



# cSound Architecture

Ultrasound for today, platform for tomorrow

The breadth of clinical scenarios in general imaging ultrasound places significant demands on the ultrasound device. A patient who cannot hold her breath while a renal Doppler is performed. A patient whose tendon tear requires sub millimeter resolution. An obese patient needing a liver biopsy. A brain scan of a neonate in an incubator. A liver fibrosis assessment that depends on detecting a shear wave signal thinner than a human hair. In today's demanding clinical environment, the ultrasound machine is a partner in helping the clinician meet every challenge.

GE Healthcare has designed its advanced cSound™ Architecture to put the latest ultrasound technology in the hands of clinicians. It combines the power of XDclear™ probes with a new cSound Imageformer to enable confident diagnoses, provide comprehensive tools, and support concise workflow.

## cSound Imageformer

The cSound Imageformer is the data acquisition and processing engine of the new architecture. At its core are cutting-edge NVIDIA® GPUs, the same graphics processing technology that is advancing the driverless car industry and the next generation of video gaming. This technology gives GE ultrasound engineers access to 48 times the data throughput and 10 times the processing power of our previous systems.\* This opens up new opportunities, allowing the cSound Imageformer to collect and use more data to create every ultrasound image.



## Traditional Beamforming

To understand cSound Imageforming, it helps to review how traditional beamforming works. As shown in Figure 1, traditional beamforming is performed in customized hardware and only the resulting beam or vector data is provided to the flexible, software-based processor that creates the ultrasound images.

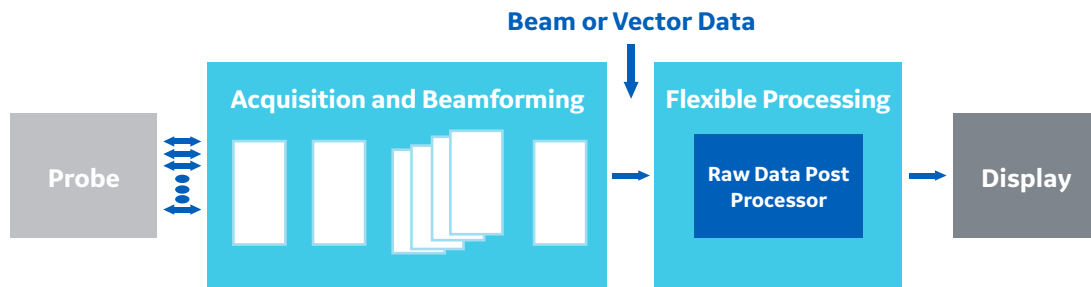
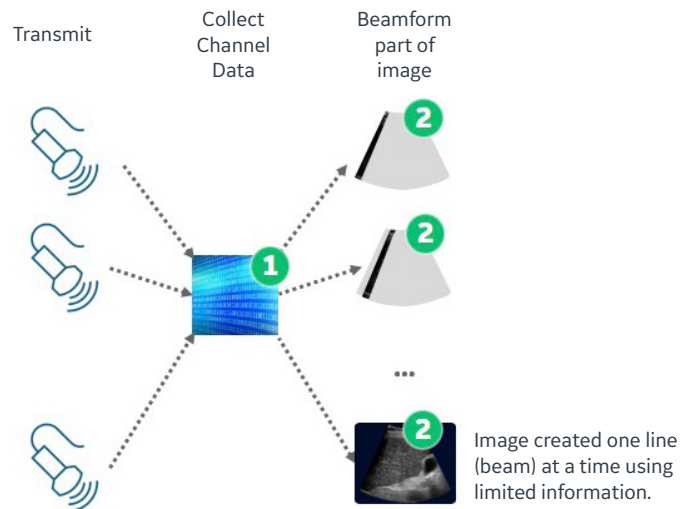


Figure 1. A traditional beamforming architecture.

### Traditional Beamforming Steps

1. A transmit event is performed. The return ultrasound data is dynamically received and collected in a single instance of channel memory.
2. The collected channel data is processed to create a particular portion of the image often referred to as one or more vectors or beams.  
*Note: If multiple focal depths are desired, steps 1 and 2 are also repeated with a transmit event focused at a different depth.*
3. Steps 1-2 are repeated for another portion of the image until the entire image has been created.

### Traditional Beamformer



The channel data processed in step 2 and then overwritten still has useful information. However, a traditional beamformer has no means to extract this additional value before the channel data associated with the next transmit event overwrites it.

## cSound Imageforming – Methodology

As shown in Figure 2, cSound Imageforming is performed using flexible, GPU-based processing. In contrast to traditional beamforming, the cSound Architecture moves raw channel data at high speeds from the acquisition system to components that perform flexible, software-based processing, including the cSound Imageformer. This channel data can be retained in memory even as channel data from subsequent transmit events is acquired and transferred to the cSound Imageformer.

