Digital Imaging and Communications in Medicine (DICOM)

Supplement 139: Enhanced XA/XRF IOD Informative Annex

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Scope and Field

This Supplement delivers explanatory information on the usage of DICOM attributes for Enhanced XA. Additionally, it clarifies the definitions of patient orientation, isocenter projection and the projection calibration method.

The detailed purpose can be summarized as follows:

- Give more information beyond the definitions in PS 3.3 (detailed text vs. scenarios, examples, drawings, etc.);
- Identify scenarios where the Enhanced XA will be applied;
- Indicate restrictions on the applicable scenarios (defined terms recommended, values ranges, recommended presence of attributes);
- Promote usage of Type 3 attributes under particular scenarios;
- Assess the applicability for some conditional attributes under particular scenarios;
- Ensure that the introduction of private attributes is a “last resort only” situation.

Some of the concepts described in this Supplement, e.g., handling FoV Origin, are common to any X-Ray cone-beam projection modality, although the application cases only apply to Enhanced XA SOP Class.

Change the note in PS 3.3 Section C.8.19.6.13.1

C.8.19.6.13.1 Isocenter Reference System Attribute Description

The Isocenter Reference System Attributes describe the 3D geometry of the X-Ray equipment composed by the X-Ray positioner and the X-Ray table.

These attributes define three coordinate systems in the 3D space:

- Isocenter coordinate system
- Positioner coordinate system
- Table coordinate system

The Isocenter Reference System attributes describe the relationship between the 3D coordinates of a point in the table coordinate system and the 3D coordinates of such point in the positioner coordinate system (both systems moving in the equipment), by using the Isocenter coordinate system that is fixed in the equipment.

Note: PS 3.17 Annex ~~X~~ **Z: Enhanced XA/XRF Encoding Examples (Informative)** describes the transformations necessary to transpose between coordinate systems

Change in PS 3.3 section C.8.19.6.13.1.3

C.8.19.6.13.1.3 Table Coordinate System

The table coordinate system (O_t, X_t, Y_t, Z_t) is defined as follows:

- Origin O_t, so-called Table Reference Point, is on the Table Top plane
- $+X_t$ direction to the TABLE LEFT
- $+Z_t$ direction to the TABLE HEAD
- $+Y_t$ direction to the TABLE DOWN

The table coordinate system (O_t, X_t, Y_t, Z_t) is characterized, with respect to the Isocenter coordinate system (O, X, Y, Z), by a 3D translation and 3 angles describing the tilting and rotation:

Table X Position to Isocenter (0018,9466) (so-called $\mathbf{T_X}$ in Figure C.8.19.6-8) is defined as the translation of the Table Reference Point O_t with respect to the Isocenter **coordinate** system in the X direction. Table motion toward~~s~~ +X is positive.

Table Y Position to Isocenter (0018,9467) (so-called $\mathbf{T_Y}$ in Figure C.8.19.6-8) is defined as the translation of the Table Reference Point O_t with respect to the Isocenter **coordinate** system in the Y direction. Table motion toward~~s~~ +Y is positive.

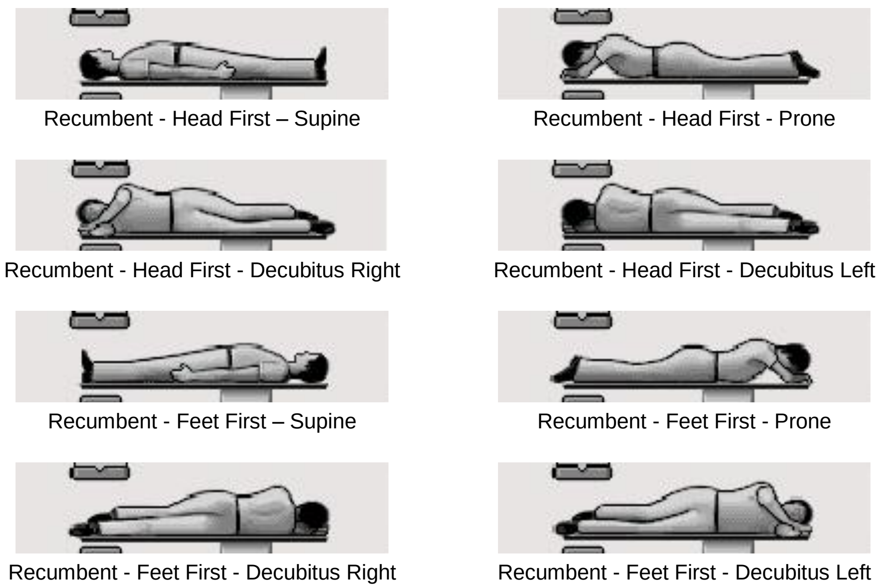
Table Z Position to Isocenter (0018,9468) (so-called $\mathbf{T_Z}$ in Figure C.8.19.6-8) is defined as the translation of the Table Reference Point O_t with respect to the Isocenter **coordinate** system in the Z direction. Table motion toward~~s~~ +Z is positive.

Add in PS 3.3 section C.7.3.1.1.2

The Defined Terms are:

HFP	= Head First-Prone	HFS	= Head First-Supine
HFDR	= Head First-Decubitus Right	HFDL	= Head First-Decubitus Left
FFDR	= Feet First-Decubitus Right	FFDL	= Feet First-Decubitus Left
FFP	= Feet First-Prone	FFS	= Feet First-Supine

<u>The Figure x.x illustrates these defined terms for imaging equipments with a table, such as in X-Ray Angiography. The orientation of the patient related to gravity is always recumbent.</u>



<u>Figure x.x</u>
<u>Representation of the eight Different Patient Positions on the X-Ray Table</u>

Change in PS3.3 section C.8.19.5

C.8.19.5 X-Ray Detector Module

Table C.8.19.5-1 contains IOD Attributes that describe an X-Ray detector.

Table C.8.19.5-1
X-RAY DETECTOR MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Include 'Digital X-Ray Detector Macro' Table C.8-71b			
Physical Detector Size	(0018,9429)	1	Dimensions of the physical detector measured in mm as a row size followed by a column size.
Position of Isocenter Projection	(0018,9430)	1C	Position of the Isocenter **projection on the detector plane** measured in **fractional** physical detector elements as a **distance along the column direction** ~~row offset~~ followed by a **distance along the row direction** ~~column offset~~ from the **center of the** TLHC **detector element** of a rectangle circumscribing the physical detector area. Required if Isocenter Reference System Sequence (0018,9462) is present.

Change in PS3.6

(0018,9430) Position of Isocenter Projection PositionOfIsocenterProjection ~~US~~**FL** 2

Change in PS3.3 section C.8.19.6.9.1

C.8.19.6.9.1 Projection Calibration Method

The X-Ray Projection Pixel Calibration Macro defines the attributes needed to completely describe the specific inputs and results from projection image pixel calibration based on isocenter reference. The attributes are provided to allow usage of calibration result as well as recalibration. The below included figures illustrate the relationship of the attributes. ~~**The term ISO refers to Distance Source to Isocenter attribute (0018,9402). The Imager Pixel Spacing (0018,1164) is defined in the XA/XRF Acquisition Module**~~.

In these figures, the object of interest of size D (in mm) is projected on the stored image over a distance of #*Px* (in pixels). The pixel spacing on the stored image is called *ΔPx*. The “Source to Isocenter Distance” is called *ISO*. The “Source Image Receptor Distance” is called *SID*. The shortest distance from the tabletop plane to the Isocenter and to the object of interest are called respectively *TH* and *TO*. The angle between the X-Ray beam and the axis perpendicular to the tabletop plane is called *Beam Angle*. Finally, the distance from the X-Ray source to the object of interest in the direction of the X-Ray beam is called *SOD* and is calculated from the other distances.

ΔPx: **Imager Pixel Spacing (0018,1164)**

ISO : **Source Isocenter Distance (0018,9402)**

SID : **Distance Source to Detector (0018,1110)**

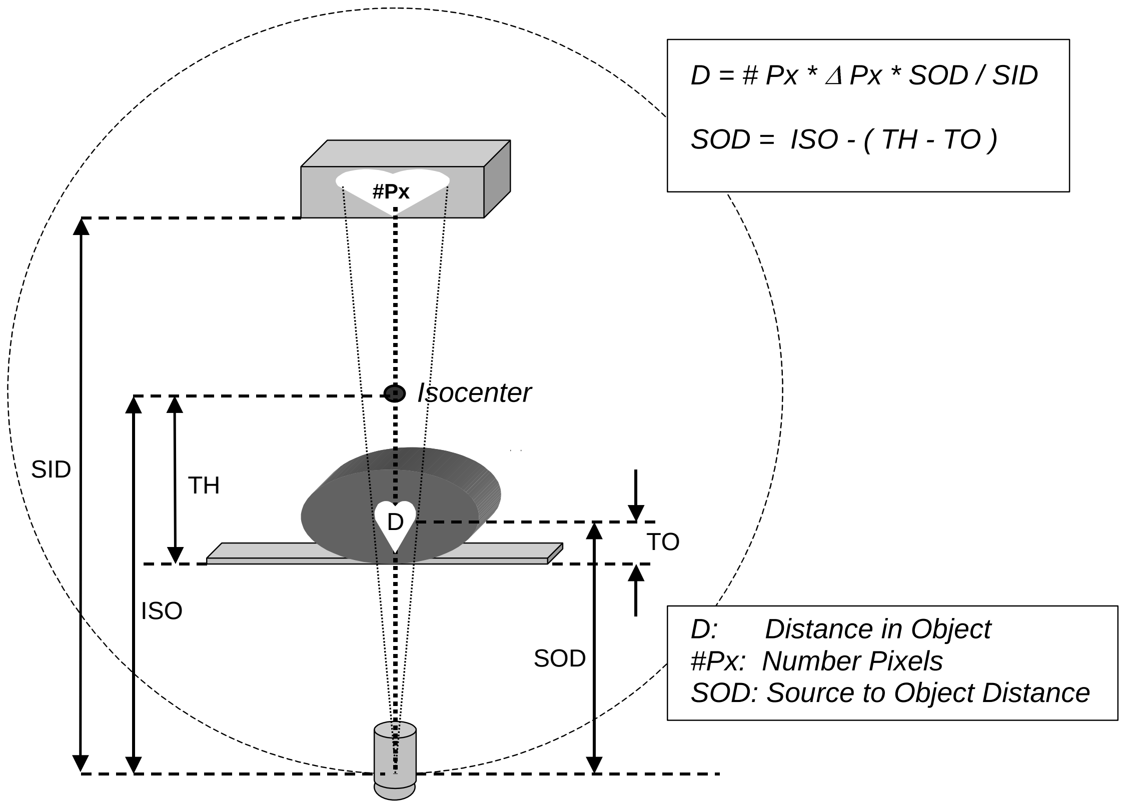
TH : **Table Height (0018,1130)**

TO : **Distance Object to Table Top (0018,9403)**

Beam Angle: **Beam Angle (0018,9449)**

Note: The equipment related Beam Angle attribute (0018,9449) shall be consistent with the patient oriented Positioner Primary Angle (0018,1510) and Positioner Secondary Angle (0018,1511) together with the patient orientation on the table specified in Patient Orientation Code Sequence (0054,0410) attributes.

Replace in PS3.3 section C.8.19.6.9.1 the Figure C.8.19.6-1



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332 **Figure C.8.19.6-1**
Project Calibration without angulation of the X-Ray beam (Beam Angle = 0)

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Replace Annex Z of PS 3.17 with the following Annex

Annex Z Enhanced XA/XRF Encoding Examples (Informative)

Z.1 GENERAL CONCEPTS OF X-RAY ANGIOGRAPHY

This chapter describes the general concepts of the X-Ray Angiography equipment and the way these concepts can be encoded in SOP Instances of the Enhanced XA SOP Class. It covers the time relationships during the image acquisition, the X-Ray generation parameters, the conic projection geometry in X-Ray Angiography, the pixel size calibration as well as the display pipeline.

The following general concepts provide better understanding of the examples for the different application cases in the rest of this Annex.

Z.1.1 Time Relationships

Z.1.1.1 Time Relationships of a Multi-frame Image

The following figure shows the time-related attributes of the acquisition of X-Ray multi-frame images. The image and frame time attributes are defined as absolute times, the duration of the entire image acquisition can be then calculated.

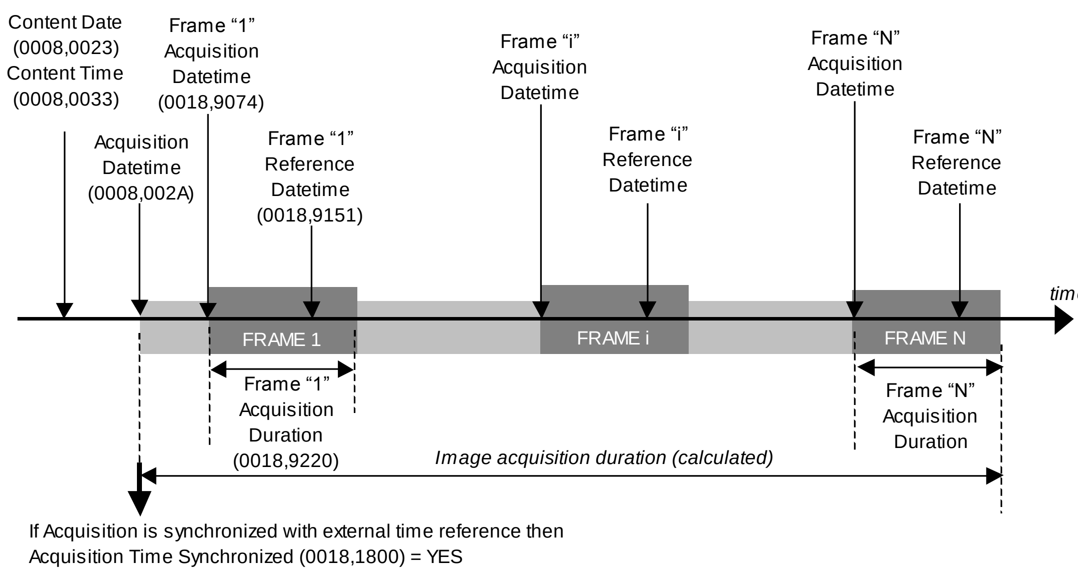


Figure Z.1.1-1
Time Relationships of a Multi-frame Image

Z.1.1.2 Time Relationships of one Frame

The following figure shows the time-related attributes of the acquisition of an individual frame “i” and the relationship with the X-Ray detector reading time and simultaneous ECG waveform acquisition.

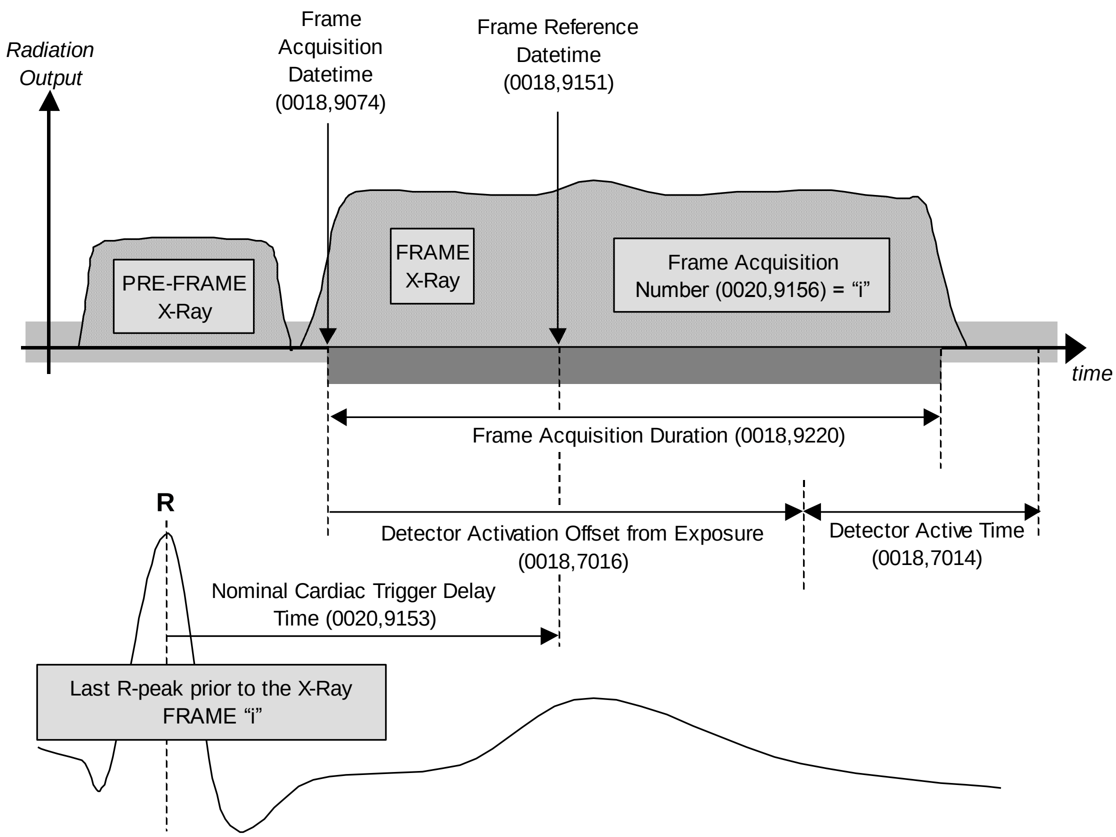


Figure Z.1.1-2
Time Relationships of one Frame

Notes: 1. Positioner angle values, table position values etc… are measured at the Frame Reference Datetime.
2. Dose of the frame is the cumulative dose: PRE-FRAME + FRAME

Z.1.2 Acquisition Geometry

This chapter illustrates the relationships between the geometrical models of the patient, the table, the positioner, the detector and the pixel data.

The following figure shows the different steps in the X-Ray acquisition that influences the geometrical relationship between the patient and the pixel data.

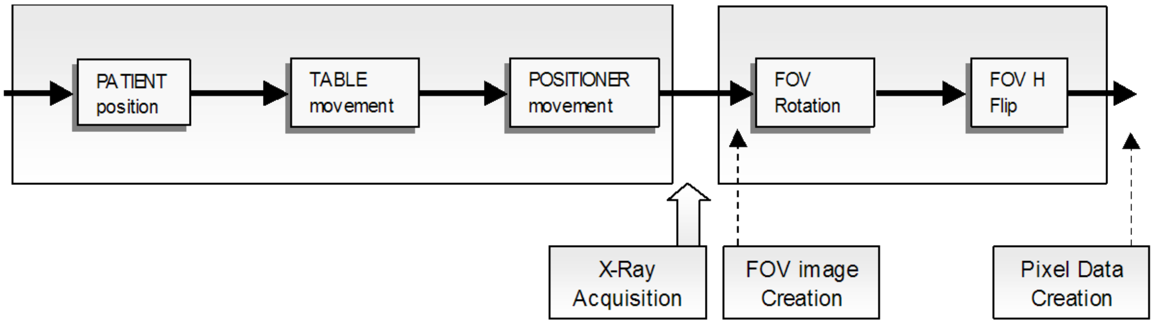


Figure Z.1.2-1
Acquisition Steps Influencing the Geometrical Relationship Between the Patient and the Pixel Data

Z.1.2.1 Patient Description

Refer to Annex A for the definition of the patient orientation.

A point of the patient is represented as: $P = (P_{left}, P_{posterior}, P_{head})$.

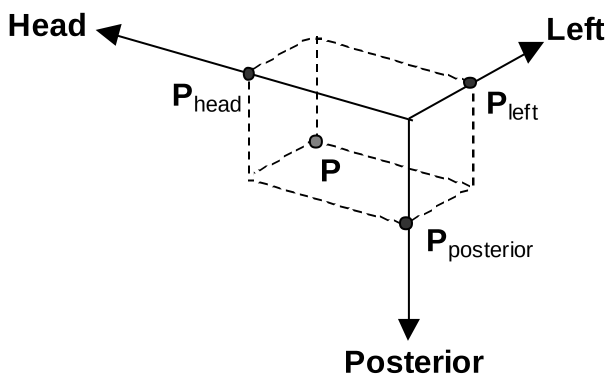


Figure Z.1.2-2
Point P Defined in the Patient Orientation

Z.1.2.2 Patient Position

Z.1.2.2.1 Table Description

The table coordinates are defined in the section C.8.7.4.1.4 of PS 3.3.

The table coordinate system is represented as: (O_t, X_t, Y_t, Z_t) where the origin O_t is located on the tabletop and is arbitrarily defined for each system.

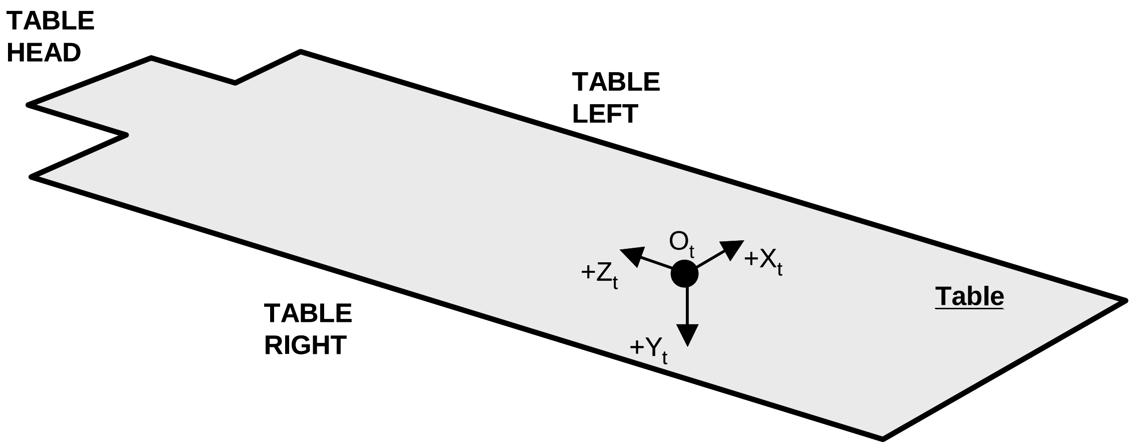


Figure Z.1.2-3
Table Coordinate System

Z.1.2.2.2 Options for Patient Position on the X-Ray Table

The position of the patient in the X-Ray table is described in the section C.7.3.1.1.2 of PS 3.3.

The table below shows the direction cosines for each of the three patient directions (Left, Posterior, Head) related to the Table coordinate system (X_t, Y_t, Z_t), for each patient position on the X-Ray table:

Patient Position	Patient left direction	Patient posterior direction	Patient head direction
Recumbent - Head First - Supine	(1, 0, 0)	(0, 1, 0)	(0, 0, 1)
Recumbent - Head First - Prone	(-1, 0, 0)	(0, -1, 0)	(0, 0, 1)
Recumbent - Head First - Decubitus Right	(0, -1, 0)	(1, 0, 0)	(0, 0, 1)
Recumbent - Head First - Decubitus Left	(0, 1, 0)	(-1, 0, 0)	(0, 0, 1)
Recumbent - Feet First - Supine	(-1, 0, 0)	(0, 1, 0)	(0, 0, -1)
Recumbent - Feet First - Prone	(1, 0, 0)	(0, -1, 0)	(0, 0, -1)
Recumbent - Feet First- Decubitus Right	(0, -1, 0)	(-1, 0, 0)	(0, 0, -1)
Recumbent - Feet First -Decubitus Left	(0, 1, 0)	(1, 0, 0)	(0, 0, -1)

Z.1.2.3 Table Movement

Z.1.2.3.1 Isocenter Coordinate System

The Isocenter coordinate system is defined in section C.8.19.6.13.1.1 of PS 3.3.

Z.1.2.3.2 Table Movement in the Isocenter Coordinate System

The table coordinate system is defined in section C.8.19.6.13.1.3 of PS 3.3 where the table translation is represented as (T_X,T_Y,T_Z). The table rotation is represented as (At_1, At_2, At_3).

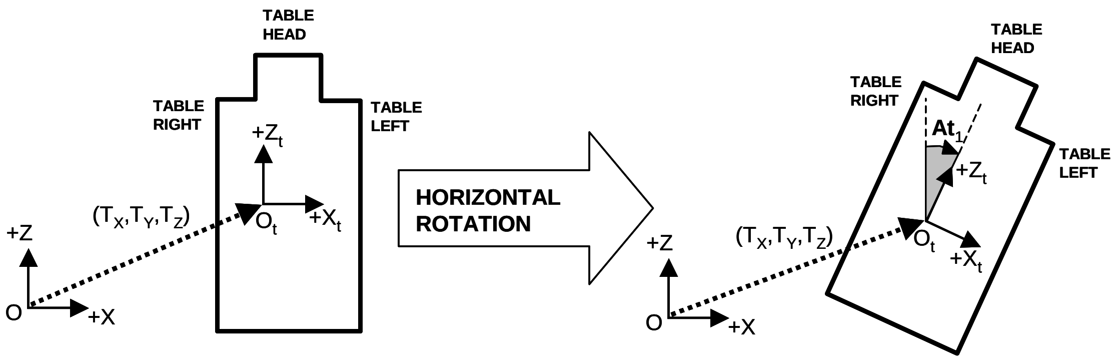


Figure Z.1.2-4
At1: Table Horizontal Rotation Angle

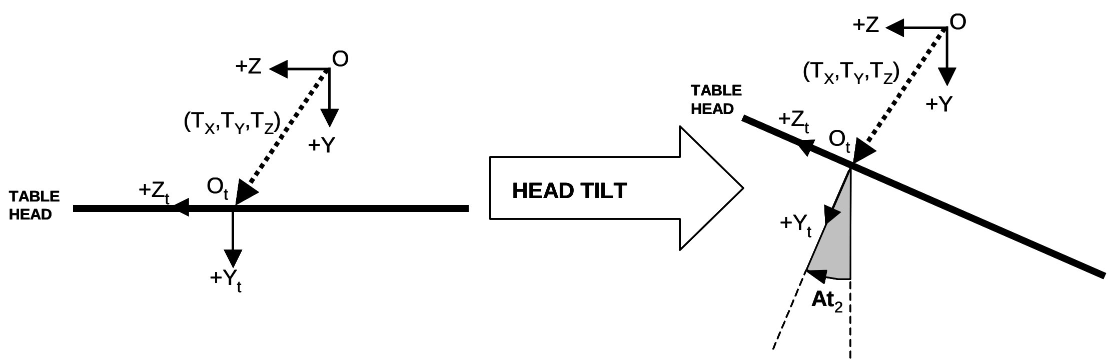


Figure Z.1.2-5
At2: Table Head Tilt Angle

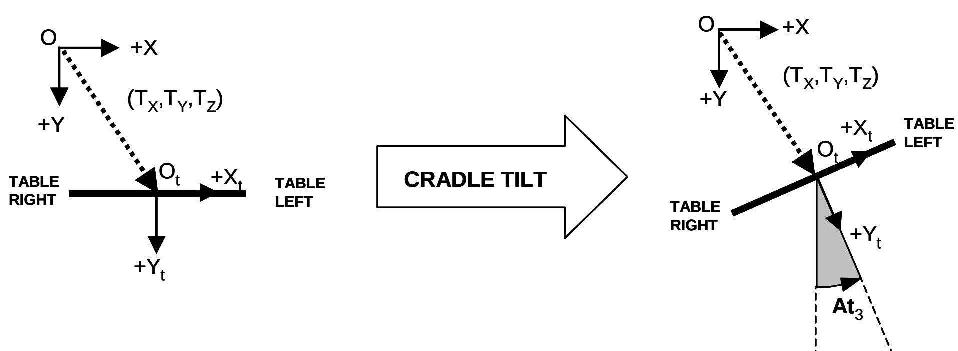


Figure Z.1.2-6
At3: Table Cradle Tilt Angle

A point (P_{Xt}, P_{Yt}, P_{Zt}) in the table coordinate system (see Figure Z.1.2-7) can be expressed as a point (P_X, P_Y, P_Z) in the Isocenter coordinate system by applying the following transformation:

$$\mathbf{(P_X, P_Y, P_Z)^T = (R_3 \cdot R_2 \cdot R_1)^T \cdot (P_{Xt}, P_{Yt}, P_{Zt})^T + (T_X, T_Y, T_Z)^T}$$

And inversely, a point (P_X, P_Y, P_Z) in the Isocenter coordinate system can be expressed as a point (P_{Xt}, P_{Yt}, P_{Zt}) in the table coordinate system by applying the following transformation:

$$\mathbf{(P_{Xt}, P_{Yt}, P_{Zt})^T = (R_3 \cdot R_2 \cdot R_1) \cdot ((P_X, P_Y, P_Z)^T - (T_X, T_Y, T_Z)^T)}$$

Where $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ are defined as follows:

$$R_1 = \begin{pmatrix} \cos(At_1) & 0 & -\sin(At_1) \\ 0 & 1 & 0 \\ \sin(At_1) & 0 & \cos(At_1) \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(At_2) & \sin(At_2) \\ 0 & -\sin(At_2) & \cos(At_2) \end{pmatrix}$$

$$R_3 = \begin{pmatrix} \cos(At_3) & -\sin(At_3) & 0 \\ \sin(At_3) & \cos(At_3) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

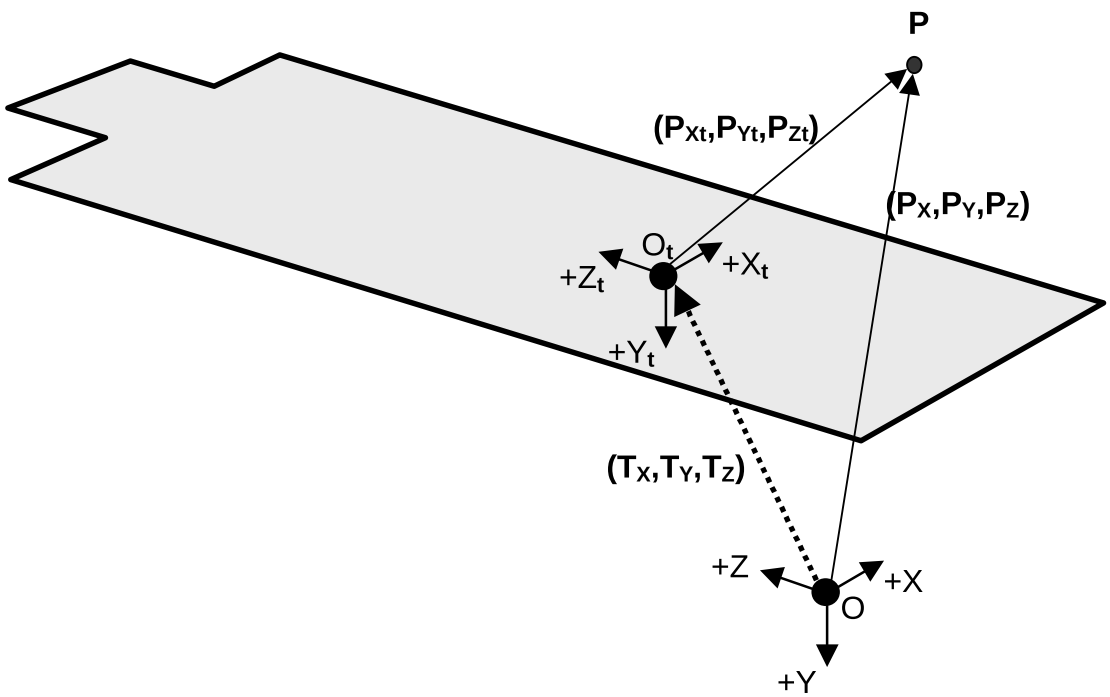


Figure Z.1.2-7
Point P in the Table and Isocenter Coordinate Systems

Z.1.2.4 Positioner Movement

Z.1.2.4.1 Positioner Movement in the Isocenter Coordinate System

The positioner coordinate system is defined in section C.8.19.6.13.1.2 of PS 3.3 where the positioner angles are represented as (Ap_1, Ap_2, Ap_3).

