84” See Table 11-3.
	IARP		R		1	Image Area Reference Point (IARP). The IARP is the origin of the Image Area Coordinate system (IAX, IAY, IAZ).		Note: The IARP is always on the reference surface.
		ECF	R	XYZ	1	IARP position in ECEF coordinates.	m	Use ECEF position for all precise computations.
		LLH	R	LLH	1	IARP position in geodetic coordinates. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 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 reference surface is one of two allowed types: PLANAR or HAE. The surface type is specified by including one of the two branches below. See Sect 5.1.1 and CPHD D&I DD Sect 6.2.							
		Planar	C		1	Parameters for SurfaceType = PLANAR The reference surface is a plane that contains the IARP.		
		uIAX	R	XYZ	1	Image Area X-coordinate (IAX) unit vector in ECEF 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 ECEF 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. uIAX • uIAY = 0 uIAZ = uIAX × uIAY

Table 12-3 Scene Geographic Coordinates

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		HAE	C		1	Parameters for SurfaceType = HAE The 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 increments 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.
		uIAYLL	R	LL	1	Image coordinate IAY “unit vector” expressed as an increment in latitude and longitude. The precise increments 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). For CRSDrcv or CRSDtx, see Sect 5.2 and Sect 5.3.		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: $IA_X1 \leq IAX \leq IA_X2$ $IA_Y1 \leq IAY \leq IA_Y2$
		X2Y2	R	XY	1	Corner of the Image Area Rectangle in Image Area coordinates, (IA_X2, IA_Y2).	m	Require: $IA_X1 < IA_X2$ and $IA_Y1 < IA_Y2$
		Polygon	R		1	Polygon that specifies the full resolution image area within the Image Area Rectangle. Vertices are indexed: $n = 1, 2, \dots, NumVertices$.		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.

Table 12-3 Scene Geographic Coordinates

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		IACP	R	LL	4	Corner points located on the reference surface. Convert Image Area Rectangle corner positions to LL. Corners in clockwise order.	dd	Attribute: index = 1 to 4 Allowed values: $-90.0 \leq \text{Lat} \leq 90.0$, $-180.0 \leq \text{Lon} \leq 180.0$
	ExtendedArea		O SAR		1	Extended Area is defined by a rectangle aligned with Image Area coordinates (IAX, IAY).		
		X1Y1	R	XY	1	Corner of the Extended Area Rectangle in Image Area coordinates, (EA_X1, EA_Y1).	m	Extended area rectangle: $\text{EA_X1} \leq \text{IAX} \leq \text{EA_X2}$ $\text{EA_Y1} \leq \text{IAY} \leq \text{EA_Y2}$
		X2Y2	R	XY	1	Corner of the Extended Area Rectangle in Image Area coordinates, (EA_X2, EA_Y2).	m	Require: $\text{EA_X1} < \text{EA_X2}$ and $\text{EA_Y1} < \text{EA_Y2}$
		Polygon	R		1	Polygon specifies the extended area portion of the Extended Area Rectangle. Vertices are indexed: $n = 1, 2, \dots, \text{NumVertices}$.		Attribute: size = NumVertices Require $\text{NumVertices} \geq 3$.
		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 SAR		1	Parameters that describe a geo-referenced image grid for image data products that may be formed from the signal array(s).		
		Identifier	O	TXT	1	String that 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). Image grid line and sample are pixel-centered indices.		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 $\text{LineSpacing} > 0$.
		FirstLine	R	INT	1	Index of the first line (IG_L1).		

Table 12-3 Scene Geographic Coordinates									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
			NumLines	R	INT	1	Number of Lines		Require NumLines $\geq$ 1.
			IAYExtent	R		1	Increasing sample index is in the +IAY direction.		
			SampleSpacing	R	DBL	1	Sample spacing (S_SP)	m	Require SampleSpacing > 0.
			FirstSample	R	INT	1	Index of the first sample (IG_S1).		
			NumSamples	R	INT	1	Number of Samples		Require NumSamples $\geq$ 1.
			SegmentList	O		1	List of 1 or more image grid segments defined relative to the image grid.		
			NumSegments	R	INT	1	Number of image segments. Segments are referenced by their unique Segment ID.		
			Segment	R		1+	Parameters that specify the segment size and location – one instance included for each image segment.		
			Identifier	R	TXT	1	String that uniquely identifies the Image Segment (Seg_ID).		Allowed values specified per Product Design Document.
			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	R		1	Polygon that describes a portion of the segment rectangle.		Attribute: size = NumVertices Require NumVertices $\geq$ 3.
			SV	R	LS	3+	Segment Polygon vertex specified in line and sample. Vertices are in clockwise order.		Attribute: index = 1 to NumVertices

12.5.4 XML: Data

Table 12-4 Binary Data Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / Data				R		1	Parameters that describe binary data components contained in the product. See Sect 2.4 through Sect 2.8.		
	Support			R		1	Parameters that specify support arrays contained in the product. See Sect 2.4.		
		NumSupportArrays		R	INT	1	Number of binary support arrays (Num_SA) contained in the product. Support Arrays are referenced by their unique Support Array ID.		Allowed values: Num_SA ≥ 1
		SupportArray		R		1+	Parameters that specify the Support Array size and location – one instance included for each support array.		
			SAId	R	TXT	1	Specifies the support array for which the data applies.		Value is equal to an SA_ID for a support array included in the product. See Table 12-9.
			NumRows	R	INT	1	Number of rows in the array, NumRows. Rows are indexed: m = 0, 1, 2, 3, . . . , NumRows(SA_ID) – 1.		
			NumCols	R	INT	1	Number of columns per row in the array, NumCols. Columns are indexed: n = 0, 1, 2, 3, . . . , NumCols(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.	bytes	For a CRSD product file, all binary parameters are stored in Big Endian format.
			ArrayByteOffset	R	INT	1	Array offset from the start of the Support block (in bytes) to the start of the support array.	bytes	
	Transmit			SAR TX		1	Parameters that specify transmit pulse PPP arrays. See Sect 2.5.		

Table 12-4 Binary Data Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		NumBytesPPP	R	INT	1	Number of bytes per set of PPPs. One set of PPPs for each transmit pulse.	bytes	Value is always a multiple of 8.
		NumTxSequences	R	INT	1	Number of transmit pulse sequences (Num_TX) contained in the product. Transmit sequences are referenced by their unique sequence Identifier		Allowed values: Num_TX $\geq$ 1
		TxSequence	R		1+	Parameters that specify the PPP array size and location – one instance included for each transmit sequence.		
		TxId	R	TXT	1	Specifies the transmit sequence for which the data applies.		Value is equal to a Tx_ID for a Tx Sequence included in the product. See Table 12-5.
		NumPulses	R	INT	1	Number of pulses in the transmit pulse sequence, NP_TX. Pulses are indexed: $p = 0, 1, 2, 3, \dots, NP_TX(Tx_ID) - 1$.		
		PPPArrayByteOffset	R	INT	1	PPP Array offset from the start of the PPP block (in bytes) to the start of the PPP Array for the transmit sequence.	bytes	
	Receive		SAR RCV		1	Parameters that specify the receive signal arrays and PVP arrays. See Sect 2.6 thru Sect 2.8.		
		SignalArrayFormat	R	ENU	1	Signal Array sample binary format of the CRSD signal arrays. 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 11-3. For all signal arrays: (1) The real and imaginary components are stored in adjacent bytes, real component stored first. (2) For a CRSD product file, all binary parameters are stored in Big Endian format.

Table 12-4 Binary Data Parameters

Table 12-4 Binary Data Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		NumBytesPVP	R	INT	1	Number of bytes per set of PVPs. One set of PVPs for each CRSD signal vector.	bytes	Value is always a multiple of 8.
		NumCRSDChannels	R	INT	1	Number of CRSD channels (Num_CH) contained in the product. Channels are referenced by their unique Channel Identifier		Allowed values: Num_CH ≥ 1
		SignalCompression	O		1	Parameters that are included when the signal arrays are in compressed format. See Sect 2.8.		
		Identifier	R	TXT	1	Identifies the method of compression. May also include information needed for decompression.		Allowed methods and ID values specified per PDD.
		CompressedSignalSize	R	INT	1	Size (in bytes) of the compressed signal byte sequence.	bytes	
		Processing	O		1+	Parameters that describe the type of compression processing used or the type of decompression processing to be used.		Use specified per PDD.
		Type	R	TXT	1	Identifies the type of processing.		Values specified per PDD.
		Parameter	O	TXT	1+	Parameter associated with the type of processing.		Attribute name = “xxxx” identifies the parameter.
		Channel	R		1+	Parameters that specify the receive channel signal array and PVP array size and location – one instance included for each receive channel.		
		ChId	R	TXT	1	Specifies the receive channel for which the data applies.		Value is equal to a Ch_ID for a receive channel included in the product. See Table 12-6.
		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.		Value is equal to the number of vectors in the signal array in standard format.