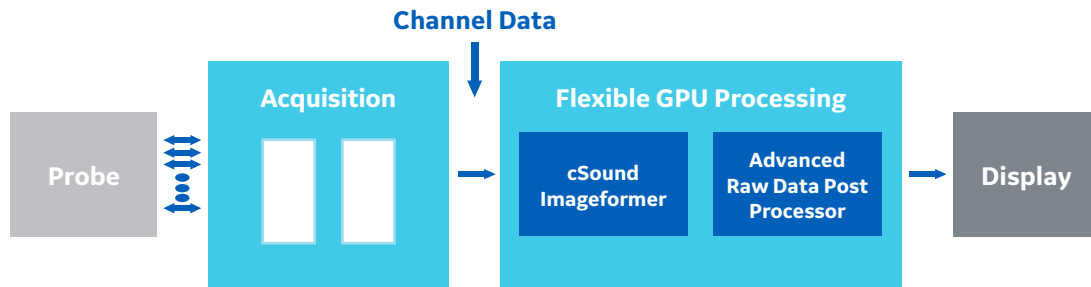
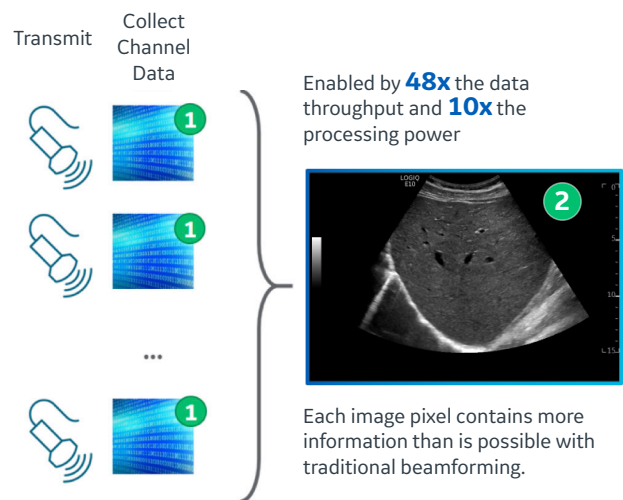


Figure 2. cSound Architecture.

### cSound Imageforming Phases

1. Acquisition – A series of transmit events are performed with the return ultrasound data being dynamically received and transferred to memory.
2. Reconstruction – The channel data from all of the transmits is combined to form the image.

### New cSound Imageformer



Similar to CT and MRI, cSound Imageforming has a distinct acquisition phase followed by a reconstruction phase. This requires the cSound Architecture to acquire, move and store large amounts of channel data and, once collected, the cSound Imageformer must be able to process the data at high speeds to enable real-time image reconstruction. The image formation process leverages channel data that would have been discarded in traditional beamforming. This additional data provides numerous samples for every point in the image. The image formation process combines these samples to achieve transmit focus for each point in the image, enhance contrast resolution and deliver fine spatial resolution.

## cSound Imageformer – Retrospective Transmit Focus

In traditional beamforming, each transmit event has a transmit focus that is created by adjusting the time delays of individual transducer elements. This generates a curved wave front that converges until reaching a particular depth (the focus depth) and then diverges as it continues to propagate beyond the focus depth. The focus is the location that is insonified from multiple directions.

For each transmit event, the cSound Imageformer collects and saves the receive ultrasound data for each element. This is referred to as channel data. *Even when a new transmit event occurs, the channel data associated with previous transmit events is retained and not overwritten.*

Individual transmit events are spatially and/or angularly offset from one another creating significant overlap. As a result, for any point in the image, there are multiple transmit events that have insonified the point, each from a different direction. Knowing the spatial locations of a particular point in the image relative to a given transmit event, the cSound Imageformer can retrospectively process the channel data of each intersecting transmit event, and then coherently

combine the results to achieve retrospective transmit focus at that point. It is worth noting that noise associated with each transmit beam is independent and therefore sums incoherently while the signal itself sums coherently. This increases the signal-to-noise ratio, further improving contrast resolution throughout the image.

This approach to focusing at each point in an image is possible for all types of transmit events providing there is overlap.

- **Converging waves** – Sound from multiple elements converges at a finite depth relative to the transducer face
- **Plane waves** – Sound from multiple elements is unfocused or essentially focused at an infinite depth
- **Diverging waves** – Sound from multiple elements diverges as if the focus was behind the transducer face

The cSound Imageformer is capable of all types of transmit events, giving engineers the flexibility to optimize the system uniquely depending on the needs of each clinical application.

## cSound Imageformer – Retrospective Transmit Focus, an Example

For illustrative purposes consider a simplified scenario, as shown in Figure 3.

