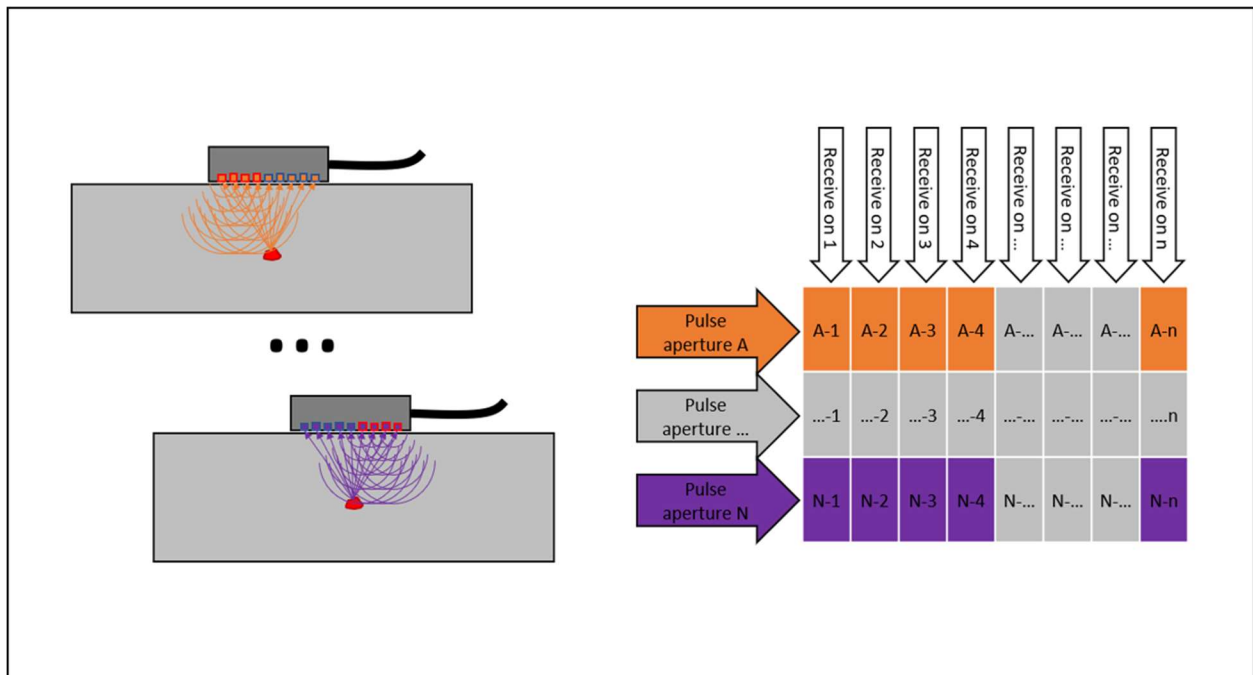


# UltraVision Classic

How To Guide – Release 3.11R4 & Higher

## *Live Plane Wave Imaging with EMERALD and TOPAZ64*



## Revision History

<i>Revision</i>	<i>Modifications</i>	<i>Date</i>
1	Original	2021.11.02
2	Added PWI with DMA probes	2023.04.05

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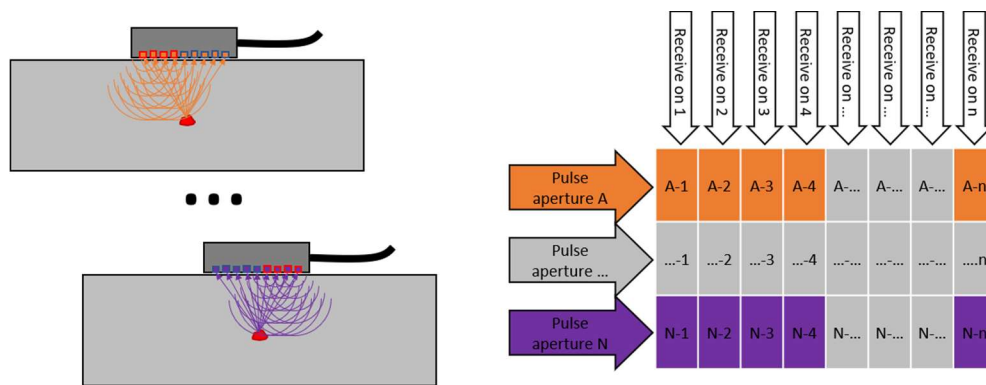
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# 1 Introduction on Plane Wave Imaging

Both the new **EMERALD** remote data acquisition unit, and the **TOPAZ<sup>64</sup>** integrated phased array unit (HR and HR-D models) have the capability to perform Plane Wave Imaging (PWI) data recording, when controlled by UltraVision Classic, version 3.11R4 or higher.

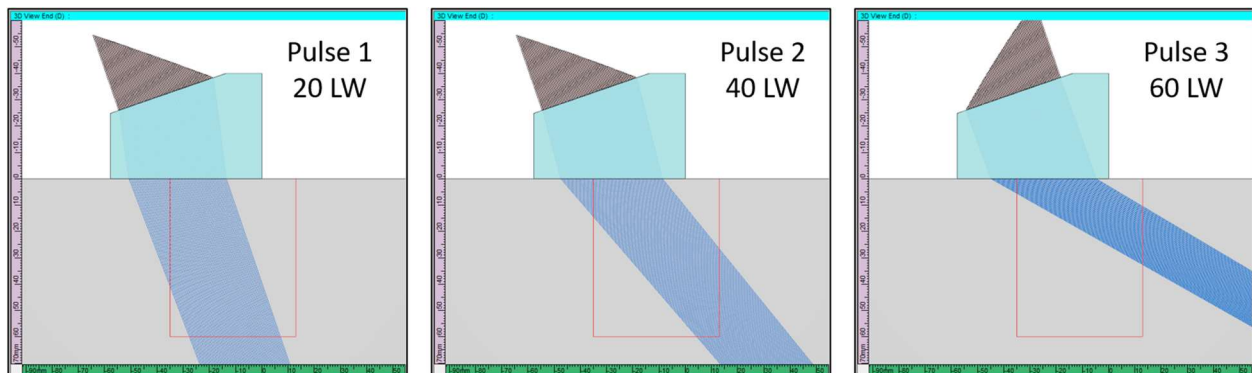
Plane Wave Imaging (PWI) is an alternative firing technique that uses a multi-element aperture for pulsing, instead of firing each element individually like Full Matrix Capture (FMC).

The PWI firing sequence consists of one or more focal laws, with varying angle and/or aperture.



The receiving process is done with each element individually, and a TFM frame is processed from the raw data. Live PWI-TFM imaging is done during inspection, and the encoded data can be saved just like for regular phased array UT or live TFM.

The principles of PWI-TFM imaging are further illustrated by this simple example (see figure below).



Three pulses are fired sequentially using the full aperture of the probe, and with three different refracted angles. The region of interest (shown in red) is essentially covered by the three naturally focused beams.

After each pulse, the raw A-scans from the reception by each individual element of the probe will be collected and will be processed to generate a TFM image. Obviously, by firing more pulses at a wider range of angles, more and better information from the reflectors in the region of interest will be captured, and the quality of the resulting image will be very close to the classic FMC-TFM processing.

PWI data recording has several benefits compared to FMC data recording:

- The emitted pulse from the full aperture has more energy and is more directional than a single element excitation; therefore, it provides greater sensitivity and potentially better SNR
- The firing sequence is significantly shorter (# pulses vs. # probe elements), which results in a higher PRF and scanning speed
- Less elementary A-scans need to be recorded and processed

So basically, PWI has the potential to considerably increase the scanning speed, while conserving most of the benefits and the quality of classic FMC-TFM imaging.

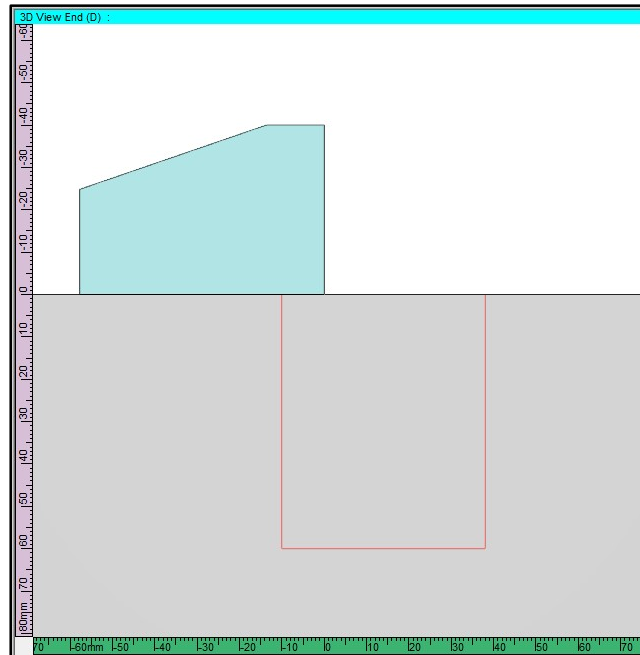
The second section of this document illustrates how the live PWI-TFM technique can be implemented in UltraVision Classic for some “Typical User Cases”. For each case the results will be compared with classic live FMC-TFM. The examples will also show how PWI-TFM can be combined with other new tools in UltraVision, TFM Envelope and Multi-mode TFM.

