SIEMENS

White Paper

IN Focus Coherent Technology

By Rickard Loftman, Ph.D.

Abstract

IN Focus coherent technology imaging on the ACUSON SC2000™ ultrasound system introduced round-trip confocal imaging to the echocardiography market. The same ACUSON SC2000 system technologies that brought true real-time non-stitched volumetric imaging with color flow to the market, namely best-in-class parallel beamformation capability and proprietary coherent imageformation, enabled this achievement. IN Focus technology effectively focuses the image at all depths in both transmit and receive which results in improved contrast resolution, lateral resolution, and image uniformity. The transmit focus user control is made obsolete, and all of this is achieved without penalty to frame rate.

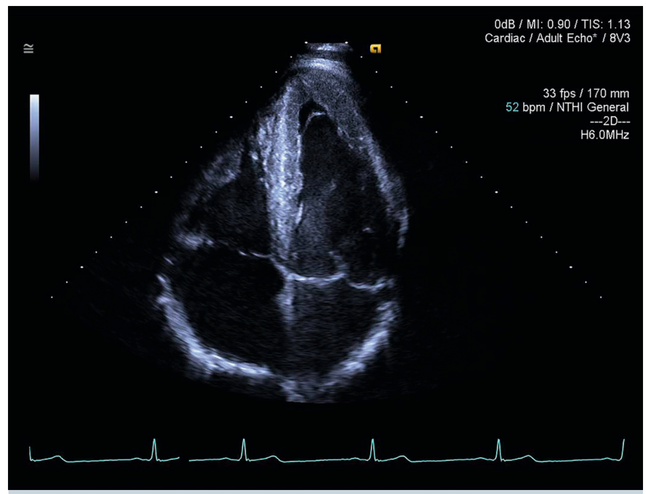


Figure 1: Cardiac ultrasound with IN Focus technology.

Background: Processing Rate, Use in Ultrasound, and Deployment

The ACUSON SC2000 volume imaging ultrasound system with 3D Coherent Imageformer is the first and only commercial system to achieve non-stitched volumetric echocardiography. A substantial increase in the processing capability over conventional ultrasound systems and advanced techniques are required to achieve native full volume real-time echocardiography and color flow without gating or stitching of data from multiple heart cycles. Two references help to understand the basis of these accomplishments. The reference **High Information Rate Volumetric Ultrasound Imaging**[1] defines the critical measure Information Rate in ultrasound and explains the importance of it. The reference **Retrospective Transmit Beamformation**[2] introduces multiple-transmit synthesis as an important enabler of image quality in the volume echocardiography context. The ACUSON SC2000 system is also the first system to synthesize transmit focus throughout the field of view in 2D echocardiography with IN Focus technology. It is the only commercial system that has the degree of computation power required to support full field of view non-stitched volume imaging, and is the only system that applies this enabling computational power to transmit focus synthesis.

[1] High Information Rate Volumetric Ultrasound Imaging, Kutay Üstüner, Siemens Healthcare Sector, Ultrasound Business Unit, Mountain View, California USA, August 2008

[2] Retrospective Transmit Beamformation, Chuck Bradley, Ph.D., Siemens Healthcare Sector, Ultrasound Business Unit, Mountain View, California USA, August 2008

Conventional Focusing

Until the release of IN Focus technology in 2010, fixed transmit focus/dynamic receive focus 2D B-mode had been the state of the art in clinical echocardiography. Differentiation of structure in range is achieved in ultrasound by tracking time of flight of high-bandwidth pulses. Differentiation of structure laterally is achieved by focusing – creating an electronic lens by timing the signals of the many array elements so that reflections from the point of interest reinforce one another. Dynamic receive focus is achieved by continuously adjusting the electronic focusing "lens" of the scanning array to maintain correct receive focus as ultrasound propagates from scan-head to full scan depth.

Dynamic transmit focus is not directly possible because it is not possible to alter the choice of "lens" applied after the transmit event.