Table 12-4 Binary Data Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
			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.		Value is equal to the number of samples in the signal array in standard format.
			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.	bytes	For signal arrays in compressed format, set Byte Offset = 0 for all channels.
			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.	bytes	

12.5.5 XML: TxSequence

Table 12-5 Transmit Sequence Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDtx / TxSequence			SAR TX		1	Parameters that describe the transmit pulse sequences specified in the product. See Sect 6.		
	RefTxId		R	TXT	1	Transmit ID for the Reference Transmit Sequence (Ref_Tx_ID) in the product.		For CRSDsar: Value is equal to the Reference Channel Tx Sequence - Tx_ID(Ref_Ch_ID)
	TxWFType		R	ENU	1	Type of transmit waveforms used during for all Tx Sequences. See Sect 6.2.		Allowed values: “LFM”, “XM, and “LFM w XM”. See Table 11-3.
	Parameters		R		1+	Parameter set that describes a single transmit sequence – one instance included for each sequence.		Transmit sequences are referenced by their unique Tx Sequence ID (Tx_ID).
		Identifier	R	TXT	1	String that uniquely identifies the transmit pulse sequence (Tx_ID) for which the data applies.		Allowed values specified per Product Design Document.
		RefPulseIndex	R	INT	1	Index of the reference pulse (p_TX_REF) for the channel. See Sect 6-1.		May be any pulse in the sequence.
		XMId	C	TXT	1	Specifies the XM array used to compute pulse waveforms for the transmit sequence. Only included for WF types “LFM w XM” and “XM”.		Value is equal to an SA_ID for an XM array included in the product.
		FxResponseId	R	TXT	1	Specifies the Fx Response array used to compute pulse waveforms for the transmit sequence.		Value is equal to an SA_ID for an Fx Response array included in the product.
		FxBWFixed	R	BOOL	1	Flag to indicate a constant transmit frequency band. Flag is “true” if for all pulses in the sequence: fx_1(p) is constant and fx_2(p) is constant.		Value based upon the values of PPPs {fx_1(p)} and {fx_2(p)}.
		FxC	R	DBL	1	Transmit center frequency (fx_C) for total span of FX frequencies for the sequence. fx_C = ½•(fx_2_Max + fx_1_Min)	Hz	Computed from the set of fx_1 and fx_2 PPPs for the sequence. See Sect 6.3.

Table 12-5 Transmit Sequence Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		FxBW	R	DBL	1	Transmit band (fx_BW) of FX frequencies for the sequence. $fx_BW = fx_2_Max - fx_1_Min$	Hz	Computed from the set of fx_1 and fx_2 PPPs for the sequence. See Section 6.3.
		TXmtMin	R	DBL	1	Minimum transmit pulse length in the sequence.	sec	Minimum value in the PPP {T_Xmt(p)} array.
		TXmtMax	R	DBL	1	Maximum transmit pulse length in the sequence.	sec	Maximum value in the PPP {T_Xmt(p)} array.
		TxTime1	R	DBL	1	Earliest transmit center time for the sequence – sum of Integer + Fraction.	sec	Value computed from PPP TxTime(0).
		TxTime2	R	DBL	1	Latest transmit center time for the sequence – sum of Integer + Fraction.	sec	Value computed from PPP TxTime(NP_TX-1).
		TxAPCId	R	TXT	1	Specifies the transmit APC used for the pulse sequence.		Value is equal to an APC_ID for an APC specified in the product. See Table 12-12.
		TxAPATId	R	TXT	1	Specifies the transmit antenna pattern used for the pulse sequence.		Value is equal to an APAT_ID for an antenna pattern specified in the product.
		TxRefPoint	R		1	Transmit Reference Point (TRP) for the pulse sequence located on the reference surface. See Sect 6.3		
		ECF	R	XYZ		Transmit Ref Point position in ECEF coordinates.	m	
		IAC	R	XY		Transmit Ref Point position in Image Area coordinates (IAX, IAY)	m	
		TxPolarization	R		1	Polarization parameters computed for the H & V directions computed at the TRP. See Sect 6.3.4.		Parameters describes the E-field orientation of the transmit pulse signal.

Table 12-5 Transmit Sequence Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		PolarizationID	R	ENU	1	Polarization identifier for the Pulse Sequence. Selection criteria specified per PDD.		Allowed values listed in Table 11-3. Also see Table 9-1.
		AmpH	R	DBL	1	E-field relative amplitude for the component in the H direction for the reference pulse (p_TX_REF).		Relative amplitude: $0 \leq \text{AmpH} \leq 1.0$
		AmpV	R	DBL	1	E-field relative amplitude for the component in the V direction for the reference pulse. Require: $\text{AmpH}^2 + \text{AmpV}^2 = 1.0$		Relative amplitude: $0 \leq \text{AmpV} \leq 1.0$
		PhaseH	R	DBL	1	E-field phase of the component in the H direction for the reference pulse.	cycles	Allowed values: $-0.5 \leq \text{PhaseH} \leq 0.5$
		PhaseV	R	DBL	1	E-field phase of the component in the V direction for the reference pulse.	cycles	Allowed values: $-0.5 \leq \text{PhaseV} \leq 0.5$
		TxRefRadIntensity	R	DBL	1	Transmit radiant intensity for the reference pulse. Value averaged across the pulse length $T_Xmt(p_TX_REF)$. See Sect 6.4.	dBW/sr	Value equal to PPP $TxRadInt(p_TX_REF)$.
		TxRadIntErrorStdDev	R	DBL	1	Estimated standard deviation for the error in transmit radiant intensity for the sequence. Nominal value for all pulses in the sequence.	dBW/sr	Require error standard deviation to be ≥ 0.0
		TxRefLAtm	R	DBL	1	One-way atmospheric loss ($L_Atm_X_{NOM}$) for the LOS path from the Tx APC to the TRP. Nominal value for the pulse sequence.	dB	Require $TxRefLAtm \geq 0.0$
		Parameter	O	TXT	1+	Text-based string that conveys the value of the parameter.		Attribute: name = xxx identifies the parameter.

12.5.6 XML: Channel

Table 12-6 Receive Channel Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrcv / Channel			SAR RCV		1	Parameters that describe the receive data channels contained in the product. See Sect 7.		
	RefChId		R	TXT	1	Channel ID for the Reference Channel (Ref_Ch_ID) in the product. See Sect 7.1.		Method for selecting the reference channel is specified per Product Design Document.
	Parameters		R		1+	Parameter set that describes a single receive channel – one instance included for each channel.		Receive channels are referenced by their unique channel ID (Ch_ID).
		Identifier	R	TXT	1	String that uniquely identifies the receive data channel (Ch_ID) for which the data applies.		Allowed values specified per Product Design Document.
		RefVectorIndex	R	INT	1	Index of the reference vector (v_CH_REF) for the channel. See Sect 7-1.		For CRSDsar: Reference signal vector contains transmit pulse echoes from the imaged scene.
		ReffFreqFixed	R	BOOL	1	Flag to indicate a constant reference frequency is used for the channel. For all vectors of the channel: f_0(v) is constant. See Sect 7.3.1.		
		FrcvFixed	R	BOOL	1	Flag to indicate a constant receive band is saved for the channel. Flag is “true” if for all vectors of the channel: frcv_1(v) is constant and frcv_2(v) is constant. See Sect 7.3.1.		
		SignalNormal	R	BOOL	1	Flag is set “true” when all signal vectors contain normal signal. For all vectors of the channel: SIGNAL(v) = 1. See Sect 7.3.1.		
		F0Ref	R	DBL	1	Reference frequency for the reference signal vector (v_CH_REF).	Hz	f_0_REF = f_0(v_CH_REF)

Table 12-6 Receive Channel Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		Fs	R	DBL	1	Fast time sample rate for the signal array. Sample rate fs used to compute sample period Ts = 1/fs (sec).	samps/ sec	
		BWInst	R	DBL	1	Nominal instantaneous bandwidth (BW_I) for the channel. See Sect 4.8 and 4.9.	Hz	
		RcvStartTime1	R	DBL	1	Earliest receive start time for the channel – sum of Integer + Fraction.	sec	Value computed from PVP RcvStartTime(0).
		RcvStartTime2	R	DBL	1	Latest receive start time for the channel – sum of Integer + Fraction.	sec	Value computed from PVP RcvStartTime(NV_CH-1).
		FrcvMin	R	DBL	1	Minimum value of frcv_1(v) for the channel.	Hz	Value selected from PVP Frcv1.
		FrcvMax	R	DBL	1	Maximum value of frcv_2(v) for the channel.	Hz	Value selected from PVP Frcv2.
		RcvAPCId	R	TXT	1	Specifies the receive APC used for the receive channel.		Value is equal to an APC_ID for an APC specified in the product. See Table 12-12.
		RcvAPATId	R	TXT	1	Specifies the receive antenna pattern used for the receive channel.		Value is equal to an APAT_ID for an antenna pattern specified in the product.
		RcvRefPoint	R			Receive Reference Point (RRP) for the receive channel located on the reference surface. See Sect 7.3		
		ECF	R	XYZ		Receive Ref Point position in ECEF coordinates.	m	
		IAC	R	XY		Receive Ref Point position in Image Area coordinates (IAX, IAY)	m	
		RcvPolarization	R		1	Polarization parameters computed for the H & V directions computed at the RRP. See Sect 7.3.3		Parameters describes the E-Field orientation on receive with peak receive sensitivity.