In the third section, “Reference Guide”, the various parameters and options will be highlighted and explained in detail.

## 2 Typical User Cases

### 2.1 1D-Linear Probe, LW Wedge, Pulse-Echo Mode

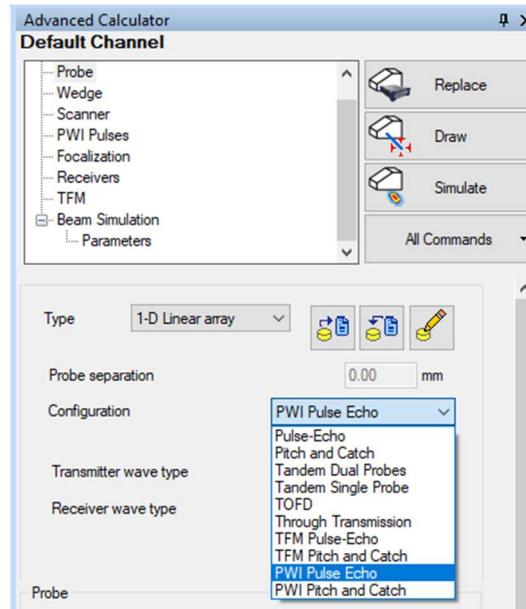
In the first user case, a standard 5 MHz linear array probe with 64 elements is used, coupled to an L-wave wedge. The region of interest is a zone of 50 mm wide and 60 mm through-wall, as shown on the figure below.



To optimize the use of the PWI-TFM technique, the operator should:

- select the refracted angle range in the firing sequence to adequately cover the region of interest.
- adjust the number of pulses to maximize PRF while maintaining good image quality compared to FMC-TFM

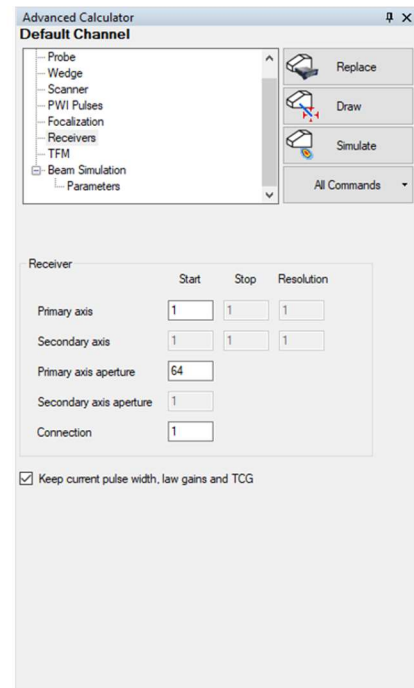
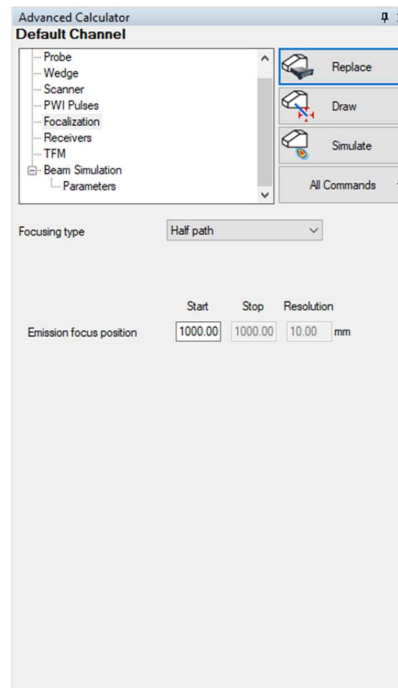
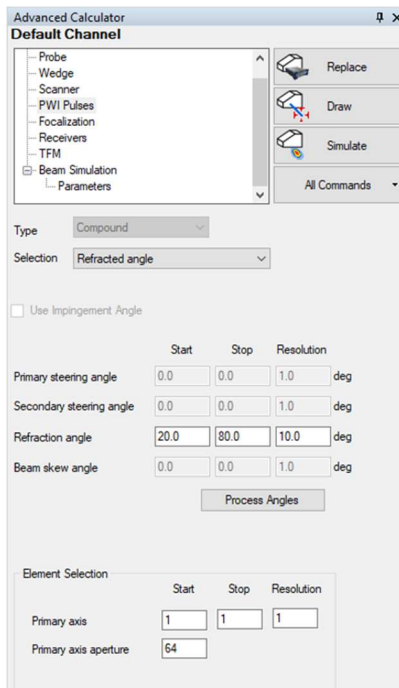
To start using the PWI technique for this probe configuration, select **Configuration PWI Pulse-Echo** in the **Probe** tab of the Advanced Calculator, and the dedicated tabs for PWI will appear.



### 2.1.1 Setting up the Firing Sequence

To set up the firing sequence, define the parameters in the **PWI Pulses**, **Focalization** and **Receivers** tabs.

In the **PWI Pulses** tab, an azimuthal sweep from 20 to 80 degrees LW has been selected, with an increment of 10 degrees. This is a total of 7 pulses. The full 64-element aperture is used for the firing.

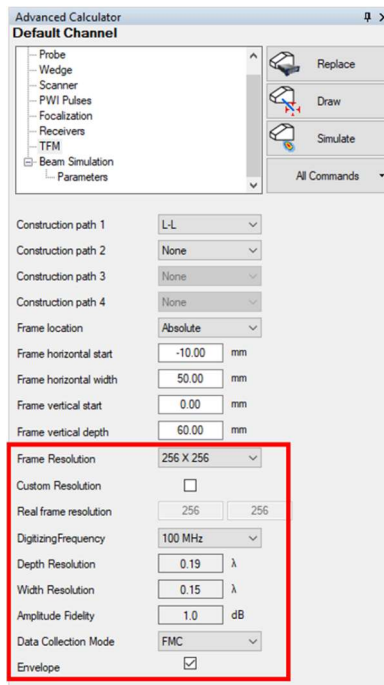


In the **Focalization** tab, the default setting is **Half path 1000 mm**, which basically corresponds to “natural focusing” of the beam or “Plane Wave” excitation.

In the **Receivers** tab, all 64 elements of the probe are selected for individual reception of signals from the various pulses fired.

### 2.1.2 Setting up the live TFM Processing

To set up the TFM processing, define the parameters in the **TFM** tab, very similar to the regular live FMC-TFM technique.

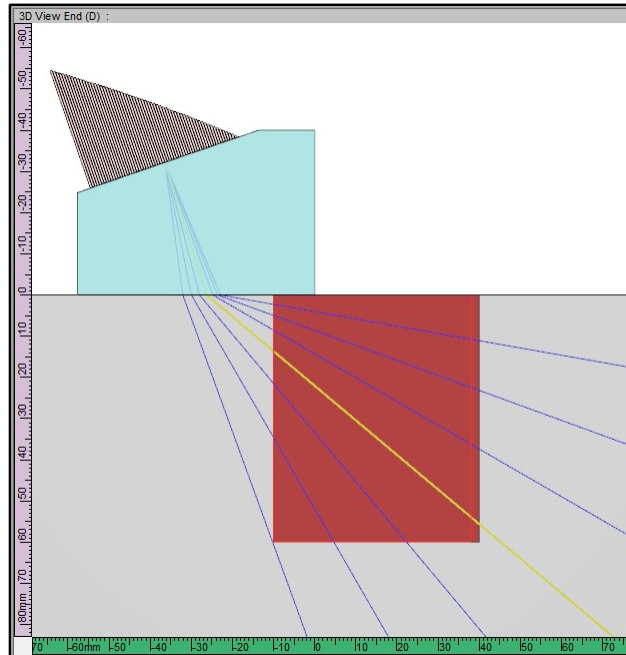


On the receiving side, a 256 by 256 TFM frame is selected. With the Envelope feature activated, this configuration provides an Amplitude Fidelity of 1.0 dB, well below the threshold of 2 dB required to be Code Compliant.

Upon hitting the **Draw** button, the Advanced Calculator will visualize the PWI-TFM configuration as shown in the image below. It can be observed that the 7 focal laws (pulses) adequately cover the region of interest where the TFM image will be generated.

And upon hitting the **Replace** button, the configuration will be applied to the acquisition unit.