A point (P_{Xp}, P_{Yp}, P_{Zp}) in the positioner coordinate system can be expressed as a point (P_X, P_Y, P_Z) in the Isocenter coordinate system by applying the following transformation:

$$(P_X, P_Y, P_Z)^T = (R_2 \cdot R_1)^T \cdot (R_3^T \cdot (P_{Xp}, P_{Yp}, P_{Zp})^T)$$

And inversely, a point (P_X, P_Y, P_Z) in the Isocenter coordinate system can be expressed as a point (P_{Xp}, P_{Yp}, P_{Zp}) in the positioner coordinate system by applying the following transformation:

$$(P_{Xp}, P_{Yp}, P_{Zp})^T = R_3 \cdot ((R_2 \cdot R_1) \cdot (P_X, P_Y, P_Z)^T)$$

Where $\mathbf{R_1}$, $\mathbf{R_2}$ and $\mathbf{R_3}$ are defined as follows:

$$R_1 = \begin{pmatrix} \cos(Ap_1) & \sin(Ap_1) & 0 \\ -\sin(Ap_1) & \cos(Ap_1) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(Ap_2) & -\sin(Ap_2) \\ 0 & \sin(Ap_2) & \cos(Ap_2) \end{pmatrix}$$

$$R_3 = \begin{pmatrix} \cos(Ap_3) & 0 & -\sin(Ap_3) \\ 0 & 1 & 0 \\ \sin(Ap_3) & 0 & \cos(Ap_3) \end{pmatrix}$$

Z.1.2.4.2 X-Ray Incidence and Image Coordinate System

The following concepts illustrate the model of X-Ray cone-beam projection:

The **X-Ray incidence** represents the vector going from the X-Ray source to the Isocenter.

The **receptor plane** represents the plane perpendicular to the X-Ray Incidence, at distance SID from the X-Ray source. Applies for both image intensifier and digital detector. In case of digital detector it is equivalent to the detector plane.

The **image coordinate system** is represented by (o, u, v), where “o” is the projection of the Isocenter on the receptor plane.

The **source to isocenter distance** is called ISO. The **source image receptor distance** is called SID.

The projection of a point (P_{Xp}, P_{Yp}, P_{Zp}) in the positioner coordinate system is represented as a point (P_u, P_v) in the image coordinate system.

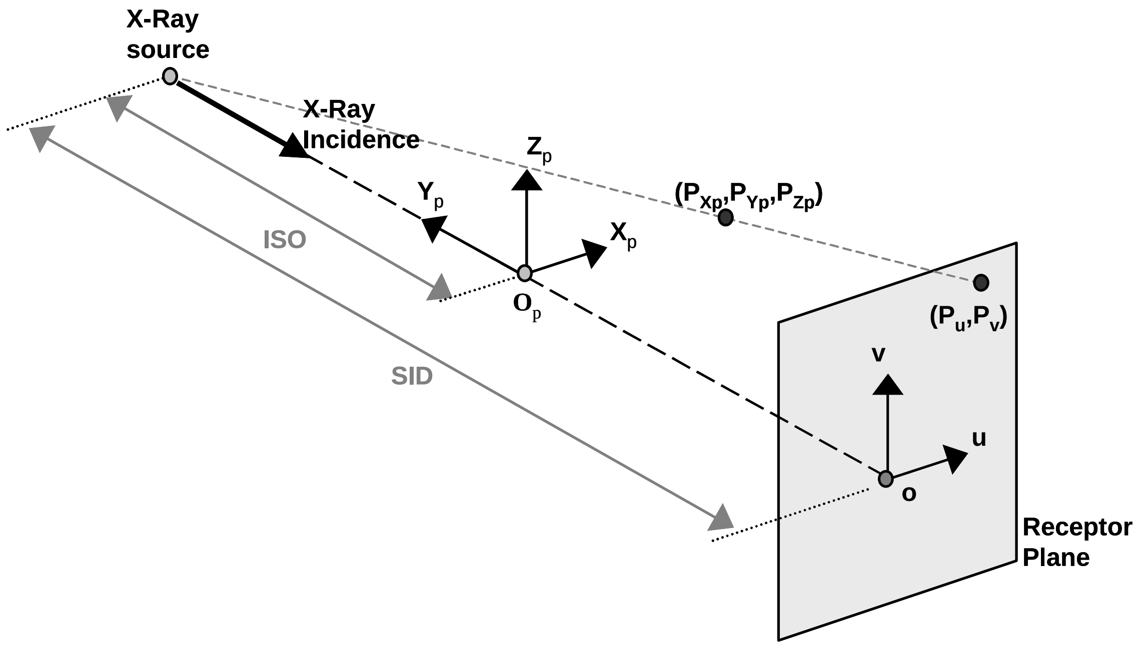


Figure Z.1.2-8
Projection of a Point of the Positioner Coordinate System

A point (P_{Xp}, P_{Yp}, P_{Zp}) in the positioner coordinate system (O_p, X_p, Y_p, Z_p) can be expressed as a point (P_u, P_v) in the image coordinate system by applying the following transformation:

$P_u = (SID / (ISO - P_{Yp})) \cdot P_{Xp}$

$P_v = (SID / (ISO - P_{Yp})) \cdot P_{Zp}$

The ratio SID / (ISO - P_{Yp}) is also called magnification ratio of this particular point.

Z.1.2.5 Field of View Transformations

Z.1.2.5.1 Detector

The following concepts illustrate the model of the X-Ray detector:

Physical detector array (or physical detector matrix) is the matrix composed of **physical detector elements**.

Note: Not all the detector elements are activated during an X-Ray exposure. The active detector elements are in the detector active area, which can be equal to or smaller than the physical detector area.

Physical detector element coordinates represented as ($i_{det,}$ j_{det}) are columns and rows of the physical detector element in the physical detector array.

Detector TLHC element is the detector element in the Top Left Hand Corner of the physical detector array and corresponds to ($i_{det,}$ j_{det}) = (0,0).

The attribute **Detector Element Physical Size** (0018,7020) represents the physical dimensions in mm of a detector element in the row and column directions.

The attribute **Detector Element Spacing** (0018,7022) contains the two values Δ_{jdet} and Δ_{idet}, which represent the physical distance in mm between the centers of each physical detector element:

- Δ_{idet} = detector element spacing between two adjacent columns;
- Δ_{jdet} = detector element spacing between two adjacent rows.

The attribute Detector Element Physical Size (0018,7020) may be different from the Detector Element Spacing (0018,7022) due to the presence of spacing material between detector elements.

The attribute **Position of Isocenter Projection** (0018,9430) contains the point ($ISO\_P_{idet,}$ ISO_P_{jdet}), which represents the projection of the Isocenter on the detector plane, measured as the offset from the center of the detector TLHC element. It is measured in physical detector elements.

The attribute **Imager Pixel Spacing** (0018,1164) contains the two values Δ_j and Δ_i, which represent the physical distance measured at the receptor plane between the centers of each pixel of the FOV image:

- Δ_i = imager pixel spacing between two adjacent columns;
- Δ_j = imager pixel spacing between two adjacent rows.

The **zoom factor** represents the ratio between Imager Pixel Spacing (0018,1164) and Detector Element Spacing (0018,7022). It may be different from the detector binning (e.g., when a digital zoom has been applied to the pixel data).

- Zoom factor (columns) = Δ_i / Δ_{idet};
- Zoom factor (rows) = Δ_j / Δ_{jdet}.

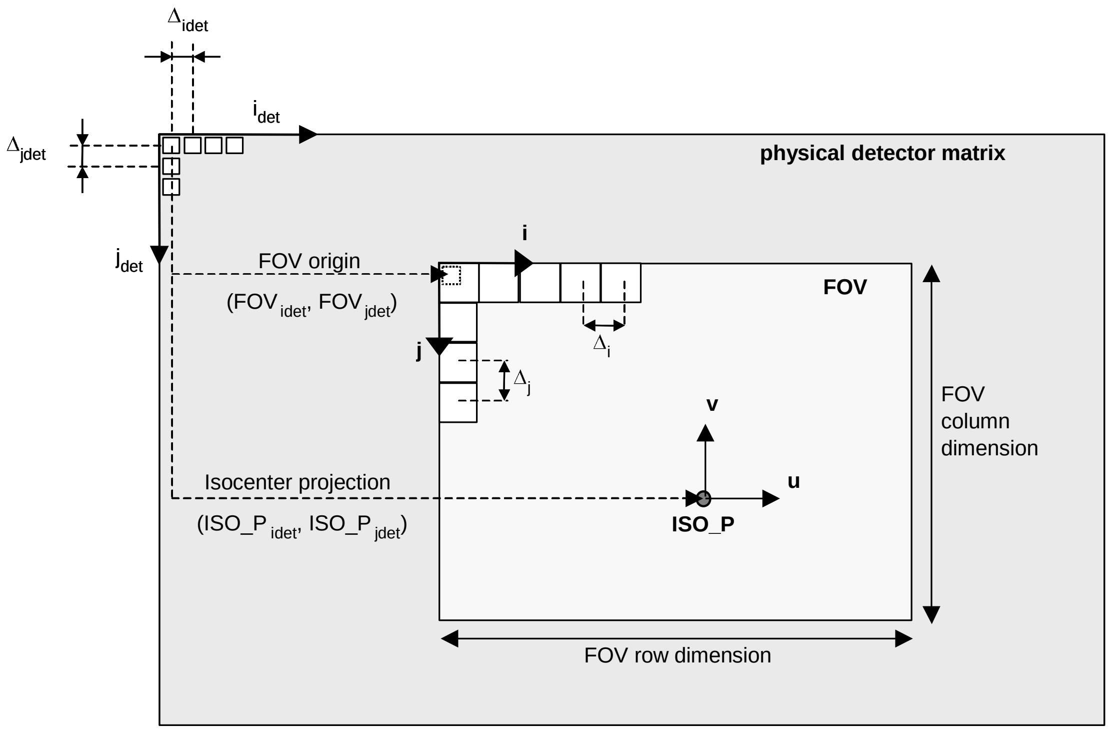


Figure Z.1.2-9
Physical Detector and Field of View Areas

Z.1.2.5.2 Field of View

The following concepts illustrate the model of the field of view:

The **field of view** (FOV) corresponds to a region of the physical detector array that has been irradiated.

The **field of view image** is the matrix of pixels of a rectangle circumscribing the field of view. Each pixel of the field of view image may be generated by multiple physical detector elements.

The attribute **FOV Origin** (0018,7030) contains the two values (FOV_{idet}, FOV_{jdet}), which represent the offset of the center of the detector element at the TLHC of the field of view image, before rotation or flipping, from the center of the detector TLHC element. It is measured in physical detector elements. FOV Origin = (0,0) means that the detector TLHC element is at the TLHC of a rectangle circumscribing the field of view.

The attribute **FOV Dimension** (0018,9461) contains the two values FOV row dimension and FOV column dimension, which represent the dimension of the FOV in mm:

- FOV row dimension = dimension in mm of the field of view in the row direction;
- FOV column dimension = dimension in mm of the field of view in the column direction.

FOV pixel coordinates represented as (i, j) are columns and rows of the pixels in the field of view image.

FOV TLHC pixel is the pixel in the Top Left Hand Corner of the field of view image and corresponds to (i, j) = (0,0).

As an example, the point (ISO_P_i, ISO_P_j) representing the projection of the Isocenter on the field of view image, and measured in FOV pixels as the offset from the center of the FOV TLHC pixel, can be calculated as follows:

$$ISO\_P_i = (ISO\_P_{idet} - FOV_{idet}) \cdot \Delta_{idet} / \Delta_i - (1 - \Delta_{idet} / \Delta_i) / 2$$

$$ISO\_P_j = (ISO\_P_{jdet} - FOV_{jdet}) \cdot \Delta_{jdet} / \Delta_j - (1 - \Delta_{jdet} / \Delta_j) / 2$$

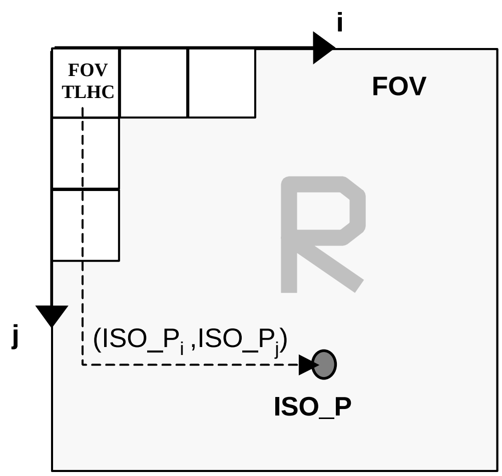


Figure Z.1.2-10
Field of View Image

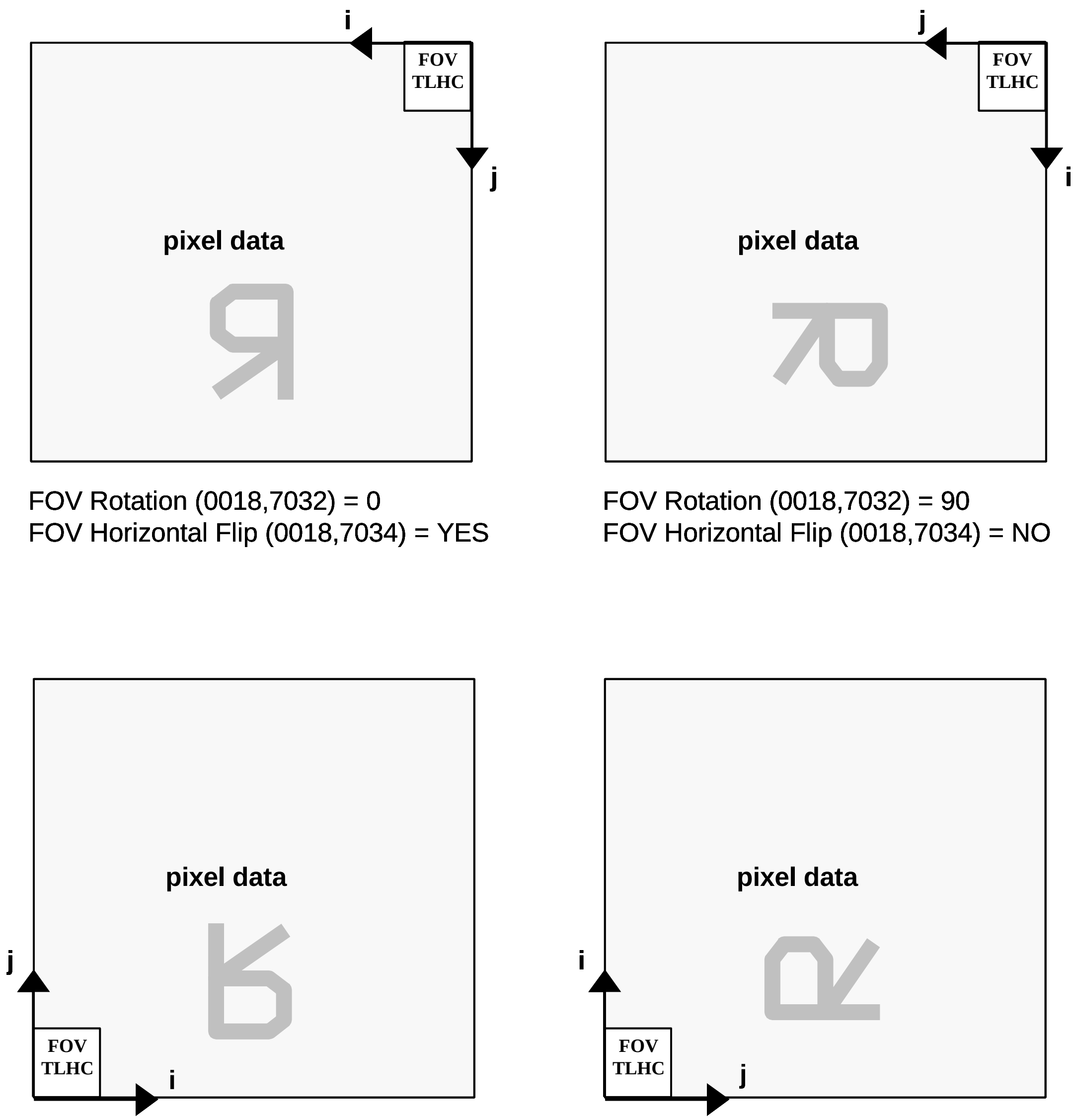
Z.1.2.5.3 Field of View Rotation and Flip

The attribute **FOV Rotation** (0018,7032) represents the clockwise rotation in degrees of field of view relative to the physical detector.

The attribute **FOV Horizontal Flip** (0018,7034) defines whether or not a horizontal flip has been applied to the field of view after rotation relative to the physical detector.

The attribute **Pixel Data** (7FE0,0010) contains the FOV image after rotation and/or flipping.

Pixel data coordinates is the couple (c,r) where c is the column number and r is the row number.



FOV Rotation (0018,7032) = 0
FOV Horizontal Flip (0018,7034) = YES

FOV Rotation (0018,7032) = 90
FOV Horizontal Flip (0018,7034) = NO

FOV Rotation (0018,7032) = 180
FOV Horizontal Flip (0018,7034) = YES

FOV Rotation (0018,7032) = 270
FOV Horizontal Flip (0018,7034) = NO

Figure Z.1.2-11
Examples of Field of View Rotation and Horizontal Flip

Z.1.3 Calibration

The X-Ray projection pixel calibration macro of the PS 3.3 C.8.19.6.9 specifies the attributes of the image pixel size calibration model in X-Ray conic projection, applicable to the Enhanced XA SOP Class.

In this model, the table plane is specified relative to the Isocenter. As default value for the attribute Distance Object to Table Top (0018,9403), the half distance of the patient thickness may be used.

Oblique projections are considered in this model by the encoding of the attribute Beam Angle (0018,9449), which can be calculated from Positioner Primary Angle (0018,1510) and Positioner Secondary Angle (0018,1511) as follows:

For Patient Positions HFS, FFS, HFP, FFP:
Beam Angle = arcos(|cos(Positioner Primary Angle)| * |cos(Positioner Secondary Angle)|).

For Patient Positions HFDR, FFDR, HFDL, FFDL:
Beam Angle = arcos(|sin(Positioner Primary Angle)| * |cos(Positioner Secondary Angle)|).

The resulting pixel spacing, defined as $\Delta Px * SOD / SID$, is encoded in the attribute Object Pixel Spacing in Center of Beam (0018,9404). Its accuracy is practically limited to a beam angle range of +/- 60 degrees.

Z.1.4 X-Ray Generation

This chapter illustrates the relationships between the X-Ray generation parameters:

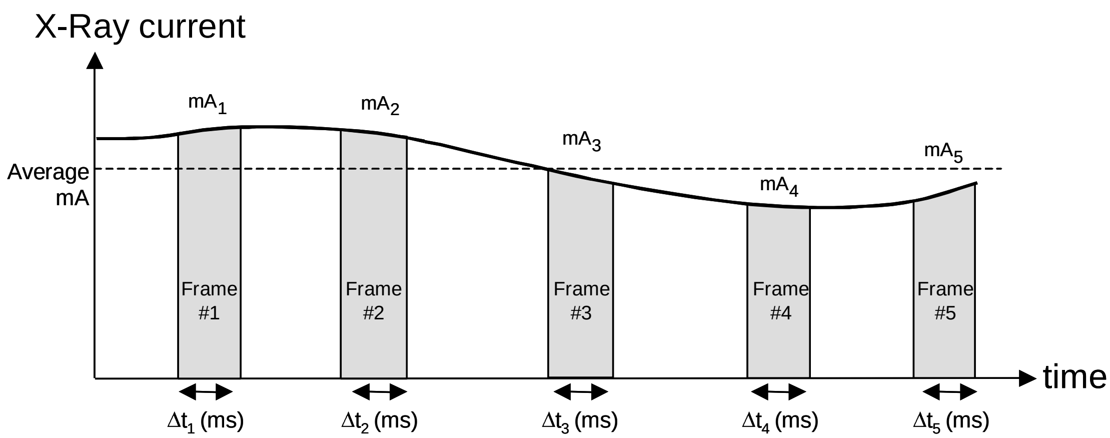


Figure Z.1.4-1
Example of X-Ray Current Per-Frame of the X-Ray Acquisition

Values **per frame** are represented by the following symbols in this section:

In the Frame Content Sequence (0020,9111):

- Frame Acquisition Duration (0018,9220) in ms of frame « i » $= \Delta t_i$

In the Frame Acquisition Sequence (0018,9417):

- KVP (0018,0060) of frame « i » $= kVp_i$
- X-Ray Tube Current in mA (0018,9330) of frame « i » $= mA_i$

The following shows an example of calculation of the cumulative and average values per image relative to the values per-frame:

- Number of Frames (0028,0008) $= N$
- Exposure Time (0018,9328) in ms $= SUM_N (\Delta t_i)$
- X-Ray Tube Current (0018,9330) in mA $= 1/N * SUM_N (mA_i)$
- Average Pulse Width (0018,1454) in ms $= 1/N * SUM_N (\Delta t_i)$
- KVP (0018,0060) $= 1/N * SUM_N (kVp_i)$
- Exposure (0018,9332) in mAs $= SUM_N (\Delta t_i * mA_i / 1000)$

Z.1.5 Pixel Data Properties and Display Pipeline

This chapter describes the concepts of the display pipeline.

The X-Ray intensity (I) at the image receptor is inversely proportional to the exponential function of the product of the object's thickness (x) traversed by the X-Ray beam and its effective absorption coefficient (μ): $I \sim e^{-\mu x}$.

The X-Ray intensity that comes into contact with the image receptor is converted to the stored pixel data by applying specific signal processing. As a first step in this conversion, the amplitude of the digital signal out of the receptor is linearly proportional to the X-Ray intensity. In further steps, this digital signal is processed in order to optimize the rendering of the objects of interest present on the image.

The Enhanced XA IOD includes attributes that describe the characteristics of the stored pixel data, allowing to relate the stored pixel data to the original X-Ray intensity independently from the fact that the image is "original" or "derived".

When the attribute Pixel Intensity Relationship (0028,1040) equals LIN:

- P ~ I : The pixel values (P) are approximately proportional to X-Ray beam intensity (I).

When the attribute Pixel Intensity Relationship (0028,1040) equals LOG:

- P ~ x : The pixel values (P) are approximately proportional to the object thickness (x).

In order to ensure consistency of the displayed stored pixel data, the standard display pipeline is defined.

On the other side, the stored pixel data is also used by applications for further analysis like segmentation, structure detection and measurement, or for display optimization like mask subtraction. For this purpose, the Pixel Intensity Relationship LUT described in PS 3.3 C.7.6.16.2.13.1 defines a transformation LUT enabling the conversion from the stored pixel data values to linear, logarithmic or other relationship.

For instance, if the image processing applied to the X-Ray intensity before storing the Pixel Data allows returning to LIN, then a Pixel Intensity Relationship LUT with the function "TO_LINEAR" is provided. The following figure shows some examples of image processing, and the corresponding description of the relationship between the stored pixel data and the X-Ray intensity.

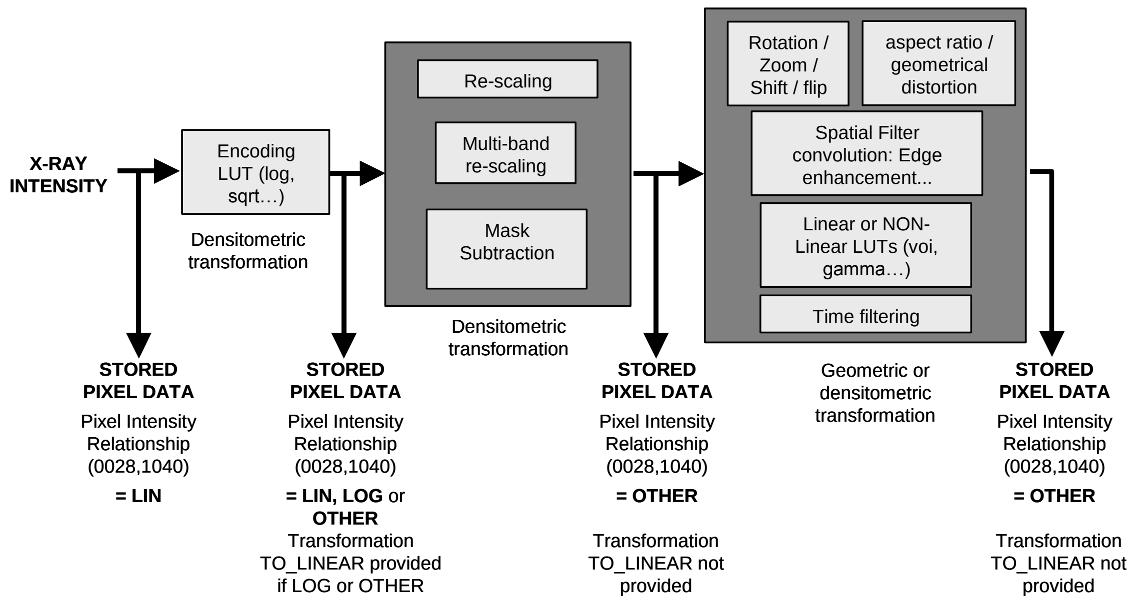


Figure Z.1.5-1
Examples of Image Processing prior to the Pixel Data Storage

No solution is proposed in the Enhanced XA SOP Class to standardize the subtractive display pipeline. As the Enhanced XA image is not required to be stored in a LOG relationship, the Pixel Intensity Relationship LUT may be provided to convert the images to the logarithmic space before subtraction. The creation of subtracted data to be displayed is a manufacturer-dependent function.

As an example of subtractive display, the pixel values are first transformed to a LOG relationship, and then subtracted to bring the background level to zero and finally expanded to displayable levels by using a non-linear function EXP similar to an exponential.

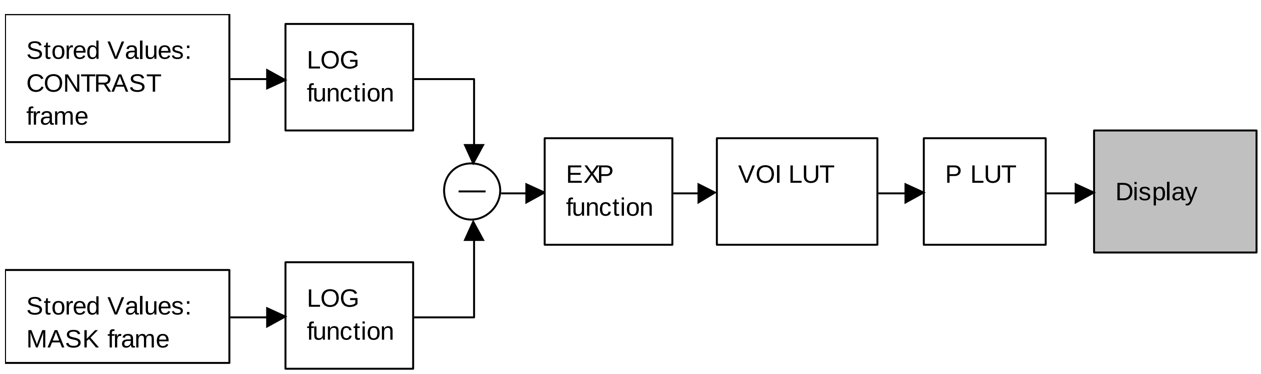


Figure Z.1.5-2
Example of Manufacturer-Dependent Subtractive Pipeline with Enhanced XA

Z.2 APPLICATION CASES

This chapter describes different scenarios and application cases organized by domains of application. Each application case is basically structured in four sections:

1) **User Scenario**: Describes the user needs in a specific clinical context, and/or a particular system configuration and equipment type.

2) **Encoding Outline**: Describes the specificities of the XA SOP Class and the Enhanced XA SOP Class related to this scenario, and highlights the key aspects of the Enhanced XA SOP Class to address it.