Table 12-6 Receive Channel Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		PolarizationID	R	ENU	1	Polarization identifier for the Channel. Selection criteria specified per PDD.		Allowed values listed in Table 11-3. Also see Table 9-1.
		AmpH	R	DBL	1	E-field relative amplitude for the component in the H direction for the reference vector (v_CH_REF).		Relative amplitude: $0 \leq \text{AmpH} \leq 1.0$
		AmpV	R	DBL	1	E-field relative amplitude for the component in the V direction for the reference vector. Require: $\text{AmpH}^2 + \text{AmpV}^2 = 1.0$		Relative amplitude: $0 \leq \text{AmpV} \leq 1.0$
		PhaseH	R	DBL	1	E-field phase of the component in the H direction for the reference vector.	cycles	Allowed values: $-0.5 \leq \text{PhaseH} \leq 0.5$
		PhaseV	R	DBL	1	E-field phase of the component in the V direction for the reference vector.	cycles	Relative phase: $-0.5 \leq \text{PhaseV} \leq 0.5$
		RcvRefIrradiance	R	DBL	1	Reference irradiance incident at the receive APC that results in signal vector power $\text{PS}_{\text{CRSD}} = 1.0$. For receive antenna gain $\text{G}_{\text{RBS}}(\text{frcv}) = 0$ dB.	dBW/ m ²	Value for a CW tone at $f = \text{frcv}$ for $ \text{frcv} - f_{\text{IC}}(v,t) \leq \frac{1}{2} \bullet \text{BW}_I$
		RcvIrradianceErrorStdDev	R	DBL	1	Estimated standard deviation for the error in reference irradiance for the channel.	dBW/ m ²	Require error standard deviation to be ≥ 0.0
		RcvRefLAtm	R	DBL	1	One-way atmospheric loss ($\text{L_Atm_R}_{\text{NOM}}$) for the LOS path from the RRP to the Rcv APC. Nominal value for receive channel.	dB	Require $\text{RcvRefLAtm} \geq 0.0$
		PNCRSD	R	DBL	1	Thermal noise power level for the signal array, $\text{PN_CRSD}(\text{Ch_ID})$. Nominal value for all signal vectors of the channel. See Sect 7.4.		$\text{PN_CRSD}(v, s) = E \{ \text{Re}(\text{Sig}(v, s))^2 + \text{Im}(\text{Sig}(v, s))^2 \}$
		BNCRSD	R	DBL	1	Noise Equivalent BW for the noise signal. Bandwidth BN_CRSD is expressed relative to the fast time sample rate for the channel (fs). $\text{BN_CRSD} = 1.0 \rightarrow$ noise signal uncorrelated.		Allowed values: $0 < \text{BN_CRSD} \leq 1.0$
		Parameter	O	TXT	1+	Text-based string that conveys the value of the parameter.		Attribute: name = xxx identifies the parameter.

Table 12-6 Receive Channel Parameters

Field Name							Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		SARImage		SAR		1				Parameters that specify the transmit pulse sequence used and the SAR image that may be formed from the channel signal array.		
			TxId	R	TXT	1				Specifies the transmit pulse sequence that illuminated the imaged scene and was received to form the channel signal array.		Value is equal to a Tx_ID for a Tx Sequence included in the product. See Table 12-5.
			RefVectorPulseIndex	R	INT	1				Reference vector pulse index (p_CH_REF). Vector v_CH_REF contains the echo signals from the imaged scene for pulse p_CH_REF.		Value equal to PVP TxPulseIndex(v_CH_REF).
			TxPolarization	R		1				Polarization parameters computed for the H & V directions computed at the RRP. See Sect 7.5.4.		Parameters describes the E-Field orientation of the transmit pulse signal.
			PolarizationID	R	ENU	1				Polarization identifier for signals incident at the RRP. Selection criteria specified per PDD.		Allowed values listed in Table 11-3. Also see Table 9-1.
			AmpH	R	DBL	1				E-field relative amplitude for the component in the H direction for the reference vector pulse (p_CH_REF).		Relative amplitude: $0 \leq \text{AmpH} \leq 1.0$
			AmpV	R	DBL	1				E-field relative amplitude for the component in the V direction for the reference vector pulse. Require: $\text{AmpH}^2 + \text{AmpV}^2 = 1.0$		Relative amplitude: $0 \leq \text{AmpV} \leq 1.0$
			PhaseH	R	DBL	1				E-field phase of the component in the H direction for the reference vector pulse.	cycles	Allowed values: $-0.5 \leq \text{PhaseH} \leq 0.5$
			PhaseV	R	DBL	1				E-field phase of the component in the V direction for the reference vector pulse.	cycles	Relative phase: $-0.5 \leq \text{PhaseV} \leq 0.5$
			DwellTimes	R		1				Center of Dwell (COD) Time and Dwell Time (T_Dwell) for image area supported the channel.		
			The COD Times and Dwell Times may be specified one of two ways: (1) Using 2-D polynomial functions of image area coordinates, or (2) Using a Dwell Time support array.									

Table 12-6 Receive Channel Parameters

Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
				Polynomials	C		1	Specify the COD & Dwell Time polynomials.		
				CODId	R	TXT	1	Specifies the COD Time polynomial used to compute COD times for points in the channel image area.		Value is equal to a COD_ID for a COD poly included in the product. See Table 12-8.
				DwellId	R	TXT	1	Specifies the dwell time polynomial used to compute dwell times for points in the channel image area.		Value is equal to a Dwell_ID for a Dwell time poly included in the product. See Table 12-8.
				Array	C		1	Specify the Dwell Time support array.		
				DTAId	R	TXT	1	Specifies the Dwell Time array used to compute COD times and dwell times for points in the channel image area.		Value is equal to an SA_ID for a Dwell Time array included in the product. See Table 12-9.
				ImageArea	R		1	SAR Image Area for the channel defined by a rectangle aligned with (IAX, IAY).		
				X1Y1	R	XY	1	Corner of the channel Image Area rectangle in Image Area coordinates, (IA_X1, IA_Y1).	m	Image area rectangle: $IA_X1 \leq IAX \leq IA_X2$ $IA_Y1 \leq IAY \leq IA_Y2$
				X2Y2	R	XY	1	Corner of the channel Image Area rectangle in Image Area coordinates, (IA_X2, IA_Y2).	m	Require: $IA_X1 \leq IAX \leq IA_X2$ $IA_Y1 \leq IAY \leq IA_Y2$
				Polygon	R		1	Polygon that specifies the image area for the channel. Polygon is bounded by the Rectangle. Vertices are indexed: $n = 1, 2, \dots, NumVertices$.		Attribute: size = NumVertices Require NumVertices ≥ 3 .
				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

12.5.7 XML: ReferenceGeometry

Table 12-7 Reference Geometry Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / ReferenceGeometry			R		1	Parameters that specify the reference geometry for the reference channel or reference transmit sequence. See Sect 8.		
	RefPoint		R		1	Reference Point used for computing all ranges and angles. Point is located on the reference surface. See Sect 8.1.		
		ECF	R	XYZ	1	Reference Point position in ECEF coordinates.	m	
		IAC	R	XY	1	Reference Point position in Image Area coordinates (IAX, IAY).	m	
	SARImage		SAR		1	Geometry parameters for SAR imaging collections. Computed using two APC positions and velocities. See Sect 8.4.		
		CODTime	R	DBL	1	Center of Dwell time for the Ref Point.	sec	
		DwellTime	R	DBL	1	Dwell Time for the Ref Point.	sec	
		ReferenceTime	R	DBL	1	Reference time (t_{REF}) for the reference vector (v_{CH_REF}) of the reference channel.	sec	
		ARPPos	R	XYZ	1	ARP position in ECEF coordinates. Computed using bistatic pointing vector. See Figure 8-7.	m	
		ARPVel	R	XYZ	1	ARP velocity in ECEF coordinates as the derivative w.r.t. time of the ARP position.	m/sec	
		BistaticAngle	R	DBL	1	Bistatic angle for the reference geometry. See Figure 8-7.	deg	Range: [0, 180]

Table 12-7 Reference Geometry Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		BistaticAngleRate	R	DBL	1	Rate of change of the bistatic angle (d(Bistat_Ang)/dt).	deg/sec	
		SideOfTrack	R	ENU	1	Side of Track relative to the ARP trajectory. L → Left-looking or R → Right-looking		Allowed values: “L” and “R” See Table 11-3.
		SlantRange	R	DBL	1	Slant range from the ARP to the Ref Point computed by average of the ranges to the APCs. See Figure 8-8.	m	
		GroundRange	R	DBL	1	Ground range from the ARP nadir to the Ref Point measured along the spherical earth model. See Figure 8-8.	m	
		DopplerConeAngle	R	DBL	1	Doppler Cone Angle between the ARP velocity and the LOS from the ARP to the Ref Point.	deg	Range: [0, 180]
		SquintAngle	R	DBL	1	Angle to the reference point off the normal to the ARP ground track. See Figure 8-9	deg	Range: [-90, 90]
		AzimuthAngle	R	DBL	1	Angle from north to the projection of the bistatic pointing vector into the ETP. Measured from +North toward +East. See Figure 8-12.	deg	Range: [0, 360)
		GrazeAngle	R	DBL	1	Angle between the bistatic pointing vector and the ETP at the Ref Point. See Figure 8-10.	deg	Range: [-90, 90]
		IncidenceAngle	R	DBL	1	Angle between the bistatic pointing vector and the normal to the ETP at the Ref Point.	deg	Range: [0, 180] Note: Graze + Incidence = 90.
		TwistAngle	R	DBL	1	Angle between iso-TOA (cross range) direction in the ETP and iso-TOA (cross range) direction in the slant plane. See Figure 8-11.	deg	Range: [-90, 90]
		SlopeAngle	R	DBL	1	Angle between the ETP normal and the normal to the slant plane.	deg	Range: [0, 90]
		LayoverAngle	R	DBL	1	Angle from north to the layover direction in the ETP. Measured from +North toward +East.	deg	Range: [0, 360)