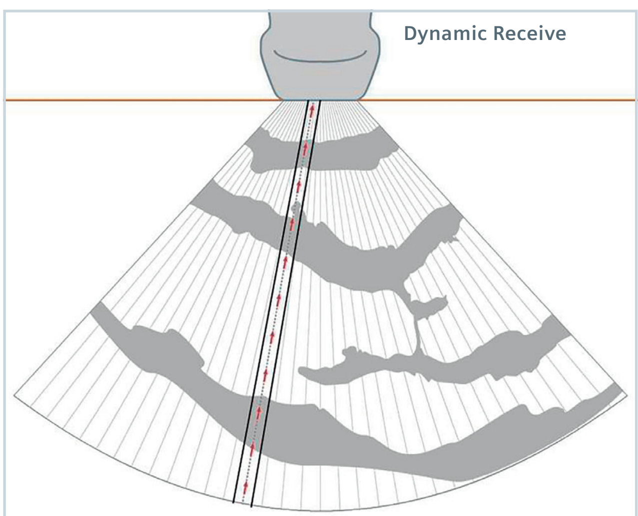
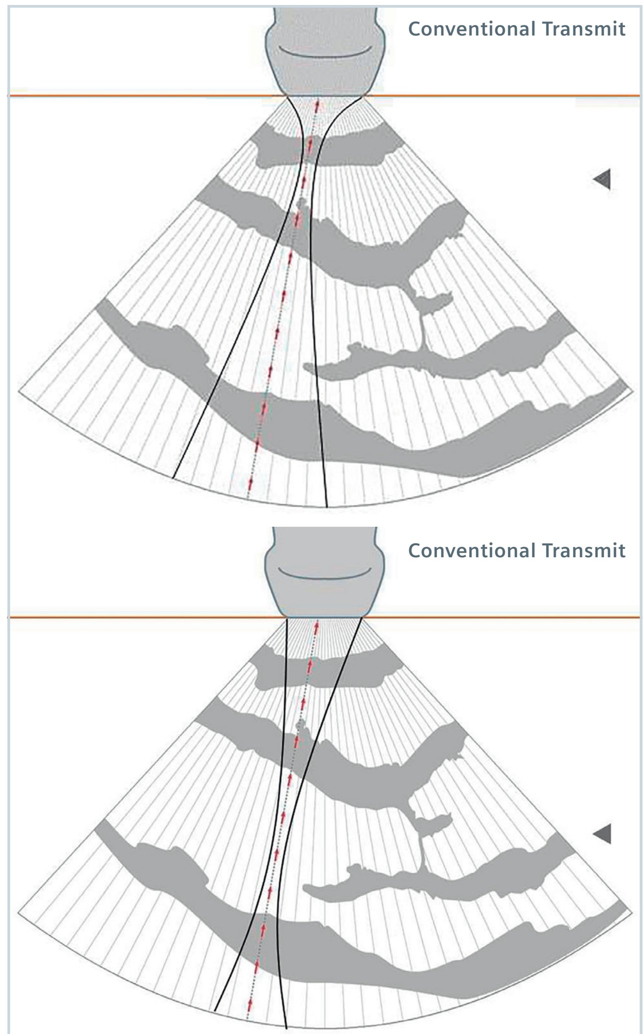


Figure 2: Illustration of uniform receive beam profile generated by dynamic receive focus.



Figures 3 and 4: Illustrations of transmit beam profiles for shallow and deep focal-depth control placements.

New Standard: IN Focus Technology Explained

Transmit cannot be focused at all depths directly, but it can be reconstructed retrospectively. And it can be done without any compromise to frame rate by improving the use of information that has always been available during conventional scanning.

The focus quality of ultrasound images always depends on the focusing applied to both transmit and receive. The effects of transmit focusing and receive focusing multiply in the body. This multiplicative relationship leads to sensitivity and resolution improvements as well as significant suppression of off-axis clutter which doubles in terms of Decibels measure. However, to graphically illustrate the effect of transmit focus alone, we can modify the scanner to disable the receive focusing. This allows direct observation of the differences in transmit focus between methods by simply scanning a standard quality assurance phantom, as shown in the Figures 5, 6 and 7. The two images in Figures 5 and 6, show conventional transmit-only focusing results at two different focus depth selections. These images clearly illustrate the need for improving transmit focus quality. The third image, in Figure 7, is created with IN Focus technology and clearly illustrates significant improvement.