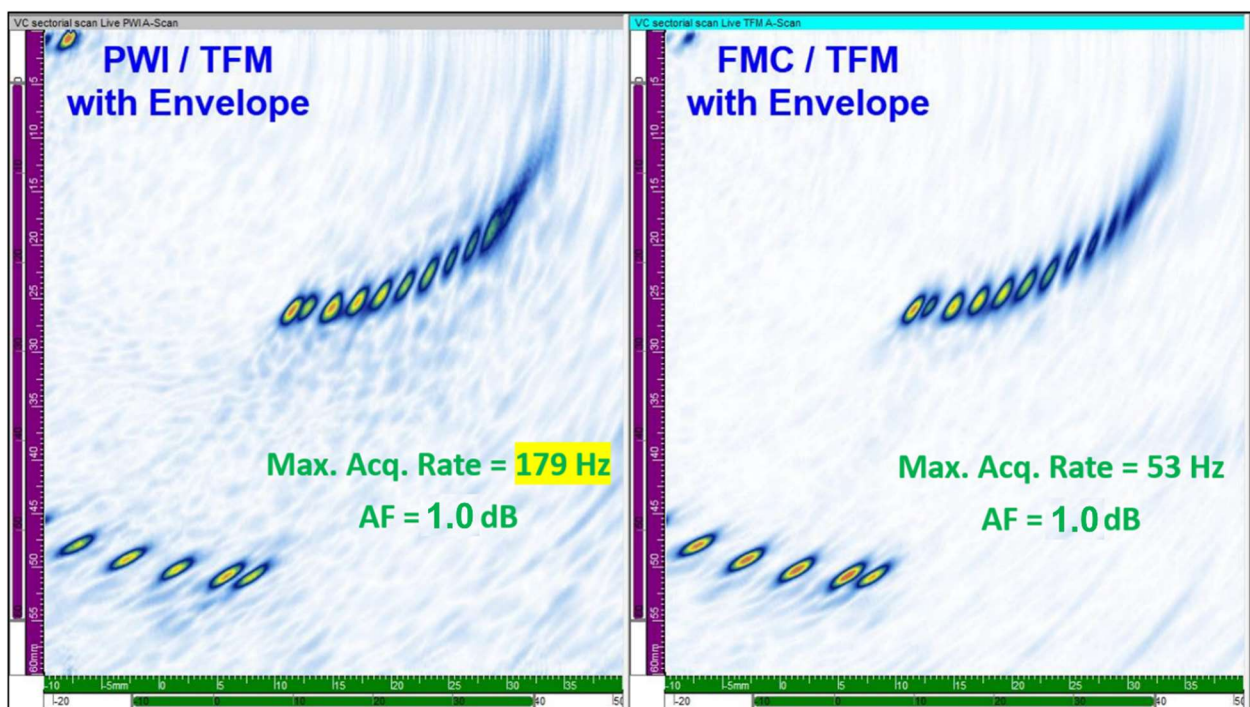


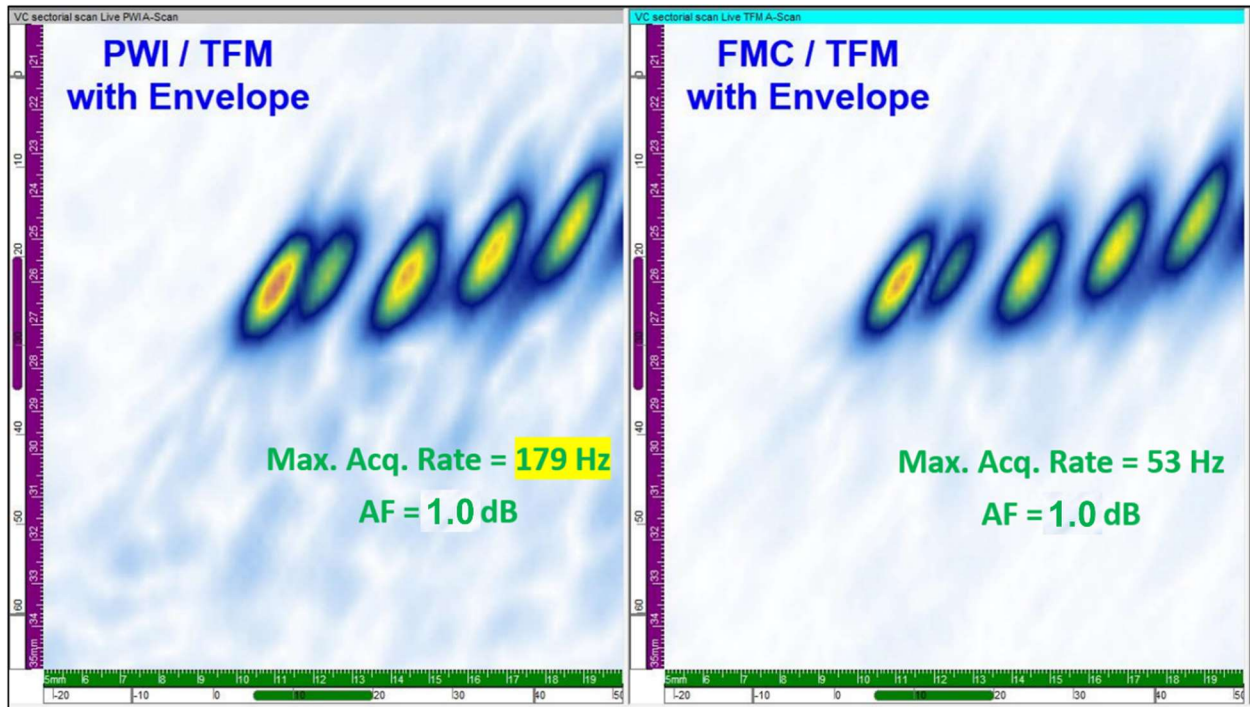


### 2.1.3 Comparison with regular live FMC-TFM

In order to verify the quality of the PWI-TFM image for the considered inspection configuration, it is very useful to compare with the regular live FMC-TFM image during the setup phase of the inspection.

The figures below shows actual images on the ASTM E2491 phased array assessment block, from the set of 1 mm diameter SDH, located on a radius of 25 mm.





The PWI-TFM images are shown on the left and the regular FMC-TFM images on the right. The Envelope feature is applied in both cases.

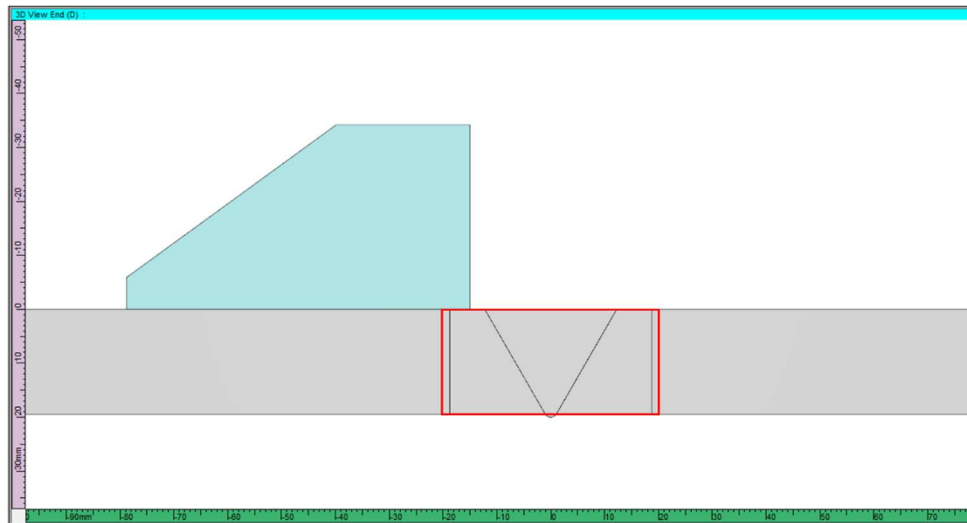
It can be observed that with only 7 laws in the PWI firing sequence, the image quality is nearly as good as for the FMC firing sequence. The two reflectors, that are barely more than 1 mm apart, can be very clearly resolved, and with an excellent SNR.

In terms of maximum inspection speed, for this example, the PWI configuration will allow to go roughly 3 times faster than live FMC-TFM.

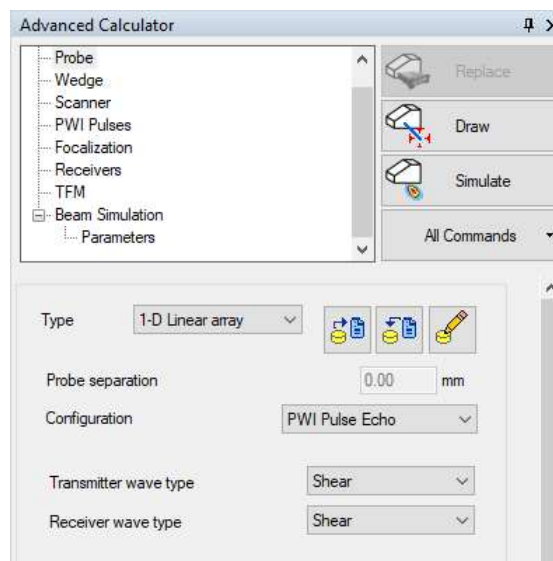
## 2.2 1D-Linear Probe, SW Wedge, Pulse-Echo Mode

The second user case is a more practical example, the examination of a 19 mm thick carbon steel weld with a V-bevel.

The same 5 MHz probe with 64 elements is used, this time with a S-wave wedge. The region of interest is the weld volume and the HAZ, as shown on the figure below. The positioning of the probe assembly relative to the WCL should essentially be like for regular PA UT, to fully benefit from second half skip insonification.