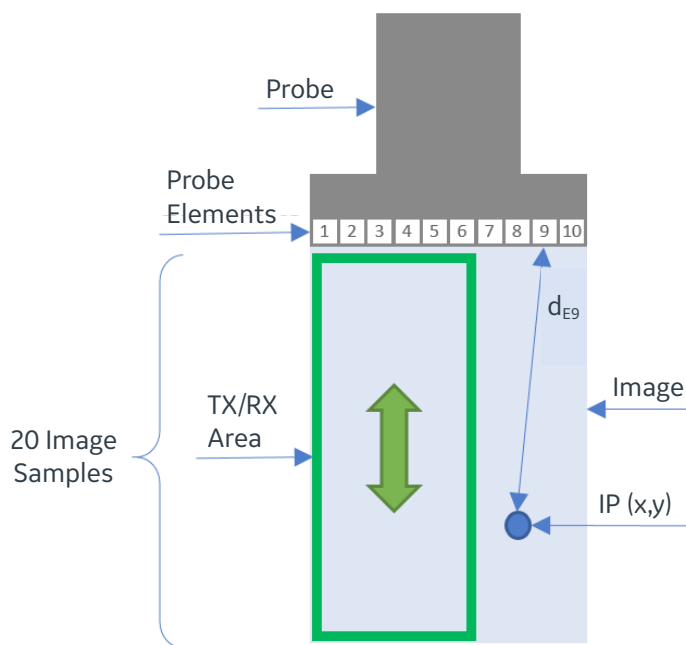


Figure 3. A simplified imaging scenario for illustrating retrospective transmit focus.

- Linear transducer with just 10 elements (E1 – E10)
- Each transmit event uses just six elements for transmitting and receiving. In this case, the first transmit event uses elements 1 through 6 (1-6) and then subsequent transmit events shift by a single element to use elements 2-7, 3-8, 4-9, and 5-10 for a total of 5 transmit events to create the image
- All transmit events are unfocused
- The receive signal is sampled so that 20 samples cover the depth of the image
- Each point in the image can be represented by IP (x,y) where x is the lateral direction and is restricted to the width of the image (which equals the width of the probe) and y is the axial direction and is restricted to the depth of the image
- The distance between IP (x,y) and a particular probe element is defined as  $d_{EN}$  where N is the element number 1-10

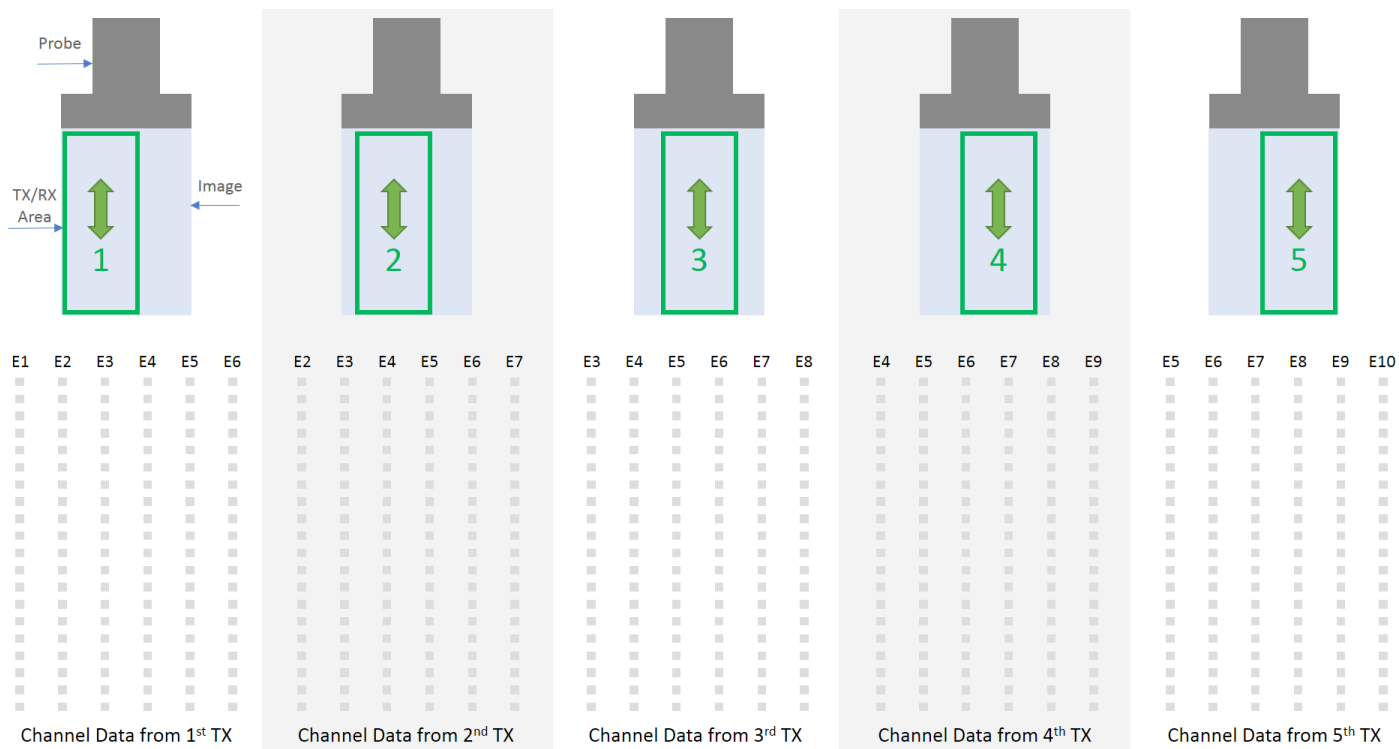


Figure 4. The first transmit (1) occurs and channel data is collected and stored. This is repeated for subsequent transmits (2 through 5) which are each offset from the previous.