3) **Encoding Details**: Provides detailed recommendations of the key attributes of the object(s) to address this particular scenario.

4) **Example**: Presents a typical example of the scenario, with realistic sample values, and gives details of the encoding of the key attributes of the object(s) to address this particular scenario. In the values of the attributes, the text in bold face indicates specific attribute values; the text in italic face gives an indication of the expected value content.

Z.2.1 Acquisition

Z.2.1.1 ECG Recording at Acquisition Modality

This application case is related to the results of an X-Ray acquisition and parallel ECG data recording on the same equipment.

Z.2.1.1.1 User Scenario

The image acquisition system records ECG signals simultaneously with the acquisition of the Enhanced XA multi-frame image. All the ECG signals are acquired at the same sampling rate.

The acquisition of both image and ECG data are not triggered by an external signal.

The information can be exchanged via Offline Media or Network.

Synchronization between the ECG Curve and the image frames allows synchronized navigation in each of the datasets.

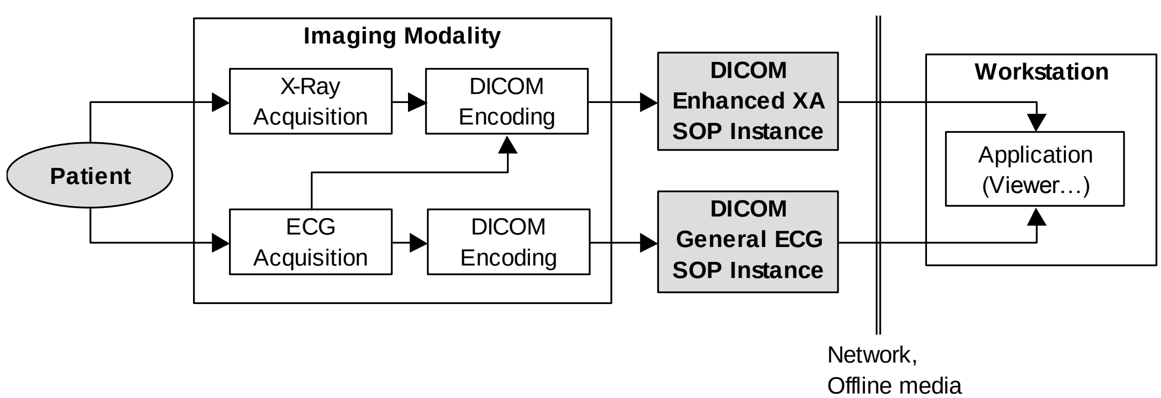


Figure Z.2.1-1
Scenario of ECG Recording at Acquisition Modality

Z.2.1.1.2 Encoding outline

The General ECG IOD is used to store the waveform data recorded in parallel to the image acquisition encoded as Enhanced XA IOD.

The Synchronization Module is used to specify a common time-base.

The option of encoding trigger information is not recommended by this case.

The solution assumes implementation on a single imaging modality and therefore the mutual UID references between the General ECG and Enhanced XA objects is recommended. This will allow faster access to the related object.

Z.2.1.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Z.2.1.1.3.1 Enhanced XA Image

Table Z.2.1-1
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Series	General Series	C.7.3.1	The General Series Module Modality (0008,0060) attribute description in PS 3.3 enforces the storage of waveform and pixel data in different Series IE.
Frame of Reference	Synchronization	C.7.4.2	Specifies that the image acquisition is synchronized. Will have the same content as the General ECG SOP Instance.
Equipment	General Equipment	C.7.5.1	Same as in the General ECG SOP Instance.
Image	Cardiac Synchronization	C.7.6.18.1	Contains information of the type of relationship between the ECG waveform and the image.
	Enhanced XA/XRF Image	C.8.19.2	Contains UID references to the related General ECG SOP Instance.

Table Z.2.1-2
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame Content	C.7.6.16.2.2	Provides timing information to correlate each frame to the recorded ECG samples.
Cardiac Synchronization	C.7.6.16.2.7	Provides time relationships between the angiographic frames and the cardiac cycle.

Z.2.1.1.3.1.1 Synchronization Module Recommendations

The usage of this Module is recommended to encode a “synchronized time” condition.

The specialty of Synchronization Triggers is not part of this scenario.

Table Z.2.1-3
SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Synchronization Frame of Reference UID	(0020,0200)	Same UID as in the related General ECG SOP Instance.
Synchronization Trigger	(0018,106A)	In this scenario with no external trigger signal, the value “NO TRIGGER” is used.
Acquisition Time Synchronized	(0018,1800)	The value “Y” is used in this scenario.

Z.2.1.1.3.1.2 General Equipment Module Recommendations

The usage of this Module is recommended to assure that the image contains identical equipment identification information as the referenced General ECG SOP Instance.

Z.2.1.1.3.1.3 Cardiac Synchronization Module Recommendations

The usage of this module is recommended to indicate that the ECG is not used to trig the X-Ray acquisition, rather to time relate the frames to the ECG signal.

Table Z.2.1-4
CARDIAC SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Cardiac Synchronization Technique	(0018,9037)	The value “REAL TIME” is used in this scenario.
Cardiac Signal Source	(0018,9085)	In this scenario, the value “ECG” is used to indicate that the cardiac waveform is an electrocardiogram.

Z.2.1.1.3.1.4 Enhanced XA/XRF Image Module Recommendations

The usage of this module is recommended to reference from the image object to the related General ECG SOP Instance that contains the ECG data recorded simultaneously.

Table Z.2.1-5
ENHANCED XA/XRF IMAGE MODULE Recommendations

Attribute Name	Tag	Comment
Referenced Instance Sequence	(0008,114A)	Reference to “General ECG SOP Instance” acquired in conjunction with this image. Contains a single item.
>Referenced SOP Class UID	(0008,1150)	“1.2.840.10008.5.1.4.1.1.9.1.2” i.e. reference to an General ECG SOP Instance
>Referenced SOP Instance UID	(0008,1155)	Instance UID of referenced waveform
>Purpose of Reference Code Sequence	(0040,A170)	CID 7004 is used; identify clear reason for the Reference.

Z.2.1.1.3.1.5 Cardiac Synchronization Macro Recommendations

If there is a specific ECG analysis that determines the time between the R-peaks and the angiographic frames, the usage of this macro is recommended.

As the frames are acquired at a frame rate independent of cardiac phases, this macro is used in a "per frame functional group" to encode the position of each frame relative to its prior R-peak.

Z.2.1.1.3.1.6 Frame Content Macro Recommendations

In this scenario the timing information is important to correlate each frame to the recorded ECG.

If there is a specific ECG analysis, this macro allows the encoding of the position in the cardiac cycle that is most representative of each frame.

The following table gives recommendations for usage in this scenario.

Table Z.2.1-6
FRAME CONTENT MACRO Recommendations

Attribute Name	Tag	Comment
Frame Content Sequence	(0020,9111)	
>Frame Reference Datetime	(0018,9151)	Exact Time taken from the internal clock.
>Frame Acquisition Datetime	(0018,9074)	Exact Time taken from the internal clock.
>Cardiac Cycle Position	(0018,9236)	Optional, if ECG analysis is available.

Z.2.1.1.3.2 General ECG Object

This IOD will encode the recorded ECG waveform data, which is done by the image acquisition system. Since this is not a dedicated waveform modality device, appropriate defaults for most of the data have to be recommended to fulfill the requirements according to PS 3.3.

Table Z.2.1-7
General ECG IOD Modules

IE	Module	PS 3.3 Reference	Usage
Series	General Series	C.7.3.1	The General Series Module Modality (0008,0060) attribute description in PS 3.3 enforces the storage of waveform and pixel data in different Series IE.
Frame of Reference	Synchronization	C.7.4.2	Specifies that the waveform acquisition is synchronized. Will have the same content as the image.
Equipment	General Equipment	C.7.5.1	Same as in the image.
Waveform	Waveform Identification	C.10.8	Contains references to the related image object.
	Waveform	C.10.9	Contains one multiplex group with the same sampling rate.

Z.2.1.1.3.2.1 General Series Module Recommendations

A new Series is created to set the modality "ECG" for the waveform.

Most of the attributes are aligned with the contents of the related series level attributes in the image object.

The Related Series Sequence (0008,1250) is not recommended because instance level relationship can be applied to reference the image instances.

Table Z.2.1-8
GENERAL SERIES MODULE Recommendations

Attribute Name	Tag	Comment
Modality	(0008,0060)	"ECG"
Series Instance UID	(0020,000E)	Different from the one of the image object.
Series Date	(0008,0021)	Identical to the contents of related image object
Series Time	(0008,0031)	Identical to the contents of related image object.
Other attributes of General Series Module		Match contents of related image object, if set there.

Z.2.1.1.3.2.2 Synchronization Module Recommendations

The usage of this Module is recommended to encode a "synchronized time" condition, which was previously implicit when using the curve module.

Table Z.2.1-9
SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Synchronization Frame of Reference UID	(0020,0200)	Same UID as in the related image object.
Synchronization Trigger	(0018,106A)	The value "NO TRIGGER" is used in this scenario with no external trigger signal.
Acquisition Time Synchronized	(0018,1800)	The value "Y" is used to allow synchronized navigation.

Z.2.1.1.3.2.3 General Equipment Module Recommendations

The usage of this Module is recommended to assure that the General ECG SOP Instance contains identical equipment identification information as the referenced image objects.

Z.2.1.1.3.2.4 Waveform Identification Recommendations

The usage of this module is recommended to relate the acquisition time of the waveform data to the image acquired simultaneously.

The module additionally includes an instance level reference to the related image.

Table Z.2.1-10
WAVEFORM IDENTIFICATION MODULE Recommendations

Attribute Name	Tag	Comment
Acquisition Datetime	(0008,002A)	Exact start of the waveform acquisition taken from common (or synchronized) clock. Note: In case the ECG acquisition started before the image acquisition itself, the given datetime value is not the same as for the image.

Referenced Instance Sequence	(0008,114A)	Only one item used in this application case.
>Referenced SOP Class UID	(0008,1150)	"1.2.840.10008.5.1.4.1.1.12.1.1" i.e. Enhanced XA
>Referenced SOP Instance UID	(0008,1155)	Instance UID of Enhanced XA Image Object to which this parallel ECG recording is related.
>Purpose of Reference Code Sequence	(0040,A170)	The referenced image is related to this ECG.

Z.2.1.1.3.2.5 Waveform Module Recommendations

The usage of this module is a basic requirement of the General ECG IOD.

Any application displaying the ECG is recommended to scale the ECG contents to its output capabilities (esp. the amplitude resolution).

If more than one ECG signal needs to be recorded, the grouping of the channels in multiplex groups depends on the ECG sampling rate. All the channels encoded in the same multiplex group have identical sampling rate.

Table Z.2.1-11
WAVEFORM MODULE Recommendations

Attribute Name	Tag	Comment
Waveform Sequence	(5400,0100)	Only one item is used in this application case, as all the ECG signals have the same sampling rate.
> Multiplex Group Time Offset	(0018,1068)	If needed, specify the Group Offset from the Acquisition Datetime.
> Waveform Originality	(003A,0004)	The value "ORIGINAL" is used in this scenario.

Z.2.1.1.4 Examples

In the two following examples, the Image Modality acquires a multi-frame image of the coronary arteries lasting 4 seconds, at 30 frames per second.

Simultaneously, the same modality acquires two channels of ECG from a 2-Lead ECG (the first channel on Lead I and the second on Lead II) starting one second before the image acquisition starts, and lasting 5 seconds, with a sampling frequency of 300 Hz on 16 bits signed encoding, making up a number of 1500 samples per channel. The first ECG sample is 10 ms after the nominal start time of the ECG acquisition. Both ECG channels are sampled simultaneously. The time skew of both channels is 0 ms.

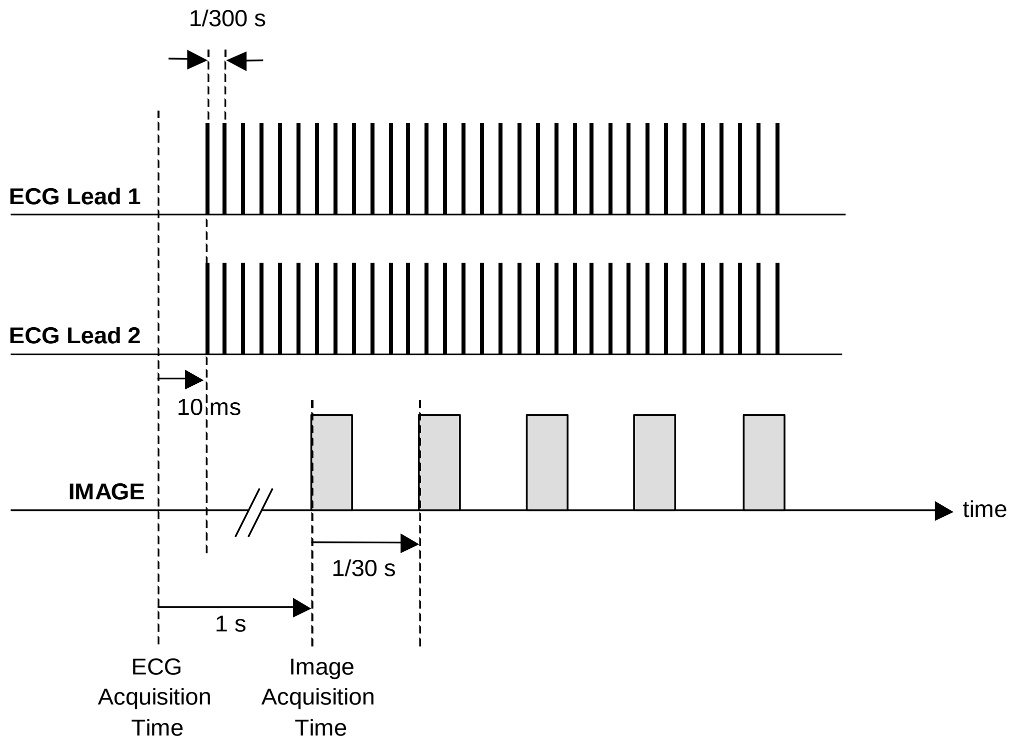


Figure Z.2.1-2
Example of ECG Recording at Acquisition Modality

Z.2.1.1.4.1 Enhanced XA image without cardiac synchronization

In this example, the Enhanced XA image does not contain information of the cardiac cycle phases.

The attributes that define the two different SOP Instances (Enhanced XA and General ECG) of this example are described in the following figures:

ENHANCED XA SOP INSTANCE

Study Instance UID	(0020,000D)	=	*UID "A"*
…			
Series Instance UID	(0020,000E)	=	*UID "B"*
Modality	(0008,0060)	=	**XA**
…			
Synchronization Frame of Reference UID	(0020,0200)	=	*UID "C"*
Synchronization Trigger	(0018,106A)	=	**NO TRIGGER**
Acquisition Time Synchronized	(0018,1800)	=	**Y**
…			
SOP Instance UID	(0008,0018)	=	*UID "D"*
Referenced Instance Sequence	(0008,114A)		
Item 1			
>Referenced SOP Class UID	(0008,1150)	=	**1.2.840.10008.5.1.4.1.1.9.1.2**

>Referenced SOP Instance UID	(0008,1155)	=	*UID "E"*
>Purpose of Reference Code Sequence	(0040,A170)		
Item 1			
>>Code Value	(0008,0100)	=	**121303**
>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>Code meaning	(0008,0104)	=	**Simultaneous ECG**

GENERAL ECG SOP INSTANCE

Study Instance UID	(0020,000D)	=	*UID "A"*

…

Series Instance UID	(0020,000E)	=	*UID "F"*
Modality	(0008,0060)	=	**ECG**

…

Synchronization Frame of Reference UID	(0020,0200)	=	*UID "C"*
Synchronization Trigger	(0018,106A)	=	**NO TRIGGER**
Acquisition Time Synchronized	(0018,1800)	=	**Y**

…

SOP Instance UID	(0008,0018)	=	*UID "E"*
Referenced Instance Sequence	(0008,114A)		
Item 1			
>Referenced SOP Class UID	(0008,1150)	=	**1.2.840.10008.5.1.4.1.1.12.1.1**
>Referenced SOP Instance UID	(0008,1155)	=	*UID "D"*
>Purpose of Reference Code Sequence	(0040,A170)		
Item 1			
>>Code Value	(0008,0100)	=	**121316**
>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>Code meaning	(0008,0104)	=	**Image related to standalone object**

…

Waveform Sequence	(5400,0100)		
Item 1			<u>*Only one ECG Multiplex Group*</u>
>Multiplex Group Time Offset	(0018,1068)	=	**10**
>Waveform Originality	(003A,0004)	=	**ORIGINAL**
>Number of Waveform Channels	(003A,0005)	=	**2**
>Number of Waveform Samples	(003A,0010)	=	**1500**
>Sampling Frequency	(003A,001A)	=	**300**
>Channel Definition Sequence	(003A,0200)		

Attribute	Tag		Value
Item 1			*First ECG Channel*
>>Waveform Channel Number	(003A,0202)	=	**1**
>>Channel Label	(003A,0203)	=	**ECG Recording 1**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**2:1**
>>>Coding Scheme Descr.	(0008,0102)	=	**MDC**
>>>Code Meaning	(0008,0104)	=	**Lead I**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
Item 2			
>>Waveform Channel Number	(003A,0202)	=	**2**
>>Channel Label	(003A,0203)	=	**ECG Recording 2**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**2:2**
>>>Coding Scheme Descr.	(0008,0102)	=	**MDC**
>>>Code Meaning	(0008,0104)	=	**Lead II**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
>Waveform Bits Allocated	(5400,1004)	=	**16**
>Waveform Sample Interpretation	(5400,1006)	=	**SS**

Figure Z.2.1-3
Attributes of ECG Recording at Acquisition Modality

Z.2.1.1.4.2 Enhanced XA image with cardiac synchronization

In this example, the heart rate is 75 beats per minute. As the image is acquired during a period of four seconds, it contains five heartbeats.

The ECG signal is analyzed to determine the R-peaks and to relate them to the angiographic frames. Thus the Enhanced XA image contains information of this relationship between the ECG signal and the frames.

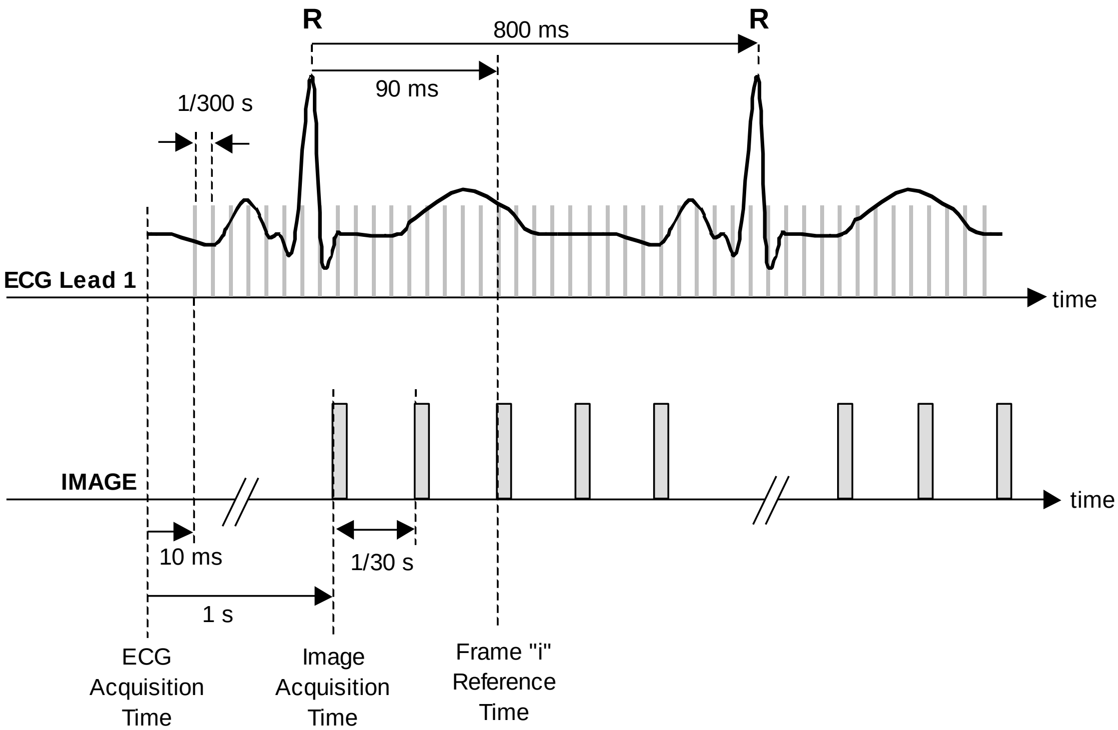


Figure Z.2.1-4
Example of ECG information in the Enhanced XA image

The attributes that define the two different SOP Instances (Enhanced XA and General ECG) of this example are described in the figures of the previous example, in addition to the attributes described in the following figures:

ENHANCED XA SOP INSTANCE

Cardiac Synchronization Technique	(0018,9037)	=	**REALTIME**
Cardiac Signal Source	(0018,9085)	=	**ECG**
Cardiac RR Interval Specified	(0018,9070)	=	**800**
Intervals Acquired	(0018,1083)	=	**5**
Intervals Rejected	(0018,1084)	=	**0**

…

Per-Frame Functional Groups Sequence	(5200,9230)		
…			
Item i			*Frame "i"*
>Cardiac Synchronization Sequence	(0018,9118)		
Item 1			
>>Nominal Cardiac Trigger Delay Time	(0020,9153)	=	**90.0**

Figure Z.2.1-5
Attributes of cardiac synchronization in ECG Recording at Acquisition Modality

Z.2.1.2 Multi-Modality Waveform Synchronization

These application cases are related to the results of an X-Ray acquisition and simultaneous ECG data recording on different equipment. The concepts of synchronized time and triggers are involved.

The two modalities may share references on the various entity levels below the Study, i.e. Series and Image UID references using non standard mechanisms. Nothing in the workflow requires such references. For more details about UID referencing, refer to the previous application case “ECG Recording at Acquisition Modality” (see Z.2.1.1).

If both modalities share a common data store, a dedicated post-processing station can be used for combined display of waveform and image information, and/or combined functional analysis of signals and pixel data to time relate the cardiac cycle phases to the angiographic frames. The storage of the waveform data and images to PACS or media will preserve the combined functional capabilities.

In these application cases, this post-processing activity is outside the scope of the acquisition modalities. For more details about the relationship between cardiac cycle and angiographic frames, refer to the previous application case “ECG Recording at Acquisition Modality” (see Z.2.1.1).

Z.2.1.2.1 Both Modalities synchronized via NTP

Z.2.1.2.1.1 User Scenario

Image runs are taken by the image acquisition modality. Waveforms are recorded by the waveform acquisition modality. Both modalities are time synchronized via NTP. The time server may be one of the modalities or an external server. The resulting objects will include the time synchronization concept.

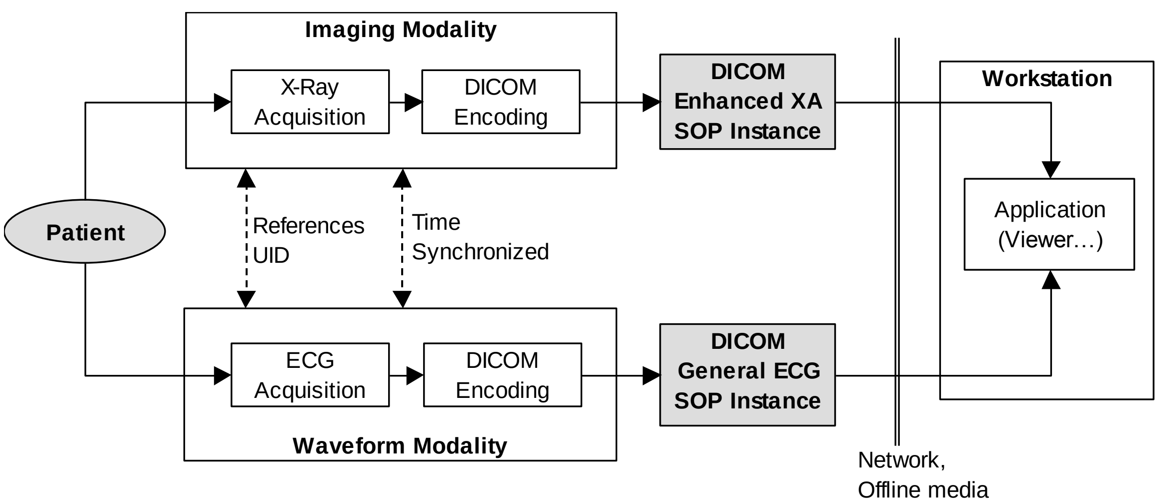


Figure Z.2.1-6
Scenario of Multi-modality Waveform Synchronization

Z.2.1.2.1.2 Encoding outline

Dedicated Waveform IODs exist to store captured waveforms. In this case, General ECG IOD is used to store the waveform data.

Depending on the degree of coupling of the modalities involved, the usage of references on the various entity levels can vary. While there is a standard DICOM service to share Study Instance UID between modalities (i.e. Worklist), there are no standard DICOM services for sharing references below the Study level, so any UID reference to the Series and Image levels is shared in a proprietary manner.

With the Synchronization Module information, the method to implement the common time-base can be documented.

The Enhanced XA IOD provides a detailed "per frame" timing to encode timing information related to each frame.

Z.2.1.2.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Z.2.1.2.1.3.1 Enhanced XA Image

Table Z.2.1-12
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Frame of Reference	Synchronization	C.7.4.2	Specifies that the image acquisition is time synchronized with the ECG acquisition. Will have the same content as the General ECG SOP Instance.
Image	Enhanced XA/XRF Image	C.8.19.2	Specifies the date and time of the image acquisition.

Table Z.2.1-13
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame Content	C.7.6.16.2.2	Provides timing information to correlate each frame to any externally recorded waveform.

Z.2.1.2.1.3.1.1 Synchronization Module Recommendations

This Module is used to document the synchronization of the two modalities.

Table Z.2.1-14
SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Synchronization Frame of Reference UID	(0020,0200)	The UTC Synchronization UID "1.2.840.10008.15.1.1" is used in this case.
Synchronization Trigger	(0018,106A)	The value "NO TRIGGER" is used for the case of time synchronization via NTP.

Acquisition Time Synchronized	(0018,1800)	The value “Y” is used in this scenario.
Time Source	(0018,1801)	The same value as in the related General ECG SOP Instance is used in this scenario.
Time Distribution Protocol	(0018,1802)	The value “NTP” is used in this scenario.
NTP Source Address	(0018,1803)	The same value as in the related General ECG SOP Instance is used in this scenario.

Z.2.1.2.1.3.1.2 Enhanced XA/XRF Image Module Recommendations

This module includes the acquisition date and time of the image, which is in the same time basis as the acquisition date and time of the ECG in this scenario.

Z.2.1.2.1.3.1.3 Frame Content Macro Recommendations

In this scenario the timing information is important to correlate each frame to any externally recorded waveform.

Table Z.2.1-15
FRAME CONTENT MACRO Recommendations

Attribute Name	Tag	Comment
Frame Content Sequence	(0020,9111)	
>Frame Reference Datetime	(0018,9151)	Exact date and time taken from the synchronized clock.
>Frame Acquisition Datetime	(0018,9074)	Exact date and time taken from the synchronized clock.

Z.2.1.2.1.3.2 Waveform Object

The ECG recording system will take care of filling in the waveform-specific contents in the General ECG SOP Instance. This section will address only the specifics for attributes related to synchronization.

Table Z.2.1-16
Waveform IOD Modules

IE	Module	PS 3.3 Reference	Usage
Frame of Reference	Synchronization	C.7.4.2	Specifies that the ECG acquisition is time synchronized with the image acquisition. Will have the same content as the Enhanced XA SOP Instance. See section Z.2.1.2.1.3.1.1.
Waveform	Waveform Identification	C.10.8	Provides timing information to correlate the waveform data to any externally recorded image.

Z.2.1.2.1.3.2.1 Waveform Identification Recommendations

The usage of this module is recommended to relate the acquisition time of the waveform data to the related image(s).

Table Z.2.1-18
WAVEFORM IDENTIFICATION MODULE Recommendations

Attribute Name	Tag	Comment
Acquisition Datetime	(0008,002A)	Exact start of the waveform acquisition: taken from synchronized clock.

Z.2.1.2.1.4 Example

In this example, there are two modalities that are synchronized with an external clock via NTP. The Image Modality acquires three multi-frame images within the same Study and same Series. Simultaneously, the Waveform Modality acquires the ECG non-stop during the same period, leading to one single Waveform SOP Instance on a different Study.

In this example, there is no UID referencing capability between the two modalities.