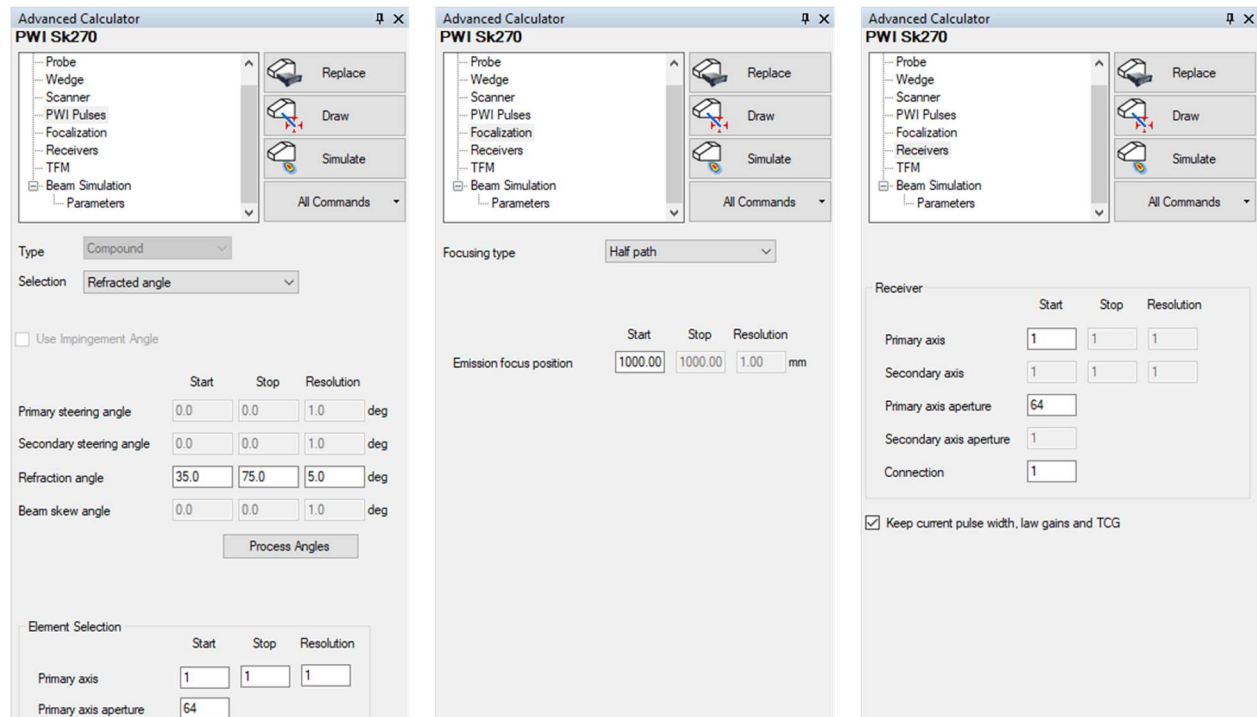
With the considered probe and wedge selection, the **Configuration PWI Pulse-Echo** is selected in the **Probe** tab of the Advanced Calculator, and the dedicated tabs for PWI appear.



### 2.2.1 Setting up the Firing Sequence – Azimuthal Sweep

To set up the firing sequence, define the parameters in the **PWI Pulses**, **Focalization** and **Receivers** tabs.

For a typical weld inspection in full skip, we have selected an azimuthal sweep with the full aperture of the probe, from 35 to 75 SW. In the **PWI Pulses** tab, the azimuthal sweep from 35 to 75 degrees SW has been defined, with an increment of 5 degrees, for a total of 9 pulses. Again, the full 64-element aperture is used for the firing.



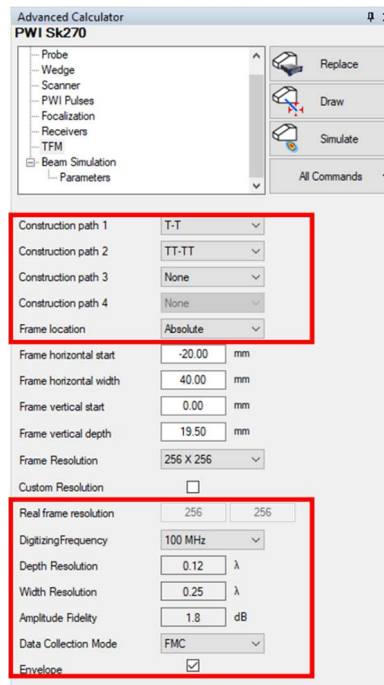
In the **Focalization** tab, the default setting is **Half path 1000 mm**, which basically corresponds to “natural focusing” of the beam or “Plane Wave” excitation.

In the **Receivers** tab, all 64 elements of the probe are selected for individual reception of signals from the various pulses fired.

### 2.2.2 Setting up the live TFM Processing – Azimuthal Sweep

To set up the TFM processing, the parameters in the **TFM** tab are selected to adequately cover the region of interest.

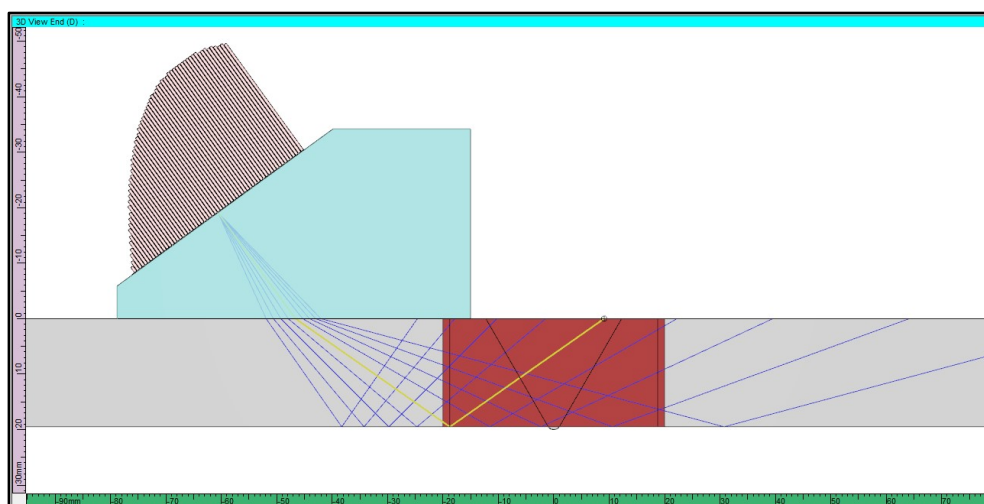
As shown on the figure below, a 256 by 256 TFM frame is selected, with the Envelope feature activated. This configuration provides an Amplitude Fidelity of 1.8 dB, just below the threshold of 2 dB.



It can also be observed that the UltraVision Classic software now allows to select and process multiple (up to 4) reconstruction paths for a single FMC or PWI firing sequence. In this user case, 2 reconstruction paths have been selected:

- T-T reconstruction, representing examination in the first half skip
- TT-TT reconstruction, representing examination after skipping off the back-wall of the component

Upon hitting the **Draw** button, the Advanced Calculator will visualize the PWI-TFM configuration as shown in the image below. It can be observed that the 9 focal laws (pulses) adequately cover the region of interest where the TFM image will be generated, by using both first and second half skip insonification.



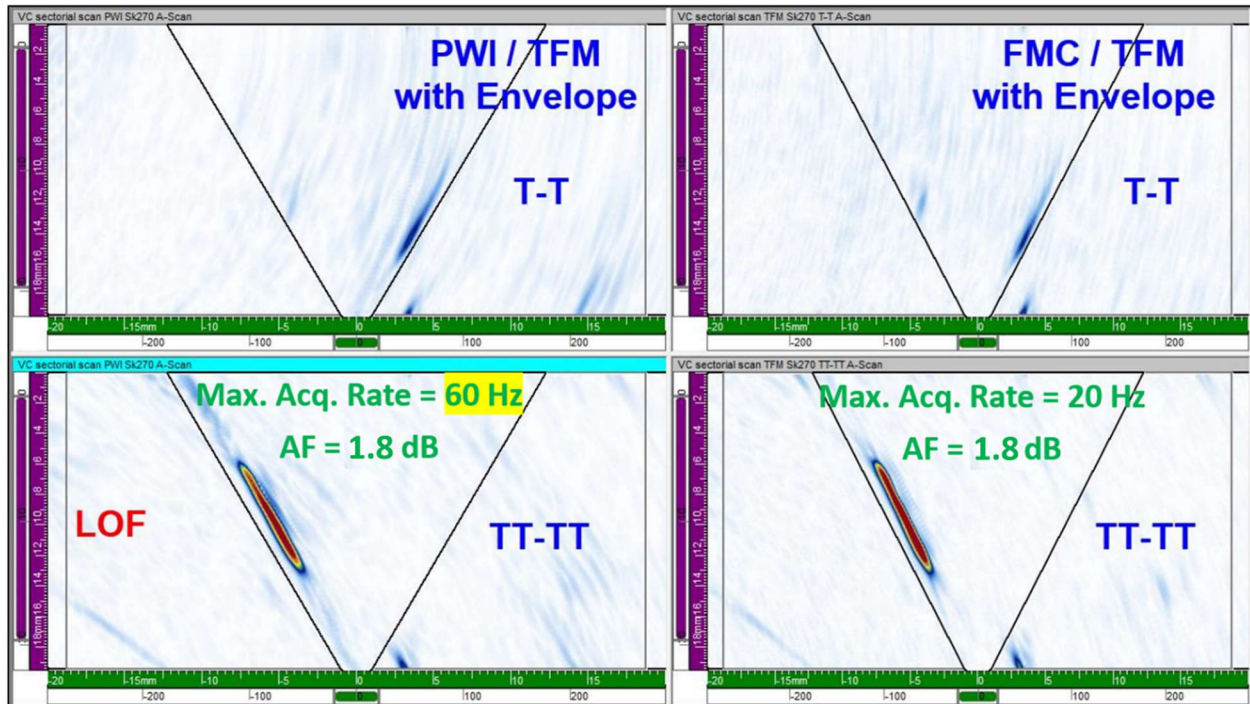
And upon hitting the **Replace** button, the configuration is applied to the acquisition unit.