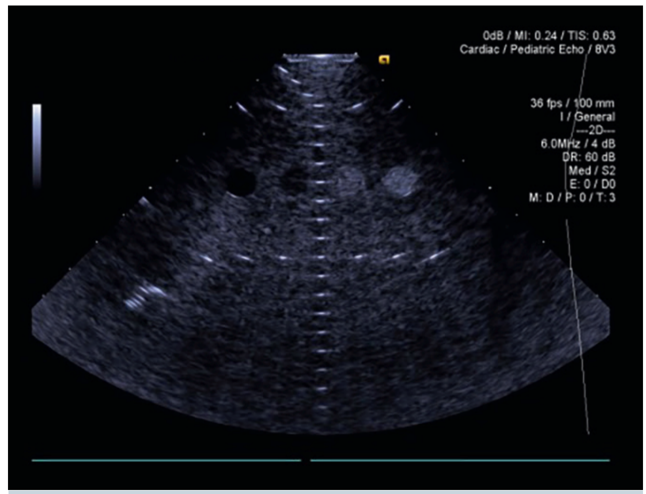


Figure 7: Gammex 404Gs imaged with ACUSON SC2000 8V3 **transmit-only beamforming**, IN Focus technology.

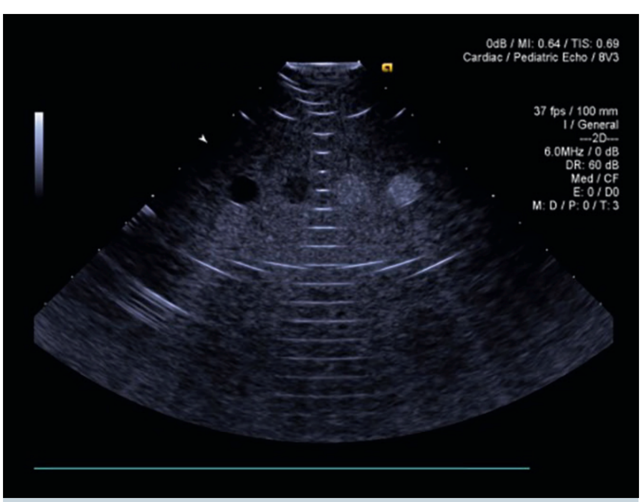


Figure 5: Gammex 404Gs imaged with ACUSON SC2000 8V3 **transmit-only beamforming**, conventional focus at 30 mm.

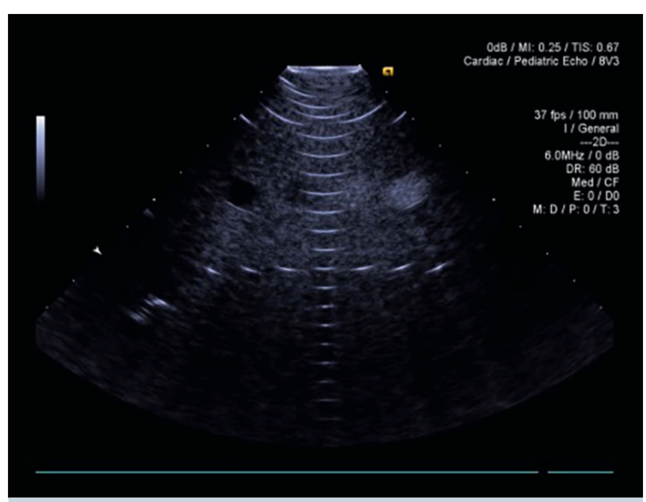


Figure 6: Gammex 404Gs imaged with ACUSON SC2000 8V3 **transmit-only beamforming**, conventional focus at 70 mm.