Table 12-7 Reference Geometry Parameters

Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	TxParameters	SAR TX		1	Parameters for Transmit APC relative to the Reference Point. See Sect 8.3.2.		
	Time	R	DBL	1	Transmit center time $tx_{REF} = txc(p_CH_REF)$ for CRSD:SAR / $txc(p_TX_REF)$ for CRSD:TX.	sec	Computed from the PPP TxTime (Integer + Frac)
	APCPos	R	XYZ	1	Transmit APC position in ECEF coordinates at tx_{REF} .	m	
	APCVel	R	XYZ	1	Transmit APC velocity in ECEF coordinates at tx_{REF} .	m/sec	
	SideOfTrack	R	ENU	1	Side of Track parameter for the Transmit sensor. L → Left-looking or R → Right-looking		Allowed values: “L” and “R” See Table 11-3.
	SlantRange	R	DBL	1	Slant range along the Line of Sight (LOS) from the APC to the Ref Point.	m	
	GroundRange	R	DBL	1	Ground range from the APC nadir to the Ref Point measured along the spherical earth model.	m	
	DopplerConeAngle	R	DBL	1	Doppler Cone Angle between the APC velocity and the LOS from the APC to the Ref Point.	deg	Range: [0, 180]
	SquintAngle	R	DBL	1	Angle to the reference point off the normal to the APC ground track. See Figure 8-3.	deg	Range: [-90, 90]
	AzimuthAngle	R	DBL	1	Angle from north to the line from the Ref Point to APC ETP nadir. Measured from +North toward +East.	deg	Range: [0, 360]
	GrazeAngle	R	DBL	1	Grazing angle for the LOS from the APC to the Ref Point LOS and the ETP at the Ref Point.	deg	Range: [-90, 90]
	IncidenceAngle	R	DBL	1	Incidence angle for the LOS from the APC to the Ref Point and the normal to the ETP.	deg	Range: [0, 180] Note: Graz + Incidence = 90

Table 12-7 Reference Geometry Parameters

Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	RcvParameters	SAR RCV		1	Parameters for Receive APC relative to the Reference Point. See Sect 8.3.3.		
	Time	R	DBL	1	Receive start time $tr_{SREF} = trs(v_CH_REF)$ for the reference vector. Time relative to CRT.	sec	Computed from the PVP RcvStart (Integer + Frac)
	APCPos	R	XYZ	1	Receive APC position in ECEF coordinates at time $t = tr_{SREF}$.	m	
	APCVel	R	XYZ	1	Receive APC velocity in ECEF coordinates at time $t = tr_{SREF}$.	m/sec	
	SideOfTrack	R	ENU	1	Side of Track parameter for the Receive sensor. L → Left-looking or R → Right-looking		Allowed values: “L” and “R” See Table 11-3.
	SlantRange	R	DBL	1	Slant range along the Line of Sight (LOS) from the APC to the Ref Point.	m	
	GroundRange	R	DBL	1	Ground range from the APC nadir to the Ref Point measured along the spherical earth model.	m	
	DopplerConeAngle	R	DBL	1	Doppler Cone Angle between the APC velocity and the LOS from the APC to the Ref Point.	deg	Range: [0, 180]
	SquintAngle	R	DBL	1	Angle to the reference point off the normal to the APC ground track. See Figure 8-3.	deg	Range: [-90, 90]
	AzimuthAngle	R	DBL	1	Angle from north to the line from the Ref Point to APC ETP nadir. Measured from +North toward +East.	deg	Range: [0, 360]
	GrazeAngle	R	DBL	1	Grazing angle for the LOS from the APC to the Ref Point LOS and the ETP at the Ref Point.	deg	Range: [-90, 90]
	IncidenceAngle	R	DBL	1	Incidence angle for the LOS from the APC to the Ref Point and the normal to the ETP.	deg	Range: [0, 180] Note: Graz + Incidence = 90

12.5.8 XML: DwellPolynomials

Table 12-8 Dwell Time Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar.DwellPolynomials		O SAR		1	Polynomial functions that specify the SAR dwell time supported by the signal arrays contained in a CRSDsar product. See Sect 7.5.3. Also, refer to CPHD D&I DD, Sect 7.3.		
	NumCODTimes	R	INT	1	Number of COD Time polynomials included in the product.		
	CODTime	R		1+	Parameter set that specify a Center of Dwell (COD) Time polynomial – one instance included for each COD time polynomial.		COD time polynomials are referenced by their unique ID (COD_ID).
	Identifier	R	TXT	1	String that uniquely identifies this COD Time polynomial (COD_ID).		Allowed values specified per Product Design Document.
	CODTimePoly	R	2D POLY	1	Polynomial that yields COD Time as a function of IAX and IAY.	sec, sec/m, etc.	Attributes: order1 = IAX_Order and order2 = IAY_Order
	NumDwellTimes	R	INT	1	Number of Dwell Time polynomials included in the product.		
	DwellTime	R		1+	Parameter set that specify a Dwell Time polynomial – one instance included for each dwell time polynomial.		Dwell time polynomials are referenced by their unique ID (Dwell_ID).
	Identifier	R	TXT	1	String that uniquely identifies this Dwell Time polynomial (Dwell_ID).		Allowed values specified per Product Design Document.
	DwellTimePoly	R	2D POLY	1	Polynomial that yields Dwell Time as a function of IAX and IAY.	sec, sec/m, etc.	Attributes: order1 = IAX_Order and order2 = IAY_Order

12.5.9 XML: SupportArray

Table 12-9 Support Array Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / SupportArray		R		1	Parameters that specify the binary support arrays content and grid coordinates. See Sect 2.4. Also see CPHD D&I DD.		
For the defined support arrays, the data elements, the array coordinates, and the 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.							
GainPhaseArray		R		1+	Antenna Gain and Phase array: GP(m, n) Array of antenna gains (dB) and phases (cycles). See Sect 9.3.1.		One or more arrays included in all products.
	Identifier	R	TXT	1	String that uniquely identifies the antenna Gain/Phase support array (SA_ID or GP_ID).		Each SA identifier value is unique within a product.
	ElementFormat	R	TXT	1	Data element format. Each element contains a gain value, G(m, n), and a phase value, $\Phi(m, n)$.	dB, cycles	Allowed value: “Gain=F4;Phase=F4;”
	X0	R	DBL	1	Row 0 dcx coordinate (dcx_0). Row coordinates are: $dcx(m) = dcx_0 + m \cdot dcx_SS$	dir cos	Require $-1.0 \leq X0 < 1.0$.
	Y0	R	DBL	1	Column 0 dcy coordinate (dcy_0). Column coordinates are: $dcy(n) = dcy_0 + n \cdot dcy_SS$	dir cos	Require $-1.0 \leq Y0 < 1.0$.
	XSS	R	DBL	1	Row coordinate sample spacing (dcx_SS).	dir cos	Require $XSS > 0$.
	YSS	R	DBL	1	Column coordinate sample spacing (dcy_SS).	dir cos	Require $YSS > 0$.
	NODATA	O	HEX	1	Value that indicates the element does not contain valid data for any of the parameters. May be omitted if all elements contain valid data.		Value is a string of length 2 times the number of bytes per element.

Table 12-9 Support Array Parameters

Table 12-9 Support Array Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	FxResponseArray		SAR TX		1+	Fx Response Array: FXR(m, n) Array of one or more sampled Fx Response functions. See Sect 6.5.		
		Identifier	R	TXT	1	String that uniquely identifies the Fx Response support array (SA_ID or FxResponse_ID).		Each SA identifier value is unique within a product.
		ElementFormat	R	TXT	1	Data element format. Each element FXR(m, n) is a complex-number with amplitude and phase components.	-, cycles	Allowed values: “Amp=F4;Phase=F4;”
		Fx0FXR	R	DBL	1	Fx Frequency value for sample n = 0 (fx_0_FXR) for all Fx Response functions.	Hz	Require fx_0_FXR > 0.
		FxSSFxR	R	DBL	1	Frequency sample spacing for all Fx response functions, fx_SS_FXR. Frequency sample values: fx(n) = fx_0_FXR + fx_SS_FXR•n	Hz	Require: fx_SS_FXR > 0
	XMArray		O SAR TX		1+	XM Array: XMA(w, n) Array of one or more sampled XM functions. See Sect 6.6 and Table 12-5.		One or more arrays included for TxWFTType = “LFM w XM” or “XM”.
		Identifier	R	TXT	1	String that uniquely identifies the XM support array (SA_ID or XM_ID).		Each SA identifier value is unique within a product.
		ElementFormat	R	TXT	1	Data element format. Each element XMA(w, n) is a complex-number with real and imaginary components. Allowed formats are the same as the allowed formats for signal array samples.		Allowed values: “CI2”, “CI4” and “CF8” See Table 12-4.
		TsXMA	R	DBL	1	Sample spacing for all functions, Ts_XMA. Center sample nCTR = FLOOR(NS_XMA/2).	sec	Require: 1.10•Max_XMBW ≤ 1/Ts_XMA
		MaxXMBW	R	DBL	1	Maximum modulation BW for any XM function contained in the array.	Hz	Require MaxXMBW > 0.