### 2.2.3 Comparison with regular live FMC-TFM

As mentioned in the previous user case, it is “good practice” to compare the PWI-TFM image with the regular live FMC-TFM image when optimizing the inspection configuration.

The figures below show actual images of a lack-of-fusion defect in the considered carbon steel weld.



On the left side of the images, the T-T and TT-TT reconstruction modes from the PWI firing sequence are shown, and on the right the same wave modes for the regular FMC-TFM.

The image resolution for the PWI firing sequence with 9 pulses is very close to the FMC-TFM result. The two realistic flaws are clearly detected and visualized with excellent resolution.

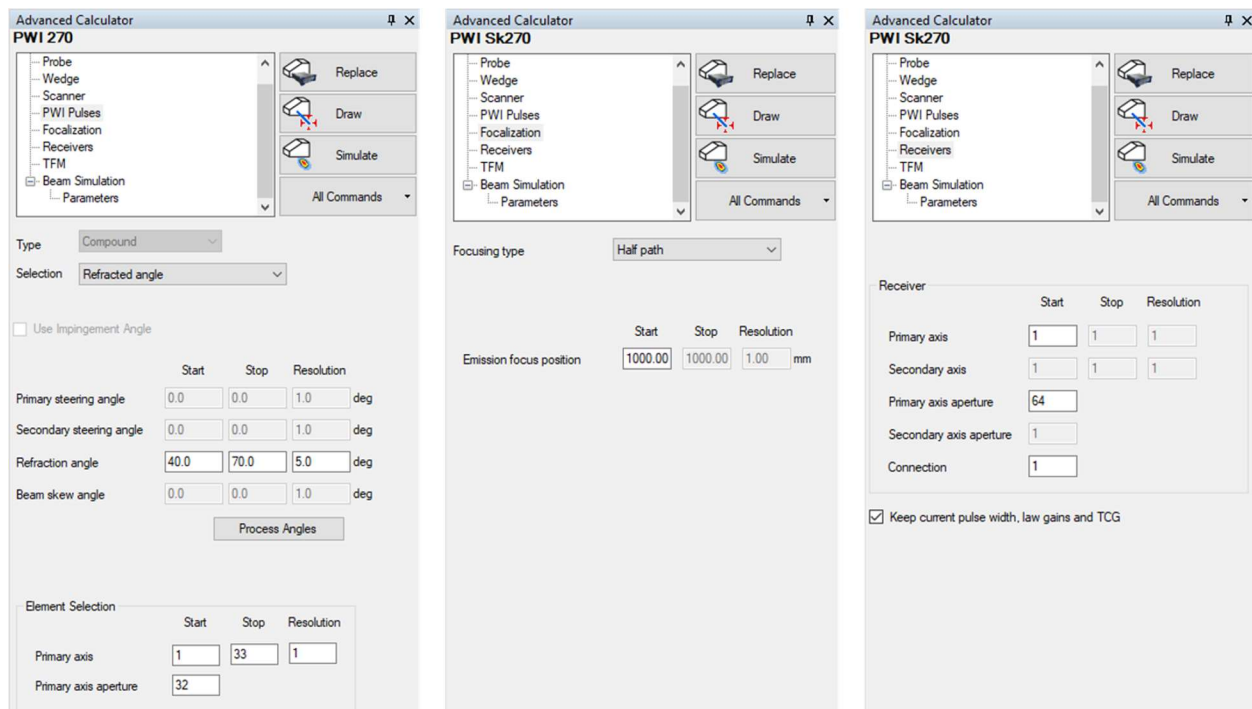
As for the increase in inspection speed, with the EMERALD phased array unit, an encoded inspection with two-sided PWI and both reconstruction modes can be performed at 60 mm per second. This is three times faster than with regular FMC-TFM.

### 2.2.4 Setting up the Firing Sequence – Compound Sweep

To set up the firing sequence, define the parameters in the **PWI Pulses**, **Focalization** and **Receivers** tabs.

In the **PWI Pulses** tab, we have now selected a compound sweep with a partial aperture of 32 elements, and from 40 to 70 SW with an increment of 5 degrees. We can select less angles and still cover when using the compound sweep. In this case we have a total of 7 laws.

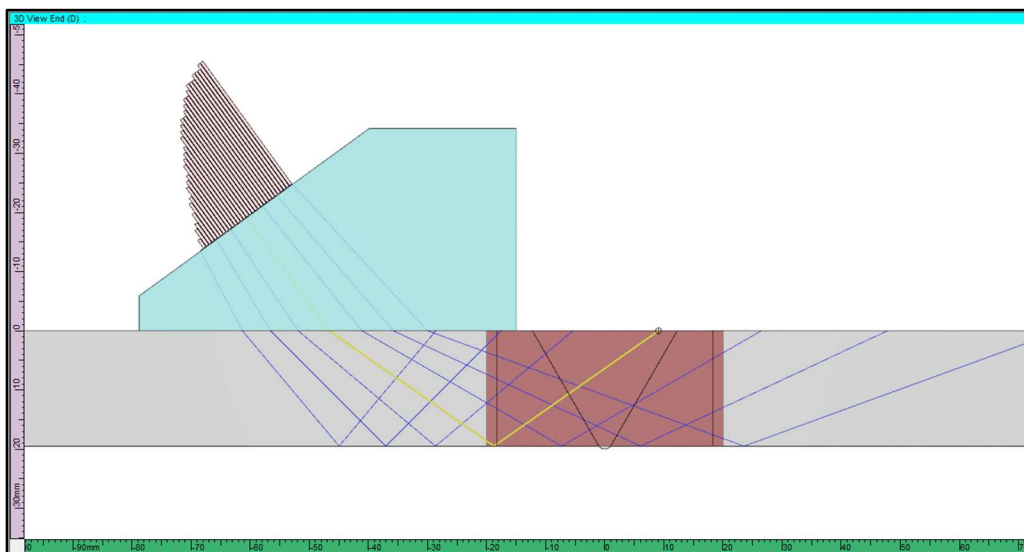
No changes were made in the **Focalization** tab and the **Receivers** tab compared to § 2.1.



## 2.2.5 Setting up the live TFM Processing – Compound Sweep

The same parameters in the **TFM** tab are selected as in § 2.2.2

Upon hitting the **Draw** button, the Advanced Calculator will visualize the PWI-TFM configuration as shown in the image below. It can be observed that the 7 focal laws (pulses) adequately cover the region of interest where the TFM image will be generated, by using both first and second half skip insonification.



And upon hitting the **Replace** button, the configuration is applied to the acquisition unit.

## 2.3 Dual 2D-Matrix Array (DMA), TRL Wedge, Pitch & Catch Mode

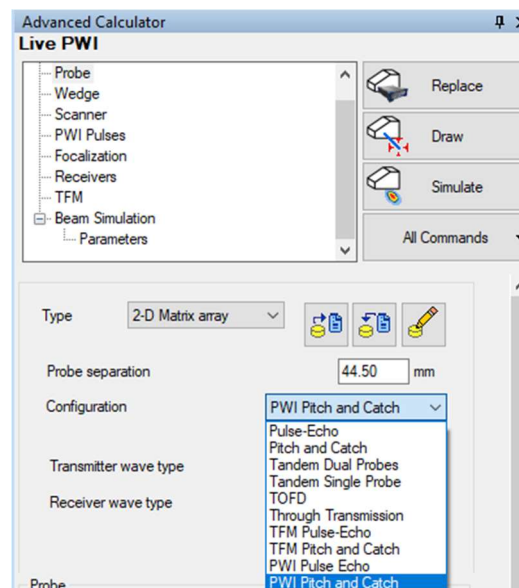
In the last user case, a dual 2D-matrix array (DMA) probe at 1.5 MHz is considered. Both transmitter and receiver are 10 x 6 element arrays, and coupled to a TRL wedge. The region of interest is a zone of 50 mm wide and 60 mm through-wall.

This low-frequency probe is used to detect simulated branched cracks in a stainless steel specimen with a wall thickness of 50 mm.