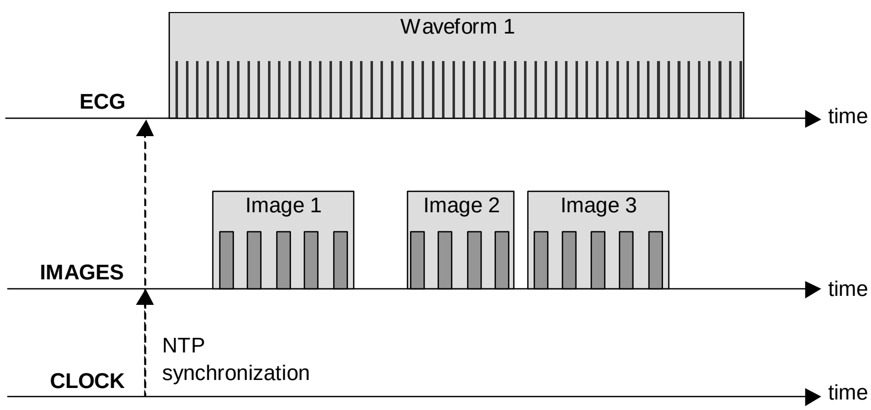


Figure Z.2.1-7
Example of Multi-modality Waveform Synchronization

The attributes that define the relevant content in the two different SOP Instances (Enhanced XA and General ECG) are described in the following figure:

ENHANCED XA SOP INSTANCES

Study Instance UID	(0020,000D)	=	*UID "A"*
…			
Series Instance UID	(0020,000E)	=	*UID "B"*
Modality	(0008,0060)	=	**XA**
…			
Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**NO TRIGGER**
Acquisition Time Synchronized	(0018,1800)	=	**Y**

Time Source	(0018,1801)	=	**Clock System ID**
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*

…

SOP Instance UID	(0008,0018)	=	*UID "D1", "D2" and "D3" resp.*

GENERAL ECG SOP INSTANCE

Study Instance UID	(0020,000D)	=	*UID "E"*

…

Series Instance UID	(0020,000E)	=	*UID "F"*
Modality	(0008,0060)	=	**ECG**

…

Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**NO TRIGGER**
Acquisition Time Synchronized	(0018,1800)	=	**Y**
Time Source	(0018,1801)	=	**Clock System ID**
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*

…

SOP Instance UID	(0008,0018)	=	*UID "H"*

Figure Z.2.1-8
Attributes of Multi-modality Waveform NTP Synchronization

Z.2.1.2.2 One Modality Sends Trigger to the other Modality

Z.2.1.2.2.1 User Scenario

Image runs are taken by the image acquisition modality. Waveforms are recorded by waveform recording modality. Both modalities are time synchronized via NTP. The acquisition in one modality is triggered by the other modality. The resulting objects will include the time synchronization and trigger synchronization concepts.

There are two cases depending on the triggering modality:

1- At X-Ray start, the image modality sends a trigger signal to the waveform modality.

2- The waveform modality sends trigger signals to the image modality to start the acquisition of each frame.

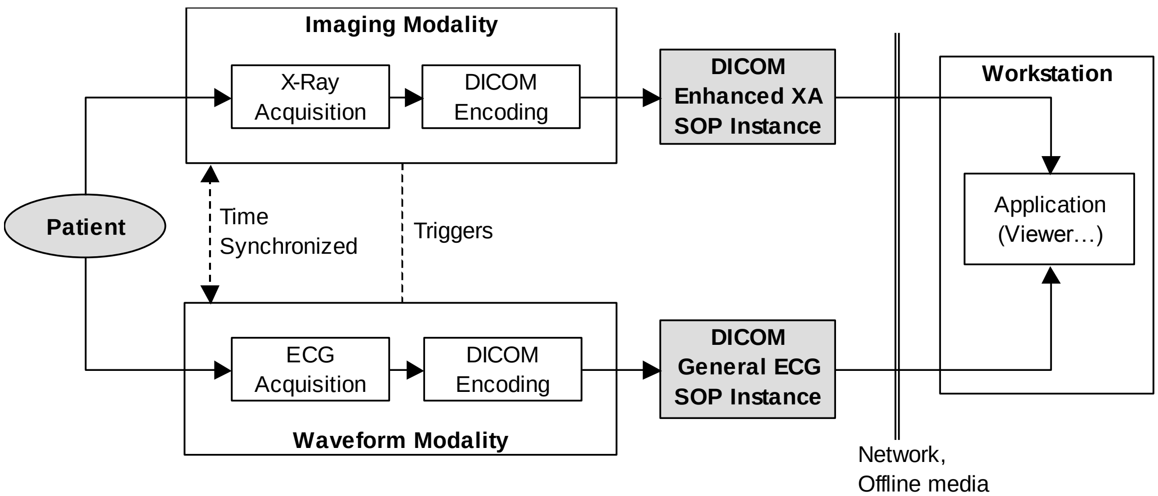


Figure Z.2.1-9
Scenario of Multi-modality Waveform Synchronization

Z.2.1.2.2.2 Encoding outline

Dedicated Waveform IODs exist to store captured waveforms. In this case, General ECG IOD is used to store the waveform data.

With the Synchronization Module information, the method to implement the triggers can be documented.

The Enhanced XA IOD provides per-frame encoding of the timing information related to each frame.

Z.2.1.2.2.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Z.2.1.2.2.3.1 Enhanced XA Image

Table Z.2.1-19
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Frame of Reference	Synchronization	C.7.4.2	Specifies that the image acquisition triggers (or is triggered by) the ECG acquisition, and that they are time synchronized.
Image	Enhanced XA/XRF Image	C.8.19.2	Specifies the date and time of the image acquisition. .

Table Z.2.1-20
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame Content	C.7.6.16.2.2	Provides timing information of each frame.

Z.2.1.2.2.3.1.1 Synchronization Module Recommendations

The usage of this Module is recommended to document the triggering role of the image modality.

Table Z.2.1-21
SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Synchronization Frame of Reference UID	(0020,0200)	The UTC Synchronization UID “1.2.840.10008.15.1.1” is used in this case.
Synchronization Trigger	(0018,106A)	The value “SOURCE” is used when the image modality sends a trigger signal to the waveform modality. The value “EXTERNAL” is used when the image modality receives a trigger signal from the waveform modality.
Trigger Source or Type	(0018,1061)	If Synchronization Trigger (0018,106A) equals SOURCE, then ID of image equipment. If Synchronization Trigger (0018,106A) equals EXTERNAL, then ID of waveform equipment if it is known.
Acquisition Time Synchronized	(0018,1800)	The value “Y” is used in this scenario.
Time Source	(0018,1801)	The same value as in the related General ECG SOP Instance is used in this scenario.
Time Distribution Protocol	(0018,1802)	The value “NTP” is used in this scenario.
NTP Source Address	(0018,1803)	The same value as in the related General ECG SOP Instance is used in this scenario.

Z.2.1.2.2.3.1.2 Enhanced XA/XRF Image Module Recommendations

This module includes the acquisition date and time of the image.

Table Z.2.1-22
ENHANCED XA/XRF IMAGE MODULE Recommendations

Attribute	Tag	Comment
Acquisition DateTime	(0008,002A)	Exact date and time taken from the synchronized clock.

Z.2.1.2.2.3.1.3 Frame Content Macro Recommendations

In this scenario the timing information does not allow relating each frame to any externally recorded waveform.

Table Z.2.1-23
FRAME CONTENT MACRO Recommendations

Attribute Name	Tag	Comment
Frame Content Sequence	(0020,9111)	
>Frame Reference Datetime	(0018,9151)	Exact date and time taken from the synchronized clock.
>Frame Acquisition Datetime	(0018,9074)	Exact date and time taken from the synchronized clock.

Z.2.1.2.2.3.2 Waveform Object

The recording system will take care of filling in the waveform-specific contents, based on the IOD relevant for the type of system (e.g., EP, Hemodynamic, etc.). This section will address only the specifics for attributes related to synchronization.

Table Z.2.1-24
Waveform IOD Modules

IE	Module	PS 3.3 Reference	Usage
Frame of Reference	Synchronization	C.7.4.2	Specifies that the ECG acquisition triggers (or is triggered by) the image acquisition, and that they are time synchronized.
Waveform	Waveform Identification	C.10.8	Specifies the date and time of the ECG acquisition.
	Waveform	C.10.9	Specifies the time relationship between the trigger signal and the ECG samples.

Z.2.1.2.2.3.2.2 Synchronization Module Recommendations

The usage of this Module is recommended to document the triggering role of the waveform modality.

Table Z.2.1-25
SYNCHRONIZATION MODULE Recommendations

Attribute Name	Tag	Comment
Synchronization Frame of Reference UID	(0020,0200)	The UTC Synchronization UID “1.2.840.10008.15.1.1” is used in this case.
Synchronization Trigger	(0018,106A)	The value “EXTERNAL” is used when the waveform modality receives a trigger signal from the image modality. The value “SOURCE” is used when the waveform modality sends a trigger signal to the image modality.

Trigger Source or Type	(0018,1061)	If Synchronization Trigger (0018,106A) equals SOURCE, then ID of Waveform equipment. If Synchronization Trigger (0018,106A) equals EXTERNAL, then ID of image equipment if it is known.
Synchronization Channel	(0018,106C)	Number or ID of Synchronization channel recorded in this waveform.
Acquisition Time Synchronized	(0018,1800)	The value “Y” is used in this scenario.
Time Source	(0018,1801)	The same value as in the related image SOP Instance is used in this scenario.
Time Distribution Protocol	(0018,1802)	The value “NTP” is used in this scenario.
NTP Source Address	(0018,1803)	The same value as in the related image SOP Instance is used in this scenario.

Z.2.1.2.2.3.2.3 Waveform Identification Module Recommendations

This module includes the acquisition date and time of the waveform, which may be different than the acquisition date and time of the image in this scenario.

Table Z.2.1-26
WAVEFORM IDENTIFICATION MODULE Recommendations

Attribute Name	Tag	Comment
Acquisition Datetime	(0008,002A)	Exact date and time taken from the internal clock of the Waveform modality. It may be different from the acquisition datetime of the Enhanced XA SOP instance.

Z.2.1.2.2.3.2.4 Waveform Module Recommendations

The usage of this module is recommended to encode the time relationship between the trigger signal and the ECG samples.

Table Z.2.1-27
WAVEFORM MODULE Recommendations

Attribute Name	Tag	Comment
Waveform Sequence	(5400,0100)	Only one item is used in this application case, as all the ECG signals have the same sampling rate.
>Multiplex Group Time Offset	(0018,1068)	If needed, specify the Group Offset from the Acquisition Datetime.
>Waveform Originality	(003A,0004)	The value “ORIGINAL” is used in this scenario.
>Trigger Time Offset	(0018,1069)	In case the waveform recording started with a synchronization trigger from the image modality, this value allows specifying the time relationship between the trigger and the ECG samples.

>Trigger Sample Position	(0018,106E)	In case the waveform recording started with a synchronization trigger from the image modality, this value allows specifying the waveform sample corresponding to the trigger sent from the image modality.

Z.2.1.2.2.4 Examples

Z.2.1.2.2.4.1 Image modality sends trigger to the waveform modality

In this example, there are two modalities that are synchronized with an external clock via NTP. The Image Modality acquires three multi-frame images within the same Study and same Series. Simultaneously, the Waveform Modality acquires the ECG non-stop during the same period, leading to one single Waveform SOP Instance on a different Study. The ECG sampling frequency is 300 Hz on 16 bits signed encoding, making up a number of 1500 samples per channel. The first ECG sample is acquired at nominal start time of the ECG acquisition.

The image modality sends a trigger to the waveform modality at the start time of each of the three images. This signal is stored in one channel of the waveform modality, together with the ECG signal.

In this example, there is no UID referencing capability between the two modalities.

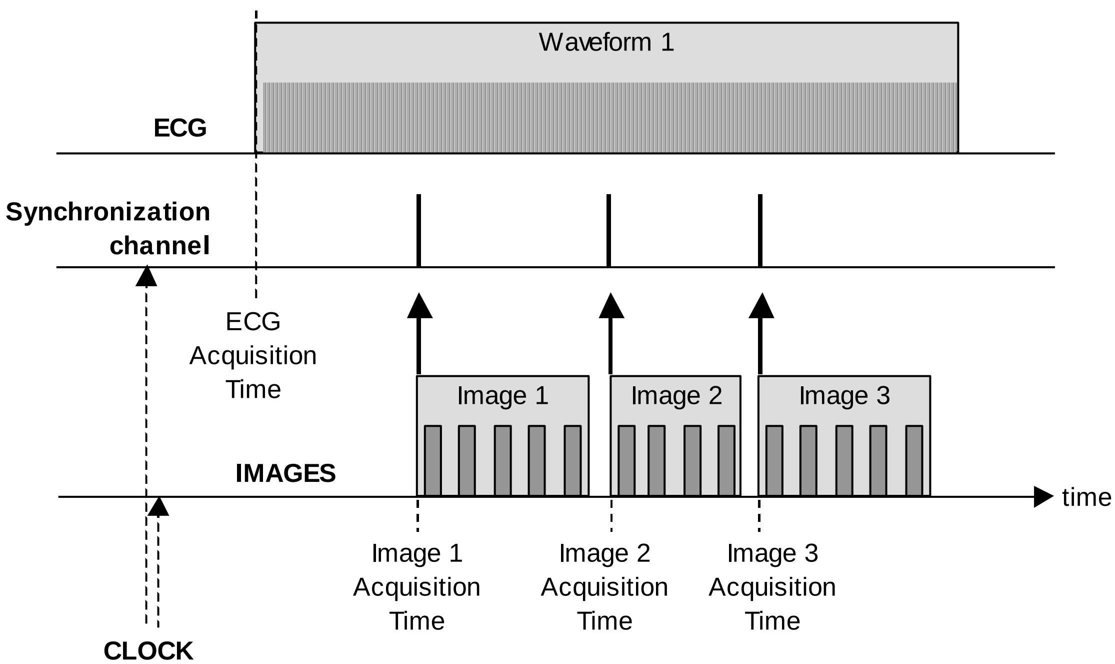


Figure Z.2.1-10
Example of Image Modality as Source of Trigger

The attributes that define the relevant content in the two different SOP Instances (Enhanced XA and General ECG) are described in the following figure:

ENHANCED XA SOP INSTANCES

Study Instance UID	(0020,000D)	=	*UID "A"*

…

Series Instance UID	(0020,000E)	=	*UID "B"*
Modality	(0008,0060)	=	**XA**

…

Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**SOURCE**
Trigger Source or Type	(0018,1061)	=	*Imaging System ID*
Acquisition Time Synchronized	(0018,1800)	=	**Y**
Time Source	(0018,1801)	=	*Clock System ID*
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*

…

SOP Instance UID	(0008,0018)	=	*UID "D1", "D2" and "D3" resp.*

GENERAL ECG SOP INSTANCE

Study Instance UID	(0020,000D)	=	*UID "E"*

…

Series Instance UID	(0020,000E)	=	*UID "F"*
Modality	(0008,0060)	=	**ECG**

…

Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**EXTERNAL**
Trigger Source or Type	(0018,1061)	=	*Imaging System ID*
Synchronization Channel	(0018,106C)	=	**1\2**
Acquisition Time Synchronized	(0018,1800)	=	**Y**
Time Source	(0018,1801)	=	*Clock System ID*
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*

…

SOP Instance UID	(0008,0018)	=	*UID "H"*

…

Waveform Sequence	(5400,0100)		
Item 1			*Only one ECG Multiplex Group*
>Multiplex Group Time Offset	(0018,1068)	=	**0**
>Waveform Originality	(003A,0004)	=	**ORIGINAL**
>Number of Waveform Channels	(003A,0005)	=	**2**
>Number of Waveform Samples	(003A,0010)	=	**1500**
>Sampling Frequency	(003A,001A)	=	**300**

Attribute	Tag		Value
>Channel Definition Sequence	(003A,0200)		
Item 1			*First ECG Channel*
>>Waveform Channel Number	(003A,0202)	=	**1**
>>Channel Label	(003A,0203)	=	**ECG Recording 1**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**2:1**
>>>Coding Scheme Descr.	(0008,0102)	=	**MDC**
>>>Code Meaning	(0008,0104)	=	**Lead I**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
Item 2			
>>Waveform Channel Number	(003A,0202)	=	**2**
>>Channel Label	(003A,0203)	=	**Synchronization**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**109005**
>>>Coding Scheme Descr.	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**X-ray On Trigger**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
>Waveform Bits Allocated	(5400,1004)	=	**16**
>Waveform Sample Interpretation	(5400,1006)	=	**SS**

Figure Z.2.1-11
Attributes when Image Modality is the Source of Trigger

Z.2.1.2.2.4.2 Waveform modality sends trigger to the image modality

In this example, there are two modalities that are synchronized with an external clock via NTP.

The Image Modality starts the X-Ray image acquisition and simultaneously the Waveform Modality acquires the ECG and analyzes the signal to determine the phases of the cardiac cycles. At each cycle, the waveform modality sends a trigger to the image modality to start the acquisition of a frame. This trigger is stored in one channel of the waveform modality, together with the ECG signal.

The ECG sampling frequency is 300 Hz on 16 bits signed encoding, making up a number of 1500 samples per channel. The first ECG sample is acquired 10 ms after the nominal start time of the ECG acquisition.

In this example, there is no UID referencing capability between the two modalities.

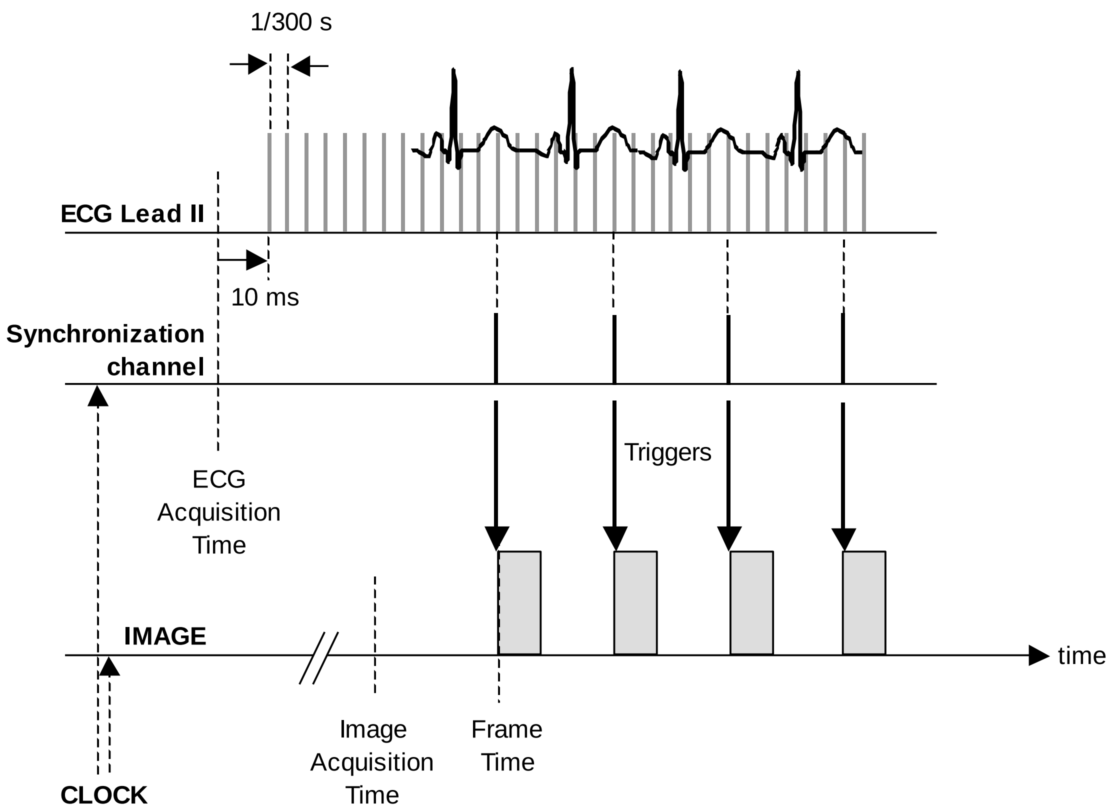


Figure Z.2.1-12
Example of Waveform Modality as Source of Trigger

The attributes that define the relevant content in the two different SOP Instances (Enhanced XA and General ECG) are described in the following figure:

ENHANCED XA SOP INSTANCES

Study Instance UID	(0020,000D)	=	*UID "A"*
…			
Series Instance UID	(0020,000E)	=	*UID "B"*
Modality	(0008,0060)	=	**XA**
…			
Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**EXTERNAL**
Trigger Source or Type	(0018,1061)	=	*ECG Equipment ID*
Acquisition Time Synchronized	(0018,1800)	=	**Y**
Time Source	(0018,1801)	=	*Clock System ID*
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*
…			

SOP Instance UID	(0008,0018)	=	*UID "D"*

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Study Instance UID	(0020,000D)	=	*UID "E"*
…			
Series Instance UID	(0020,000E)	=	*UID "F"*
Modality	(0008,0060)	=	**ECG**
…			
Synchronization Frame of Reference UID	(0020,0200)	=	**1.2.840.10008.15.1.1**
Synchronization Trigger	(0018,106A)	=	**SOURCE**
Trigger Source or Type	(0018,1061)	=	*ECG Equipment ID*
Synchronization Channel	(0018,106C)	=	**1\2**
Acquisition Time Synchronized	(0018,1800)	=	**Y**
Time Source	(0018,1801)	=	*Clock System ID*
Time Distribution Protocol	(0018,1802)	=	**NTP**
NTP Source Address	(0018,1803)	=	*aaa.bbb.ccc.ddd*
…			
SOP Instance UID	(0008,0018)	=	*UID "H"*
…			

Waveform Sequence	(5400,0100)		
Item 1			*Only one ECG Multiplex Group*
>Multiplex Group Time Offset	(0018,1068)	=	**10**
>Waveform Originality	(003A,0004)	=	**ORIGINAL**
>Number of Waveform Channels	(003A,0005)	=	**2**
>Number of Waveform Samples	(003A,0010)	=	**1500**
>Sampling Frequency	(003A,001A)	=	**300**
>Channel Definition Sequence	(003A,0200)		
Item 1			*First ECG Channel*
>>Waveform Channel Number	(003A,0202)	=	**1**
>>Channel Label	(003A,0203)	=	**ECG Recording 1**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**2:2**
>>>Coding Scheme Descr.	(0008,0102)	=	**MDC**
>>>Code Meaning	(0008,0104)	=	**Lead II**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
Item 2			
>>Waveform Channel Number	(003A,0202)	=	**2**

>>Channel Label	(003A,0203)	=	**Synchronization**
>>Channel Source Sequence	(003A,0208)		
Item 1			
>>>Code Value	(0008,0100)	=	**109002**
>>>Coding Scheme Descr.	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**ECG-based gating signal, processed**
>>Channel Time Skew	(003A,0214)	=	**0.0**
>>Waveform Bits Stored	(003A,021A)	=	**16**
>Waveform Bits Allocated	(5400,1004)	=	**16**
>Waveform Sample Interpretation	(5400,1006)	=	**SS**

994 **Figure Z.2.1-13**
Attributes when Waveform Modality is the Source of Trigger

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Z.2.1.3 Mechanical Movement

Z.2.1.3.1 Rotational Acquisition

This section provides information on the encoding of the movement of the X-Ray Positioner during the acquisition of a rotational angiography.

The related image presentation parameters of the rotational acquisition that are defined in the Enhanced XA SOP Class, such as the mask information of subtracted display, are described in further sections of this annex.

Z.2.1.3.1.1 User Scenario

The multi-frame image acquisition is performed during a continuous rotation of the X-Ray Positioner, starting from the initial incidence and acquiring frames in a given angular direction at variable angular steps and variable time intervals.

Typically such rotational acquisition is performed with the purpose of further 3D reconstruction. The rotation axis is not necessarily the patient head-feet direction, which may lead to images where the patient is not heads-up oriented.

There may be one or more rotations of the X-Ray Positioner during the same image acquisition, performed by following different patterns, such as:

1. One rotation for non-subtracted angiography;
2. Two rotations in the same or in opposite angular directions, for subtracted angiography;
3. Several rotations at different time intervals for cardiac triggered acquisitions.

Z.2.1.3.1.2 Encoding outline

The XA SOP Class encodes the absolute positioner angles as the sum of the angle of the first frame and the increments relative to the first frame. The Enhanced XA SOP Class encodes per-frame absolute angles.

In the XA SOP Class, the encoding of the angles is always with respect to the patient, so-called anatomical angles, and the image is assumed to be patient-oriented (i.e. heads-up display). In case of positioner rotation around an axis oblique to the patient, not aligned with the head-feet axis, it is not possible to encode the rotation of the image necessary for 3D reconstruction.

The Enhanced XA SOP Class encodes the positioner angles with respect to the patient as well as with respect to a fixed coordinate system of the equipment.

Z.2.1.3.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-28
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Acquisition	C.8.19.3	Specifies the type of positioner.

Table Z.2.1-29
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
X-Ray Positioner	C.8.19.6.10	Specifies the anatomical angles per-frame.
X-Ray Isocenter Reference System	C.8.19.6.13	Specifies the angles of the positioner per-frame in equipment coordinates for further applications based on the acquisition geometry (e.g., 3D reconstruction, registration…).

Z.2.1.3.1.3.1 XA/XRF Acquisition Module Recommendations

The usage of this module is recommended to define the type of positioner.

Table Z.2.1-30
XA/XRF ACQUISITION MODULE Example

Attribute Name	Tag	Comment
Positioner Type	(0018,1508)	The value CARM is used in this scenario.
C-arm Positioner Tabletop Relationship	(0018,9474)	Both values YES and NO are applicable to this scenario. Note: On mobile systems where this attribute equals NO, it is possible to do rotation and 3D reconstruction. In such case, the table is assumed to be static during the acquisition.

Z.2.1.3.1.3.2 X-Ray Positioner Macro Recommendations

This macro is used in the per-frame context in this scenario.

Table Z.2.1-31
X-RAY POSITIONER MACRO Example

Attribute Name	Tag	Comment
Positioner Position Sequence	(0018,9405)	
>Positioner Primary Angle	(0018,1510)	Angle with respect to the patient coordinate system.
>Positioner Secondary Angle	(0018,1511)	Angle with respect to the patient coordinate system.

Z.2.1.3.1.3.3 X-Ray Isocenter Reference System Macro Recommendations

If the value of the C-arm Positioner Tabletop Relationship (0018,9474) is NO, the following macro may not be provided by the acquisition modality. This macro is used in the per-frame context in this scenario.

Table Z.2.1-32
X-RAY ISOCENTER REFERENCE SYSTEM MACRO Example

Attribute Name	Tag	Comment
Isocenter Reference System Sequence	(0018,9462)	

>Positioner Isocenter Primary Angle	(0018,9463)	Angle with respect to the Isocenter coordinate system, independent of table angulations and how the patient is positioned on the table.
>Positioner Isocenter Secondary Angle	(0018,9464)	Angle with respect to the Isocenter coordinate system, independent of table angulations and how the patient is positioned on the table.
>Positioner Isocenter Detector Rotation Angle	(0018,9465)	Angle with respect to the Isocenter coordinate system, independent of table angulations and how the patient is positioned on the table.

Z.2.1.3.1.4 Example

In this example, the patient is on the table, in position “Head First Prone”. The table horizontal, tilt and rotation angles are equal to zero.

The positioner performs a rotation of 180 deg from the left to the right side of the patient, with the image detector going above the back of the patient, around an axis parallel to the head-feet axis of the patient.

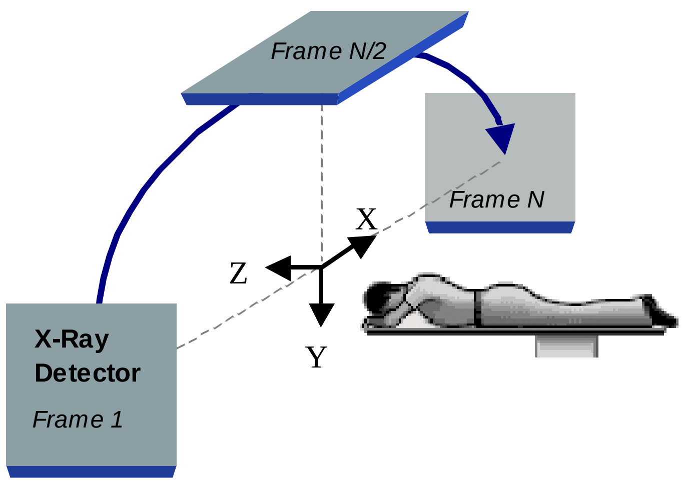

Figure Z.2.1-14
Detector Trajectory during Rotational Acquisition

Below are the encoded values of the key attributes of this example:

Positioner Type	(0018,1508)	= **CARM**
C-arm Positioner Tabletop Relationship	(0018,9474)	= **YES**

…

Per-Frame Functional Groups Sequence	(5200,9230)	
Item 1		*Frame 1*
>Positioner Position Sequence	(0018,9405)	
Item 1		
>>Positioner Primary Angle	(0018,1510)	= **90.0**

Attribute	Tag	Value	
>>Positioner Secondary Angle	(0018,1511)	= **0.0**	
>Isocenter Reference System Sequence	(0018,9462)		
Item 1			
>>Positioner Isocenter Primary Angle	(0018,9463)	= **-90.0**	
>>Positioner Isocenter Secondary Angle	(0018,9464)	= **0.0**	
>>Positioner Isocenter Detector Rotation Angle	(0018,9465)	= **0.0**	
…..			
Item "N/2"			*Frame "N/2"*
>Positioner Position Sequence	(0018,9405)		
Item 1			
>>Positioner Primary Angle	(0018,1510)	= **180.0**	
>>Positioner Secondary Angle	(0018,1511)	= **0.0**	
>Isocenter Reference System Sequence	(0018,9462)		
Item 1			
>>Positioner Isocenter Primary Angle	(0018,9463)	= **0.0**	
>>Positioner Isocenter Secondary Angle	(0018,9464)	= **0.0**	
>>Positioner Isocenter Detector Rotation Angle	(0018,9465)	= **0.0**	
…..			
Item "N"			*Frame "N"*
>Positioner Position Sequence	(0018,9405)		
Item 1			
>>Positioner Primary Angle	(0018,1510)	= **-90.0**	
>>Positioner Secondary Angle	(0018,1511)	= **0.0**	
>Isocenter Reference System Sequence	(0018,9462)		
Item 1			
>>Positioner Isocenter Primary Angle	(0018,9463)	= **90.0**	
>>Positioner Isocenter Secondary Angle	(0018,9464)	= **0.0**	
>>Positioner Isocenter Detector Rotation Angle	(0018,9465)	= **0.0**	

Figure Z.2.1-15
Attributes of X-Ray Positioning per-frame on Rotational Acquisition

Z.2.1.3.2 Peripheral/Stepping Acquisition

This section provides information on the encoding of the movement of the X-Ray Table during the acquisition of a stepping angiography.