Table 12-9 Support Array Parameters

Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	DwellTimeArray	O SAR		1+	Dwell Time Array: DT(m, n) Array of COD times (sec) and dwell times (sec) for points on the reference surface. See Sect 7.5.3		
	Identifier	R	TXT	1	String that identifies the Dwell Time support array (SA_ID or DTA_ID).		Each SA identifier value is unique within a product.
	ElementFormat	R	TXT	1	Data element format. Each element is one COD time and one Dwell Time, both formatted as F4. COD times are relative to CRT.	sec, sec	Allowed value: “COD=F4;DT=F4;”
	X0	R	DBL	1	Row 0 IAX coordinate (IAX_0). Row coordinates are: $IAX(m) = IAX_0 + m \cdot IAX_SS$	m	
	Y0	R	DBL	1	Column 0 IAY coordinate (IAY_0). Row coordinates are: $IAY(n) = IAY_0 + n \cdot iay_SS$	m	
	XSS	R	DBL	1	Row coordinate sample spacing (IAX_SS).	m	Require XSS > 0.
	YSS	R	DBL	1	Column coordinate sample spacing (IAY_SS).	m	Require YSS > 0.
	NODATA	O	HEX	1	Value that indicates the element does not contain valid data for any of the parameters. May be omitted if all elements contain valid data.		Value is a string of length 2 times the number of bytes per element.
	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).		
	Identifier	R	TXT	1	String that identifies the IAZ support array (SA_ID or IAZ_ID).		Each SA identifier value is unique within a product.
	ElementFormat	R	TXT	1	Data element format. Each element is one parameter (IAZ) formatted as one F4.	m	Allowed values: “IAZ=F4;”

Table 12-9 Support Array Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		X0	R	DBL	1	Row 0 IAX coordinate (IAX_0). Row coordinates are: $IAX(m) = IAX_0 + m \cdot IAX_SS$	m	
		Y0	R	DBL	1	Column 0 IAY coordinate (IAY_0). Row coordinates are: $IAY(n) = IAY_0 + n \cdot iay_SS$	m	
		XSS	R	DBL	1	Row coordinate sample spacing (IAX_SS).	m	Require XSS > 0.
		YSS	R	DBL	1	Column coordinate sample spacing (IAY_SS).	m	Require YSS > 0.
		NODATA	O	HEX	1	Value that indicates the element does not contain valid data for any of the parameters. May be omitted if all elements contain valid data.		Value is a string of length 2 times the number of bytes per element.
		AddedSupportArray	O		1+	Added Array: Z(m, n) is a two-dimensional array of data elements. Content and format of each element is user defined. Array coordinates X(m) and Y(n) are also user defined.		
		Identifier	R	TXT	1	String that identifies the added support array (SA_ID).		Each SA identifier value is unique within a product.
		ElementFormat	R	TXT	1	Data element format. Specifies the number of parameters and the binary format for each parameter.		Allowed formats are specified in Table 11-2
		X0	R	DBL	1	Row 0 X coordinate. Row coordinates are: $X(m) = X0 + m \cdot XSS$		
		Y0	R	DBL	1	Column 0 Y coordinate. Row coordinates are: $Y(n) = Y0 + n \cdot YSS$		
		XSS	R	DBL	1	Row coordinate (X) sample spacing.		Require XSS > 0.
		YSS	R	DBL	1	Column coordinate (Y) sample spacing.		Require YSS > 0.

Table 12-9 Support Array Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		NODATA	O	HEX	1	Value that indicates the element does not contain valid data for any of the parameters. May be omitted if all elements contain valid data.		Value is a string of length 2 times the number of bytes per element.
		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

12.5.10 XML: PPP

Table 12-10 Per Pulse Parameters						
Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDtx / PPP	SAR TX		1	Structure that specifies the set of PPPs provided for each transmit pulse. All PPP Sizes and Offsets are specified in 8-byte fields.		
See Table 4-2 for definition of each parameter. See Table 11-1 and Table 11-2 for a description of allowed types and formats. PxP: Defined PPP → Size and Format are fixed. Offset values allow parameters to be in any order in the binary PPP array.						
TxTime	R	PxP	1	TxTime PPP Structure Size = 2 Format: “Int=I8;Frac=F8;”		Size = 2 → Binary parameter is 2 x 8 bytes.
TxPos	R	PxP	1	TxPos PPP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		Size = 3 → Binary parameter is 3 x 8 bytes.
TxVel	R	PxP	1	TxVel PPP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		
FX1	R	PxP	1	FX1 PPP Structure Size = 1 Format: “F8”		
FX2	R	PxP	1	FX2 PPP Structure Size = 1 Format: “F8”		
TXmt	R	PxP	1	TXmt PPP Structure Size = 1 Format: “F8”		
PhiX0	R	PxP	1	PhiX0 PPP Structure Size = 2 Format: “Int=I8;Frac=F8;”		
FxFreq0	R	PxP	1	FxFreq0 PPP Structure Size = 1 Format: “F8”		
FxRate	R	PxP	1	FxRate PPP Structure Size = 1 Format: “F8”		
TxRadInt	R	PxP	1	TxRadInt PPP Structure Size = 1 Format: “F8”		
TxACX	R	PxP	1	TxACX PPP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		

Table 12-10 Per Pulse Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	TxACy	R	PxP	1	TxACy PPP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		
	TxEB	R	PxP	1	TxEB PPP Structure Size = 2 Format: “DCX=F8;DCY=F8;”		
	FxResponseIndex	R	PxP	1	FxResponseIndex PPP Structure Size = 1 Format: “I8”		
	XMIndex	O	PxP	1	XMIndex PPP Structure Size = 1 Format: “I8”		Included for TxWFTType = “LFM w XM” or “XM”.
	AddedPPP	O	APxP	1+	Added PPP Structure – Used to include user defined Per Pulse Parameter. See Sect 2.5 for guidance. See Table 11-2 for allowed formats.		Added parameters defined per Product Design Document. Each Added PPP in a product is uniquely named.

12.5.11 XML: PVP

Table 12-11 Per Vector Parameters						
Field Name	Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev / PVP	SAR RCV		1	Structure that specifies the set of PVPs provided for each signal vector. All PVP Sizes and Offsets are specified in 8-byte fields. See Figure 2-7.		
	See Table 4-4 for definition of each parameter. See Table 11-1 and Table 11-2 for a description of allowed types and formats. PxP: Defined PVP → Size and Format are fixed. Offset values allow parameters to be in any order in the binary PVP array.					
RcvStart	R	PxP	1	RcvStart PVP Structure Size = 2 Format: “Int =I8;Frac=F8;”		Size = 2 → Binary parameter is 2 x 8 bytes.
RcvPos	R	PxP	1	RcvPos PVP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		Size = 3 → Binary parameter is 3 x 8 bytes.
RcvVel	R	PxP	1	RcvVel PVP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		
FRCV1	R	PxP	1	FRCV1 PVP Structure Size = 1 Format: “F8”		
FRCV2	R	PxP	1	FRCV2 PVP Structure Size = 1 Format: “F8”		
RefPhi0	R	PxP	1	RefPhi0 PVP Structure Size = 2 Format: “Int =I8;Frac=F8;”		
RefFreq	R	PxP	1	RefFreq PVP Structure Size = 1 Format: “F8”		
DFIC0	R	PxP	1	DFIC0 PVP Structure Size = 1 Format: “F8”		
FICRate	R	PxP	1	FICRate PVP Structure Size = 1 Format: “F8”		
RcvACX	R	PxP	1	RcvACX PVP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		
RcvACY	R	PxP	1	RcvACY PVP Structure Size = 3 Format: “X=F8;Y=F8;Z=F8;”		

Table 12-11 Per Vector Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	RcvEB	R	PxP	1	RcvEB PVP Structure Size = 2 Format: “DCX=F8;DCY=F8;”		
	SIGNAL	R	PxP	1	SIGNAL PVP Structure Size = 1 Format: “I8”		
	AmpSF	R	PxP	1	AmpSF PVP Structure Size = 1 Format: “F8”		Require AmpSF > 0.
	DGRGC	R	PxP	1	DGRGC PVP Structure Size = 1 Format: “F8”		
	TxPulseIndex	SAR	PxP	1	PulseIndex PVP Structure Size = 1 Format: “I8”		
	AddedPVP	O	APxP	1+	Added PVP Structure – Used to include user defined Per Vector Parameter. See Sect 2.7 for guidance. See Table 11-2 for allowed formats.		Added parameters defined per Product Design Document. Each Added PVP in a product is uniquely named.