To understand how IN Focus technology works, consider a traditional scanning sequence with the transmit focus set deeper than a current point of interest in the image.

First, massive parallel beamforming capability is necessary to simultaneously listen to the entire area that is insonified by each transmit, not just a line or a few parallel lines that cover the narrowest part of the transmit beam at its focus.

Next, this data is stored for later access by the Coherent Imageformer processor. Examining the data retrospectively for each depth in the image, the many beams per transmit provide many unique transmit interrogations of each point in the image.

When the data of these multiple transmit events are adjusted in time, phase, and amplitude for each single depth in the image, data from each transmit event provides a useful piece of the information necessary to synthesize focus. This useful piece of information is echo data relevant to a subset of the active transmit aperture. This subset is in a region where a point of tangency can be achieved between the actual and desired transmit wave front. This idea is motivated mathematically by applying a stationary phase approximation to the Huygens-Fresnel integral model for pressure in the body.

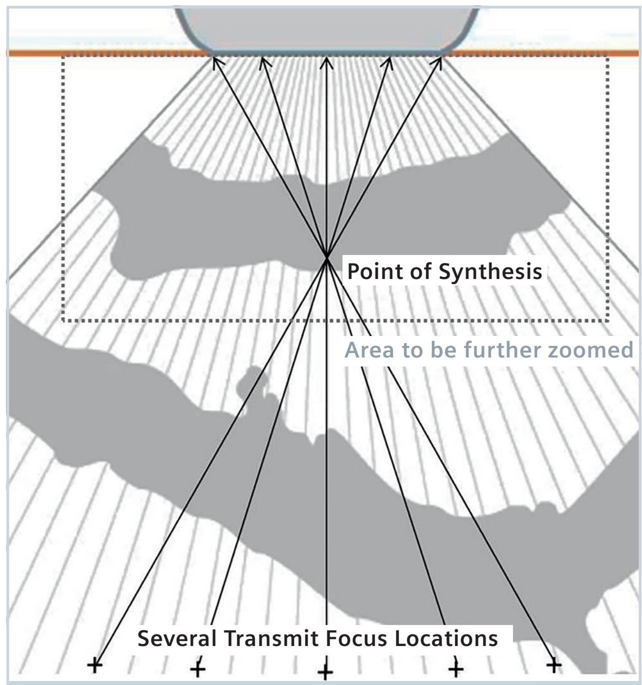


Figure 9: Zoomed graphic. Many receive beams per transmission event lead to many interrogations per image point.

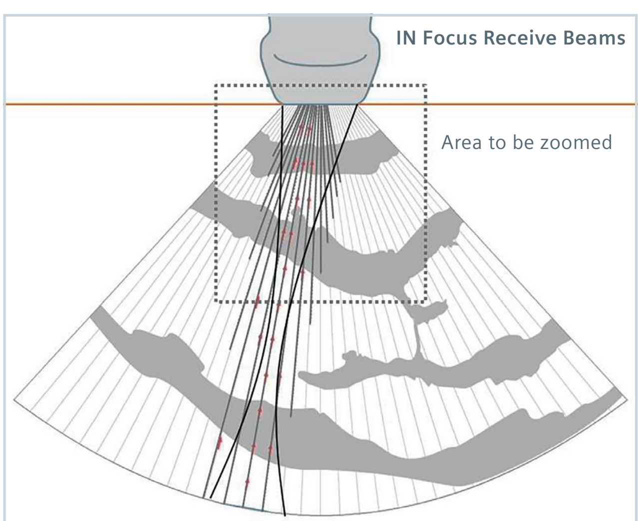


Figure 8: Illustration of multiple simultaneous receive beams covering region of a single transmit.