To optimize the use of the PWI-TFM technique, the operator should:

- select the refracted angle range in the firing sequence to adequately cover the region of interest.
- adjust the skew angle of the PWI pulses; this is important for DMA probes, because the acoustic energy needs to be directed towards the region of interest in the middle of the transmitter and the receiver probes (see § 3. Reference Guide)
- adjust the emission focus position; this is to ensure that the acoustic energy is focused in the region of interest in the middle of the transmitter and the receiver probe
- adjust the number of pulses to maximize PRF while maintaining good image quality compared to FMC-TFM

To start using the PWI technique for a DMA probe, select **Configuration PWI Pitch and Catch** in the **Probe** tab of the Advanced Calculator, and the dedicated tabs for PWI will appear.



### 2.3.1 Setting up the Firing Sequence

To set up the firing sequence, define the parameters in the **PWI Pulses**, **Focalization** and **Receivers** tabs.

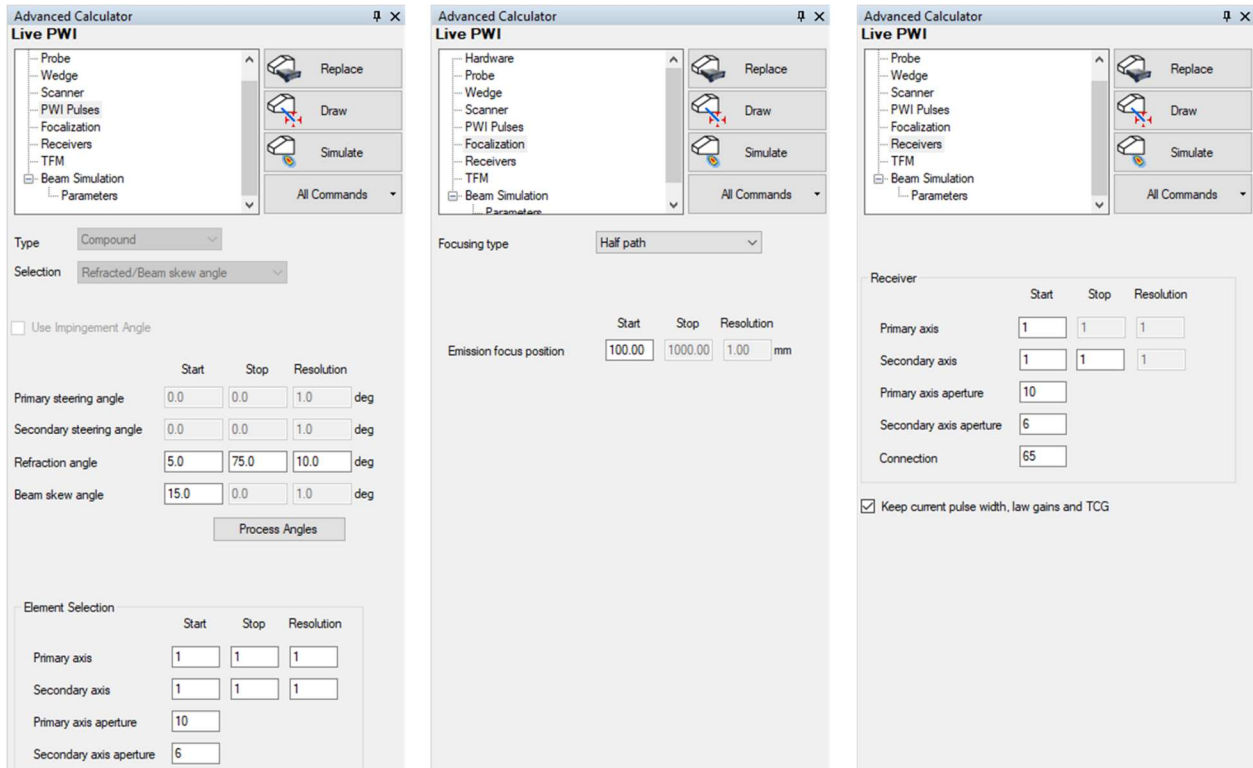
In the **PWI Pulses** tab, an azimuthal sweep from 5 to 75 degrees LW has been selected, with an increment of 10 degrees. This is a total of 8 pulses. A skew angle of a 15 degrees is used to ensure appropriate



insonification of the region of interest. The full 60-element aperture of the transmitter probe is used for the firing.

In the **Focalization** tab, the **Emission focus position** is set to **Half path 100 mm**, to ensure appropriate insonification of the region of interest.

In the **Receivers** tab, all 60 elements of the receiver probe are selected for individual reception of signals from the various pulses fired.



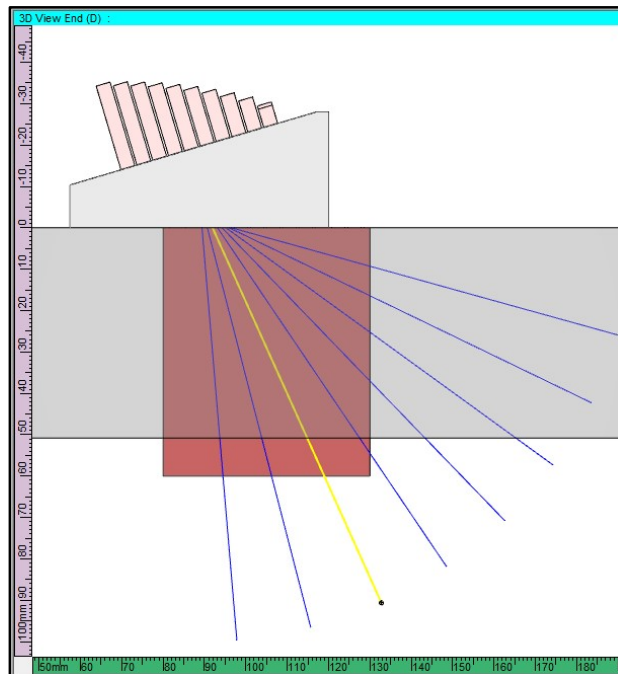
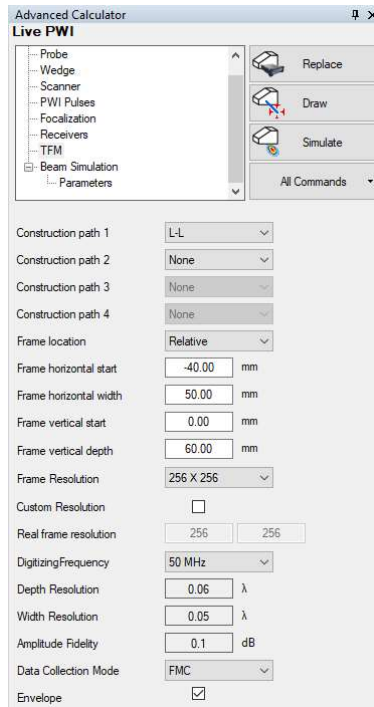
### 2.3.2 Setting up the live TFM Processing

To set up the TFM processing, define the parameters in the **TFM** tab, very similar to the regular live FMC-TFM technique.

On the receiving side, a 256 by 256 TFM frame is selected. With the Envelope feature activated, this configuration provides an Amplitude Fidelity of 0.1 dB.

Upon hitting the **Draw** button, the Advanced Calculator will visualize the PWI-TFM configuration as shown in the image below. It can be observed that the 8 focal laws (pulses) adequately cover the region of interest where the TFM image will be generated.

And upon hitting the **Replace** button, the configuration will be applied to the acquisition unit.



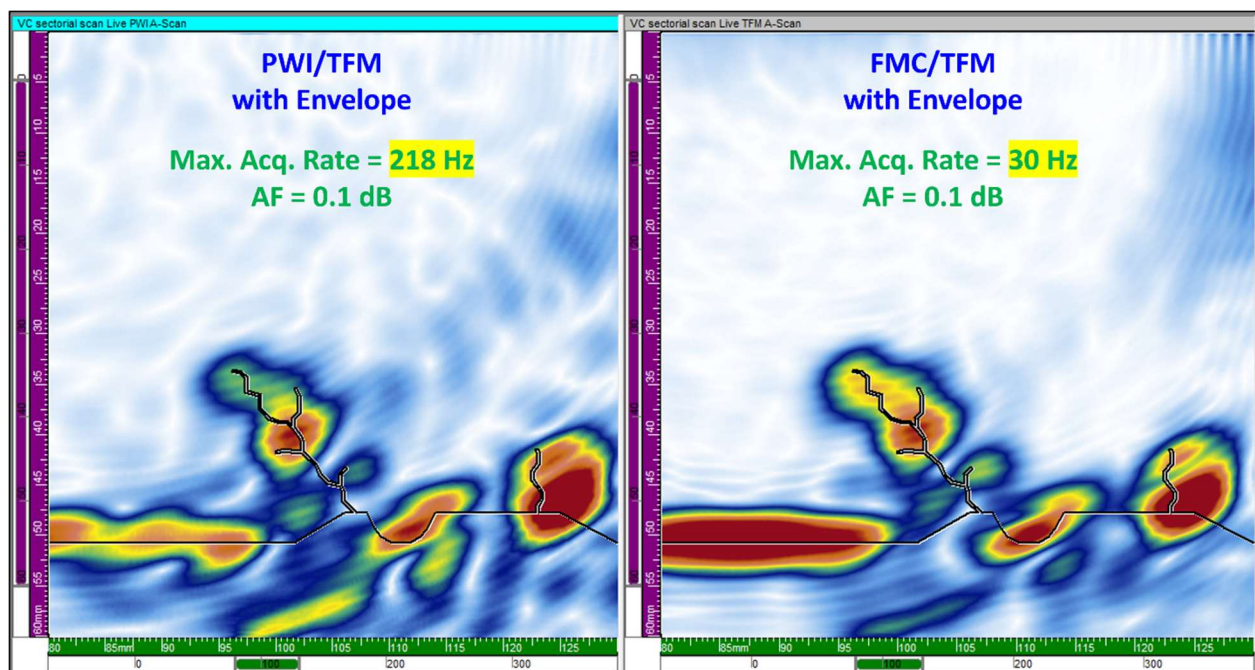
### 2.3.3 Comparison with regular live FMC-TFM

In order to verify the quality of the PWI-TFM image for the considered inspection configuration, it is very useful to compare with the regular live FMC-TFM image during the setup phase of the inspection.