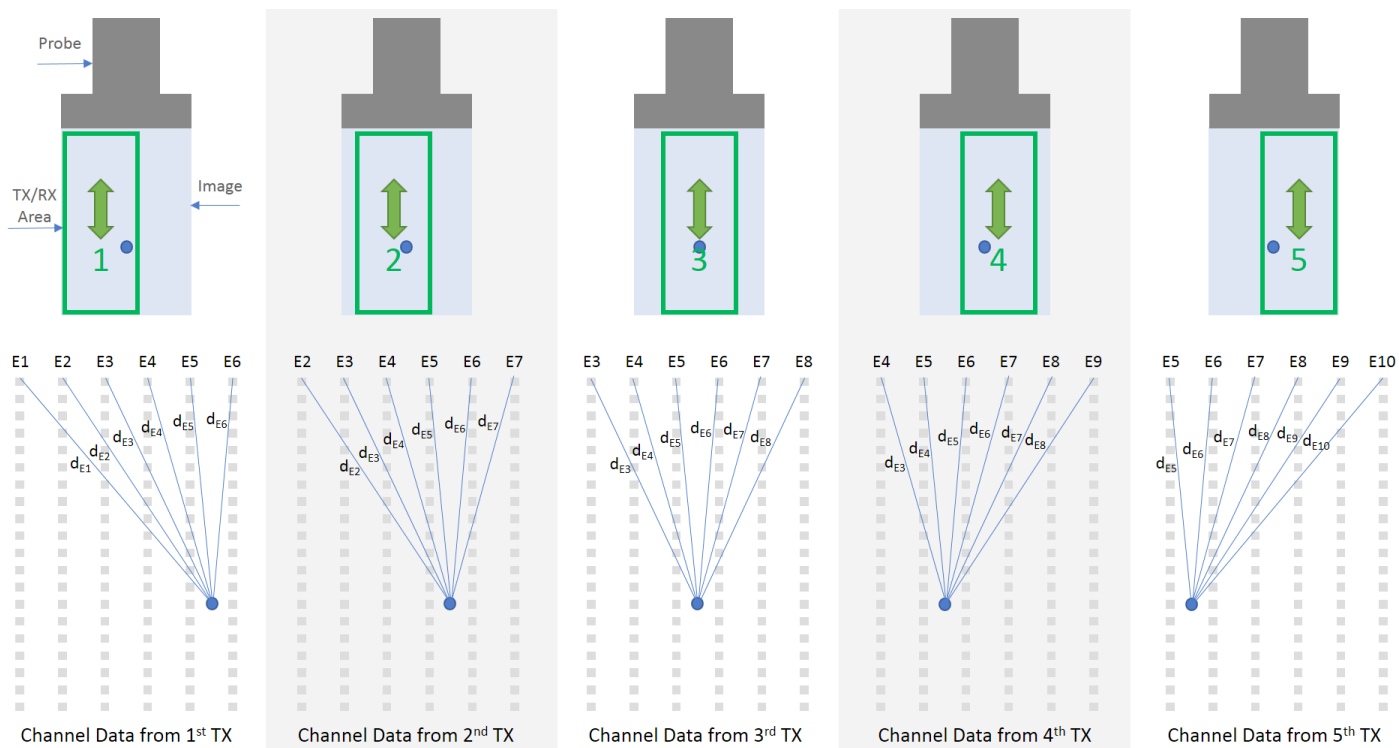


Figure 5. For each set of relevant channel data, the distance between the deep image point (represented by the circle) and each probe element is computed.