The related image presentation parameters of the stepping acquisition that are defined in the Enhanced XA SOP Class, such as the mask information of subtracted display, are described in further sections of this annex.

Z.2.1.3.2.1 User Scenario

The multi-frame image acquisition is performed during a movement of the X-Ray Table, starting from the initial position and acquiring frames in a given direction along the Z axis of the table at variable steps and variable time intervals.

There may be one or more “stepping movements” of the X-Ray Table during the same image acquisition, leading to one or more instances of the Enhanced XA SOP Class. The stepping may be performed by different patterns, such as:

1. One stepping for non-subtracted angiography;
2. Two stepping acquisitions, one for each leg, for non-subtracted angiography, stored in two different multi-frame images;
3. Two or more stepping acquisitions for subtracted angiography, in the same or in opposite directions.

Z.2.1.3.2.2 Encoding outline

The XA SOP Class encodes table position as increments relative to the position of the first frame, while the position of the first frame is not encoded.

The Enhanced XA SOP Class encodes per-frame absolute table vertical, longitudinal and lateral position, as well as table horizontal rotation angle, table head tilt angle and table cradle tilt angle.

This allows registration between separate multi-frame images in the same table frame of reference, as well as accounting for magnification ratio and other aspects of geometry during registration. Issues of patient motion during acquisition of the images is not addressed in this scenario.

Z.2.1.3.2.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-33
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Acquisition	C.8.19.3	Specifies the relationship between the table and the positioner.

Table Z.2.1-34
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
X-Ray Table Position	C.8.19.6.11	Specifies the table position per-frame in three dimensions.
X-Ray Isocenter Reference System	C.8.19.6.13	Specifies the position and the angles of the table per-frame in equipment coordinates, for further applications based on the acquisition geometry (e.g., registration…).

Z.2.1.3.2.3.1 XA/XRF Acquisition Module Recommendations

The usage of this module is recommended to specify the relationship between the table and the positioner.

Table Z.2.1-35
XA/XRF ACQUISITION MODULE Example

Attribute Name	Tag	Comment
C-arm Positioner Tabletop Relationship	(0018,9474)	Both values YES and NO are applicable to this scenario. Note: On mobile systems where this attribute equals NO, it is possible to do table stepping. In such case, the system is not able to determine the absolute table position relative to the Isocenter, which is necessary for 2D-2D registration.

Z.2.1.3.2.3.2 X-Ray Table Position Macro Recommendations

This macro is used in the per-frame context in this scenario.

Table Z.2.1-36
X-RAY TABLE POSITION MACRO Example

Attribute Name	Tag	Comment
Table Position Sequence	(0018,9406)	
>Table Top Vertical Position	(300A,0128)	The same value for all frames.
>Table Top Longitudinal Position	(300A,0129)	The same value for all frames.
>Table Top Lateral Position	(300A,012A)	Different values per frame, corresponding to the “stepping” intervals in the table plane.
>Table Horizontal Rotation Angle	(0018,9469)	The same value for all frames.
>Table Head Tilt Angle	(0018,9470)	The same value for all frames.
>Table Cradle Tilt Angle	(0018,9471)	The same value for all frames.

Z.2.1.3.2.3.3 X-Ray Isocenter Reference System Macro Recommendations

If the value of the C-arm Positioner Tabletop Relationship (0018,9474) is NO, the following macro may not be provided by the acquisition modality. This macro is used in the per-frame context in this scenario.

Table Z.2.1-37
X-RAY ISOCENTER REFERENCE SYSTEM MACRO Example

Attribute Name	Tag	Comment
Isocenter Reference System Sequence	(0018,9462)	
>Table X Position to Isocenter	(0018,9466)	X-position of a fixed point in the table top, it changes per-frame if table horizontal rotation is not zero
>Table Y Position to Isocenter	(0018,9467)	Vertical position of a fixed point in the table top, it changes per-frame if table head tilt is not zero

>Table Z Position to Isocenter	(0018,9468)	Z-position of a fixed point in the table top, it changes per-frame
>Table Horizontal Rotation Angle	(0018,9469)	The same value for all frames.
>Table Head Tilt Angle	(0018,9470)	The same value for all frames.
>Table Cradle Tilt Angle	(0018,9471)	The same value for all frames.

Z.2.1.3.2.4 Example

In this example, the patient is on the table in position “Head First Supine”. The table is tilted of -10 degrees, with the head of the patient below the feet, and the image detector is parallel to the tabletop plane. The table cradle and rotation angles are equal to zero.

The image acquisition is performed during a movement of the X-Ray Table in the tabletop plane, at constant speed and of one meter of distance, acquiring frames from the abdomen to the feet of the patient in one stepping movement for non-subtracted angiography.

The table is related to the C-arm positioner so that the coordinates of the table position are known in the isocenter reference system. This allows determining the projection magnification of the table top plane with respect to the detector plane.

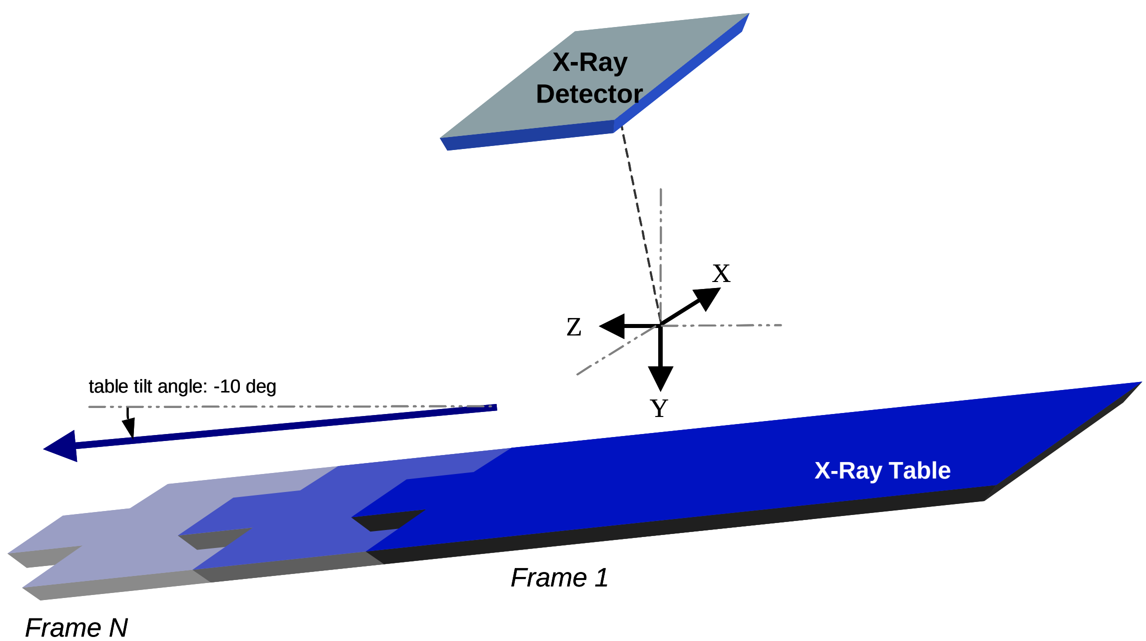

Figure Z.2.1-16
Table Trajectory during Table Stepping

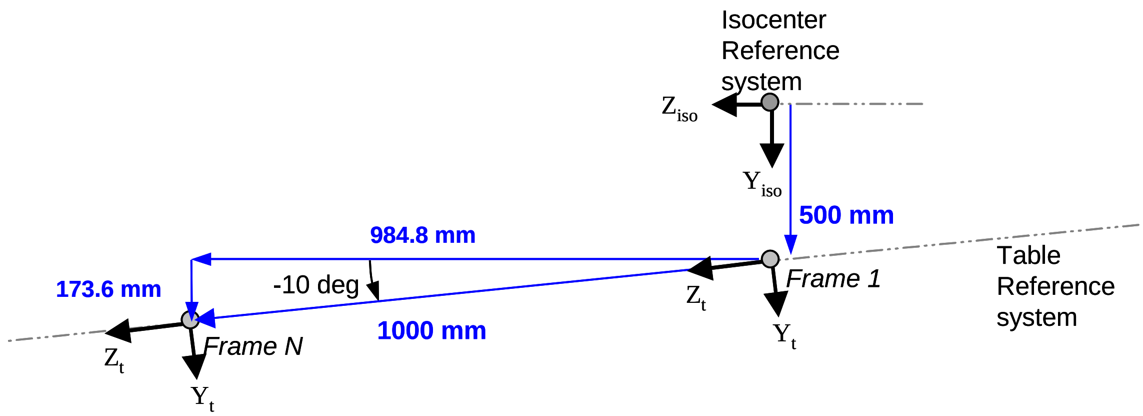

Figure Z.2.1-17
Example of table positions per-frame during table stepping

Below are the encoded values of the key attributes of this example:

Positioner Type	(0018,1508)	= **CARM**	
C-arm Positioner Tabletop Relationship	(0018,9474)	= **YES**	

…

Per-Frame Functional Groups Sequence	(5200,9230)		
Item 1			*Frame 1*
>Table Position Sequence	(0018,9406)		
Item 1			
>>Table Top Vertical Position	(300A,0128)	= **0.0**	
>>Table Top Longitudinal Position	(300A,0129)	= **0.0**	
>>Table Top Lateral Position	(300A,012A)	= **0.0**	
>>Table Horizontal Rotation Angle	(0018,9469)	= **0.0**	
>>Table Head Tilt Angle	(0018,9470)	= **-10.0**	
>>Table Cradle Tilt Angle	(0018,9471)	= **0.0**	
>Isocenter Reference System Sequence	(0018,9462)		
Item 1			
>>Table X Position to Isocenter	(0018,9466)	= **0.0**	
>>Table Y Position to Isocenter	(0018,9467)	= **500.0**	
>>Table Z Position to Isocenter	(0018,9468)	= **0.0**	
>>Table Horizontal Rotation Angle	(0018,9469)	= **0.0**	
>>Table Head Tilt Angle	(0018,9470)	= **-10.0**	
>>Table Cradle Tilt Angle	(0018,9471)	= **0.0**	
…..			
Item "N"			*Frame "N"*
>Table Position Sequence	(0018,9406)		
Item 1			

Attribute	Tag	Value
>>Table Top Vertical Position	(300A,0128)	= **0.0**
>>Table Top Longitudinal Position	(300A,0129)	= **0.0**
>>Table Top Lateral Position	(300A,012A)	= **1000.0**
>>Table Horizontal Rotation Angle	(0018,9469)	= **0.0**
>>Table Head Tilt Angle	(0018,9470)	= **-10.0**
>>Table Cradle Tilt Angle	(0018,9471)	= **0.0**
>Isocenter Reference System Sequence	(0018,9462)	
Item 1		
>>Table X Position to Isocenter	(0018,9466)	= **0.0**
>>Table Y Position to Isocenter	(0018,9467)	= **673.6**
>>Table Z Position to Isocenter	(0018,9468)	= **984.8**
>>Table Horizontal Rotation Angle	(0018,9469)	= **0.0**
>>Table Head Tilt Angle	(0018,9470)	= **-10.0**
>>Table Cradle Tilt Angle	(0018,9471)	= **0.0**

Figure Z.2.1-18
Attributes of the X-Ray Table per frame on Table Stepping

Z.2.1.4 Changes in X-Ray Controls

Z.2.1.4.1 Exposure Regulation Control

This section provides information on the encoding of the “sensitive areas” used for regulation control of the X-Ray generation of an image that resulted from applying these X-Rays.

Z.2.1.4.1.1 User Scenario

The user a) takes previous selected regulation settings or b) manually enters regulation settings or c) automatically gets computer-calculated regulation settings from requested procedures.

Acquired images are networked or stored in offline media.

Later problems of image quality are determined and user wants to check for reasons by assessing the positions of the sensing regions.

Z.2.1.4.1.2 Encoding outline

The Enhanced XA IOD includes a module to supply information about active regulation control sensing fields, their shape and position relative to the pixel matrix.

Z.2.1.4.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-38
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
X-Ray Exposure Control Sensing Regions	C.8.19.6.3	Specifies the shape and size of the sensing regions in pixels, as well as their position relative to the top left pixel of the image.

Z.2.1.4.1.3.1 X-Ray Exposure Control Sensing Regions Macro Recommendations

This macro is recommended to encode details about sensing regions.

If the position of the sensing regions is fixed during the multi-frame acquisition, the usage of this macro is shared.

If the position of the sensing regions was changed during the multi-frame acquisition, this macro is encoded per-frame to reflect the individual positions.

The same number of regions is typically used for all the frames of the image. However it is technically possible to activate or deactivate some of the regions during a given range of frames, in which case this macro is encoded per-frame.

Table Z.2.1-39
X-RAY EXPOSURE CONTROL SENSING REGIONS MACRO Recommendations

Attribute Name	Tag	Comment
Exposure Control Sensing Regions Sequence	(0018,9434)	As many items as number of regions.

Z.2.1.4.1.4 Example

In this section, two examples are given.

The first example shows how three sensing regions are encoded: 1) central (circular), 2) left (rectangular) and 3) right (rectangular).

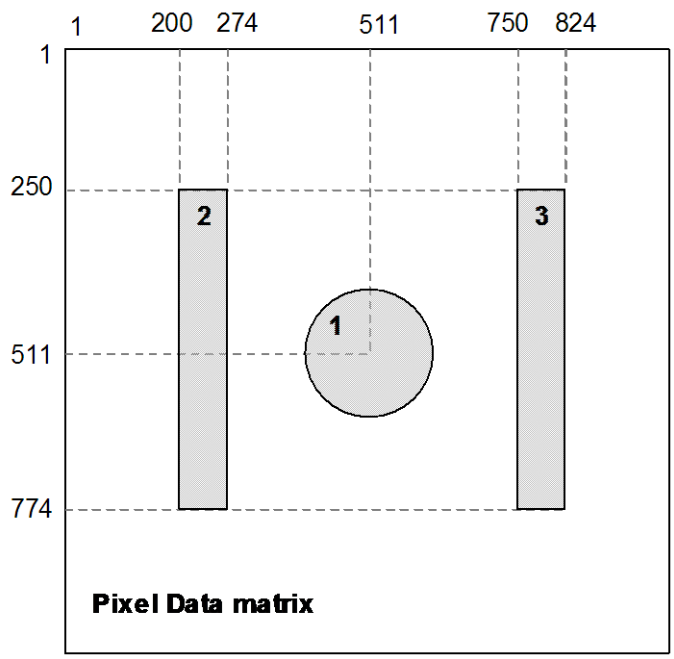

Figure Z.2.1-19
Example of X-Ray Exposure Control Sensing Regions inside the Pixel Data matrix

Below are the encoded values of the key attributes of this example:

…

Attribute	Tag		Value	Note
Shared Functional Group Sequence	(5200,9229)			
Item 1				*All frames*
…				*Other functional groups*
>Exposure Control Sensing Regions Sequence	(0018,9434)			
Item 1				*Region 1*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**CIRCULAR**	
>>Center of Circular Exposure Control Sensing Region	(0018,9440)	=	**511\511**	
>>Radius of Circular Exposure Control Sensing Region	(0018,9441)	=	**100**	
Item 2				*Region 2*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**RECTANGULAR**	
>>Exposure Control Sensing Region Left Vertical Edge	(0018,9436)	=	**200**	
>>Exposure Control Sensing Region Right Vertical Edge	(0018,9437)	=	**274**	
>>Exposure Control Sensing Region Upper Horizontal Edge	(0018,9438)	=	**250**	
>>Exposure Control Sensing Region Lower Horizontal Edge	(0018,9439)	=	**774**	
Item 3				*Region 3*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**RECTANGULAR**	
>>Exposure Control Sensing Region Left Vertical Edge	(0018,9436)	=	**750**	
>>Exposure Control Sensing Region Right Vertical Edge	(0018,9437)	=	**824**	
>>Exposure Control Sensing Region Upper Horizontal Edge	(0018,9438)	=	**250**	
>>Exposure Control Sensing Region Lower Horizontal Edge	(0018,9439)	=	**774**	
…				

…

Figure Z.2.1-20
Attributes of first the example of the X-Ray Exposure Control Sensing Regions

The second example shows the same regions, but the field of view region encoded in the Pixel Data matrix has been shifted of 240 pixels right and 310 pixels down, thus the left rectangular sensing region is outside the Pixel Data matrix as well as both rectangular regions overlap the top row of the image matrix.

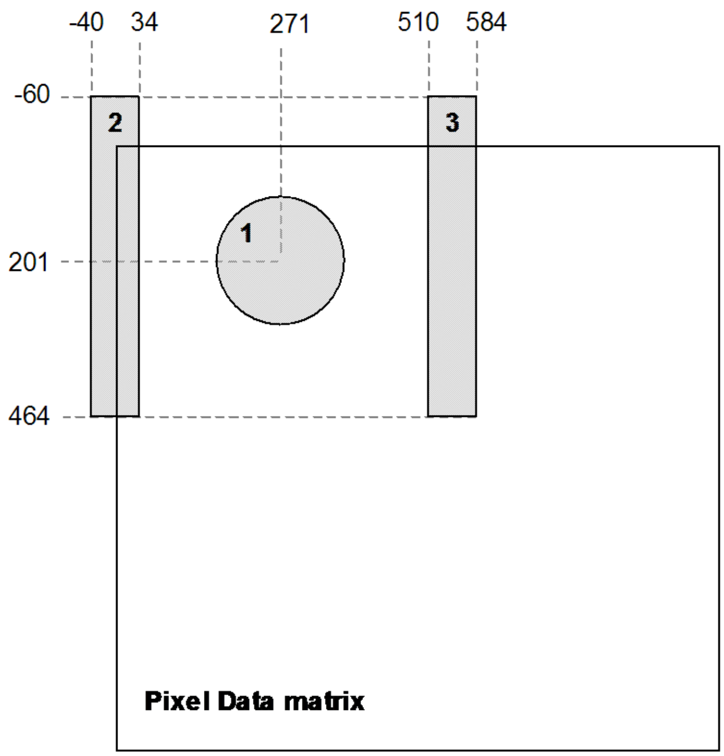

Figure Z.2.1-21
Example of X-Ray Exposure Control Sensing Regions partially outside the Pixel Data matrix

Below are the encoded values of the key attributes of this example:

…

Shared Functional Group Sequence	(5200,9229)		
Item 1			*All frames*
…			*Other functional groups*
>Exposure Control Sensing Regions Sequence	(0018,9434)		
Item 1			*Region 1*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**CIRCULAR**
>>Center of Circular Exposure Control Sensing Region	(0018,9440)	=	**201\271**
>>Radius of Circular Exposure Control Sensing Region	(0018,9441)	=	**100**
Item 2			*Region 2*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**RECTANGULAR**
>>Exposure Control Sensing Region Left Vertical Edge	(0018,9436)	=	**-40**
>>Exposure Control Sensing Region Right Vertical Edge	(0018,9437)	=	**34**

>>Exposure Control Sensing Region Upper Horizontal Edge	(0018,9438)	=	**-60**
>>Exposure Control Sensing Region Lower Horizontal Edge	(0018,9439)	=	**464**
Item 3			*Region 3*
>>Exposure Control Sensing Region Shape	(0018,9435)	=	**RECTANGULAR**
>>Exposure Control Sensing Region Left Vertical Edge	(0018,9436)	=	**510**
>>Exposure Control Sensing Region Right Vertical Edge	(0018,9437)	=	**584**
>>Exposure Control Sensing Region Upper Horizontal Edge	(0018,9438)	=	**-60**
>>Exposure Control Sensing Region Lower Horizontal Edge	(0018,9439)	=	**464**
…			

…

Figure Z.2.1-22
Attributes of the second example of the X-Ray Exposure Control Sensing Regions

Z.2.1.5 Image Detector and Field of View

This section provides information on the encoding of the image detector parameters and field of view applied during the X-Ray acquisition.

Z.2.1.5.1 User Scenario

The user selects a given size of the field of view before starting the acquisition. This size can be smaller than the size of the Image Detector.

The position of the field of view in the detector area changes during the acquisition in order to focus on an object of interest.

Acquired image is networked or stored in offline media, then the image is:

1. Displayed and reviewed in cine mode, and the field of view area needs to be displayed on the viewing screen;
2. Used for quality assurance, to relate the pixels of the stored image to the detector elements, for instance to understand the image artifacts due to detector defects;
3. Used to measure the dimension of organs or other objects of interest;
4. Used to determine the position in the 3D space of the projection of the objects of interest.

Z.2.1.5.2 Encoding outline

The XA SOP Class does not encode some information to fully characterize the geometry of the conic projection acquisition, such as the position of the Positioner Isocenter on the FOV area. Indeed, the XA SOP Class assumes that the isocenter is projected in the middle of the FOV.

The Enhanced XA SOP Class encodes the position of the Isocenter on the detector, as well as specific FOV attributes (origin, rotation, flip) per-frame or shared. It encodes some existing attributes from DX to specify information of the Digital Detector and FOV. It also allows differentiating the image intensifier vs. the digital detector and then defines conditions on attributes depending on image intensifier or digital detector.

Z.2.1.5.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-40
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Acquisition	C.8.19.3	Specifies the type of detector.
	X-Ray Image Intensifier	C.8.19.4	Conditional to type of detector. Applicable in case of IMG_INTENSIFIER.
	X-Ray Detector	C.8.19.5	Conditional to type of detector. Applicable in case of DIGITAL_DETECTOR.

Table Z.2.1-41
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
X-Ray Field of View	C.8.19.6.2	Specifies the field of view.
XA/XRF Frame Pixel Data Properties	C.8.19.6.4	Specifies the Imager Pixel Spacing.

Z.2.1.5.3.1 XA/XRF Acquisition Module Recommendations

The usage of this module is recommended to specify the type and details of the receptor.

Table Z.2.1-42
XA/XRF ACQUISITION MODULE Recommendations

Attribute Name	Tag	Comment
X-Ray Receptor Type	(0018,9420)	Two values are applicable to this scenario: IMG_INTENSIFIER or DIGITAL_DETECTOR
Distance Receptor Plane to Detector Housing	(0018,9426)	Applicable to this scenario, regardless the type of receptor.

Distance Receptor Plane to Detector Housing (0018,9426) is a positive value except in the case of an image intensifier where the receptor plane is a virtual plane located outside the detector housing, which depends on the magnification factor of the intensifier.

The Distance Receptor Plane to Detector Housing (0018,9426) may be used to calculate the pixel size of the plane in the patient when markers are placed on the detector housing.

Z.2.1.5.3.2 X-Ray Image Intensifier Module Recommendations

When the X-Ray Receptor Type (0018,9420) equals “IMG_INTENSIFIER” this module specifies the type and characteristics of the image intensifier.

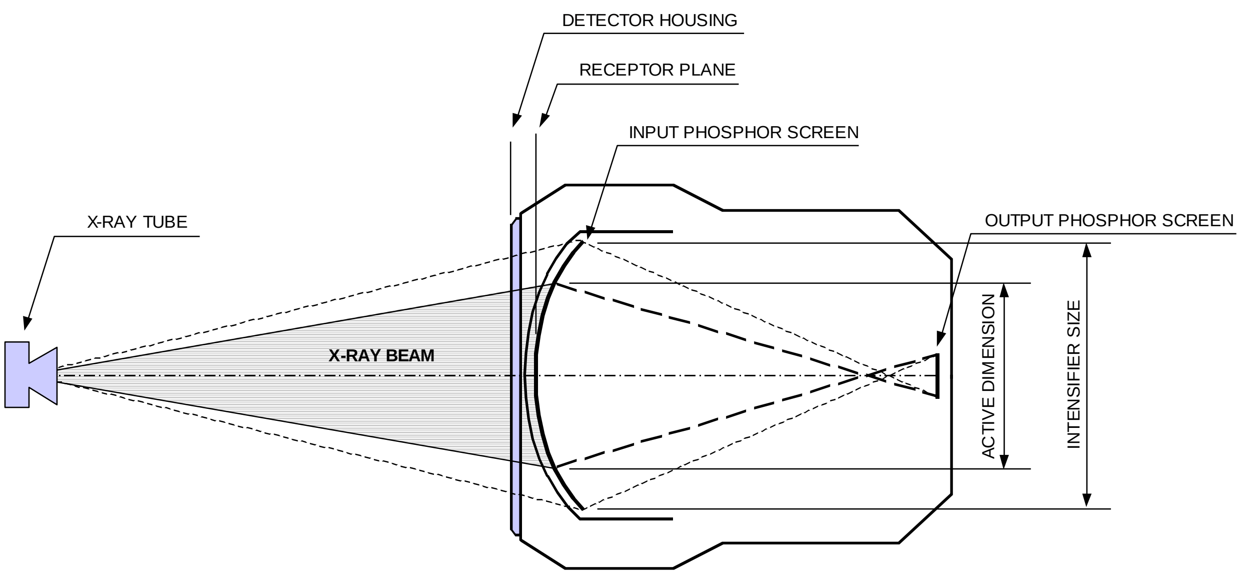

Figure Z.2.1-23
Schema of the Image Intensifier

The Intensifier Size (0018,1162) is defined as the physical diameter of the maximum active area of the image intensifier. The active area is the region of the input phosphor screen that is projected on the output phosphor screen. The image intensifier device may be configured for several predefined active areas to allow different levels of magnification.

The active area is described by the Intensifier Active Shape (0018,9427) and the Intensifier Active Dimension(s) (0018,9428).

The field of view area is a region equal to or smaller than the active area, and is defined as the region that is effectively irradiated by the X-Ray beam when there is no collimation. The stored image is the image resulting from digitizing the field of view area.

There is no attribute that relates the FOV origin to the intensifier. It is commonly assumed that the FOV area is centered in the intensifier.

The position of the projection of the isocenter on the active area is undefined. It is commonly understood that the X-Ray positioner is calibrated so that the isocenter is projected in the approximate center of the active area, and the field of view area is centered in the active area.

Z.2.1.5.3.3 X-Ray Detector Module Recommendations

When the X-Ray Receptor Type (0018,9420) equals "DIGITAL_DETECTOR" this module specifies the type and characteristics of the image detector.

The size and pixel spacing of the digital image generated at the output of the digital detector are not necessarily equal to the size and element spacing of the detector matrix. The detector binning is defined as the ratio between the pixel spacing of the detector matrix and the pixel spacing of the digital image.

If the detector binning is higher than 1.0 several elements of the detector matrix contribute to the generation of one single digital pixel.

The digital image may be processed, cropped and resized in order to generate the stored image. The schema below shows these two steps of the modification of the pixel spacing between the detector physical elements and the stored image:

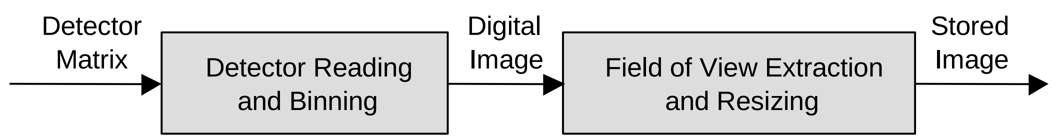

Figure Z.2.1-24
Generation of the Stored Image from the Detector Matrix

Table Z.2.1-43
X-RAY DETECTOR MODULE Recommendations

Attribute Name	Tag	Comment
Detector Binning	(0018,701A)	The ratio between the pixel spacing of the detector matrix and the pixel spacing of the digital image. It does not describe any further post-processing to resize the pixels to generate the stored image.
Detector Element Spacing	(0018,7022)	Pixel spacing of the detector matrix.
Position of Isocenter Projection	(0018,9430)	Relates the position of the detector elements to the isocenter reference system. It is independent from the detector binning and from the field of view origin. This attribute is defined if the Isocenter Reference System Sequence (0018,9462) is present.

Z.2.1.5.3.4 X-Ray Field of View Macro Recommendations

The usage of this macro is recommended to specify the characteristics of the field of view.

When the field of view characteristics change across the multi-frame image, this macro is encoded on a per-frame basis.

The field of view region is defined by a shape, origin and dimension. The region of irradiated pixels corresponds to the interior of the field of view region.

When the X-Ray Receptor Type (0018,9420) equals "IMG_INTENSIFIER", the intensifier TLHC is undefined. Therefore the field of view origin cannot be related to the physical area of the receptor. It is commonly understood that the field of view area corresponds to the intensifier active area, but there is no definition in the DICOM standard that forces a manufacturer to do so. As a consequence, it is impossible to relate the position of the pixels of the stored area to the isocenter reference system.

Table Z.2.1-44
X-RAY FIELD OF VIEW MACRO Recommendations

Attribute Name	Tag	Comment
Field of View Sequence	(0018,9432)	
>Field of View Shape	(0018,1147)	Applicable in this scenario.
>Field of View Dimension(s) in Float	(0018,9461)	Applicable in this scenario.
>Field of View Origin	(0018,7030)	Applicable only in the case of digital detector.
>Field of View Rotation	(0018,7032)	Applicable regardless the type of receptor.
>Field of View Horizontal Flip	(0018,7034)	Applicable regardless the type of receptor.
>Field of View Description	(0018,9433)	Free text defining the type of field of view as displayed by the manufacturer on the acquisition system. For display purposes.

Z.2.1.5.3.5 XA/XRF Frame Pixel Data Properties Macro Recommendations

The usage of this macro is recommended to specify the Imager Pixel Spacing.

When the field of view characteristics change across the multi-frame image, this macro is encoded on a per-frame basis.

Table Z.2.1-45
XA/XRF FRAME PIXEL DATA PROPERTIES MACRO Recommendations

Attribute Name	Tag	Comment
Frame Pixel Data Properties Sequence	(0028,9443)	
>Imager Pixel Spacing	(0018,1164)	Applicable regardless the type of receptor.

In case of image intensifier, the Imager Pixel Spacing (0018,1164) may be non-uniform due to the pincushion distortion, and this attribute corresponds to a manufacturer-defined value (e.g., average, or value at the center of the image).