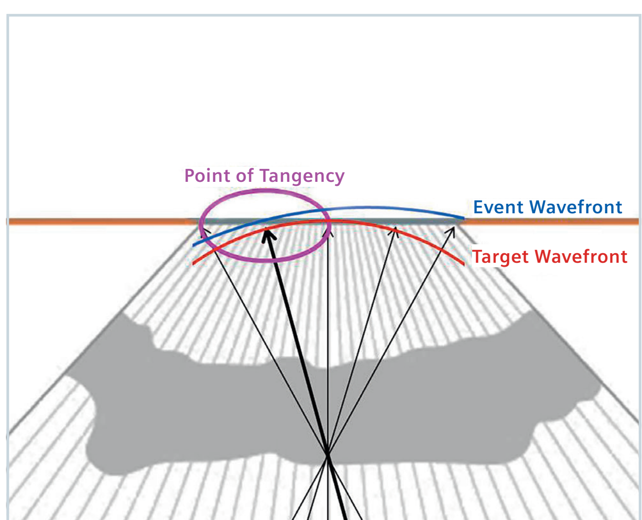


Figure 10: Further zoomed graphic. Relevant piece of aperture echo data provided by transmit contributor.

In Vitro Example Data

Analyzing data from a pin target in a quality assurance phantom can help to illustrate the process of retrospective transmit focus synthesis. The following electronic beam plots and associated lateral spectra are acquired scanning a Gammex 404Gs phantom with the 8V3 pediatric echocardiography transducer on the ACUSON SC2000 system.

While the amplitude of the lateral responses do not reveal the information diversity inherent in each component, the lateral spectra do in fact reveal that each one has unique lateral information to contribute. Examining the coherence factor[3] image from pin target is also illustrative. It reveals how the component images sum constructively only within the extent of the properly resolved pin target, while we observe destructive interference which cancels the poorly focused extent of the component pin target images.

A focused profile emerges from the data due to properly adjusted summation of signals from the various transmission events. The data was acquired during the normal sequence of imaging. There is no inherent cost to frame rate.

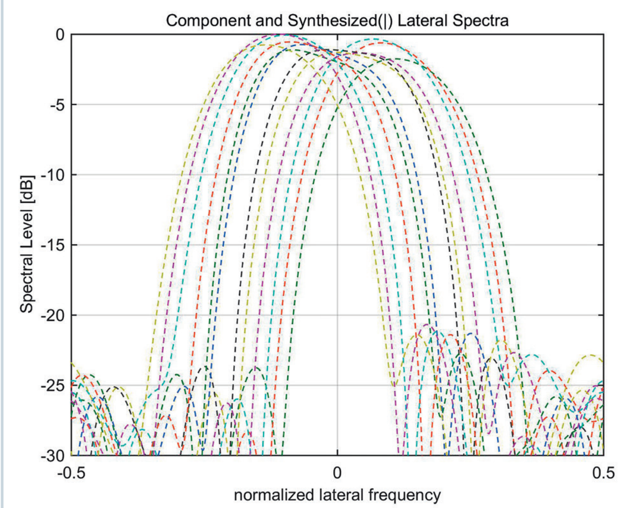


Figure 12: Component lateral spectra illustrating independent lateral frequency content contributed to synthesis by each transmit event.

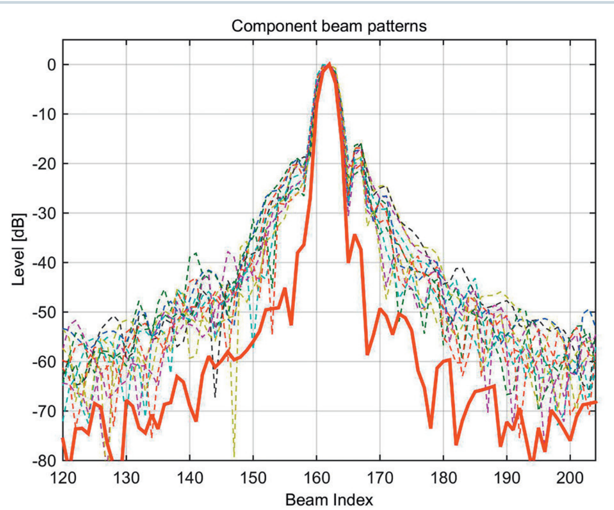


Figure 11: Component lateral beam patterns (dashed) and resulting synthesized beam pattern (red) illustrating improved beam-width and improved off-axis suppression.