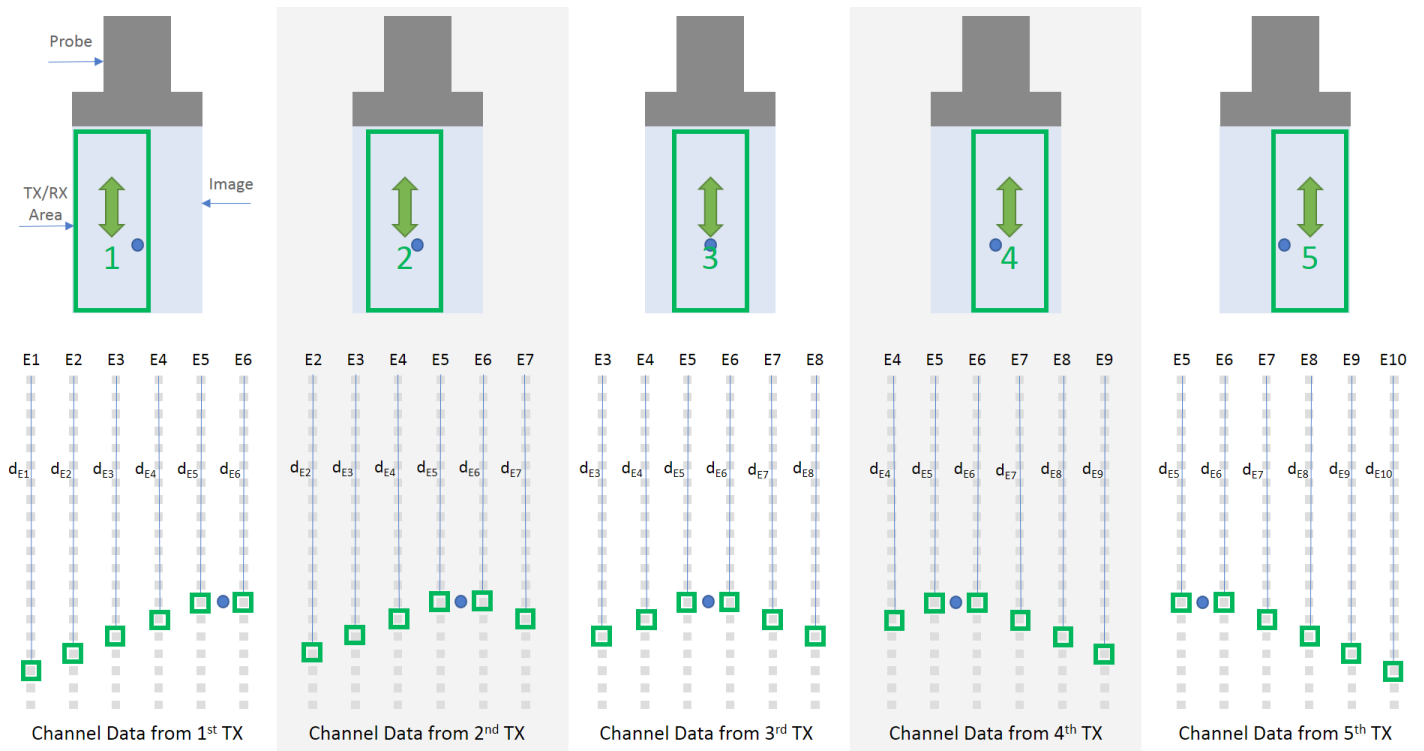


Figure 6. The computed distances between the image point and each element are used to access the channel data that focuses on the image point. The selected channel data from each transmit is coherently summed to determine the signal associated with the image point.

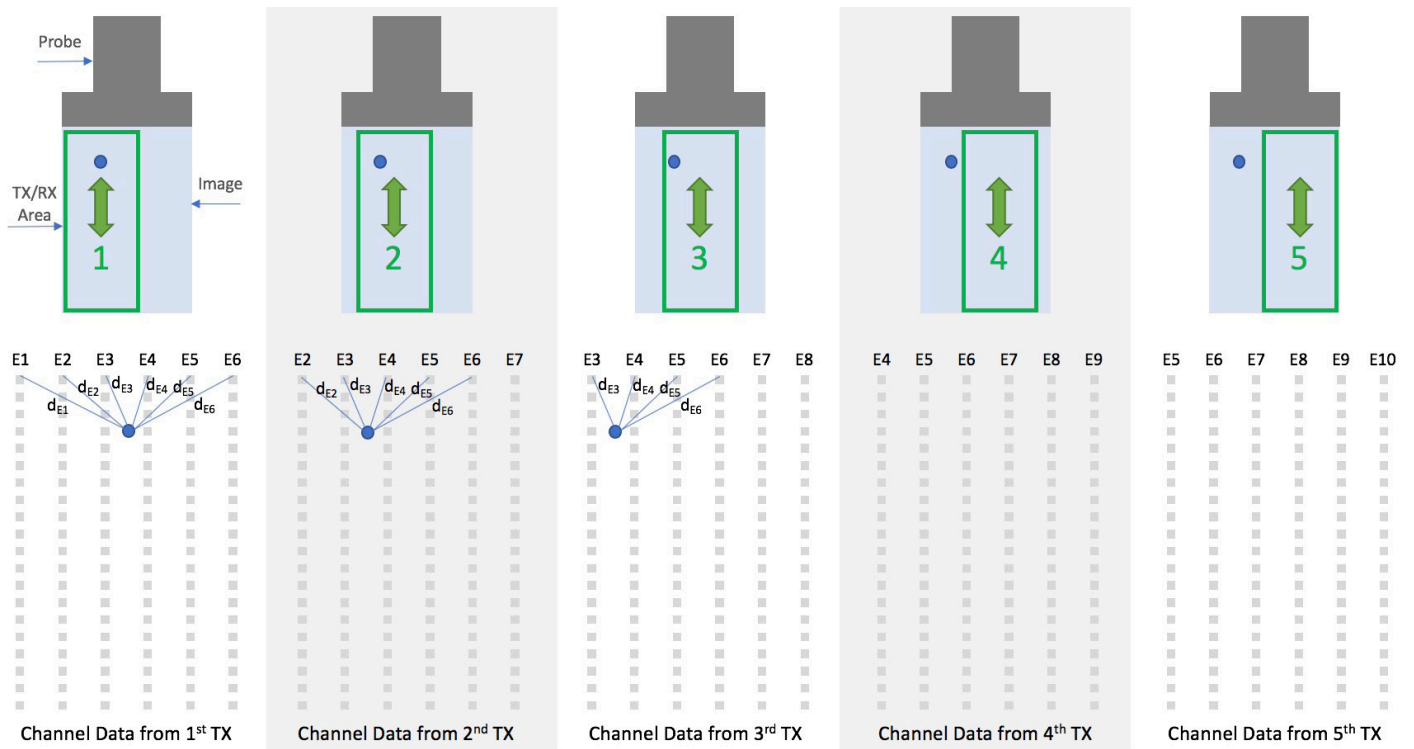


Figure 7. For each set of relevant channel data, the distance between the shallow image point (represented by the circle) and each probe element is computed. Note that transmits 4 and 5 do not overlap with the image point. Further note that some elements, such as E7 and E8 on transmit 3, are not included because of their steep angle relative to the image point.