Z.2.1.5.4 Examples

Z.2.1.5.4.1 Field of View on Image Intensifier

This example illustrates the encoding of the dimensions of the intensifier device, the intensifier active area and the field of view in case of image intensifier.

In this example, the diameter of the maximum active area is 410 mm. The image acquisition is performed with an electron lens that focuses the photoelectron beam inside the intensifier so that an active area of 310 mm of diameter is projected on the output phosphor screen.

The X-Ray beam is projected on an area of the input phosphor screen of 300 mm of diameter, and the corresponding area on the output phosphor screen is digitized on a matrix of 1024 x1024 pixels. This results on a pixel spacing of the digitized matrix of 0.3413 mm.

The distance from the Receptor Plane to the Detector Housing in the direction from the intensifier to the X-Ray tube is 40 mm.

Below are the encoded values of the key attributes of this example:

…

Rows	(0028,0010)	=	**1024**
Columns	(0028,0011)	=	**1024**
X-Ray Receptor Type	(0018,9420)	=	**IMG_INTENSIFIER**
Distance Receptor Plane to Detector Housing	(0018,9426)	=	**40.0**
Intensifier Size	(0018,1162)	=	**410.0**
Intensifier Active Shape	(0018,9427)	=	**ROUND**
Intensifier Active Dimension(s)	(0018,9428)	=	**310.0**

…

Shared Functional Groups Sequence	(5200,9229)		
Item 1			
…			
>Field of View Sequence	(0018,9432)		
Item 1			
>>Field of View Shape	(0018,1147)	=	**CIRCULAR**
>>Field of View Dimension(s) in Float	(0018,9461)	=	**300.0**
>>Field of View Rotation	(0018,7032)	=	**0**
>>Field of View Horizontal Flip	(0018,7034)	=	**NO**
>Frame Pixel Data Properties Sequence	(0028,9443)		
Item 1			
>>Imager Pixel Spacing	(0018,1164)	=	**0.3413\0.3413**
…			

Figure Z.2.1-25
Attributes of the example of Field of View on Image Intensifier

Z.2.1.5.4.2 Field of View on Digital Detector

The following examples show three different ways to create the stored image from the same detector matrix.

In the figures below:

- The blue dotted-line squares represent the physical detector pixels;
- The blue square represents the TLHC pixel of the physical detector area;
- The purple square represents the physical detector pixel in whose center the Isocenter is projected;

- The dark green square represents the TLHC pixel of the region of the physical detector that is exposed to X-Ray when there is no collimation inside the field of view;
- The light green square represents the TLHC pixel of the stored image;
- The thick black straightline square represents the stored image, which is assumed to be the field of view area. The small thin black straightline squares represent the pixels of the stored image;
- The blue dotted-line arrow represents Field Of View Origin (0018,7030);
- The purple arrow represents the position of the Isocenter Projection (0018,9430).

Note that the detector active dimension is not necessarily the FOV dimension.

In all the examples,

- The physical detector area is a matrix of 10x10 square detector elements, the TLHC element being the element (1,1);
- The detector elements irradiated during this acquisition (defining the field of view) are in a matrix of 8x8 whose TLHC element is the element (3,3) of the physical detector area.

In the first example, there is neither binning nor resizing between the detector matrix and the stored image.

Below are the encoded values of the key attributes of this example:

…

Rows	(0028,0010)	=	**8**
Columns	(0028,0011)	=	**8**
X-Ray Receptor Type	(0018,9420)	=	**DIGITAL_DETECTOR**
Detector Binning	(0018,701A)	=	**1.0\1.0**
Detector Element Spacing	(0018,7022)	=	**0.2\0.2**
Position of Isocenter Projection	(0018,9430)	=	**5\7**

…

Per-Frame Functional Groups Sequence	(5200,9230)		
…			
Item i			
>Field of View Sequence	(0018,9432)		
Item 1			
>>Field of View Shape	(0018,1147)	=	**RECTANGLE**
>>Field of View Dimension(s) in Float	(0018,9461)	=	**1.6\1.6**
>>Field of View Origin	(0018,7030)	=	**2.0\2.0**
>>Field of View Rotation	(0018,7032)	=	**0**
>>Field of View Horizontal Flip	(0018,7034)	=	**NO**
>Frame Pixel Data Properties Sequence	(0028,9443)		
Item 1			

>>Imager Pixel Spacing	(0018,1164)	= **0.2\0.2**
…		

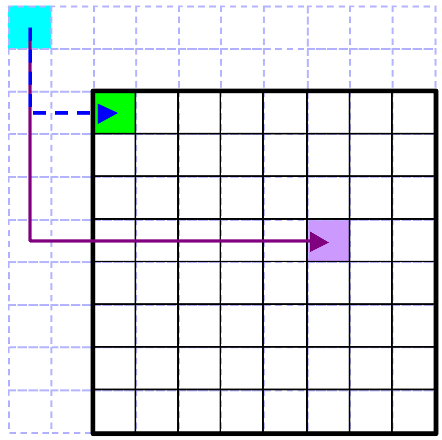

Figure Z.2.1-26
Attributes of the first example of Field of View on Digital Detector

In the second example, there is a binning factor of 2 between the detector matrix and the digital image. There is no resizing between the digital image (binned) and the stored image.

Below are the encoded values of the key attributes of this example:

…

Rows	(0028,0010)	= **4**
Columns	(0028,0011)	= **4**
X-Ray Receptor Type	(0018,9420)	= **DIGITAL_DETECTOR**
Detector Binning	(0018,701A)	= **2.0\2.0**
Detector Element Spacing	(0018,7022)	= **0.2\0.2**
Position of Isocenter Projection	(0018,9430)	= **5\7**

…

Per-Frame Functional Groups Sequence	(5200,9230)	
…		
Item i		
>Field of View Sequence	(0018,9432)	
Item 1		
>>Field of View Shape	(0018,1147)	= **RECTANGLE**
>>Field of View Dimension(s) in Float	(0018,9461)	= **1.6\1.6**
>>Field of View Origin	(0018,7030)	= **2.0\2.0**
>>Field of View Rotation	(0018,7032)	= **0**
>>Field of View Horizontal Flip	(0018,7034)	= **NO**

>Frame Pixel Data Properties Sequence	(0028,9443)	
Item 1		
>>Imager Pixel Spacing	(0018,1164)	= **0.4\0.4**
…		

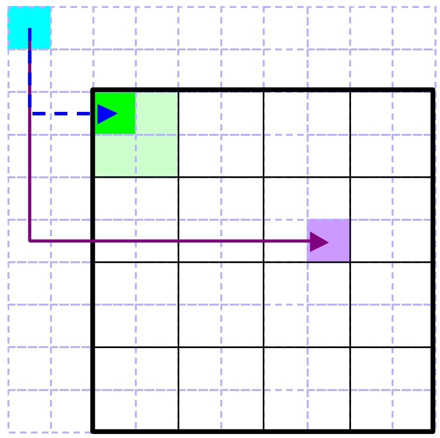

Figure Z.2.1-27
Attributes of the second example of Field of View on Digital Detector

In the third example, in addition to the binning factor of 2 between the detector matrix and the digital image, there is a resizing of 0.5 (downsizing) between the digital image (binned) and the stored image.

Below are the encoded values of the key attributes of this example:

…

Rows	(0028,0010)	= **2**
Columns	(0028,0011)	= **2**
X-Ray Receptor Type	(0018,9420)	= **DIGITAL_DETECTOR**
Detector Binning	(0018,701A)	= **2.0\2.0**
Detector Element Spacing	(0018,7022)	= **0.2\0.2**
Position of Isocenter Projection	(0018,9430)	= **5\7**

…

Per-Frame Functional Groups Sequence	(5200,9230)	
…		
Item i		
>Field of View Sequence	(0018,9432)	
Item 1		
>>Field of View Shape	(0018,1147)	= **RECTANGLE**
>>Field of View Dimension(s) in Float	(0018,9461)	= **1.6\1.6**
>>Field of View Origin	(0018,7030)	= **2.0\2.0**
>>Field of View Rotation	(0018,7032)	= **0**

>>Field of View Horizontal Flip	(0018,7034)	= **NO**
>Frame Pixel Data Properties Sequence	(0028,9443)	
Item 1		
>>Imager Pixel Spacing	(0018,1164)	= **0.8\0.8**
…		

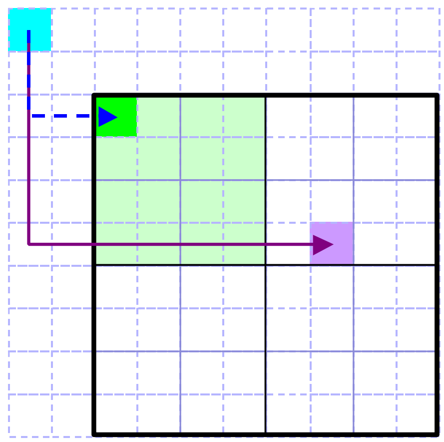

Figure Z.2.1-28
Attributes of the third example of Field of View on Digital Detector

Note that the description of the field of view attributes (dimension, origin) is the same in these three examples. The field of view definition is independent from the binning and resizing processes.

Z.2.1.6 Acquisitions with Contrast

This section provides information on the encoding of the presence and type of contrast bolus administered during the X-Ray acquisition.

Z.2.1.6.1 User Scenario

The user performs image acquisition with injection of contrast agent during the X-Ray acquisition. Some frames are acquired without contrast, some others with contrast.

The type of contrast agent can be radio-opaque (e.g., iodine) or radio-transparent (e.g., CO_2).

The information of the type of contrast and its presence or absence in the frames can be used by post-processing applications to set up e.g., vessel detection or image quality algorithms automatically.

Z.2.1.6.2 Encoding outline

The Enhanced XA SOP Class encodes the characteristics of the contrast agent(s) used during the acquisition of the image, including the type of absorption (radio-opaque or radio-transparent).

The Enhanced XA SOP Class also allows encoding the presence of contrast in a particular frame or set of frames, by encoding the Contrast/Bolus Usage per-frame.

Z.2.1.6.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-46
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Enhanced Contrast/Bolus	C.7.6.4b	Specifies the characteristics of the contrast agent(s) administered.

Table Z.2.1-47
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Contrast/Bolus Usage	C.7.6.16.2.12	Specifies the presence of contrast in the frame(s).

Z.2.1.6.3.1 Enhanced Contrast/Bolus Module Recommendations

The usage of this module is recommended to specify the type and characteristics of the contrast agent administered.

Z.2.1.6.3.2 Contrast/Bolus Usage Macro Recommendations

The usage of this macro is recommended to specify the characteristics of the contrast per-frame.

Table Z.2.1-48
CONTRAST/BOLUS USAGE MACRO Recommendations

Attribute Name	Tag	Comment
Contrast/Bolus Usage Sequence	(0018,9341)	One item per contrast agent used in this frame.
>Contrast/Bolus Agent Number	(0018,9337)	Contains the internal number of the agent administered as specified in the Enhanced Contrast/Bolus Module.
>Contrast/Bolus Agent Administered	(0018,9342)	The value “YES” indicates that the contrast may be visible on the frame, but not necessarily if the frame is acquired before the contrast reaches the imaged region.
>Contrast/Bolus Agent Detected	(0018,9343)	The value “YES” is used if the contrast is visible on that particular frame. Note that it is not expected to be YES if Contrast/Bolus Agent Administered (0018,9342) equals NO.

Z.2.1.6.4 Example

In this example, the user starts the X-Ray acquisition at 4 frames per second at 3:35pm. After one second the user starts the injection of 45 milliliters of contrast media Iodipamide (350 mg/ml Cholographin (Bracco)) at a flow rate of 15 ml/sec during three seconds, in intra-arterial route. When the injection of contrast agent is finished, the user continues the X-Ray acquisition for two seconds until wash out of the contrast agent.

There could be two ways to determine the presence of contrast agent on the frames:

1) The injector is connected to the X-Ray acquisition system, the presence of contrast agent is determined based on the injector start/stop signals and a preconfigured delay to allow the contrast to reach the artery of interest, or

2) The X-Ray system processes the images in real time and detects the presence or absence of contrast agent on the images.

In this example, the image acquired contains 25 frames: From frames 5 to 17, the contrast is being injected. From frames 8 to 23, the contrast is visible on the pixel data.

The figure below shows the attributes of this example in a graphical representation of the multi-frame acquisition.

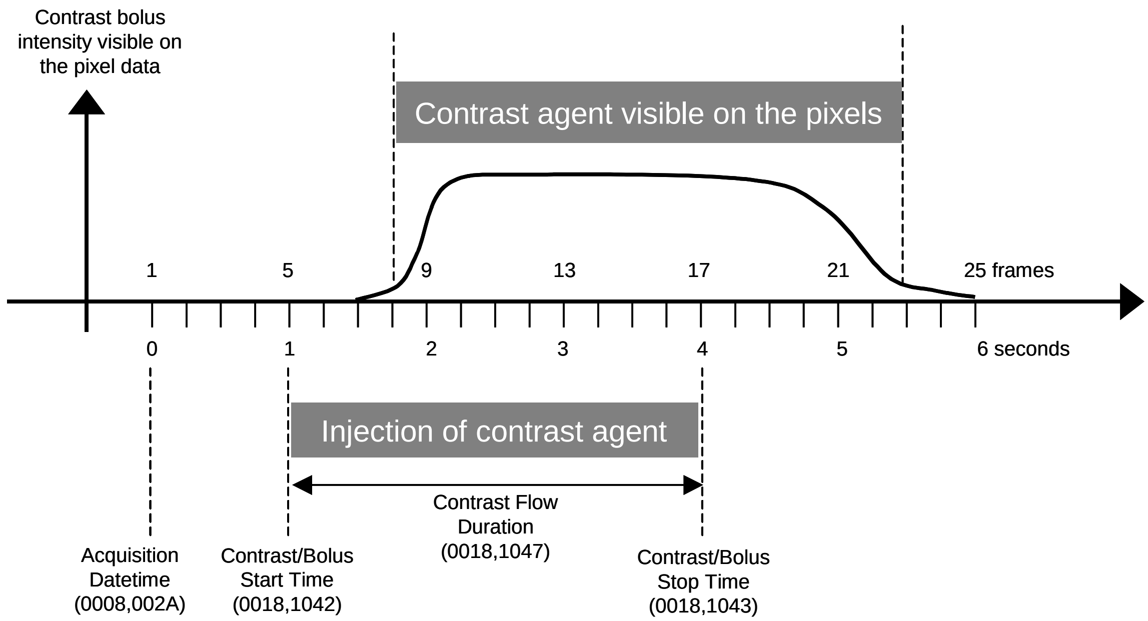

Figure Z.2.1-29
Example of contrast agent injection

Below are the encoded values of the key attributes of this example:

Contrast/Bolus Agent Sequence	(0018,0012)	
Item 1		*Contrast agent 1*
>Code Value	(0008,0100)	= **C-B0318**
>Coding Scheme Designator	(0008,0102)	= **SRT**
>Code Meaning	(0008,0104)	= **Iodipamide**
>Contrast/Bolus Agent Number	(0018,9337)	= **1**
>Contrast/Bolus Administration Route Sequence	(0018,0014)	
Item 1		
>>Code Value	(0008,0100)	= **G-D102**
>>Coding Scheme Designator	(0008,0102)	= **SRT**

Attribute	Tag	Value
>>Code Meaning	(0008,0104)	= **Intra-arterial route**
>Contrast/Bolus Ingredient Code Sequence	(0018,9338)	
Item 1		
>>Code Value	(0008,0100)	= **C-11400**
>>Coding Scheme Designator	(0008,0102)	= **SRT**
>>Code Meaning	(0008,0104)	= **Iodine**
>Contrast/Bolus Volume	(0018,1041)	= **45**
>Contrast/Bolus Ingredient Concentration	(0018,1049)	= **350**
>Contrast/Bolus Ingredient Opaque	(0018,9425)	= **YES**
>Contrast Administration Profile Sequence	(0018,9340)	
Item 1		*Administered phase 1*
>>Contrast/Bolus Volume	(0018,1041)	= **45**
>>Contrast/Bolus Start Time	(0018,1042)	= **001536.0**
>>Contrast/Bolus Stop Time	(0018,1043)	= **001539.0**
>>Contrast Flow Rate	(0018,1046)	= **15**
>>Contrast Flow Duration	(0018,1047)	= **3**

…

Attribute	Tag	Value
Per-Frame Functional Groups Sequence	(5200,9230)	
Items 1 to 4		*Frames 1 to 4*
>Contrast/Bolus Usage Sequence	(0018,9341)	
Item 1		
>>Contrast/Bolus Agent Number	(0018,9337)	= **1**
>>Contrast/Bolus Agent Administered	(0018,9342)	= **NO**
>>Contrast/Bolus Agent Detected	(0018,9343)	= **NO**
Items 5 to 7		*Frames 5 to 7*
>Contrast/Bolus Usage Sequence	(0018,9341)	
Item 1		
>>Contrast/Bolus Agent Number	(0018,9337)	= **1**
>>Contrast/Bolus Agent Administered	(0018,9342)	= **YES**
>>Contrast/Bolus Agent Detected	(0018,9343)	= **NO**
Items 8 to 23		*Frames 8 to 23*
>Contrast/Bolus Usage Sequence	(0018,9341)	
Item 1		
>>Contrast/Bolus Agent Number	(0018,9337)	= **1**
>>Contrast/Bolus Agent Administered	(0018,9342)	= **YES**
>>Contrast/Bolus Agent Detected	(0018,9343)	= **YES**
Items 24 to 25		*Frames 24 to 25*
>Contrast/Bolus Usage Sequence	(0018,9341)	

Item 1		
>>Contrast/Bolus Agent Number	(0018,9337)	= **1**
>>Contrast/Bolus Agent Administered	(0018,9342)	= **YES**
>>Contrast/Bolus Agent Detected	(0018,9343)	= **NO**

Figure Z.2.1-30
Attributes of contrast agent injection

Z.2.1.7 Acquisition Parameters for X-Ray Generation (kVp, mA…)

This section provides information on the encoding of the parameters related to the X-Ray generation.

Z.2.1.7.1 User Scenario

The user performs X-Ray acquisitions during the examination. Some of them are dynamic acquisitions where the positioner and/or the table have moved between frames of the multi-frame image, the acquisition parameters such as kVp, mA and pulse width may change per-frame to be adapted to the different anatomy characteristics.

Later quality assurance wants to assess the X-Ray generation techniques in order to understand possible degradation of image quality, or to estimate the level of irradiation at different skin areas and body parts examined.

Z.2.1.7.2 Encoding outline

The XA SOP Class encodes the attributes kVp, mA and pulse duration as a unique value for the whole multi-frame image. For systems that can provide only average values of these attributes, this SOP Class is more appropriate.

The Enhanced XA SOP Class encodes per-frame kVp, mA and pulse duration, thus the estimated dose per frame can be now correlated to the positioner angles and table position of each frame.

In order to accurately estimate the dose per body area, other attributes are needed such as positioner angles, table position, SID, ISO distances, Field of View, etc.

Z.2.1.7.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.1-49
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Acquisition	C.8.19.3	Specifies average values for the X-Ray generation techniques.

Table Z.2.1-50
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame Content	C.7.6.16.2.2	Specifies the frame duration.
X-Ray Frame Acquisition	C.8.19.6.8	Specifies the kVp and mA per frame.

Z.2.1.7.3.1 XA/XRF Acquisition Module Recommendations

The usage of this module is recommended to specify the average values of time, voltage and current applied during the acquisition of the multi-frame image.

It gives general information of the X-Ray radiation during the acquisition of the image. In case of dynamic acquisitions, this module is not sufficient to estimate the radiation per body area and additional per-frame information is needed.

Table Z.2.1-51
XA/XRF ACQUISITION MODULE Recommendations

Attribute Name	Tag	Comment
KVP	(0018,0060)	Recommended in this scenario.
Radiation Setting	(0018,1155)	The values “SC” and “GR” give a rough indication of the level of the dose such as “low” or “high”, nevertheless they are used more for quality assurance and/or display purposes, not for estimation of radiation values.
X-Ray Tube Current in mA	(0018,9330)	Recommended in this scenario.
Exposure Time in ms	(0018,9328)	Recommended in this scenario.
Exposure in mAs	(0018,9332)	Recommended in this scenario.
Average Pulse Width	(0018,1154)	Recommended in this scenario.
Radiation Mode	(0018,115A)	The value of this attribute is used more for quality assurance and/or display purposes, not for estimation of radiation values.

Note that the three attributes X-Ray Tube Current in mA (0018,9330), Exposure Time in ms (0018,9328) and Exposure in mAs (0018,9332) are mutually conditional to each other but all three may be present. In this scenario it is recommended to include the three attributes.

Z.2.1.7.3.2 Frame Content Macro Recommendations

The usage of this macro is recommended to specify the duration of each frame of the multi-frame image.

Note that this macro is allowed to be used only in a per-frame context, even if the pulse duration is constant for all the frames.

Z.2.1.7.3.3 X-Ray Frame Acquisition Macro Recommendations

The usage of this macro is recommended to specify the values of voltage (kVp) and current (mA) applied for the acquisition of each frame of the multi-frame image.

If the system can provide only average values of kVp and mA, the usage of the X-Ray Frame Acquisition macro is not recommended, only the XA/XRF Acquisition Module is recommended.

If the system predefines the values of the kVp and mA to be constant during the acquisition, the usage of the X-Ray Frame Acquisition macro in a shared context is recommended in order to indicate that the value of kVp and mA is identical for each frame.

If the system is able to change dynamically the kVp and mA during the acquisition, the usage of the X-Ray Frame Acquisition macro in a per-frame context is recommended.

Table Z.2.1-52
X-RAY FRAME ACQUISITION MACRO Recommendations

Attribute Name	Tag	Comment
Frame Acquisition Sequence	(0018,9417)	Recommended in this scenario if both values kVp and mA are known for each frame.

Z.2.1.7.4 Example

For more details, refer to the section Z.1.4

Z.2.2 Review

Z.2.2.1 Variable Frame-rate acquisition with Skip Frames

This application case provides information on how X-Ray acquisitions with variable time between frames can be organized by groups of frames to be reviewed with individual group settings.

Z.2.2.1.1 User Scenario

The image acquisition system performs complex acquisition protocols with groups of frames to be displayed at different frame rates and others to be skipped.

Allow frame-rates in viewing applications to be different than acquired rates.

Z.2.2.1.2 Encoding Outline

The XA IOD provides only one group of frames between start and stop trim.

The Enhanced XA/XRF IOD allows encoding of multiple groups of frames (frame collections) with dedicated display parameters.

The Enhanced XA IOD provides an exact acquisition time for each frame.

Z.2.2.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.2-1
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Multi-frame Presentation	C.8.19.7	Specifies the groups of frames and their display parameters.

Z.2.2.1.3.1 XA/XRF Multi-frame Presentation Module Recommendations

The usage of this module is recommended to encode the grouping of frames (one or more groups) for display purposes and the related parameters for each group.

Table Z.2.2-2
XA/XRF MULTI-FRAME PRESENTATION MODULE Recommendations

Attribute Name	Tag	Comment
Preferred Playback Sequencing	(0018,1244)	Specifies the direction of the playback.
Frame Display Sequence	(0008,9458)	Specifies the details on how frames are grouped for display purposes.

Z.2.2.1.4 Example

An example of a 4 position peripheral stepping acquisition with different frame-rates is provided. One group is only 2 Frames (e.g., due to fast contrast bolus) and will be skipped for display purposes.

The whole image is reviewed in looping mode:

- The first group, from frames 1 to 17, is to be reviewed at 4 frames per second;

- The second group, from frames 18 to 25, is to be reviewed at 2 frames per second;
- The third group, of frames 26 and 27, is not to be displayed;
- The fourth group, from frames 28 to 36, is to be reviewed at 1.5 frames per second.

Below are the encoded values of the key attributes of this example:

Preferred Playback Sequencing	(0018,1244)	=	**0**
Frame Display Sequence	(0008,9458)		
Item 1			
>Start Trim	(0008,2142)	=	**1**
>Stop Trim	(0008,2143)	=	**17**
>Skip Frame Range Flag	(0008,9460)	=	**DISPLAY**
>Recommended Display Frame Rate in Float	(0008,9459)	=	**4.0**
Item 2			
>Start Trim	(0008,2142)	=	**18**
>Stop Trim	(0008,2143)	=	**25**
>Skip Frame Range Flag	(0008,9460)	=	**DISPLAY**
>Recommended Display Frame Rate in Float	(0008,9459)	=	**2.0**
Item 3			
>Start Trim	(0008,2142)	=	**26**
>Stop Trim	(0008,2143)	=	**27**
>Skip Frame Range Flag	(0008,9460)	=	**SKIP**
>Recommended Display Frame Rate in Float	(0008,9459)	=	**2.0**
Item 4			
>Start Trim	(0008,2142)	=	**28**
>Stop Trim	(0008,2143)	=	**36**
>Skip Frame Range Flag	(0008,9460)	=	**DISPLAY**
>Recommended Display Frame Rate in Float	(0008,9459)	=	**1.5**

Figure Z.2.2-1
Attributes of the example of the Variable Frame-rate acquisition with Skip Frames

Z.2.3 Display

Z.2.3.1 Standard Pipeline with Enhanced XA

This section provides information on the encoding of the density and geometry characteristics of the stored pixel data and the ways to display it.

Z.2.3.1.1 User Scenario

The image acquisition may be performed with a variety of settings on the detector image pre-processing component which modifies the way the gray levels are stored in the pixel data.

In particular, it may impact the relationship between the X-Ray intensity and the gray level stored (e.g., non-linear function), as well as the geometry of the X-Ray beam (e.g., pincushion distortion).

Based on the characteristics of the stored pixel data, the acquisition system determines automatically an optimal way to display the pixel data on a frame-by-frame basis, which is expected to be applied by the viewing applications.

Z.2.3.1.2 Encoding outline

The XA SOP Class encodes the VOI settings to be common to all the frames of the image. It also restricts the Photometric Interpretation (0028,0004) to MONOCHROME2.

The Enhanced XA SOP Class encodes per-frame VOI settings. Additionally it allows the Photometric Interpretation (0028,0004) to be MONOCHROME1 in order to display low pixel values in white while using window width and window center VOI. Other characteristics and settings can be defined, such as:

- Relationship between X-Ray intensity and the pixel value stored;
- Edge Enhancement filter strength;
- Geometrical properties.

Z.2.3.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.3-1
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Enhanced XA/XRF Image	C.8.19.2	Specifies the sign of the slope of the VOI transformation to be applied during display.
	XA/XRF Multi-frame Presentation	C.8.19.7	Specifies the subtractive mode and the edge enhancement filter characteristics to be applied during display.

Table Z.2.3-2
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame VOI LUT	C.7.6.16.2.10	Specifies the VOI transformation to be applied during display.

Pixel Intensity Relationship LUT	C.7.6.16.2.13	Specifies the different LUTs to transform the stored pixel values to a given function of the X-Ray intensity.
XA/XRF Frame Pixel Data Properties	C.8.19.6.4	Specifies geometrical characteristics of the pixel data.

Z.2.3.1.3.1 Enhanced XA/XRF Image Module Recommendations

The usage of this module is recommended to specify the sign of the slope of the VOI transformation to be applied during display of the multi-frame image.

Table Z.2.3-3
ENHANCED XA/XRF IMAGE MODULE Recommendations

Attribute Name	Tag	Comment
Photometric Interpretation	(0028,0004)	The value MONOCHROME1 indicates negative slope (i.e. minimum pixel value is intended to be displayed as white), and the value MONOCHROME2 indicates positive slope (i.e. minimum pixel value is intended to be displayed as black).
Presentation LUT Shape	(2050,0020)	The values IDENTITY and INVERSE are applicable.

Z.2.3.1.3.2 XA/XRF Multi-frame Presentation Module Recommendations

The usage of this module is recommended to specify some presentation settings:

1) Whether the viewing mode is subtracted or not by using the Recommended Viewing Mode (0028,1090), and

2) The recommended edge enhancement filter as a percentage of subjective sensitivity by using the Display Filter Percentage (0028,9411).

The recommended filter percentage does not guaranty a full consistency of the image presentation across applications, rather gives an indication of the user sensitivity to such filtering to be applied consistently. To optimize the consistency of the filtering perception, the applications sharing the same images should be customized to calibrate the highest filtering (i.e. 100%) to similar perception by the users. Setting the application to the lowest filtering (i.e. 0%) means that no filter is applied at all.

Z.2.3.1.3.3 Frame VOI LUT Macro Recommendations

The usage of this macro is recommended to specify the windowing to be applied to the pixel data in native mode, i.e. non-subtracted.

Z.2.3.1.3.4 Pixel Intensity Relationship LUT Macro Recommendations

The usage of this macro is recommended to enable the applications to get the values of the stored pixel data back to a linear relationship with the X-Ray intensity.

When the value of Pixel Intensity Relationship (0028,1040) equals LOG, a LUT to get back to linear relationship (TO_LINEAR) is present to allow applications to handle linear pixel data.

Other LUTs can be added, for instance to transform to logarithmic relationship for subtraction (TO_LOG) in case the relationship of the stored pixel data is linear. Other LUTs with manufacturer-defined relationships are also allowed.

The LUTs of this macro are not used for the standard display pipeline.

Z.2.3.1.3.5 XA/XRF Frame Pixel Data Properties Macro Recommendations

The usage of this macro is recommended to specify some properties of the values of the stored pixel data with respect to the X-Ray intensity (i.e. gray level properties) and with respect to the geometry of the detector (i.e. pixel geometrical properties).

Z.2.3.1.4 Example

In this example, two different systems perform an X-Ray Acquisition of the coronary arteries injected with radio-opaque contrast agent.

The system A is equipped with a digital detector, and stores the pixel data with the lower level corresponding to the lower X-Ray intensity. Then the user creates two instances: one to display the injected vessels as black, and other to display the injected vessels as white.