The figures below shows actual images on the stainless steel specimen. A dedicated DXF overlay is used to illustrate the imaging capability of the PWI-TFM and the FMC-TFM techniques when using well-selected probes, even at this low frequency.

The PWI-TFM images are shown on the left and the regular FMC-TFM images on the right. The Envelope feature is applied in both cases.

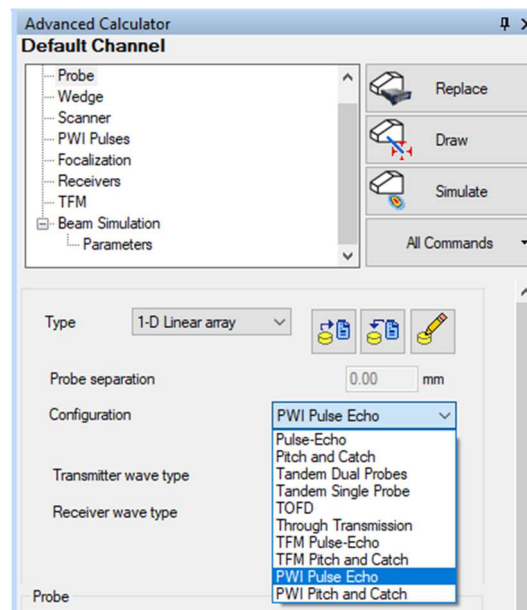
It can be observed that with only 8 laws in the PWI firing sequence, the image quality is nearly as good as for the FMC firing sequence. But in terms of maximum inspection speed, for this example, the PWI configuration will allow to go roughly 7 times faster than live FMC-TFM.



## 3 Reference Guide

### 3.1 Selecting a PWI Configuration

To start using the PWI technique, select either **Configuration PWI Pulse-Echo** or **Configuration PWI Pitch and Catch** in the **Probe** tab of the Advanced Calculator, and the dedicated tabs for PWI will appear.



### 3.2 Configuring the PWI

#### 3.2.1 PWI Pulses Tab

In the **PWI Pulses** tab, the operator can define the sweep of refracted angles and the active aperture of the firing sequence.

The **Type** of the sweep will always indicate **Compound**, but the UI allows to define:

- An **azimuthal sweep**, when using a fixed active aperture (**Element Selection Start** and **Stop** values are the same), as shown on the left side of the image below; the active aperture can be either the complete aperture or a partial aperture
- A **compound sweep**, when using a moving active aperture (**Element Selection Start** value is smaller than **Stop** value), as shown on the right side of the image below; in this case the active aperture is necessarily a partial aperture

Advanced Calculator

PWI

- Probe
- Wedge
- Scanner
- PWI Pulses
- Focalization
- Receivers
- TFM
- Beam Simulation
  - Parameters

Replace

Draw

Simulate

All Commands

Type: Compound

Selection: Refracted angle

☐ Use Impingement Angle

	Start	Stop	Resolution	
Primary steering angle	0.0	0.0	1.0	deg
Secondary steering angle	0.0	0.0	1.0	deg
Refraction angle	35.0	75.0	5.0	deg
Beam skew angle	0.0	0.0	1.0	deg

Process Angles

Element Selection

	Start	Stop	Resolution
Primary axis	17	17	1
Primary axis aperture	32		

**Azimuthal**

Advanced Calculator

PWI

- Probe
- Wedge
- Scanner
- PWI Pulses
- Focalization
- Receivers
- TFM
- Beam Simulation
  - Parameters

Replace

Draw

Simulate

All Commands

Type: Compound

Selection: Refracted angle

☐ Use Impingement Angle

	Start	Stop	Resolution	
Primary steering angle	0.0	0.0	1.0	deg
Secondary steering angle	0.0	0.0	1.0	deg
Refraction angle	35.0	75.0	5.0	deg
Beam skew angle	0.0	0.0	1.0	deg


Process Angles

Element Selection

	Start	Stop	Resolution
Primary axis	1	49	1
Primary axis aperture	16		

**Compound**

The extent and the number of pulses in the sweep are determined by entering the **Refraction angle Start**, **Stop** and **Resolution** values. If a compound sweep has been defined, the software will automatically optimize the elements to be fired for each angle.

The Calculator Information panel (click  icon to display it) can be used to show exactly which elements are used for each pulse (law) of the PWI firing sequence. In the example below, an active aperture of 16 elements is fired for each pulse.

Advanced Calculator

Information Display

Current focal law: Compound C1 : 49-64, R 35.00

Display: Law formation

Start Animation

Beam information

	Exit point	Focal point
X:	0.00	0.00 mm
Y:	-25.00	0.00 mm
Z:	0.00	0.00 mm

Compound C1 : 49-64, R 35.00

Compound C2 : 43-58, R 40.00

Compound C3 : 37-52, R 45.00

Compound C4 : 31-46, R 50.00

Compound C5 : 25-40, R 55.00

Compound C6 : 19-34, R 60.00

Compound C7 : 13-28, R 65.00

Compound C8 : 7-22, R 70.00

Compound C9 : 1-16, R 75.00

Secondary: 0.000 deg

Near-Field information

Primary Aperture Near-Field Depth: 0.00

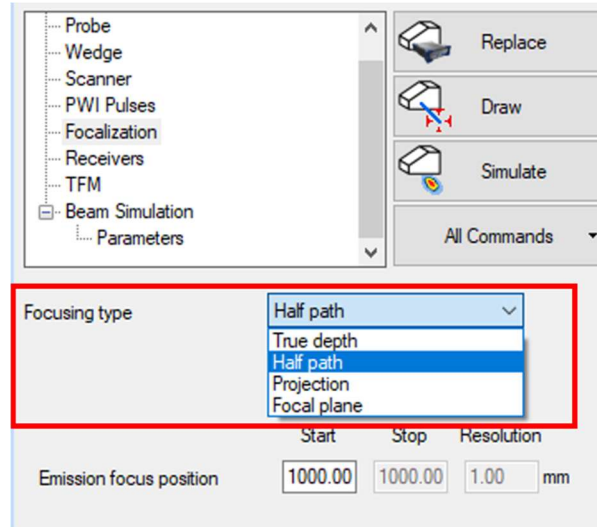
Secondary Aperture Near-Field Depth: 0.00

☒ Use Focal Laws for Inspection Surface ☐ Use approximation for wedge/specimen interface

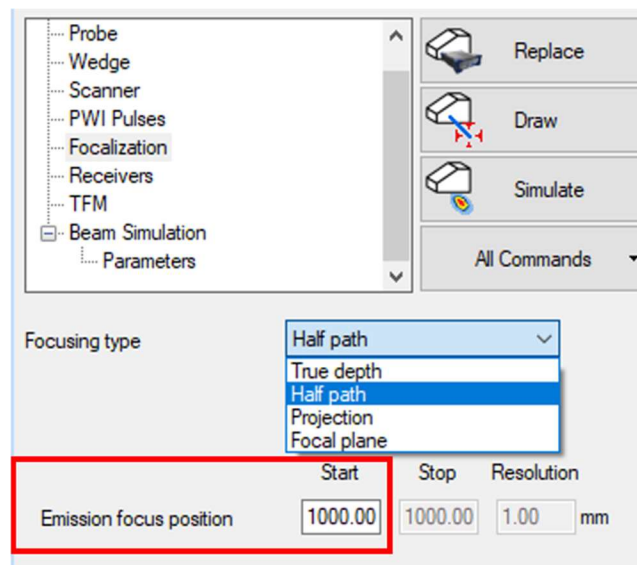
☐ Adjust Flat Specimen Beam Position For custom Specimen

### 3.2.2 Focalization Tab

For the **Focusing type**, the same options as for regular phased array UT are available, but the default setting **Half Path** is recommended because it corresponds best with the physical principle of “Plane Wave” excitation.



For the **Emission focus position**, the default setting is 1000 mm, which for most probe configurations corresponds to **natural focusing**, i.e. “Plane Wave” excitation. This is the recommended setting to perform PWI with pulse-echo configurations.