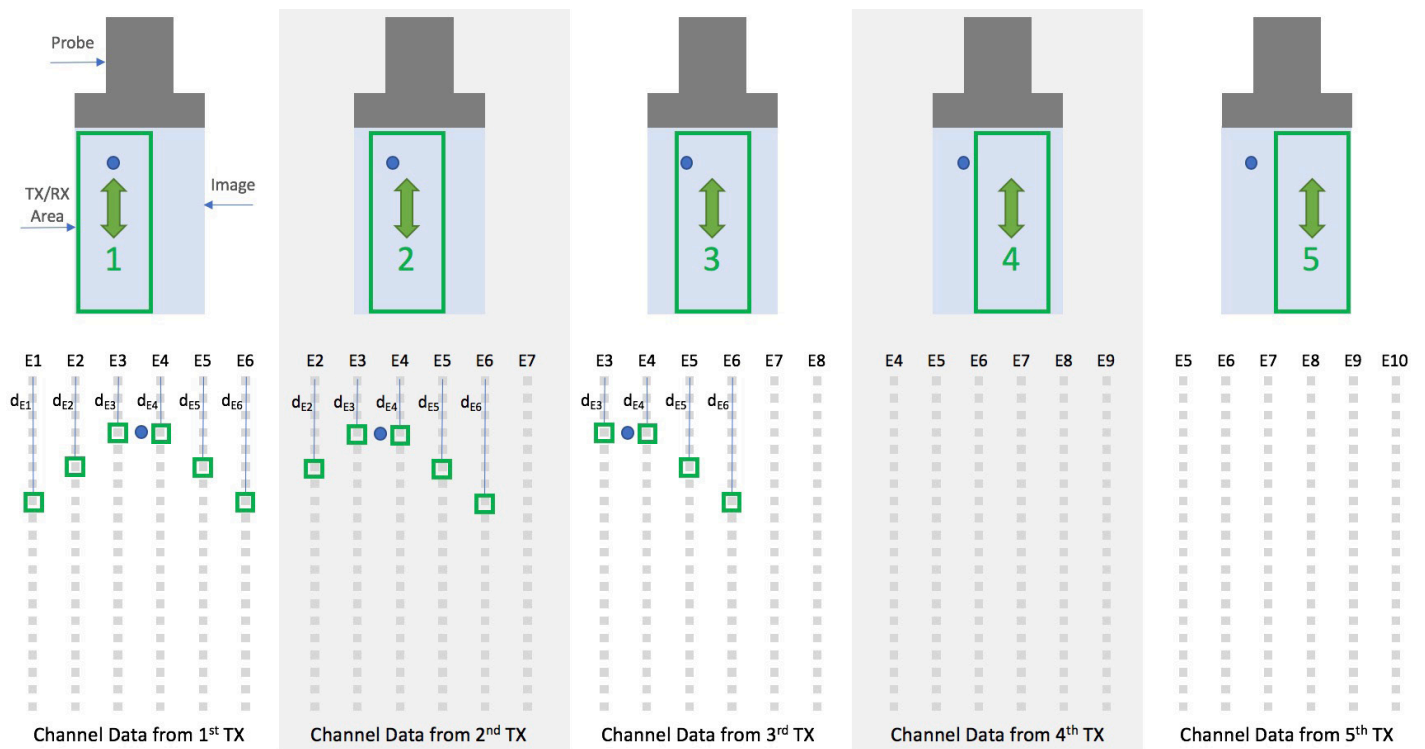


Figure 8. The computed distances between the image point and each element are used to access the channel data that focuses on the image point. The selected channel data from each transmit is coherently summed to determine the signal associated with the image point.

When extending this simplified scenario to the cSound Imageformer, there are additional complexities to consider. For example, the geometry of the transducer and the delay profile of the transmit event impact the computation of the image point to probe element distance and therefore the offset needed to reference the correct channel data. In another difference, the received elements are often larger than the number of transmit elements. Most notably, the sheer volume of data puts extensive demands on the system:

- The large quantity of collected channel data must be reliably and quickly streamed to the channel data memory before additional channel data is collected from the next transmit
- A massive amount of channel memory is required to store the channel data collected from many transmit events
- The retrospective processing of each relevant set of channel data for each point in the image requires intensive, ultra-high-speed, parallel computations to be performed to achieve real-time imaging at very high frame and volume rates

In a less powerful system, the real-time nature of imageforming could be achieved by restricting the amount of data collected by each transmit; speed would come at the expense of image quality. The cSound Architecture, in contrast, is able to keep up without restricting the data, even in radiology's most challenging applications. To put the cSound Architecture's performance in context, it can move the equivalent of multiple DVDs worth of data in one second.