12.5.12 XML: Antenna

Table 12-12 Antenna Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / Antenna			R		1	Parameters that describe the antennas used during the event. See Sect 9.		
	NumACFs		R	INT	1	Number of Antenna Coordinate Frames (ACFs). One ACF specified for each antenna used during the event.		Allowed values: NumACFs ≥ 1
	NumAPCs		R	INT	1	Number of Antenna Phase Centers (APCs) used on transmit or receive during the event. APCs are referenced by their unique APC ID.		Allowed values: NumAPCs ≥ 1
	NumAPATs		R	INT	1	Number of Antenna Patterns (APATs) specified in the product. APATs are referenced by their unique APAT ID.		Allowed values: NumAPATs ≥ 1
	AntCoordFrame		R		1+	Parameters that identify each Antenna Coordinate Frame (ACF) – one instance included for each ACF.		
		Identifier	R	TXT	1	String that uniquely identifies the ACF (ACF_ID).		Allowed values specified per Product Design Document.
	AntPhaseCenter		R		1+	Parameters that specify each Antenna Phase Center (APC) – one instance included for each APC.		
		Identifier	R	TXT	1	String that uniquely identifies the APC (APC_ID).		Allowed values specified per Product Design Document.
		ACFId	R	TXT	1	Specifies the ACF that contains the APC.		Value is equal to an ACF_ID for an ACF specified in the product.
		APCXYZ	R	XYZ	1	The APC position in ACF coordinates (ACX, ACY, ACZ).	m	

Table 12-12 Antenna Parameters

Table 12-12 Antenna Parameters								
Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
	AntPattern		R		1+	Parameter set that specifies a one-way antenna beam shape pattern (APAT) – one instance included for each APAT. See Sect 9.3.		
		Identifier	R	TXT	1	String that uniquely identifies the Antenna Pattern (APAT_ID).		Allowed values specified per Product Design Document.
		FreqZero	R	DBL	1	Reference frequency (fa_0) for the APAT. The array pattern G/Φ samples are at f = fa_0. All EB SV values in a PPP/PVP are specified at f = fa_0.	Hz	
		ArrayGPId	R	TXT	1	Specifies the antenna gain/phase array (ArrayGP_ID) used to compute the array gain/phase values for the antenna pattern.		Value is equal to an SA_ID for a gain/phase array specified in the product.
		ElemGPId	R	TXT	1	Specifies the antenna gain/phase array (ElemGP_ID) used to compute the element gain/phase values for the antenna pattern.		Value is equal to an SA_ID for a gain/phase array specified in the product.
		EBFreqShift	R		1	Parameters that specify how the electrical boresight (EB) shifts with frequency. Define frequency difference: Δf = f – fa_0. See Sect 9.2.4.		For a mechanically steered antenna, set EBFS_DCXSF = 0 and EBFS_DCYSF = 0.
		DCXSF	R	DBL	1	Scale factor EBFS_DCXSF used to compute the EB_DCX(f). EB_DCX(f) = EB_DCX ₀ •fa_0/(fa_0+EBFS_DCXSF•Δf)		Allowed values: 0 ≤ EBFS_DCXSF ≤ 1.0
		DCYSF	R	DBL	1	Scale factor EBFS_DCYSF used to compute the EB_DCY(f). EB_DCY(f) = EB_DCY ₀ •fa_0/(fa_0+EBFS_DCYSF•Δf)		Allowed values: 0 ≤ EBFS_DCYSF ≤ 1.0
		MLFreqDilation	R		1	Parameters that specify how the array pattern mainlobe (ML) varies with frequency. Define frequency difference: Δf = f – fa_0. See Sect 9.3.4.		For array patterns that do not vary with frequency, set MLFD_DCXSF = 0 and MLFD_DCYSF =0.

Table 12-12 Antenna Parameters

Field Name			Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
		DCXSF	R	DBL	1	Scale factor MLFD_DCXSF used to compute the array pattern ML dilation factor in DCX. The ML dilates in DCX by a factor of: $MLSF(f) = fa_0 / (fa_0 + MLFD_DCXSF \cdot \Delta f)$.		Allowed values: $0 \leq MLFD_DCXSF \leq 1.0$
		DCYSF	R	DBL	1	Scale factor MLFD_DCYSF used to compute the array pattern ML dilation factor in DCY. The ML dilates in DCY by a factor of: $MLSF(f) = fa_0 / (fa_0 + MLFD_DCYSF \cdot \Delta f)$.		Allowed values: $0 \leq MLFD_DCYSF \leq 1.0$
		GainBSPoly	R	POLY	1	Array pattern boresight gain (ΔG_BS) vs frequency polynomial. Frequency difference: $\Delta f = f - fa_0$. See Sect 9.3.4. $\Delta G_BS(\Delta f) = cG_BS(1) \cdot (\Delta f / fa_0) + cG_BS(2) \cdot (\Delta f / fa_0)^2 + \text{etc.}$	dB, dB, etc.	Coefficient $cG_BS(0) = 0$ in all products.
		AntPolRef	R		1	Polarization parameters for the pointing direction aligned with mechanical boresight (uLOS = uACZ). See Sect 9.4		
		AmpX	R	DBL	1	E-field relative amplitude of the component in the ACX direction.		Relative amplitude: $0 \leq AmpX \leq 1.0$
		AmpY	R	DBL	1	E-field relative amplitude of the component in the ACY direction. Require: $AmpX^2 + AmpY^2 = 1.0$		Relative amplitude: $0 \leq AmpY \leq 1.0$
		PhaseX	R	DBL	1	E-field phase on transmit of the component in the ACX direction.	cycles	Relative phase: $-0.5 \leq PhaseX \leq 0.5$
		PhaseY	R	DBL	1	E-field phase on transmit of the component in the ACY direction.	cycles	Relative phase: $-0.5 \leq PhaseY \leq 0.5$

12.5.13 XML: ErrorParameters

Table 12-13 Error Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / ErrorParameters				O		1	Parameters that specify the statistics of errors in measured or estimated parameters that specify the collection. See Sect 10.		
	SARImage			SAR		1	Error statistics for SAR imaging collections are dependent upon the Collect Type.		
		Monostatic		C		1	Statistics for CollectType = MONOSTATIC		
			PosVelError	R		1	Position and velocity error statistics for the radar platform.		
			Frame	R	ENU	1	Coordinate frame used for specifying position and velocity error statistics. See Sect 10.1.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI” See Table 11-3.
			PVCov	R	MTX	1	Sensor position & velocity error covariance matrix at $t = t_{REF}$. $C_{PV} = E\{\Delta PV \bullet \Delta PV^T\}$ where $\Delta PV = (\Delta P1, \Delta P2, \Delta P3, \Delta V1, \Delta V2, \Delta V3)^T$	m^2 , m^2/sec , m^2/sec^2	size1 = 6 and size2 = 6
			PosDecorr	O	EDF	1	Position error decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
			RadarSensor	R		1	Radar sensor time and frequency error statistics.		
			TimeFreqCov	R	MTX	1	Transmit and receive timing error covariance matrix. $C_{XRTF} = E\{\Delta XRTF \bullet \Delta XRTF^T\}$ where $\Delta XRTF = (\Delta t_{xREF}, \Delta t_{rREF}, f_Clk_SF)^T$. Transmit time error (Δt_{xREF}) and receive time error (Δt_{rREF}) are in seconds at $t = t_{REF}$. Control clock frequency error (Δf_Clk) expressed as a scale factor: $f_Clk_SF = \Delta f_Clk / f_Clk_0$	dim, sec, sec^2	size1 = 3 and size2 = 3

Table 12-13 Error Parameters										
Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
				TimeFreqDecorr	O		1	Transmit/Receive time and clock frequency error decorrelation parameters.		
				TxTimeDecorr	R	EDF	1	Transmit time error (Δt_x) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
				RcvTimeDecorr	R	EDF	1	Receive time error (Δt_r) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
				ClockFreqDecorr	R	EDF	1	Clock frequency error (Δf_{Clk}) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
		Bistatic			C		1	Statistics for CollectType = BISTATIC		
			PosVelError		R		1	Position and velocity error statistics for the two sensor platforms.		
				TxFrame	R	ENU	1	Transmit platform coordinate frame used for specifying position and velocity error statistics.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI”
				TxPVCov	R	MTX	1	Tx platform position & velocity error covariance matrix at $t = t_{REF}$. $C_{XPV} = E\{\Delta XPV \bullet \Delta XPV^T\}$ where $\Delta XPV = (\Delta XP1, \Delta XP2, \Delta XP3, \Delta XV1, \Delta XV2, \Delta XV3)^T$	m^2 , m^2/sec , m^2/sec^2	size1 = 6 and size2 = 6
				RcvFrame	R	ENU	1	Receive platform coordinate frame used for specifying position and velocity error statistics.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI”
				RcvPVCov	R	MTX	1	Rcv platform position & velocity covariance matrix at $t = t_{REF}$. $C_{RPV} = E\{\Delta RPV \bullet \Delta RPV^T\}$ where $\Delta RPV = (\Delta RP1, \Delta RP2, \Delta RP3, \Delta RV1, \Delta RV2, \Delta RV3)^T$	m^2 , m^2/sec , m^2/sec^2	size1 = 6 and size2 = 6