The system B is equipped with an image intensifier configured to store the pixel data with the lower level corresponding to the higher X-Ray intensity. Then the user creates two instances: one to display the injected vessels as black, and other to display the injected vessels as white.

The figure below illustrates, for the two systems, the gray levels of the injected vessels on both the stored pixel data and the displayed pixels, which depend on the value of the attributes Pixel Intensity Relationship Sign (0028,1041), Photometric Interpretation (0028,0004), and Presentation LUT Shape (2050,0020).

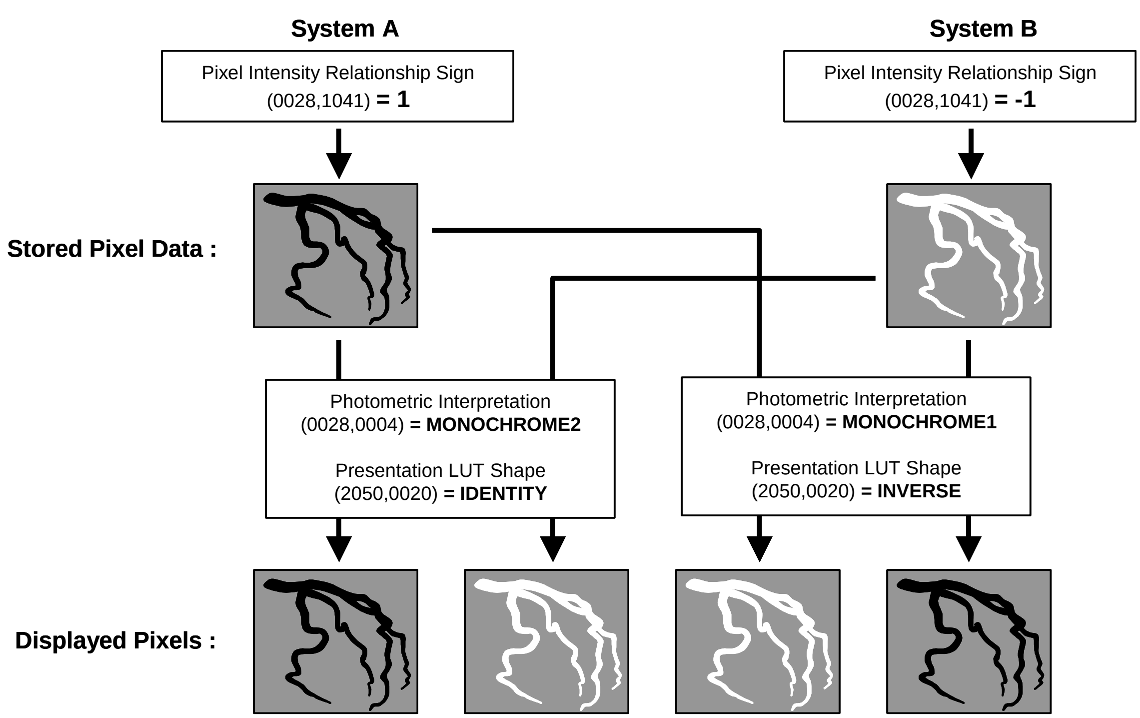

Figure Z.2.3-1
Example of usage of Photometric Interpretation

Z.2.3.2 Mask Subtraction

This section provides information on the usage of attributes to encode an image acquisition in subtracted display mode.

Z.2.3.2.1 User Scenario

A straightforward DSA acquisition is performed. The first few frames do not contain contrast, then the rest of frames contain contrast. An “averaged mask” may be selected to average some of the first frames without contrast.

A peripheral stepping DSA acquisition is performed. The acquisition is running in N steps and is timed to perform a mask run (e.g., from feet to abdomen) and then perform contrast runs at the positions of each mask, as triggered by the user.

One or more ranges of contrast frames will be used for subtraction from the mask for loop display. During the display, some ranges are to be fully subtracted, some others may be partially subtracted allowing a certain degree of visibility of the anatomical background visible on the mask, and finally some ranges are to be displayed un-subtracted.

Z.2.3.2.2 Encoding Outline

The Enhanced XA SOP Class allows the encoding of the mask attributes similar to what the XA SOP Class provides.

The Enhanced XA SOP Class allows defining of specific display settings to be applied to a subset of frames, for instance the recommended viewing mode and the degree of visibility of the mask.

Z.2.3.2.3 Encoding Details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.3-4
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Mask	C.7.6.10	Specifies the subtraction parameters.
	XA/XRF Multi-frame Presentation	C.8.19.7	Specifies display settings of the groups of frames.

Z.2.3.2.3.1 Mask Module Recommendations

This module is used to specify the subtraction parameters. The number of items depends on the number of Subtractions to be encoded. Typically, in case of AVG_SUB, the number of items is at least the number of ranges of contrast frames to be subtracted from a different mask.

Table Z.2.3-5
MASK MODULE Recommendations

Attribute Name	Tag	Comment
Recommended Viewing Mode	(0028,1090)	Recommended in this scenario, a value of “SUB” is used in this case.

Mask Subtraction Sequence	(0028,6100)	Recommended in this scenario. Items can be used to specify: - A range of contrast frames is to be subtracted from a generated mask; - A different set of pixel-shift pairs is to be applied to a range of contrast frames.

Z.2.3.2.3.2 XA/XRF Multi-frame Presentation Module Recommendations

The frame ranges of this module typically include all the masks and contrast frames defined in the Mask Module, and their presentation settings are consistent with the Mask Module definitions.

The mask frames are typically displayed non-subtracted, i.e. Recommended Viewing Mode (0028,1090) equals NAT.

If there is a frame range without mask association, the value "NAT" is used for Recommended Viewing Mode (0028,1090) in the item of the Frame Display Sequence (0008,9458) of that frame range.

In case where Recommended Viewing Mode (0028,1090) equals "NAT", the display is expected to be un-subtracted even if the Recommended Viewing Mode (0028,1090) of the Mask module equals "SUB".

Z.2.3.2.4 Examples

The user performs an X-Ray acquisition in three steps:

1. First step of 5 frames for mask acquisition, without contrast agent injection;
2. Second step of 20 frames to assess the arterial phase, with contrast agent injection, to be subtracted to the average of the 5 mask frames acquired in the first phase;
3. Third step of 10 frames to assess the venous phase, without further contrast agent injection, to be subtracted to a new mask related to that phase and with a 20% of mask visibility.

In the three steps, the system automatically identifies the mask frame(s) to be associated with the contrast frames.

Below are the encoded values of the key attributes of this example:

Recommended Viewing Mode	(0028,1090)	=	**SUB**
Mask Subtraction Sequence	(0028,6100)		
Item 1			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**1**
>Applicable Frame Range	(0028,6104)	=	**6\25**
>Mask Frame Numbers	(0028,6110)	=	**1\2\3\4\5**
>Mask Selection Mode	(0028,9454)	=	**SYSTEM**
Item 2			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**1**
>Applicable Frame Range	(0028,6104)	=	**27\35**
>Mask Frame Numbers	(0028,6110)	=	**26**
>Mask Selection Mode	(0028,9454)	=	**SYSTEM**

…

Attribute	Tag	Value
Frame Display Sequence	(0008,9458)	
Item 1		
>Start Trim	(0008,2142)	= **1**
>Stop Trim	(0008,2143)	= **5**
>Skip Frame Range Flag	(0008,9460)	= **DISPLAY**
>Recommended Viewing Mode	(0028,1090)	= **NAT**
Item 2		
>Start Trim	(0008,2142)	= **6**
>Stop Trim	(0008,2143)	= **25**
>Skip Frame Range Flag	(0008,9460)	= **DISPLAY**
>Recommended Viewing Mode	(0028,1090)	= **SUB**
>Mask Visibility Percentage	(0028,9478)	= **0**
Item 3		
>Start Trim	(0008,2142)	= **26**
>Stop Trim	(0008,2143)	= **26**
>Skip Frame Range Flag	(0008,9460)	= **SKIP**
>Recommended Viewing Mode	(0028,1090)	= **NAT**
Item 4		
>Start Trim	(0008,2142)	= **27**
>Stop Trim	(0008,2143)	= **35**
>Skip Frame Range Flag	(0008,9460)	= **DISPLAY**
>Recommended Viewing Mode	(0028,1090)	= **SUB**
>Mask Visibility Percentage	(0028,9478)	= **20**

Figure Z.2.3-2
Attributes of Mask Subtraction and display

Z.2.3.3 Pixel-shift

This section provides information on the attribute encoding for use with image acquisitions that require subtracted display modes with multiple pixel shift ranges e.g., multiple subtracted views on a DSA acquisition.

Z.2.3.3.1 User Scenario

When performing DSA acquisitions, the acquisition system may choose a default subtraction pixel-shift to allow review of the whole multi-frame, as acquired.

With advanced post-processing function the medical user may add further subtraction pixel-shifts to carve out certain details or improve contrast bolus visualization of a part of the anatomy that suffered from different movement during the acquisition.

Z.2.3.3.2 Encoding Outline

The Mask Module is used to encode the various subtractions applicable to a multi-frame image.

The Enhanced XA IOD allows creating groups of mask-contrast pairs in the Mask Module, each group identified by a unique Subtraction Item ID within the multi-frame image.

The Enhanced XA IOD, with per frame macro encoding, supports multiple and different pixel-shift values per frame, each pixel-shift value is related to a given Subtraction Item ID.

It has to be assured that all the frames in the scope of a Subtraction Item ID have the pixel-shift values defined under that Subtraction Item ID.

In case a frame does not belong to any Subtraction Item ID, that frame does not necessarily have a pixel shift value encoded.

Z.2.3.3.3 Encoding Details

This section provides detailed recommendations of the key attributes to address this particular scenario. The usage of the “Frame Pixel Shift” macro in a ‘per frame’ context is recommended. Only the usage of Mask Module and the Frame Pixel Shift Macro is further detailed.

Table Z.2.3-6
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Mask	C.7.6.10	Specifies the groups of mask-contrast pairs identified by a Subtraction Item ID.

Table Z.2.3-7
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Frame Pixel Shift	C.7.6.16.2.14	Specifies the pixel shift associated with the Subtraction IDs.

Z.2.3.3.3.1 Mask Module Recommendations

This module is recommended to specify the subtraction parameters. The number of items depends on the number of Subtractions to be applied (see section Z.2.3.2).

Table Z.2.3-8
MASK MODULE Recommendations

Attribute Name	Tag	Comment
Recommended Viewing Mode	(0028,1090)	Recommended in this scenario, a value of “SUB” is used in this case.
Mask Subtraction Sequence	(0028,6100)	Recommended in this scenario. Item can be used to specify: - A range of contrast frames is to be subtracted from a generated mask; - A different set of pixel-shift pairs is to be applied to a range of contrast frames.

Z.2.3.3.3.2 Frame Pixel Shift Macro Recommendations

The usage in this scenario is on a “per frame” context to allow individual pixel shift factors for each Subtraction Item ID.

The Subtraction Item ID specified in the Mask Subtraction Sequence (0028,6100) as well as in the Frame Pixel Shift Sequence (0028,9415) allows creating a relationship between the subtraction (mask and contrast frames) and a corresponding set of pixel shift values.

The Pixel Shift specified for a given frame in the Frame Pixel Shift Macro is the shift to be applied when this frame is subtracted to its associated mask for the given Subtraction Item ID.

Not all frames may have the same number of items in the Frame Pixel Shift Macro, but all frames that are in the scope of a Subtraction Item ID and identified as “contrast” frames in the Mask module are recommended to have a Frame Pixel Shift Sequence item with the related Subtraction Item ID.

Table Z.2.3-9
FRAME PIXEL SHIFT MACRO Recommendations

Attribute Name	**Tag**	**Comment**
Frame Pixel Shift Sequence	(0008,9415)	Recommended in this scenario. The number of items may differ for each frame.

Z.2.3.3.4 Examples

Z.2.3.3.4.1 Usage of Pixel Shift Macro in Shared Context

In this example, the pixel shift –0.3\2.0 is applied to the frames 2 and 3 when they are subtracted to the mask frame 1 as defined in the Mask Subtraction Sequence.

Below are the encoded values of the key attributes of this example:

Mask Subtraction Sequence	(0028,6100)		
Item 1			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**100**
>Applicable Frame Range	(0028,6102)	=	**2\3**
>Mask Frame Numbers	(0028,6110)	=	**1**
>Mask Operation Explanation	(0028,6190)	=	**Default Subtraction**

…

Shared Functional Group Sequence	(5200,9229)		
Item 1			*All the frames*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**-0.3\2.0**

Figure Z.2.3-3
Example of Shared FRAME PIXEL SHIFT MACRO

Z.2.3.3.4.2 Usage of Pixel Shift Macro in “per frame” context

The usage in a per-frame context is expected in a typical clinical scenario where the shift between the mask and the contrast frames is not constant across the frames of the multi-frame image to compensate for patient/organ movement.

Below are the encoded values of the key attributes of this example:

Attribute	Tag		Value
Mask Subtraction Sequence	(0028,6100)		
Item 1			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**100**
>Applicable Frame Range	(0028,6102)	=	**2\3**
>Mask Frame Numbers	(0028,6110)	=	**1**
>Mask Operation Explanation	(0028,6190)	=	**Left Leg**

…

Attribute	Tag		Value
Per-Frame Functional Groups Sequence	(5200,9230)		
Item 1			*Frame 1*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\0.0**
…			
Item 2			*Frame 2*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\1.2**
…			
Item 3			*Frame 3*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**1.0\1.4**
…			

Figure Z.2.3-4
Example of Per-Frame FRAME PIXEL SHIFT MACRO

Z.2.3.3.4.3 Usage of Pixel Shift Macro in “per frame” context for multiple shifts

The usage in a per-frame context is also appropriate to specify more than one set of shifts in case of more than one region of interest suffered from patient/organ movement independently, like in case of the two legs imaged simultaneously.

In this example, two Subtraction Item IDs are defined in the Mask Subtraction Sequence.

Below are the encoded values of the key attributes of this example:

Attribute	Tag		Value
Mask Subtraction Sequence	(0028,6100)		
Item 1			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**100**
>Applicable Frame Range	(0028,6102)	=	**2\3**
>Mask Frame Numbers	(0028,6110)	=	**1**
>Mask Operation Explanation	(0028,6190)	=	**Left Leg**
Item 2			
>Mask Operation	(0028,6101)	=	**AVG_SUB**
>Subtraction Item ID	(0028,9416)	=	**101**
>Applicable Frame Range	(0028,6102)	=	**2\3**
>Mask Frame Numbers	(0028,6110)	=	**1**
>Mask Operation Explanation	(0028,6190)	=	**Right Leg**

…

Attribute	Tag		Value
Per-Frame Functional Groups Sequence	(5200,9230)		
Item 1			*Frame 1*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\0.0**
Item 2			
>>Subtraction Item ID	(0028,9416)	=	**101**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\0.0**
..			
Item 2			*Frame 2*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\1.2**
Item 2			
>>Subtraction Item ID	(0028,9416)	=	**101**
>>Mask Sub-pixel Shift	(0028,6114)	=	**0.0\2.3**
…			
Item 3			*Frame 3*
>Frame Pixel Shift Sequence	(0028,9415)		
Item 1			
>>Subtraction Item ID	(0028,9416)	=	**100**

>>Mask Sub-pixel Shift	(0028,6114)	=	**1.0\1.4**
Item 2			
>>Subtraction Item ID	(0028,9416)	=	**101**
>>Mask Sub-pixel Shift	(0028,6114)	=	**1.0\2.7**
…			

Figure Z.2.3-5
Example of Per-Frame FRAME PIXEL SHIFT MACRO for multiple shifts

Z.2.4 Processing

Z.2.4.1 Projection Pixel Calibration

This section provides information on the encoding of the projection pixel size calibration and the underlying geometry.

Z.2.4.1.1 User Scenario

The user wants to measure the size of objects in the patient with a default system calibration based on the acquisition geometry and the default distance from the table to the object. In order to have more accurate measurements than this default calibration, the user may provide information of the distance from the table to the object to be measured.

The image is stored in an archive system and retrieved by a second user who wants to re-use the calibration and needs to know which object this calibration applies to.

This second user may need to re-calibrate based on another object at a different geometry.

Z.2.4.1.2 Encoding Outline

In conic projection imaging, the pixel size in the patient is not constant. If a value of Pixel Spacing (0028,0030) is provided, it is best appropriate at a given distance from the X-Ray source to the object of interest in the patient (patient plane). It is less exact for other objects at other distances.

In addition, the distance from the X-Ray source to the object of interest may change per frame in case of gantry or table motion. In this case the Enhanced XA SOP Class allows the pixel size in the patient to be defined per-frame.

A macro provides a compound set of all relevant attributes.

The value “Table to Object Height” can be used for individual patient plane definition.

Automatic isocenter calibration method is supported.

Values of gantry and table positions are provided to complete all necessary attributes for a later re-calibration.

Z.2.4.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario. See PS3.3 section C.8.19.6.9.1 for detailed description of the attributes involved in the calculation of the calibration.

Table Z.2.4-1
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	XA/XRF Acquisition	C.8.19.3	Specifies system characteristics relevant for this scenario.

Table Z.2.4-2
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
XA/XRF Frame Pixel Data Properties	C.8.19.6.4	Specifies the pixel spacing on the receptor plane.

X-Ray Projection Pixel Calibration	C.8.19.6.9	Specifies the calibration-specific attributes.
X-Ray Geometry	C.8.19.6.14	Specifies the distances of the conic projection.

Z.2.4.1.3.1 XA/XRF Acquisition Module Recommendations

In order to check if a calibration is appropriate, certain values have to be set in the XA/XRF Acquisition Module.

Table Z.2.4-3
XA/XRF ACQUISITION MODULE Recommendations

Attribute Name	Tag	Comment
X-Ray Receptor Type	(0018,9420)	Recommended in this scenario. The values IMG_INTENSIFIER or DIGITAL_DETECTOR can provide information about exactness of the image plane.
Positioner Type	(0018,1508)	Recommended in this scenario. The value of CARM is typically expected for equipment providing geometry information required for calibration.
C-arm Positioner Tabletop Relationship	(0018,9474)	A value of YES is recommended in this scenario, to allow use of related information for calibration because table and gantry are geometrically aligned.

Z.2.4.1.3.2 XA/XRF Frame Pixel Data Properties Macro Recommendations

This macro is recommended to provide the Pixel Spacing in the receptor plane. Typically the Image Pixel Spacing is identical for all frames. Future acquisition system techniques may result in per frame individual values.

Table Z.2.4-4
XA/XRF FRAME PIXEL DATA PROPERTIES MACRO Recommendations

Attribute Name	Tag	Comment
Frame Pixel Data Properties Sequence	(0028,9443)	
>Imager Pixel Spacing	(0018,1164)	Recommended for this scenario, regardless the type of receptor.

Z.2.4.1.3.3 X-Ray Projection Pixel Calibration Macro Recommendations

This macro contains the core inputs and results of calibration.

When there is no movement of the gantry and table, the macro is typically used in shared functional group context.

The attribute Beam Angle (0018,9449) is supplementary for the purpose of calibration; it is derived from the Primary and Secondary Positioner Angles but is not intended to replace them as they provide information for other purposes.

Table Z.2.4-5
X-RAY PROJECTION PIXEL CALIBRATION MACRO Recommendations

Attribute Name	Tag	Comment
Projection Pixel Calibration Sequence	(0018,9401)	
>Distance Object to Table Top	(0018,9403)	Recommended in this scenario.
>Object Pixel Spacing in Center of Beam	(0018,9404)	Recommended in this scenario. The value pair corresponds to the patient plane defined by the other parameters in this macro.
>Table Height	(0018,1130)	Recommended in this scenario.
>Beam Angle	(0018,9449)	Recommended in this scenario.

Z.2.4.1.3.4 X-Ray Geometry Macro Recommendations

When there is no change of the geometry, the macro is used in shared functional group context.

Z.2.4.1.4 Example

The user performs an X-Ray acquisition with movement of the positioner during the acquisition. The patient is in Head First Supine position. During the review of the multi-frame image, a measurement of the object of interest in the frame “i” needs to be performed, which requires the calculation of the pixel spacing at the object location for that frame.

For the frame “i”, the Positioner Primary Angle is -30.0 degrees, and the Positioner Secondary Angle is 20.0 degrees. According to the definition of the positioner angles and given the patient position, the Beam Angle is calculated as follows:

Beam Angle = arcos(|cos(-30.0)| * |cos(20.0)|) = 35.53 degrees

The value of the other attributes defining the geometry of the acquisition for the frame “i” are the following:

ISO = 750 mm
SID = 983 mm
TH = 187 mm

ΔPx (Imager Pixel Spacing) = 0.2 mm/pix

The user provides, via the application interface, an estimated value of the distance from the object of interest to the tabletop: ***TO*** = 180 mm. This value can be encoded in the attribute Distance Object to Table Top (0018,9403) of the Projection Pixel Calibration Sequence (0018,9401) for further usage.

This results in an ***SOD*** of 741.4 mm (according to the equation SOD = 750mm **-** [(187mm-180mm) / cos(35.53°)]), and in a magnification ratio of SID/SOD of 1.32587.

The resulting pixel spacing at the object location and related to the center of the X-Ray beam is calculated as ***ΔPx * SOD / SID*** = 0.150844 mm/pix. This value can be encoded in the attribute Object Pixel Spacing in Center of Beam (0018,9404) of the Projection Pixel Calibration Sequence (0018,9401) for further usage.

Below are the encoded values of the key attributes of this example:

Positioner Type	(0018,1508)	=	**CARM**
X-Ray Receptor Type	(0018,9420)	=	**DIGITAL_DETECTOR**
C-arm Positioner Tabletop Relationship	(0018,9474)	=	**YES**
…			
Shared Functional Group Sequence	(5200,9229)		

Attribute	Tag		Value	
Item 1				*For all frames*
…				
X-Ray Geometry Sequence	(0018,9476)			
Item 1				
>>Distance Source to Detector	(0018,1110)	=	**983.0**	
>>Distance Source to Isocenter	(0018,9402)	=	**750.0**	
Frame Pixel Data Properties Sequence	(0028,9443			
Item 1				
>>Imager Pixel Spacing	(0018,1164)	=	**0.2\0.2**	
…				
Per-Frame Functional Groups Sequence	(5200,9230)			
…				
Item i				*Frame i*
>Projection Pixel Calibration Sequence	(0018,9401)			
Item 1				
>>Table Height	(0018,1130)	=	**187.0**	
>>Distance Object to Table Top	(0018,9403)	=	**180.0**	
>>Object Pixel Spacing in the Center of Beam	(0018,9404)	=	**0.150844\0.150844**	
>>Beam Angle	(0018,9449)	=	**35.53**	
…				

Figure Z.2.4-1
Attributes of X-Ray Projection Pixel Calibration

Z.2.4.2 Image Derivation and Pixel data Properties

This section provides information on the encoding of the derivation process and the characteristics of the stored pixel data.

Z.2.4.2.1 User Scenario

An acquisition system performs several processing steps on an original image, and then it creates a derived image with the processed pixel data.

A viewing application applies post-processing algorithms to that derived image, e.g., measurements, segmentation etc. This application needs to know what kind of post-processing can or cannot be applied depending on the characteristics of the derived image.

Z.2.4.2.2 Encoding outline

The XA SOP Class does not encode any specific attribute values to characterize the type of derivation.

The Enhanced XA SOP Class encodes defined terms for processing applied to the Pixel Data, and allows getting back to linear relationship between pixel values and X-Ray intensity. Viewing applications can consistently interpret the stored pixel data and enable/disable applications like edge detection algorithms, subtraction, filtering, etc.

Z.2.4.2.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.4-6
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Enhanced XA/XRF Image	C.8.19.2	Specifies the image type: ORIGINAL or DERIVED.

Table Z.2.4-7
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
Derivation Image	C.7.6.16.2.6	Specifies the different derivation steps (including the latest step) that led to this instance.
Pixel Intensity Relationship LUT	C.7.6.16.2.13	Specifies the relationship between the stored pixel data values and the X-Ray intensity of the resulting derived instance.
XA/XRF Frame Characteristics	C.8.19.6.1	Specifies the latest derivation step that led to this instance.
XA/XRF Frame Pixel Data Properties	C.8.19.6.4	Specifies the characteristics of the derived pixel data, both geometric and densitometric.

Z.2.4.2.3.1 Enhanced XA/XRF Image Module Recommendations

The usage of this module is recommended to specify the image type.

Table Z.2.4-8
ENHANCED XA/XRF IMAGE MODULE Recommendations

Attribute Name	Tag	Comment
Image Type	(0008,0008)	The first value is DERIVED in this scenario.

Z.2.4.2.3.2 Derivation Image Macro Recommendations

The usage of this macro is recommended to encode the information of the different derivation processes and steps, as well as the source SOP instance(s) when the image or frame are derived from other SOP Instance(s).

Table Z.2.4-9
DERIVATION IMAGE MACRO Recommendations

Attribute Name	Tag	Comment
Derivation Image Sequence	(0008,9124)	Contains one item per derivation process that led to this SOP Instance.
>Derivation Description	(0008,2111)	Free text description of this derivation process, typically for display purposes.

>Derivation Code Sequence	(0008,9215)	Contains as many items as derivation steps in this derivation process.
>Source Image Sequence	(0008,2112)	Contains one item per source SOP Instance used in this derivation process.

If this image is not derived from source SOP Instances, the Derivation Image macro is not present, and the XA/XRF Frame Characteristics macro is used instead.

Z.2.4.2.3.3 Pixel Intensity Relationship LUT Macro Recommendations

The usage of this macro is recommended to enable the applications to get the pixel values back to a linear relationship with the X-Ray intensity.

If readers of the image do not recognize the Pixel Intensity Relationship value, readers can use the value "OTHER" as default.

The number of bits in the LUT Data attribute (0028,3006) may be different from the value of Bits Stored attribute (0028,0101).

Z.2.4.2.3.4 XA/XRF Frame Characteristics Macro Recommendations

The usage of this macro is recommended to specify the derivation characteristics

Table Z.2.4-10
XA/XRF FRAME CHARACTERISTICS MACRO Recommendations

Attribute Name	Tag	Comment
XA/XRF Frame Characteristics Sequence	(0018,9412)	
>Derivation Description	(0008,2111)	Contains the description of the latest derivation process.
>Derivation Code Sequence	(0008,9215)	Contains as many items as derivation steps in this derivation process.
>Acquisition Device Processing Description	(0018,1400)	Specifies the derivation made at the acquisition system.
>Acquisition Device Processing Code	(0018,1401)	Specifies the derivation made at the acquisition system.

If the image is derived from one or more SOP Instances, the XA/XRF Frame Characteristics Sequence always contains the same values as the last item of the Derivation Image Sequence.

If the image is derived but not from other SOP Instances, it means that the derivation was performed on the Acquisition system, and the Acquisition Device Processing Description (0018,1400) and the Acquisition Device Processing Code (0018,1401) contain the information of that derivation.

An image derived from a derived image will change the Derivation Description but not the Acquisition Device Processing Description.

Z.2.4.2.3.5 XA/XRF Frame Pixel Data Properties Macro Recommendations

The usage of this macro is recommended to specify the type of processing applied to the stored pixel data of the derived frames.

Table Z.2.4-11
XA/XRF FRAME PIXEL DATA PROPERTIES MACRO Recommendations

Attribute Name	Tag	Comment
Frame Pixel Data Properties Sequence	(0028,9443)	Recommended in this scenario.
>Frame Type	(0008,9007)	The first value is DERIVED in this scenario
>Image Processing Applied	(0028,9446)	In case of derivation from a derived image, this attribute contains a concatenation of the previous values plus the new value(s) of the latest derivation process.

Z.2.4.2.4 Examples

Z.2.4.2.4.1 Various successive derivations

In this example, the acquisition modality creates two instances of the Enhanced XA object: the instance “A” with mask frames and the instance “B” with contrast frames. A temporal filtering has been applied by the modality before the creation of the instances.

The workstation 1 performs a digital subtraction of the frames of the instance “B” by using the frames of the instance “A” as mask, then the resulting subtracted frames are stored in a new instance “C”.

Finally the workstation 2 processes the instance “C” by applying a zoom and edge enhancement, and the resulting processed frames are stored in a new instance “D”.

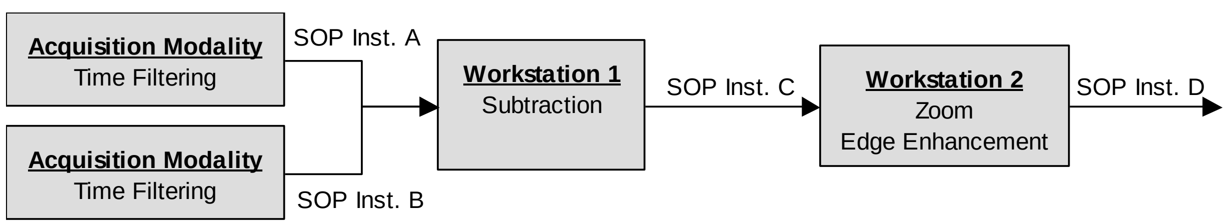

Figure Z.2.4-2
Example of various successive derivations

The following figure shows the values of the attributes of the instance “D” in the corresponding modules and macros related to derivation information. The Source Image Sequence (0008,2112) of the Derivation Image Sequence (0008,9124) does not contain the attribute Referenced Frame Number (0008,1160) because all the frames of the source images are used to generate the derived images.