## cSound Imageformer – Benefits

Imagine an ultrasound department where no image is acquired with the focal zone in the wrong position. With each point in the image in focus, the user doesn't need to select multiple focal zones or to move the focus position. Additionally, there are no trade-offs between near- and far-field image quality. Deep liver imaging provides detailed data from the capsule to the diaphragm. When biopsying a deep lesion, there is no compromise to needle visualization as it enters the image area. When surveying breast tissue, a clinician is able to see small lesions present from the skin line to the chest wall – all without the user having to make any adjustments.

While greater focal range in ultrasound has traditionally meant lower frame rates, cSound Imageforming actually increases frame rates. It requires a smaller collection of transmit events, a direct result of efficiently using the data collected from each individual transmit event. To understand this efficiency, consider that an ultrasound transmit event can be focused, but the sound energy still travels in many directions; it acts like a flashlight rather than a laser.

Though a flashlight generates maximum light energy in the center of its beam, there is still useful visual information in the light outside of the central beam. Similarly, there is much useful ultrasound image data in the sound that propagates outside the focused direction and the cSound Imageformer is designed to take full advantage of this data.

## cSound Imageformer – A Platform for Growth

cSound Imageforming runs on high performance NVIDIA GPUs, but the imageforming algorithms are software based. This affords significant flexibility; the algorithms can be adjusted for specific applications and evolve over time without impacting the underlying hardware architecture. In addition to forming the image, current algorithms can incorporate Adaptive Contrast Enhancement (ACE) and other GE proprietary techniques to boost the real image signal and suppress artifact. And with advances in GPU technology, there is potential to incorporate newer GPUs into the platform, enabling even more sophisticated algorithms.

## Advanced Raw Data Post Processor

The improved images resulting from the cSound Imageformer flow into the Advanced Raw Data Post Processor where additional enhancement is performed by spatial compounding, frame averaging, advanced speckle reduction imaging (Advanced SRI), and other functions. The post-processed image data is then mapped to gray scale levels and the scan is converted for display to the operator.

While speckle reduction imaging has been a feature of ultrasound systems for many years, Advanced SRI is GE's most sophisticated algorithm to date, and requires the expanded computational power of the cSound architecture to achieve real-time results. It employs proprietary processing steps at different resolutions of the raw image data to smooth speckle-based artifacts while simultaneously enhancing structures of all sizes within the image. The level of smoothing and enhancement is adjustable by the user.

The "Raw Data" aspect of the Advanced Raw Data Post Processor refers to the fact that image data is saved prior to the processing steps. This allows the user to continue to adjust the processing long after the images have been saved.

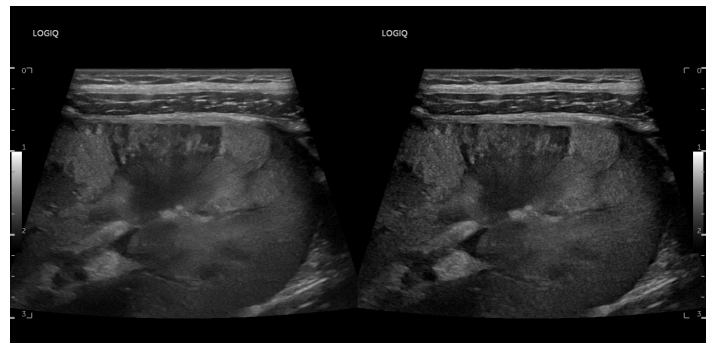
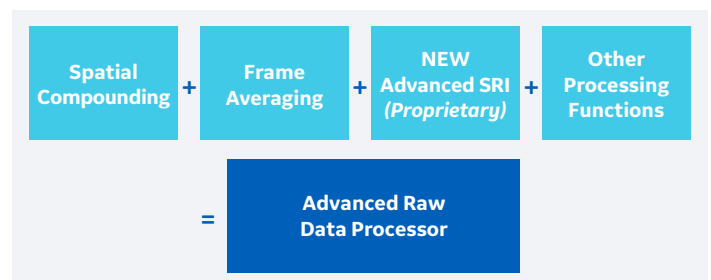


Figure 9. Advanced SRI (right) takes advantage of the increased computational power of the cSound Architecture to identify and enhance structures of all sizes while reducing speckle-based artifacts.





# XDclear Probes

While cSound Imageforming provides numerous benefits over traditional beamforming, the quality of the acoustic data coming into the system is still of utmost importance. In combination with the cSound Architecture's state-of-the-art transmit and receive electronics, XDclear transducers help deliver a more powerful, pure, and efficient sound wave with wider bandwidth than traditional GE transducer technology. This results in impressive deep penetration and high resolution, enabling ultrasound to be used effectively on a broad range of patients.



Figure 10. XDclear probes: Derive their superior performance from three key technologies: Single Crystal, Cool Stack, and Acoustic Amplifier.

XDclear transducers are a proprietary combination of advanced materials and innovative design. The XDclear design incorporates an enhanced piezoelectric material, Single Crystal, to generate a high quality acoustic signal. The quality of that signal is preserved through an innovative Acoustic Amplifier design coupled with GE's Cool Stack technology to help optimize energy management. The ability to effectively and efficiently combine these technologies is what makes XDclear extraordinary.