Table 12-13 Error Parameters										
Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
				TxRcvPVCov	R	MTX	1	Tx platform PV error / Rcv platform PV error covariance matrix. $C_XRPV = E\{\Delta XPV \bullet \Delta RPV^T\}$	m ² , m ² /sec, m ² /sec ²	size1 = 6 and size2 = 6
				PosVelDecorr	O		1	Transmit/Receive position error decorrelation parameters.		
				TxPosDecorr	R	EDF	1	Transmit position error decorrelation vs. time: CC(Δt) = Min(1.0, Max(0.0, CC0 - DCR• Δt))		
				RcvPosDecorr	R	EDF	1	Receive position error decorrelation vs. time: CC(Δt) = Min(1.0, Max(0.0, CC0 - DCR• Δt))		
			RadarSensor		R		1	Transmit and receive sensor time and frequency error statistics.		
				TimeFreqCov	R	MTX	1	Transmit and receive timing error covariance matrix. $C_XRTF = E\{\Delta XRTF \bullet \Delta XRTF^T\}$ where $\Delta XRTF = (\Delta t_{xREF}, f_Clk_X_SF, \Delta t_{rREF}, f_Clk_R_SF)^T$ Transmit time error (ΔtxREF) and receive time error (ΔtrREF) are in seconds at t = tREF. Control clock frequency errors (Δf_Clk_X and Δf_Clk_R) expressed as scale factors.	dim, sec, sec ²	size1 = 4 and size2 = 4
				TimeFreqDecorr	O		1	Transmit/Receive time and clock frequency error decorrelation parameters		
				TxTimeDecorr	R	EDF	1	Transmit time error (Δtx) decorrelation vs. time: CC(Δt) = Min(1.0, Max(0.0, CC0 - DCR• Δt))		
				RcvTimeDecorr	R	EDF	1	Receive time error (Δtr) decorrelation vs. time: CC(Δt) = Min(1.0, Max(0.0, CC0 - DCR• Δt))		
				TxClockFreqDecorr	R	EDF	1	Transmit clock frequency error (Δf_Clk_X) decorrelation vs. time: CC(Δt) = Min(1.0, Max(0.0, CC0 - DCR• Δt))		

Table 12-13 Error Parameters											
Field Name					Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values	
					RcvClockFreqDecorr	R	EDF	1	Receive clock frequency error (Δf_Clk_R) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
	TxSensor					TX		1	Error statistics for transmit events. Only included for CRSD:TX products.		
		PosVelError				R		1	Transmit platform position and velocity error statistics.		
			Frame			R	ENU	1	Transmit platform coordinate frame used for specifying position and velocity error statistics.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI”
			PVCov			R	MTX	1	Transmit platform position & velocity error covariance matrix at time $t = t_{xREF}$. $C_XPV = E\{\Delta XPV \bullet \Delta XPV^T\}$ where $\Delta XPV = (\Delta XP1, \Delta XP2, \Delta XP3, \Delta XV1, \Delta XV2, \Delta XV3)^T$	m ² , m ² /sec, m ² /sec ²	size1 = 6 and size2 = 6
			PosDecorr			O	EDF	1	Position error decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
		RadarSensor				R		1	Transmit sensor time and frequency error statistics.		
			TimeFreqCov			R	MTX	1	Transmit timing error covariance matrix. $C_XTF = E\{\Delta XTF \bullet \Delta XTF^T\}$ where $\Delta XTF = (\Delta t_{xREF}, f_Clk_X_SF)^T$ Transmit time error (Δt_{xREF}) is in seconds at $t = t_{xREF}$. Control clock frequency error (Δf_Clk_X) expressed as a scale factor.	dim, sec, sec ²	size1 = 2 and size2 = 2
			TimeFreqDecorr			O		1	Transmit time and clock frequency error decorrelation parameters.		
				TimeDecorr		R	EDF	1	Transmit time error (Δt_x) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		

Table 12-13 Error Parameters										
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values	
				ClockFreqDecorr	R	EDF	1	Control clock frequency error ($\Delta f_{\text{Clk_X}}$) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		
	RcvSensor			RCV		1	Error statistics for receive only collections. Only included for CRSD:RCV products.			
		PosVelError			R		1	Receive platform position and velocity error statistics.		
			Frame	R	ENU	1	Receive platform coordinate frame used for specifying position and velocity error statistics.		Allowed values: “ECF”, “RIC_ECF” and “RIC_ECI”	
			PVCov	R	MTX	1	Receive platform position & velocity error covariance matrix at time $t = t_{\text{SREF}}$. $C_{\text{RPV}} = E\{\Delta \text{RPV} \bullet \Delta \text{RPV}^T\}$ where $\Delta \text{RPV} = (\Delta \text{RP1}, \Delta \text{RP2}, \Delta \text{RP3}, \Delta \text{RV1}, \Delta \text{RV2}, \Delta \text{RV3})^T$	m^2 , m^2/s , m^2/s^2	size1 = 6 and size2 = 6	
			PosDecorr	O	EDF	1	Receive position error decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$			
		RadarSensor			R		1	Receive sensor time and frequency error statistics.		
			TimeFreqCov	R	MTX	1	Receive timing error covariance matrix. $C_{\text{RTF}} = E\{\Delta \text{RTF} \bullet \Delta \text{RTF}^T\}$ where: $\Delta \text{RTF} = (\Delta t_{\text{REF}}, f_{\text{Clk_R_SF}})^T$ Receive time error (Δt_{REF}) is in seconds at $t = t_{\text{SREF}}$. Control clock frequency error ($\Delta f_{\text{Clk_R}}$) expressed as a scale factor.	dim, sec, sec^2	size1 = 2 and size2 = 2	
			TimeFreqDecorr	O		1	Receive time and clock frequency error decorrelation parameters.			
			TimeDecorr	R	EDF	1	Receive time error (Δt_r) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$			

Table 12-13 Error Parameters									
Field Name				Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
				R	EDF	1	Control clock frequency error (Δf_{Clk_R}) decorrelation vs. time: $CC(\Delta t) = \text{Min}(1.0, \text{Max}(0.0, CC0 - DCR \bullet \Delta t))$		

12.5.14 XML: GeoInfo

Table 12-14 Geographic Information Parameters							
Field Name		Req/ Opt	Type	Num	Description	Units	Attributes & Allowed Values
CRSDsar or CRSDrev or CRSDtx / GeoInfo		O		1+	Parameter block that describes a geographic feature. GeoInfo branch may be repeated. Use of this branch defined per the PDD.		Attribute: “name” = descriptive name for the information in the block.
	Desc	O	TXT	1+	Used to provide a name and/or description of the geographic feature. For Geopolitical features, recommend use of NGA.STND.0033.		Attribute: “name” = descriptive name of the feature
	Point	O	LL	1+	Used to specific a single point in Lat and Lon. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd	
	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 ≥ 2.
	Endpoint	R	LL	2+	Line segment endpoints specified in Lat and Lon. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 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.		Attribute: “size” = NumVertices Require NumVertices ≥ 3.
	Vertex	R	LL	3+	Polygon vertices specified in Lat and Lon. Vertices are indexed clockwise. -90.0 ≤ Lat ≤ 90.0, -180.0 ≤ Lon ≤ 180.0	dd	Attribute: “index” = 1 to NumVertices
	GeoInfo	O		1+	Optional GeoInfo block may be embedded within a GeoInfo block.		Attribute: “name” = descriptive name for the information in the block.

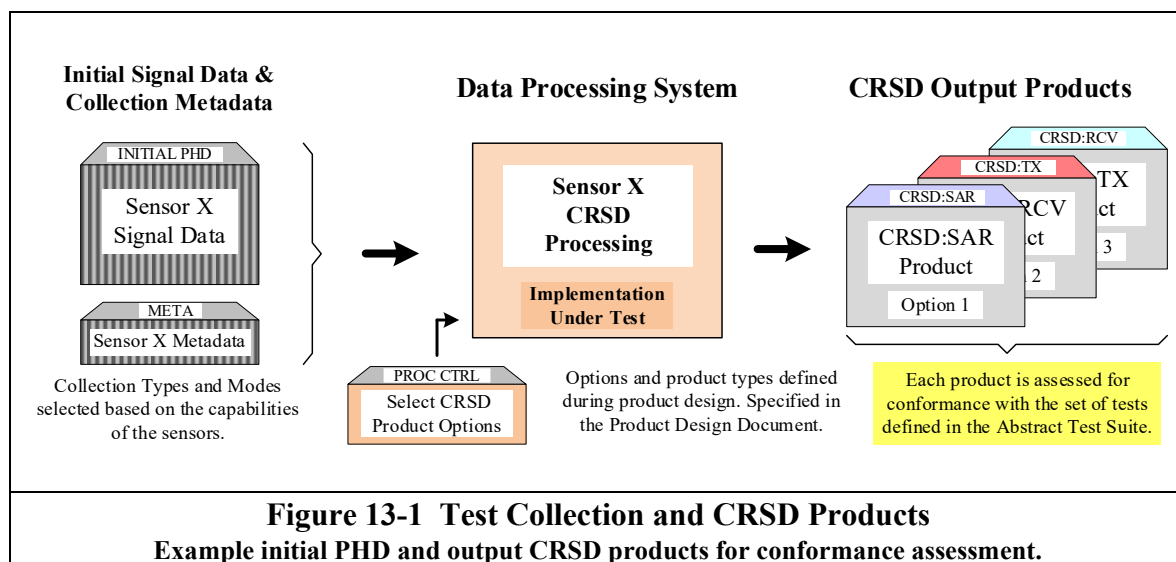
13 Conformance Guidance

For a data processing system that creates CRSD products, guidance is provided on assessing that the system conforms to the standard. A method for testing conformance to the CRSD standard is also specified.