…

Image Type	(0008,0008)	=	**DERIVED\ …**
SOP Instance UID	(0020,000E)	=	*UID "D"*

…

Shared Functional Groups Sequence	(5200,9229)		
item 1			
>Derivation Image Sequence	(0008,9124)		
Item 1			
>>Derivation Description	(0008,2111)	=	**SUBTRACTION**

Attribute	Tag		Value
>>Derivation Code Sequence	(0008,9215)		
Item 1			
>>>Code Value	(0008,0100)	=	**113062**
>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**Pixel by pixel subtraction**
>>Source Image Sequence	(0008,2112)		
Item 1			
>>>Referenced SOP Class UID	(0008,1150)	=	**1.2.840.10008.5.1.4.1.1.12.1.1**
>>>Referenced SOP Instance UID	(0008,1155)	=	*UID "A"*
>>>Purpose of Reference Code Sequence	(0040,A170)		
Item 1			
>>>>Code Value	(0008,0100)	=	**121321**
>>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>>Code Meaning	(0008,0104)	=	**Mask image for image processing operation**
Item 2			
>>>Referenced SOP Class UID	(0008,1150)	=	**1.2.840.10008.5.1.4.1.1.12.1.1**
>>>Referenced SOP Instance UID	(0008,1155)	=	*UID "B"*
>>>Purpose of Reference Code Sequence	(0040,A170)		
Item 1			
>>>>Code Value	(0008,0100)	=	**121322**
>>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>>Code Meaning	(0008,0104)	=	**Source image for image processing operation**
Item 2			
>>Derivation Description	(0008,2111)	=	**FILTER and ZOOM**
>>Derivation Code Sequence	(0008,9215)		
Item 1			
>>>Code Value	(0008,0100)	=	**113086**
>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**Edge enhancement**
Item 2			
>>>Code Value	(0008,0100)	=	**113085**
>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**Spatial resampling**
>>Source Image Sequence	(0008,2112)		
Item 1			
>>>Referenced SOP Class UID	(0008,1150)	=	**1.2.840.10008.5.1.4.1.1.12.1.1**
>>>Referenced SOP Instance UID	(0008,1155)	=	*UID "C"*
>>>Purpose of Reference Code Sequence	(0040,A170)		

Attribute	Tag		Value
Item 1			
>>>>Code Value	(0008,0100)	=	**121322**
>>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>>Code Meaning	(0008,0104)	=	**Source image for image processing operation**
>XA/XRF Frame Characteristics Sequence	(0018,9412)		
Item 1			
>>Derivation Description	(0008,2111)	=	**FILTER and ZOOM**
>>Derivation Code Sequence	(0008,9215)		
Item 1			
>>>Code Value	(0008,0100)	=	**113086**
>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**Edge enhancement**
Item 2			
>>>Code Value	(0008,0100)	=	**113085**
>>>Coding Scheme Designator	(0008,0102)	=	**DCM**
>>>Code Meaning	(0008,0104)	=	**Spatial resampling**
>>Acquisition Device Processing Description	(0018,1400)	=	**Time filtered**
>Frame Pixel Data Properties Sequence	(0028,9443)		
Item 1			
>>Frame Type	(0008,9007)	=	**DERIVED\ …**
>>Pixel Intensity Relationship	(0028,1040)	=	**OTHER**
>>Pixel Intensity Relationship Sign	(0028,1041)	=	**1**
>>Geometrical Properties	(0028,9444)	=	**UNIFORM**
>>Image Processing Applied	(0028,9446)	=	**FRAME_AVERAGING\ DIGITAL_SUBTR\ HIGH_PASS_FILTER\SPATIAL _RESAMPLING**
…			

Figure Z.2.4-3
Attributes of the example of various successive derivations

Z.2.4.2.4.2 Derivation by applying a square root transformation

In this example, the acquisition modality creates the instance “A” of the Enhanced XA object with 14 bits stored where the relationship between the pixel intensity and the X-Ray intensity is linear.

A workstation reads the instance “A”, transforms the pixel values of the stored pixel data by applying a square root function and stores the resulting frames on the instance “B” with 8 bits stored.

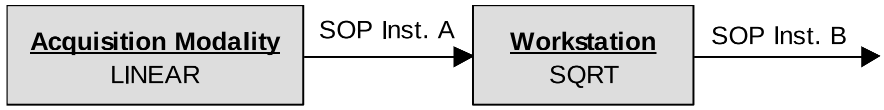

Figure Z.2.4-4
Example of derivation by square root transformation

The following figure shows the values of the attributes of the instance “B” in the corresponding modules and macros related to derivation information.

Note that the Derivation Code Sequence (0008,9215) is present when the Derivation Image Sequence (0008,9124) includes one or more items, even if the derivation code is not defined in the Context ID 7203.

The Pixel Intensity Relationship LUT Sequence (0028,9422) contains a LUT with the function “TO_LINEAR” to allow the calculation of the gray level intensity to be linear to the X-Ray intensity. Since the instance “B” has 8 bits stored, this LUT contains 256 entries (starting the mapping at pixel value 0) and is encoded in 16 bits.

The value of the Pixel Intensity Relationship (0028,1040) in the Frame Pixel Data Properties Sequence (0028,9443) could be “OTHER” as it is described in the defined terms. However, a more explicit term like “SQRT” is also allowed and will have the same effect in the reading application.

In the case of a modification of the pixel intensity relationship of an image, the value of the attribute Image Processing Applied (0028,9446) in the Frame Pixel Data Properties Sequence (0028,9443) can be “NONE” in order to indicate to the reading applications that there was no image processing applied to the original image that could modify the spatial or temporal characteristics of the pixels.

…

Image Type	(0008,0008)	= **DERIVED\ …**
SOP Instance UID	(0020,000E)	= *UID "B"*
Bits Stored	(0028,0101)	= **8**

…

Shared Functional Groups Sequence	(5200,9229)	
item 1		
>Derivation Image Sequence	(0008,9124)	
Item 1		
>>Derivation Description	(0008,2111)	= **SQUARE ROOT**
>>Derivation Code Sequence	(0008,9215)	
Item 1		
>>>Code Value	(0008,0100)	= **100001**
>>>Coding Scheme Designator	(0008,0102)	= **99MY_SCHEME**
>>>Code Meaning	(0008,0104)	= **Square Root transformation**
>>Source Image Sequence	(0008,2112)	
Item 1		
>>>Referenced SOP Class UID	(0008,1150)	= **1.2.840.10008.5.1.4.1.1.12.1.1**

Attribute	Tag	Value
>>>Referenced SOP Instance UID	(0008,1155)	= *UID "A"*
>>>Purpose of Reference Code Sequence	(0040,A170)	
Item 1		
>>>>Code Value	(0008,0100)	= **121322**
>>>>Coding Scheme Designator	(0008,0102)	= **DCM**
>>>>Code Meaning	(0008,0104)	= **Source image for image processing operation**
>Pixel Intensity Relationship LUT Sequence	(0028,9422)	
Item 1		
>>LUT Descriptor	(0028,3002)	= **256\0\16**
>>LUT Data	(0028,3006)	= *LUT data*
>>LUT Function	(0028,9474)	= **TO_LINEAR**
>XA/XRF Frame Characteristics Sequence	(0018,9412)	
Item 1		
>>Derivation Description	(0008,2111)	= **SQUARE ROOT**
>>Derivation Code Sequence	(0008,9215)	
Item 1		
>>>Code Value	(0008,0100)	= **100001**
>>>Coding Scheme Designator	(0008,0102)	= **99MY_SCHEME**
>>>Code Meaning	(0008,0104)	= **Square Root transformation**
>Frame Pixel Data Properties Sequence	(0028,9443)	
Item 1		
>>Frame Type	(0008,9007)	= **DERIVED\ …**
>>Pixel Intensity Relationship	(0028,1040)	= **SQRT**
>>Pixel Intensity Relationship Sign	(0028,1041)	= **1**
>>Geometrical Properties	(0028,9444)	= **UNIFORM**
>>Image Processing Applied	(0028,9446)	= **NONE**
…		

Figure Z.2.4-5
Attributes of the example of derivation by square root transformation

Z.2.5 Registration

Z.2.5.1 Tracking an object of interest on multiple 2D images

This section provides information on the encoding of the acquisition geometry in a fixed reference system.

Z.2.5.1.1 User Scenario

The operator identifies the position of an object of interest projected on the stored pixel data of an image A, and estimates the magnification of the conic projection by a calibration process.

The operator wants to know the position of the projection of such object of interest on a second image B acquired under different geometry, assuming that the patient does not move between image A and image B (i.e. the images share the same frame of reference).

Z.2.5.1.2 Encoding outline

The XA SOP Class encodes the information in a patient-related coordinate system.

The Enhanced XA SOP Class additionally encodes the geometry of the acquisition system with respect to a fixed reference system defined by the manufacturer, so-called Isocenter reference system. Therefore, it allows encoding the absolute position of an object of interest and to track the projection of such object across the different images acquired under different geometry.

Z.2.5.1.3 Encoding details

This section provides detailed recommendations of the key attributes to address this particular scenario.

Table Z.2.5-1
ENHANCED X-RAY ANGIOGRAPHIC IMAGE IOD MODULES

IE	Module	PS 3.3 Reference	Usage
Image	Image Pixel	C.7.6.3	Specifies the dimension of the pixel array of the frames.
	XA/XRF Acquisition	C.8.19.3	Describes some characteristics of the acquisition system that enables this scenario.
	X-Ray Detector	C.8.19.5	Specifies the type and characteristics of the image detector.

Table Z.2.5-2
ENHANCED XA IMAGE FUNCTIONAL GROUP MACROS

Functional Group Macro	PS 3.3 Reference	Usage
X-Ray Field of View	C.8.19.6.2	Specifies the dimension of the Field of View as well as the flip and rotation transformations.
X-Ray Isocenter Reference System	C.8.19.6.13	Specifies the acquisition geometry in a fixed reference system.
X-Ray Geometry	C.8.19.6.14	Specifies the distances of the conic projection.
XA/XRF Frame Pixel Data Properties	C.8.19.6.4	Specifies the dimensions of the pixels at the image reception plane.

Z.2.5.1.3.1 Image Pixel Module Recommendations

The usage of this module is recommended to specify the number of rows and columns of the Pixel Data, as well as the aspect ratio.

Z.2.5.1.3.2 XA/XRF Acquisition Module Recommendations

The usage of this module is recommended to give the necessary conditions to enable the calculations of this scenario.

Table Z.2.5-3
XA/XRF ACQUISITION MODULE Recommendations

Attribute Name	Tag	Comment
X-Ray Receptor Type	(0018,9420)	DIGITAL_DETECTOR is used in this scenario.
Positioner Type	(0018,1508)	CARM is used in this scenario.
C-arm Positioner Tabletop Relationship	(0018,9474)	YES is necessary in this scenario.

In case of X-Ray Receptor Type (0018,9420) equals “IMG_INTENSIFIER”, there are some limitations that prevent the calculations described on this scenario:

- The position of the projection of the isocenter on the intensifier active area is undefined;
- The Field of View Origin (0018,7030) cannot be related to the physical area of the receptor because the Intensifier TLHC is undefined.

As a consequence, in case of image intensifier it is impossible to relate the position of the pixels of the stored area to the isocenter reference system.

Z.2.5.1.3.3 X-Ray Detector Module Recommendations

In case of X-Ray Receptor Type (0018,9420) equals “DIGITAL_DETECTOR” the usage of this module is recommended to specify the type and characteristics of the image detector.

Z.2.5.1.3.4 X-Ray Field of View Macro Recommendations

The usage of this macro is recommended to specify the characteristics of the field of view.

The field of view characteristics may change per-frame across the multi-frame image.

Z.2.5.1.3.5 X-Ray Isocenter Reference System Macro Recommendations

The usage of this macro is recommended to specify the fixed reference system of the acquisition geometry.

Z.2.5.1.3.6 X-Ray Geometry Macro Recommendations

The usage of this macro is recommended to specify the distances between the X-Ray source, isocenter and X-Ray detector.

Z.2.5.1.3.7 XA/XRF Frame Pixel Data Properties Macro Recommendations

The usage of this macro is recommended to specify the dimensions of the pixels at the image reception plane.

Z.2.5.1.4 Example

In this example, the operator identifies the position (i, j) of an object of interest projected on the stored pixel data of an image A, and estimates the magnification of the conic projection by a calibration process.

The operator wants to know the position of the projection of such object of interest on a second image B acquired under different geometry.

The attributes that define the geometry of both images A and B are described in the following figure:

…

		Image A	*Image B*
Rows	(0028,0010)	= **850**	= **1000**
Columns	(0028,0011)	= **850**	= **1000**

…

X-Ray Receptor Type	(0018,9420)	= **DIGITAL_ DETECTOR**	= **DIGITAL_ DETECTOR**
Positioner Type	(0018,1508)	= **CARM**	= **CARM**
C-arm Positioner Tabletop Relationship	(0018,9474)	= **YES**	= **YES**

…

Detector Binning	(0018,701A)	= **1.0\1.0**	= **2.0\2.0**
Detector Element Spacing	(0018,7022)	= **0.2\0.2**	= **0.2\0.2**
Detector Active Shape	(0018,7024)	= **RECTANGLE**	= **RECTANGLE**
Detector Active Dimension(s)	(0018,7026)	= **400.0\400.0**	= **400.0\400.0**
Detector Active Origin	(0018,7028)	= **25.0\25.0**	= **25.0\25.0**
Physical Detector Size	(0018,9429)	= **410.0\410.0**	= **410.0\410.0**
Position of Isocenter Projection	(0018,9430)	= **1024.5\1024.5**	= **1024.5\1024.5**

…

Per-Frame Functional Groups Sequence	(5200,9230)		
…			
Item I			
>Field of View Sequence	(0018,9432)		
Item 1			
>>Field of View Shape	(0018,1147)	= **RECTANGLE**	= **RECTANGLE**
>>Field of View Dimension(s) in Float	(0018,9461)	= **170.0\170.0**	= **400.0\400.0**
>>Field of View Origin	(0018,7030)	= **600.0\600.0**	= **25.0\25.0**
>>Field of View Rotation	(0018,7032)	= **90**	= **180**
>>Field of View Horizontal Flip	(0018,7034)	= **YES**	= **NO**
>Frame Pixel Data Properties Sequence	(0028,9443)		
Item 1			
>>Imager Pixel Spacing	(0018,1164)	= **0.2\0.2**	= **0.4\0.4**
>Isocenter Reference System Sequence	(0018,9462)		
Item 1			
>>Positioner Isocenter Primary Angle	(0018,9463)	= **60.0**	= **-30.0**
>>Positioner Isocenter Secondary Angle	(0018,9464)	= **20.0**	= **0.0**
>>Positioner Isocenter Detector Rotation Angle	(0018,9465)	= **0.0**	= **0.0**
>>Table X Position to Isocenter	(0018,9466)	= **10.0**	= **20.0**
>>Table Y Position to Isocenter	(0018,9467)	= **30.0**	= **100.0**
>>Table Z Position to Isocenter	(0018,9468)	= **100.0**	= **0.0**
>>Table Horizontal Rotation Angle	(0018,9469)	= **-10**	= **0.0**
>>Table Head Tilt Angle	(0018,9470)	= **0.0**	= **10.0**
>>Table Cradle Tilt Angle	(0018,9471)	= **0.0**	= **0.0**
>X-Ray Geometry Sequence	(0018,9476)		

Item 1			
>>Distance Source to Isocenter	(0018,9402)	= **780.0**	= **800.0**
>>Distance Source to Detector	(0018,1110)	= **1300.0**	= **1000.0**
…			

Figure Z.2.5-1
Attributes of the example of tracking an object of interest on multiple 2D images

The following steps describe the process to calculate the position $\mathbf{(i, j)_B}$ of the projection of the object of interest in the Pixel Data of the image B, assuming that $\mathbf{(i, j)_A}$ is known and is the offset of the projection of the object of interest from the TLHC of the Pixel Data of the image A, measured in pixels of the Pixel Data matrix as a column offset "i" followed by a row offset "j". TLHC is defined as (0,0).

Step 1: Calculate the point $(i, j)_A$ in FOV coordinates of the image A.

Step 2: Calculate the point $(i, j)_A$ in physical detector coordinates of the image A.

Step 3: Calculate the point $(P_u , P_v)_A$ in positioner coordinates of the image A.

Step 4: Calculate the point $(P_{Xp}, P_{Yp}, P_{Zp})_A$ in positioner coordinates of the image A.

Step 5: Calculate the point $(P_X, P_Y, P_Z)_A$ in Isocenter coordinates of the image A.

Step 6: Calculate the point $(P_{Xt}, P_{Yt}, P_{Zt})_A$ in Table coordinates of the image A.

Step 7: Calculate the point $(P_{Xt}, P_{Yt}, P_{Zt})_B$ in Table coordinates in mm of the image B.

Step 8: Calculate the point $(P_X, P_Y, P_Z)_B$ in Isocenter coordinates in mm of the image B.

Step 9: Calculate the point $(P_{Xp}, P_{Yp}, P_{Zp})_B$ in positioner coordinates of the image B.

Step 10: Calculate the point $(P_u , P_v)_B$ in positioner coordinates of the image B.

Step 11: Calculate the point $(i, j)_B$ in physical detector coordinates of the image B.

Step 12: Calculate the point $(i, j)_B$ in FOV coordinates of the image B.

Step 13: Calculate the point $(i, j)_B$ in Pixel Data of the image B.

In this example let's assume:

$\mathbf{(i, j)_A = (310,122)}$ pixels

Magnification ratio = 1.3

Step 1: Image A: Point $\mathbf{(i, j)_A}$ in FOV coordinates

In this step, the FOV coordinates are calculated by taking into account the FOV rotation and Horizontal Flip applied to the FOV matrix when the Pixel Data were created:

1.1: Horizontal Flip: YES

new i = (columns -1) - i = 850 - 1 - 310 = 539

new j = j = 122

1.2: Image Rotation: 90 (clockwise)

new i = j = 122

new j = (columns -1) - i = 850 - 1 - 539 = 310

$(i, j)_A$ = (122, 310) in stored pixel data.

<u>Step 2</u>: Image A: Point $(i, j)_A$ in physical detector coordinates

In this step, the physical detector coordinates are calculated by taking into account the FOV origin and the ratio between Imager Pixel Spacing and Detector Element Spacing:

Δ_i = Imager Pixel Spacing (column)	= 0.2 mm
Δ_j = Imager Pixel Spacing (row)	= 0.2 mm
Δ_{idet} = Detector Element Spacing between two adjacent columns	= 0.2 mm
Δ_{jdet} = Detector Element Spacing between two adjacent rows	= 0.2 mm
Zoom Factor (column) = Δ_i / Δ_{idet}	= 1.0
Zoom Factor (row) = Δ_j / Δ_{jdet}	= 1.0
FOV Origin (column) = FOV_{idet}	= 600.0
FOV Origin (row) = FOV_{jdet}	= 600.0
new i = $FOV_{idet} + (i + (1 - \Delta_{idet} / \Delta_i) / 2) * \Delta_j / \Delta_{jdet}$ = 600 + 122 * 1.0	= 722
new j = $FOV_{jdet} + (j + (1 - \Delta_{jdet} / \Delta_j) / 2) * \Delta_i / \Delta_{idet}$ = 600 + 310 * 1.0	= 910

$(i, j)_A$ = (722, 910) in detector elements.

<u>Step 3</u>: Image A: Point $(P_u , P_v)_A$ in positioner coordinates

In this step, the $(P_u , P_v)_A$ coordinates in mm are calculated from $(i, j)_A$ by taking into account the projection of the Isocenter in physical detector coordinates, and the Detector Element Spacing:

ISO_P_{idet} = Position of Isocenter Projection (column)	= 1024.5
ISO_P_{jdet} = Position of Isocenter Projection (row)	= 1024.5
Δ_{idet} = Detector Element Spacing between two adjacent columns	= 0.2 mm
Δ_{jdet} = Detector Element Spacing between two adjacent rows	= 0.2 mm

$Pu = (i – ISO\_P_{idet}) * \Delta_{idet} = (722 – 1024.5) * 0.2$ = -60.5 mm

$Pv = (ISO\_P_{jdet} - j) * \Delta_{jdet} = (1024.5 - 910) * 0.2$ = 22.9 mm

$(P_u , P_v)_A$ = (-60.5, 22.9) in mm.

<u>Step 4: Image A: Point (PXp, PYp, PZp)A in positioner coordinates</u>

In this step, the positioner coordinates $(P_{Xp}, P_{Yp}, P_{Zp})_A$ are calculated from $(P_u , P_v)_A$ by taking into account the magnification ratio, the Distance Source to Detector and the Distance Source to Isocenter:

SID = Distance Source to Detector = 1300 mm

ISO = Distance Source to Isocenter = 780 mm

Magnification ratio = SID / (ISO - P_{Yp}) = 1.3

P_{Yp} = ISO – SID / 1.3 = 780 – 1300/1.3 = -220 mm

P_{Xp} = Pu / Magnification ratio = -60.5 / 1.3 = -46.54 mm

P_{Zp} = Pv / Magnification ratio = 22.9 / 1.3 = 17.62 mm

$(P_{Xp}, P_{Yp}, P_{Zp})_A$ = (-46.54, -220, 17.62) in mm.

<u>Step 5</u>: Image A: Point $(P_X, P_Y, P_Z)_A$ in Isocenter coordinates

In this step, the isocenter coordinates $(P_X, P_Y, P_Z)_A$ are calculated from the positioner coordinates $(P_{Xp}, P_{Yp}, P_{Zp})_A$ by taking into account the positioner angles of the image A in the Isocenter coordinate system:

Ap_1 = Positioner Isocenter Primary Angle = 60.0 deg

Ap_2 = Positioner Isocenter Secondary Angle = 20.0 deg

Ap_3 = Positioner Isocenter Detector Rotation Angle = 0.0 deg

$$R_1 = \begin{pmatrix} \cos(Ap_1) & \sin(Ap_1) & 0 \\ -\sin(Ap_1) & \cos(Ap_1) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(Ap_2) & -\sin(Ap_2) \\ 0 & \sin(Ap_2) & \cos(Ap_2) \end{pmatrix}$$

$$R_3 = \begin{pmatrix} \cos(Ap_3) & 0 & -\sin(Ap_3) \\ 0 & 1 & 0 \\ \sin(Ap_3) & 0 & \cos(Ap_3) \end{pmatrix}$$

$$(P_X, P_Y, P_Z)^T = (R_2 \bullet R_1)^T \bullet (R_3^T \bullet (P_{Xp}, P_{Yp}, P_{Zp})^T)$$

$(P_X, P_Y, P_Z)_A$ = (150.55, -65.41, 91.80) in mm.

<u>Step 6</u>: Image A: Point $(P_{Xt}, P_{Yt}, P_{Zt})_A$ in Table coordinates

In this step, the table coordinates $(P_{Xt}, P_{Yt}, P_{Zt})_A$ are calculated from the isocenter coordinates $(P_X, P_Y, P_Z)_A$ by taking into account the table position and angles of the image A in the Isocenter coordinate system:

Tx = Table X Position to Isocenter	= 10.0 mm
Ty = Table Y Position to Isocenter	= 30.0 mm
Tz = Table Z Position to Isocenter	= 100.0 mm
At_1 = Table Horizontal Rotation Angle	= -10.0 deg
At_2 = Table Head Tilt Angle	= 0.0 deg
At_3 = Table Cradle Tilt Angle	= 0.0 deg

$$R_1 = \begin{pmatrix} \cos(At_1) & 0 & -\sin(At_1) \\ 0 & 1 & 0 \\ \sin(At_1) & 0 & \cos(At_1) \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(At_2) & \sin(At_2) \\ 0 & -\sin(At_2) & \cos(At_2) \end{pmatrix}$$

$$R_3 = \begin{pmatrix} \cos(At_3) & -\sin(At_3) & 0 \\ \sin(At_3) & \cos(At_3) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$(P_{Xt}, P_{Yt}, P_{Zt})^T = (R_3 \bullet R_2 \bullet R_1) \bullet ((P_X, P_Y, P_Z)^T - (T_X, T_Y, T_Z)^T)$$

$(P_{Xt}, P_{Yt}, P_{Zt})_A$ = (136.99, -95.41, -32.48) in mm.

<u>Step 7</u>: Image B: Point $(P_{Xt}, P_{Yt}, P_{Zt})_B$ in Table coordinates

In this step, the table has moved from image A to image B. The table coordinates of the object of interest are the same on image A and image B because it is assumed that the patient is fixed on the table.

$(P_{Xt}, P_{Yt}, P_{Zt})_B$ = (136.99, -95.41, -32.48) in mm.

<u>Step 8</u>: Image B: Point $(P_X, P_Y, P_Z)_B$ in Isocenter coordinates

In this step, the isocenter coordinates $(P_X, P_Y, P_Z)_B$ are calculated from the table coordinates $(P_{Xt}, P_{Yt}, P_{Zt})_B$ by taking into account the table position and angles of the image B in the Isocenter coordinate system:

Tx = Table X Position to Isocenter = 20.0 mm

Ty = Table Y Position to Isocenter = 100.0 mm

Tz = Table Z Position to Isocenter = 0.0 mm

At_1 = Table Horizontal Rotation Angle = 0.0 deg

At_2 = Table Head Tilt Angle = 10.0 deg

At_3 = Table Cradle Tilt Angle = 0.0 deg

$$(P_X, P_Y, P_Z)^T = (R_3 \bullet R_2 \bullet R_1)^T \bullet (P_{Xt}, P_{Yt}, P_{Zt})^T + (T_X, T_Y, T_Z)^T$$

$(P_X, P_Y, P_Z)_B$ = (156.99, -12.11, -48.55) in mm.

<u>Step 9</u>: Image B: Point $(P_{Xp}, P_{Yp}, P_{Zp})_B$ in positioner coordinates

In this step, the positioner coordinates $(P_{Xp}, P_{Yp}, P_{Zp})_B$ are calculated from the isocenter coordinates $(P_X, P_Y, P_Z)_B$ by taking into account the positioner angles of the image B in the Isocenter coordinate system:

Ap_1 = Positioner Isocenter Primary Angle = -30.0 deg

Ap_2 = Positioner Isocenter Secondary Angle = 0.0 deg

Ap_3 = Positioner Isocenter Detector Rotation Angle = 0.0 deg

$$(P_{Xp}, P_{Yp}, P_{Zp})^T = R_3 \bullet ((R_2 \bullet R_1) \bullet (P_X, P_Y, P_Z)^T)$$

$(P_{Xp}, P_{Yp}, P_{Zp})_B$ = (142.01, 68.00, -48.55) in mm.

<u>Step 10</u>: Image B: Point $(P_u , P_v)_B$ in positioner coordinates

In this step, the $(P_u , P_v)_B$ coordinates in mm are calculated from the positioner coordinates $(P_{Xp}, P_{Yp}, P_{Zp})_B$ by taking into account the Distance Source to Detector and the Distance Source to Isocenter of the image B:

SID = Distance Source to Detector	= 1000 mm
ISO = Distance Source to Isocenter	= 800 mm
Magnification ratio = SID / (ISO - P_{Yp}) = 1200/(800-68)	= 1.366
Pu = P_{Xp} * Magnification ratio = 142.01 * 1.64	= 194.00 mm
Pv = P_Zp * Magnification ratio = -48.55 * 1.64	= -66.33 mm

$(P_u , P_v)_B$ = (194.00, -66.33) in mm.

<u>Step 11</u>: Image B: Point $(i, j)_B$ in physical detector coordinates

In this step, the physical detector coordinates **$(i, j)_B$** are calculated from the positioner coordinates **$(P_u, P_v)_B$** by taking into account the projection of the Isocenter in physical detector coordinates, and the Detector Element Spacing of the image B:

ISO_P_{idet} = Position of Isocenter Projection (column)	= 1024.5
ISO_P_{jdet} = Position of Isocenter Projection (row)	= 1024.5
Δ_{idet} = Detector Element Spacing between two adjacent columns	= 0.2
Δ_{jdet} = Detector Element Spacing between two adjacent rows	= 0.2
i = ISO_P_{idet} + Pu / Δ_{idet} = 1024.5 + 194.00 / 0.2	= 1994.5
j = ISO_P_{idet} - Pv / Δ_{idet} = 1024.5 - (-66.33) / 0.2	= 1356.2

$(i, j)_B$ = (1994.5, 1356.2) in detector elements.

<u>Step 12</u>: Image B: Point $(i, j)_B$ in FOV coordinates

In this step, the FOV coordinates are calculated from the physical detector coordinates by taking into account the FOV origin and the ratio between Imager Pixel Spacing and Detector Element Spacing of the image B:

Δ_i = Imager Pixel Spacing (column)	= 0.4 mm

Δ_j = Imager Pixel Spacing (row) = 0.4 mm

Δ_{idet} = Detector Element Spacing between two adjacent columns = 0.2 mm

Δ_{jdet} = Detector Element Spacing between two adjacent rows = 0.2 mm

Zoom Factor (column) = Δ_i / Δ_{idet} = 2.0

Zoom Factor (row) = Δ_j / Δ_{jdet} = 2.0

FOV Origin (column) = FOV_{idet} = 25.0

FOV Origin (row) = FOV_{jdet} = 25.0

new i = $(i - FOV_{idet}) \cdot \Delta_{idet} / \Delta_i - (1 - \Delta_{idet} / \Delta_i) / 2$ = (1994.5 - 25.0) / 2.0 - 0.25 = 984.5

new j = $(j - FOV_{jdet}) \cdot \Delta_{jdet} / \Delta_j - (1 - \Delta_{jdet} / \Delta_j) / 2$ = (1356.2 - 25.0) / 2.0 - 0.25 = 665.35

$(i, j)_B$ = (984.50, 665.35) in stored pixel data.

<u>Step 13</u>: Image B: Point $(i, j)_B$ in Pixel Data

In this step, the position **$(i, j)_B$** of the projection of the object of interest in the Pixel Data of the image B is calculated from the FOV coordinates by taking into account the FOV rotation and Horizontal Flip applied to the FOV matrix when the Pixel Data were created:

1.1: Horizontal Flip: NO

new i = i = 984.50

new j = j = 665.35

1.2: Image Rotation: 180 (clockwise)

new i = (columns -1) - i = 1000 - 1 - 984.50 = 14.50

new j = (rows -1) - j = 1000 - 1 - 665.35 = 333.65

$(i, j)_B$ = (14.50, 333.65) in stored pixel data.