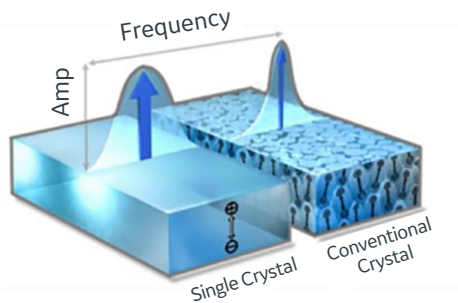
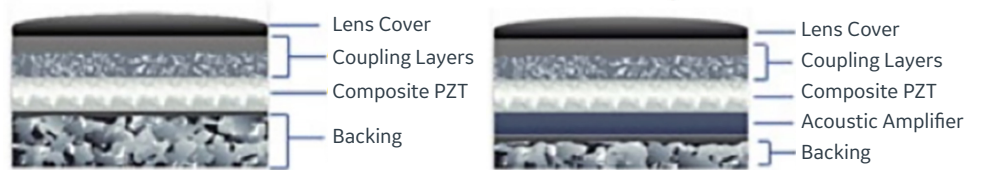


Figure 11. *Single Crystal*: Advanced piezoelectric material that delivers high quality acoustic signal with a wider bandwidth than conventional piezoelectric material.

## GE Acoustic Amplifier Evolution



Traditional GE Amplifier

Acoustic Amplifier

Figure 12. *Acoustic Amplifier*: Preserves the acoustic signal through an innovative design that captures and redirects the unused energy that passes through the crystal to enhance sensitivity, axial resolution, and penetration.

XDclear transducers enable deep penetration and resolution. One objective measure of transducer performance is bandwidth: the range of frequencies that the transducer can transmit and receive. Increased bandwidth allows a transducer to cover a broader frequency range, which makes it possible to achieve deep penetration and high resolution, as well as enhanced performance in harmonic imaging.

With sufficient bandwidth, one transducer can cover the range of acoustic frequencies that previously required separate transducers. XDclear transducers with Single Crystal materials have measurably enhanced bandwidth, achieving a -6 dB fractional bandwidth that can exceed 100 percent compared with 70 to 80 percent for traditional GE transducers. The result is a new level of penetration, resolution, and sensitivity in GE transducer performance.

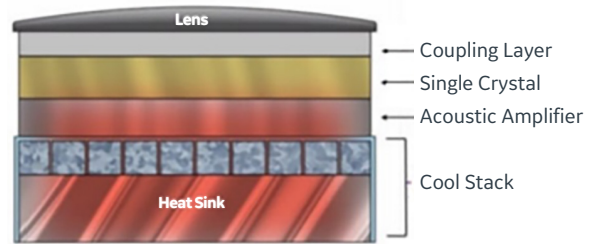


Figure 13. *Cool Stack*: Optimizes energy usage via patented technology integrated into the transducer's internal architecture; it relieves inherent heat generation that can otherwise reduce sensitivity and penetration.

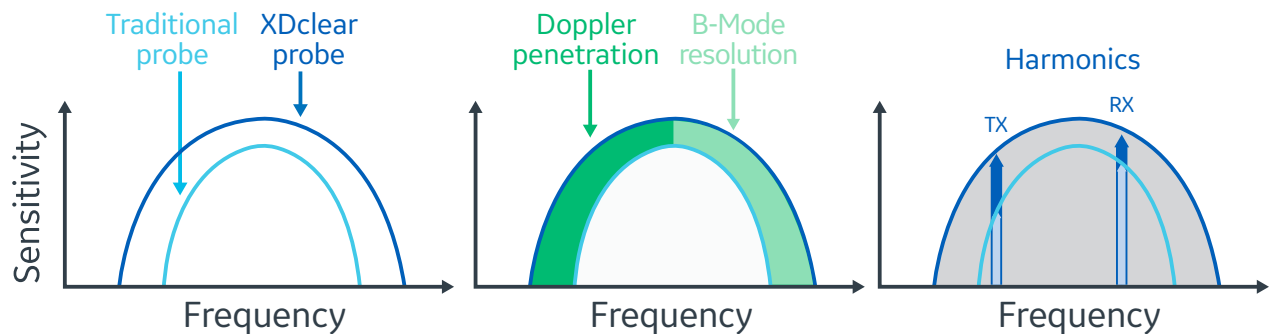


Figure 14. XDclear probe performance benefits are derived from improved sensitivity and wider bandwidth.

## cSound Architecture Summary

The cSound Architecture leverages next-generation data rates and processing power that were previously unavailable, allowing significantly more data to be collected and used to create every image. This additional data is used to achieve focus at every point and to increase contrast and spatial resolution—all while significantly improving frame rates. Combined with the performance advantages of XDclear probes and the Advanced Raw Data Post Processor, these advancements make the cSound Architecture an excellent imaging system for today and its flexible design makes it a powerful imaging platform for tomorrow.



\*As compared to the LOGIQ™ E9.

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