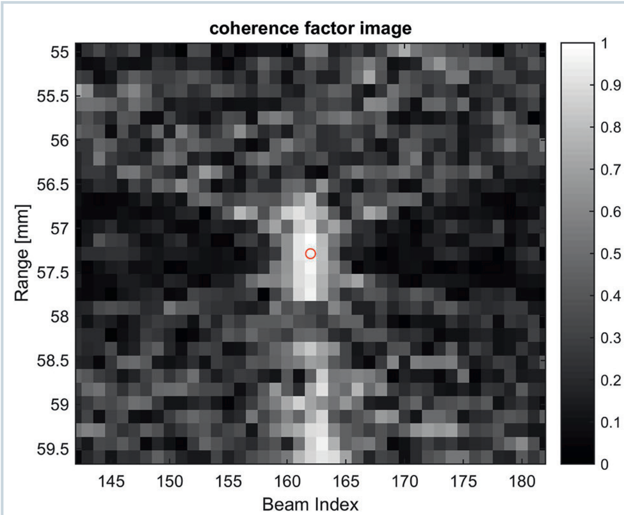


Figure 13: Coherence factor image.

[3] Coherence Factor is the ratio of the sum of components to the phase-insensitive sum of components and is useful to understand the degree of coherence among constituents.

Progressive Synthesis of Focus

The transmit focus is synthesized from signals obtained from multiple transmission events. The number of transmission events required varies depending on the scan geometry, transmission focus, and depth. Figure 14 shows the progressive improvement of focus quality as seen in both the main lobe width and side lobe reduction in the near field of the 8V3c transducer. As the number of transmission events included in the synthesis increases, quality is improved. This figure illustrates how synthesizing a transmit focus retrospectively demands substantial system capability because of the large synthesis counts that are required. The ACUSON SC2000 system can perform the substantial retrospective focusing that allows for the practical elimination of the user control of focus in phased array echocardiography.

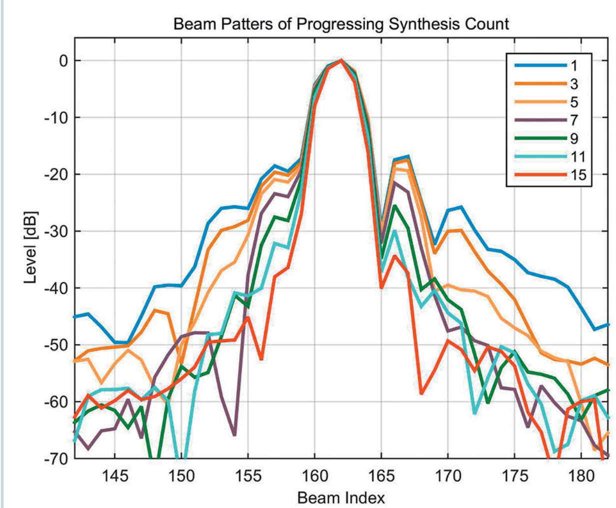


Figure 14: Progressive focus improvement with varying number of contributors.

Conclusion

Siemens introduced IN Focus coherent imaging technology to the echocardiography market in 2010. It provides continuous focus at all depths for transmit in addition to receive. This is an exciting and fundamental improvement to the state of the art of echocardiography. The benefits one is accustomed to achieving by adjusting transmit focus to the current depth of interest are achieved simultaneously at all image depths, and the need to optimize the focus position is eliminated. These advantages are achieved without traditional compromises, for instance to frame rate. However, a substantial increase in the computational capability of the system is required. This system requirement far exceeds that of traditional 2D imaging, and even exceeds that required for stitched volume imaging. The ACUSON SC2000 system, with real-time non-stitched volumetric imaging, has the capability that is required to deliver this innovation.

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