13.1 Conformance Description

For a set of sensors and the data processing system that inputs the initial received signal data and outputs CRSD products, conformance to the standard is assessed as follows. For a selected set of events, the data processing system is tasked to generate one or more CRSD data products for each of the events. The events are selected to be a representative set of the capabilities of the sensors. For each event, the number of products to be formed is based on the options that may be selected when forming the CRSD products. The products to be formed may include one or more of the three types of CRSD products: CRSD:SAR, CRSD:TX, and CRSD:RCV. Conformance to the CRSD standard is an assessment made about each product formed and about the data processing system. For the data processing system, the system is judged to conform to the standard when all CRSD products formed are judged to conform to the standard.

The conformance assessment for the CRSD products formed for a given event set is as follows. Shown in Figure 13-1 is the processing workflow that forms the CRSD products. For the example shown, Sensor X is the SAR sensor that collected the initial PHD. For the collection shown, the CRSD product design allows for all three possible CRSD product types to be formed. The conformance assessment for the CRSD products formed is as follows.



The allowed product types and design options are specified in the PDD. For a given sensor and product type, the PDD will also specify the conditional and optional metadata parameters to be included. See Section 3. For a given product, the set of metadata included is referred to as the metadata profile. For each CRSD product, the product is assessed for conformance

using the tests defined in the Abstract Test Suite (ATS). A given product that passes all tests of the ATS may claim to conform to the standard.

13.2 Abstract Test Suite

The Abstract Test Suite (ATS) is a set of test modules and test cases that are applied to a CRSD product file. The ATS is designed to assess that a given product meets a basic level of conformance to the CRSD standard. A primary objective of the ATS is to ensure that the CRSD products are correctly formatted and may be ingested by the applications that input CRSD products. Products that meet the requirements of the ATS will be ready to support further system testing to ensure the SAR image products that are formed from the CRSD are of acceptable quality.

The ATS consists of three test modules and a total of 11 test cases. The ATS may be applied to any CRSD product file. The ATS test modules are summarized below.

Test Module 1 Product File Format

Set of test cases to verify the product file is correctly formatted.

Test Module 2 XML Format and Content

Set of test cases to verify the XML instance is correctly formatted.

Test Module 3 Binary Data Block Sizes

Set of tests to verify the binary-formatted data block sizes are correct.

13.2.1 Module 1: Product File Format

Purpose: To verify the CRSD product file is correctly formatted.

Method: The File Header contains information about the contents of the file. Use parameters in the header to verify the size and placement of the data blocks in the file.

Reference: Section 2; Figure 2-1; Figure 2-2; Table 2-1

Test 1.1 File Header Format

Purpose: To verify the File Header is correctly formatted.

Method: Examine the File Header to verify that it meets the required format and content. Verify that the required Key-Value Pairs (KVPs) are included. Verify that added KVPs specified in the PDD, if any, are included and correctly formatted.

Reference: Section 2.2; Table 2-1

Test 1.2 Data Block Order and Placement

Purpose: To verify the CRSD data blocks are ordered correctly in the file.

Method: Examine the KVPs that specify the size and placement of each data block in the file. Verify the required data blocks are included. Verify that the data blocks are ordered correctly. If fill bytes are included between blocks, verify that the fill bytes are as specified.

Reference: Section 2; Figure 2-1; Figure 2-2

13.2.2 Module 2: XML Format and Content

Purpose: To verify the XML instance is correctly formatted.

Method: Examine and compare the XML instance to the schema to validate the instance. Examine key XML parameters to verify correct and consistent values.

Reference: Section 11; Section 12; CRSD XML schema; PDD

Test 2.1 XML Schema Validation

Purpose: To verify the XML instance is correctly formed.

Method: Use the CRSD XML schema to validate the XML instance.

Reference: Section 11; Section 12; CRSD XML schema

Test 2.2 Sensor & Product Information

Purpose: To verify the Sensor, SAR Image, and Product Information are correct.

Method: Verify the ProductInfo, SARInfo, TransmitInfo, and ReceiveInfo parameters and values are correct for the collection and the product. Verify the Classification and ReleaseInfo values in the File Header are matched to the values in the ProductInfo structure. Verify the Product Name is correct for the product.

Reference: Table 2-1; Table 12-1(a) through 12-1(d); PDD

Test 2.3 Transmit Sequences and Sequence Identifiers

Purpose: To verify the number of transmit sequences and Sequence Identifiers are correct in a CRSD:SAR product or CRSD:TX product.

Method: The XML structure specifies the number of transmit pulse sequences and the text-based Transmit Sequence Identifiers (Tx_IDs). Verify Tx_ID values are consistent between the CRSD / Data branch and the CRSD / TxSequence branch. Verify the Tx_ID values are correct for the type of collection.

Reference: Figure 12-1; Table 12-4; Table 12-5; PDD

Test 2.4 Receive Channels and Channel Identifiers

Purpose: To verify the number of data channels and Channel Identifiers are correct in a CRSD:SAR product or CRSD:RCV product.

Method: The XML structure specifies the number of data channels and the text-based Channel Identifiers (Ch_IDs). Verify Ch_ID values are consistent between the CRSD / Data branch and the CRSD / Channel branch. Verify the Ch_ID values are correct for the type of collection.

Reference: Figure 12-1; Table 12-4; Table 12-6; PDD

Test 2.5 XML Metadata Profile

Purpose: To verify the XML metadata profile is correct.

Method: Verify the XML metadata profile is correct for the event, the product type, and the processing options selected when forming the CRSD. Verify all

conditional parameters are correctly included. Verify all optional parameters are included per the product design.

Reference: Section 12; Tables 12-1 thru 12-14, PDD

13.2.3 Module 3: Binary Data Block Sizes

Purpose: To verify that the binary-formatted data block sizes are correct and consistent with the XML parameter values that describe them.

Method: For each binary-formatted data block in the product file, verify that the block size and XML parameters that specify the size and shape of the block are consistent.

Reference: Table 2-1; Table 12-4; Table 12-10; Table 12-11

Test 3.1 Signal Block Size

Purpose: To verify the Signal Block size and the XML parameters that describe it are consistent in CRSD:SAR and CRSD:RCV products.

Method: Compute the signal array size (in bytes) for each data channel in the product. Verify the size of the Signal block in the File Header is equal to the sum of the sizes of the signal arrays contained in the product. Verify that the signal array byte offsets are correct.

Reference: Section 2.1; Section 2.5; Table 2-1; Table 11-4; Figure 2-3

Test 3.2 PPP Block Size

Purpose: To verify the PPP Block size and the XML parameters that describe it are consistent in CRSD:SAR and CRSD:TX products.

Method: Compute the PPP array size (in bytes) for each transmit sequence in the product. Verify the size of the PPP block in the File Header is equal to the sum of the sizes of the PPP arrays contained in the product. Verify that the PPP array byte offsets are correct.

Reference: Section 2.1; Section 2.5; Table 2-1; Table 12-4; Figure 2-3

Test 3.3 PVP Block Size

Purpose: To verify the PVP Block size and the XML parameters that describe it are consistent in CRSD:SAR and CRSD:RCV products.

Method: Compute the PVP array size (in bytes) for each data channel in the product. Verify the size of the PVP block in the File Header is equal to the sum of the sizes of the PVP arrays contained in the product. Verify that the PVP array byte offsets are correct.

Reference: Section 2.1; Section 2.6; Table 2-1; Table 11-4; Figure 2-5

Test 3.4 Support Block Size

Purpose: To verify the Support Block size and the XML parameters that describe it are consistent.

Method: Compute the Support array size (in bytes) for each support array in the product. Verify the size of the PVP block in the File Header is equal to

the sum of the sizes of the PVP arrays contained in the product. Verify that the support array byte offsets are correct.

Reference: Section 2.1; Section 2.4; Table 2-1; Table 12-4, Table 12-9

13.3 Implementation Conformance Statement

Implementation Conformance Statement Pro Forma			
Test Module	Test Case	M: Mandatory O: Optional	Pass / Fail
Product File Format	1.1 File Header Format	M	
	1.2 Data Block Order	M	
XML Format & Content	2.1 XML Schema Validation	M	
	2.2 Collection Information	M	
	2.3 Tx Sequences and IDs	M	
	2.4 Rev Channels and IDs	M	
	2.5 XML Metadata Profile	M	
Binary Data Block Sizes	3.1 Signal Block Size	M	
	3.2 PPP Block Size	M	
	3.3 PVP Block Size	M	
	3.4 Support Block Size	M	