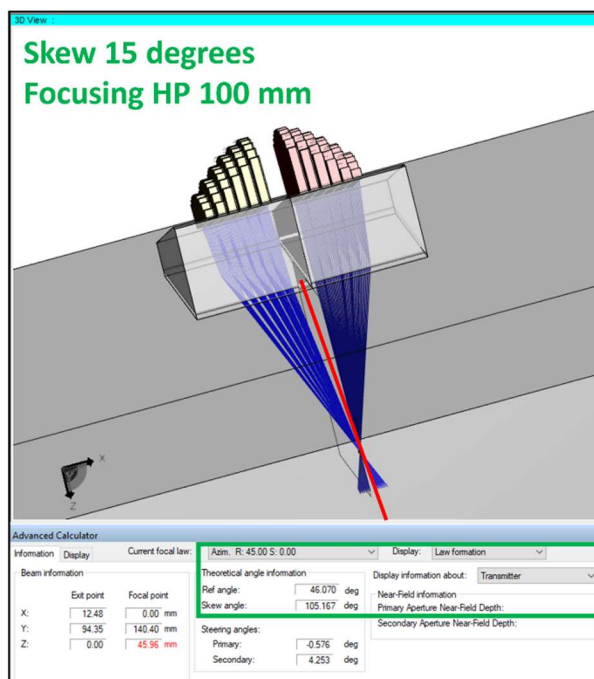
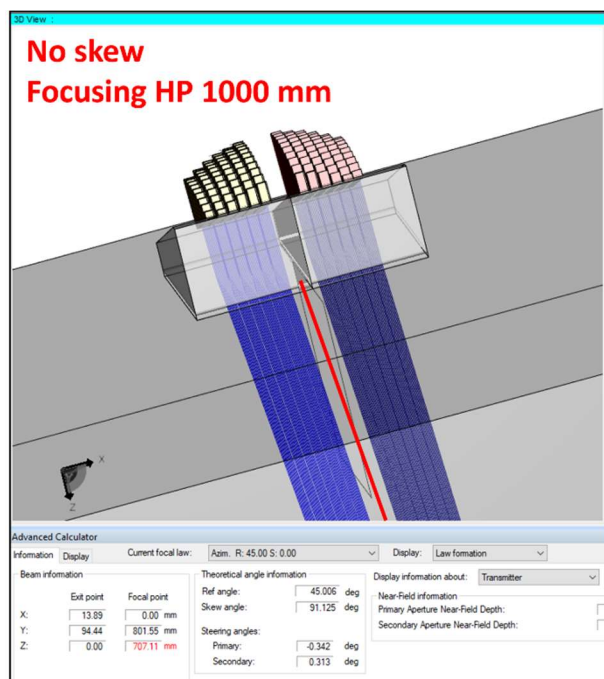
Alternatively, the **Emission focus position** can be set to a smaller value, to insonify the region of interest with focused beams. This corresponds to the physical principle of **Convergent Wave excitation** and **CWI (Convergent Wave Imaging)**.

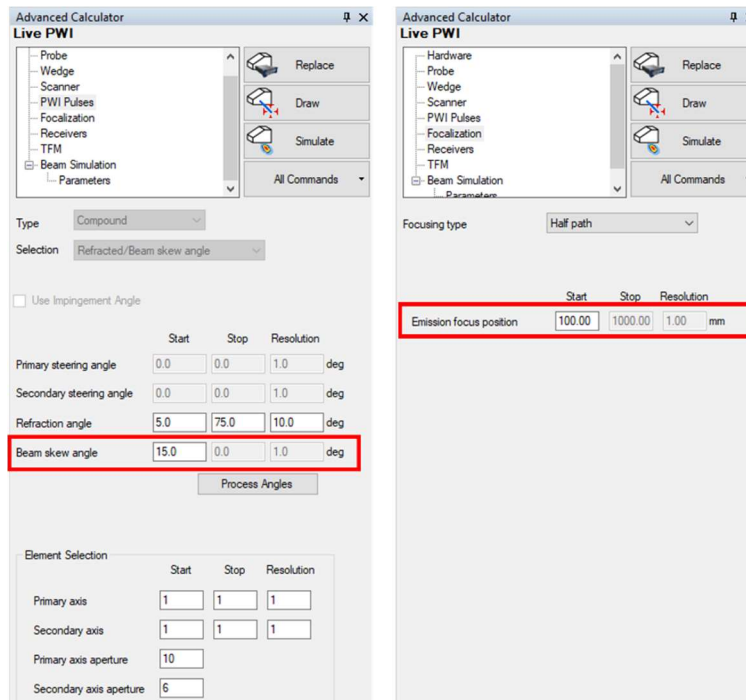
When using focused beams, this implies a smaller lateral resolution, which means that more beams (pulses) will be required in the firing sequence to adequately cover the region of interest. The benefit for using of CWI instead of PWI is application related and needs to be properly validated by the user.

### 3.2.3 PWI Pulses Tab and Focalization Tab (Case of DMA Probes)

When performing PWI-TFM with DMA probes, it is important to make sure that the acoustic energy of the emitted pulses is directed towards the region of interest in the middle of the transmitter and the receiver probes. For an optimized performance, the emitted pulses need to “cross” the incidence plane and be focused in the region of interest.

The figure below illustrates this. On the left, the default pulsing settings for pulse-echo configurations are displayed (no skew, focusing HP = 1000 mm), and it can be observed that the acoustic energy of the transmitter goes straight, without crossing the incidence plane (red line). On the right, the optimized pulsing settings for the considered DMA configuration are displayed (skew 15 degrees, focusing HP = 100 mm), and it can be observed that the acoustic energy of the transmitter is skewed to cross the incidence plane (red line).





For the value of the **Beam skew angle**, a good starting point is to look at the standard PA UT configuration with the considered DMA probe, and observe the Advanced Calculator information for the skew angle in the **Transmitter** probe (105 degrees total skew – 90 degrees probe skew = 15 degrees beam skew).

To optimize the value, the DMA probe should be positioned to image a given reflector(s), and then slightly skewed. If the image improves with skewing, the **Beam skew angle** value should be modified until the best image is obtained without skewing.

To optimize the value for **Emission focus position**, a good starting point is to look at a standard PA UT configuration that provides adequate focusing with the considered DMA probe. Obviously, When using focused beams, this means that more beams (pulses) may be required in the firing sequence to adequately cover the region of interest.

### 3.2.4 Receivers Tab

The **Receivers** tab allows to define the receiving aperture, i.e. the elements that will contribute to the generation of the live TFM image. By default, the complete aperture of the probe is used in the receiving process, because in most cases this leads to the best image quality (resolution).

The **Receivers** tab also allows to define the **Connection** of the considered probe. For a pulse-echo configuration, the default setting is 1, to be used when the probe is directly connected to the **EMERΔLD** or the **TOPΔZ**<sup>64</sup> unit.



Probe
Wedge
Scanner
PWI Pulses
Focalization
Receivers
TFM
Beam Simulation
Parameters

Replace
Draw
Simulate
All Commands

Receiver

	Start	Stop	Resolution
Primary axis	1	1	1
Secondary axis	1	1	1
Primary axis aperture	64		
Secondary axis aperture	1		
Connection	1		

For a pitch & catch configuration, the default setting is the first element of the receiver probe, and depends on the wiring of the considered pitch & catch probe assembly.

Probe
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Receiver

	Start	Stop	Resolution
Primary axis	1	1	1
Secondary axis	1	1	1
Primary axis aperture	10		
Secondary axis aperture	6		
Connection	65		

### 3.2.5 TFM Tab

The **TFM** tab allows to define the parameters for the TFM processing, very similar to the regular live FMC-TFM technique.



Most of the parameter settings have already been explained in paragraphs 2.1.2, 2.2.2 and 2.3.2 of this document.

Starting with UltraVision Classic version 3.12R18, the TFM tab also allows to adjust the **Digitizing Frequency** for live TFM imaging and raw data saving. The default value is still 100 Hz. Modifying (reducing) this value will increase the maximum acquisition rate for raw data saving, but not for live TFM imaging. It is recommended to use a **Digitizing Frequency** of at least 5 times the nominal probe frequency.

In addition, the operator can set the **Data Collection Mode**, see image below:


- When **FMC** is selected, the PWI firing sequence will collect elementary A-scans from all elements in the receiving aperture
- When **HMC** is selected, the PWI firing sequence will collect elementary A-scans from half of the elements, evenly distributed over the receiving aperture


The **FMC** option will provide the best quality image, but it will lead to a lower maximum acquisition rate.


Advanced Calculator  


**Live PWI**

- Probe
- Wedge
- Scanner
- PWI Pulses
- Focalization
- Receivers
- TFM
- Beam Simulation
  - Parameters

 Replace


 Draw

 Simulate


All Commands 


Construction path 1

L-L 


Construction path 2

None 


Construction path 3

None 

Construction path 4

None 

Frame location

Relative 

Frame horizontal start

-40.00

mm

Frame horizontal width

50.00

mm

Frame vertical start

0.00


mm

Frame vertical depth

60.00

mm

Frame Resolution

256 X 256 

Custom Resolution


☐

Real frame resolution

256

256

DigitizingFrequency

50 MHz 

Depth Resolution

0.06

$\lambda$

Width Resolution

0.05


$\lambda$

Amplitude Fidelity

0.1

dB

Data Collection Mode

FMC 

Envelope

FMC

FMC

HMC