Exploring *n*SIGHT Imaging – a totally new architecture for premium ultrasound

Philips EPIQ ultrasound system

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For the past 30 years, ultrasound has experienced dramatic changes as manufacturers strive to develop new solutions to meet the needs of clinicians. From the pioneering days of static B-scan to color Doppler and real-time imaging, each brought major dynamics in diagnostic ultrasound. New innovative beamforming technologies are emerging that promise a dramatic increase in imaging performance. These exciting developments elevate ultrasound into a more definitive modality that will potentially expand ultrasound in more diverse roles as well as improve clinical decision support.

*n*SIGHT Imaging at a glance

New precision beamforming and massive parallel processing	Processes an enormous amount of acoustic data allowing the system to focus down to the pixel level … all in real time
Reconstructs virtually perfect beams with fewer transmit operations, breaking the traditional compromise of architectures of the past	Users can now experience both highly detailed ultrasound images and extraordinary temporal resolution
Dynamically calculates and reconstructs the optimal transmit and receive focusing continually at all depths down to the pixel level	Achieve superb tissue uniformity all the way up to the skin line without the compromise of conventional transmit focus limitations
Ultra-wide dynamic range and unique beam reconstruction provides exceptional tissue information at greater depths with less noise	Visualize extraordinary levels of detail and contrast resolution with exceptional penetration at higher frequencies even on difficult patients

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Conventional ultrasound beamforming

In the early days of real-time ultrasound, a fixed focus single element transducer was mechanically swept back and forth over the image field to acquire images.
The focus of the transducer was defined by an acoustic lens and was fixed for both wave transmission and echo reception, providing the best image quality only around the fixed focal depth. The 1980s brought the advent of solid-state phased array transducers. Array-based transducers brought electronic "beamforming" technology to ultrasound, introducing new levels of clinical versatility and imaging performance. The beamformer enabled functions such as transmit beam steering, transmit focusing, and receive focusing. The programmable digital beamformer enabled the echo signals to be continually focused as they were received by the array transducer and the received beams were maintained in constant focus. This was done by constantly updating the beamformer focus delays as the echoes returned from ever-increasing depths of field. This only solved half of the focusing problem, however. The transmit beam was still only focused at one depth of field and optimal resolution was only attained around the transmit focal region **(Figure 1)**. The round-trip beam profile, a product of both the transmit beam profile and the receive beam profile, still had room for improvement.

Multi-line beamforming

The frame rate of ultrasound images is governed by the time required to scan the complete image field, which in turn is a function of the number of transmit-receive cycles needed to scan the image. In the simplest form of beamforming a single transmit will result in a single receive data line used to build the image **(Figure 2)**.

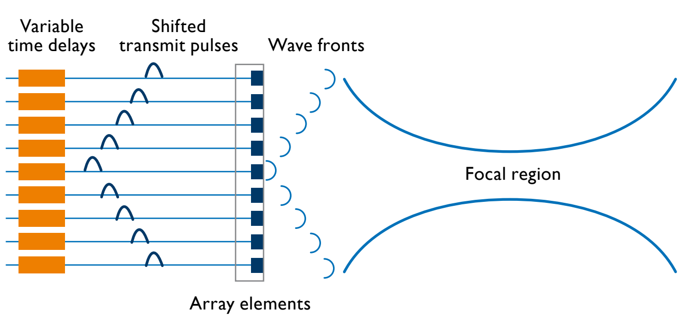


Figure 1 Simple transmit focusing

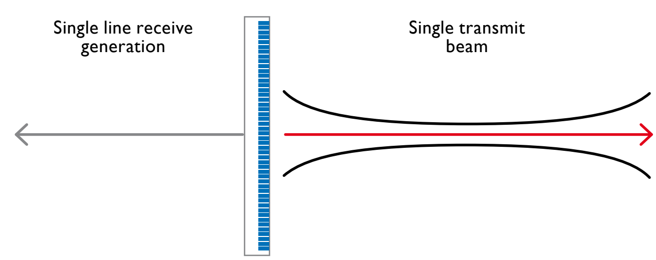


Figure 2 Single line beamformer

Efforts were made in the 1990s to reduce the number of transmit-receive cycles in two ways. One was to increase the spacing between transmitted and received scanlines, then interpolate synthetic scanlines between the actual received lines. While providing an immediate increase in frame rate, interpolation had its own limitations. Anatomical structures tended to be less resolved since the interpolated scanlines were averaged from the actual ultrasound data on either side. The extent to which the actual scanline spacing can be increased is limited by the need to adequately spatially sample the image field with transmitted and received ultrasound. While providing an improvement in temporal resolution, interpolation also required a compromise in image resolution.

The second effort toward improved temporal resolution was to prove more meaningful. Parallel receive beam processing appeared commercially in the form of multi-line beam formation. Improvements in processing power now made it possible to insonify a broad area encompassing several scanlines, then to receive and form beams at multiple scanline locations simultaneously.

Instead of obtaining four scanlines with four transmit-receive cycles, the four scanlines could be obtained in response to a single transmit event **(Figure 3)**. The time to scan a full image field and hence the frame rate of display improved by a factor of four in this example. But higher levels of multi-line requires the broadening of the transmit beam to insonify the greater expanse of multiple scanline locations.

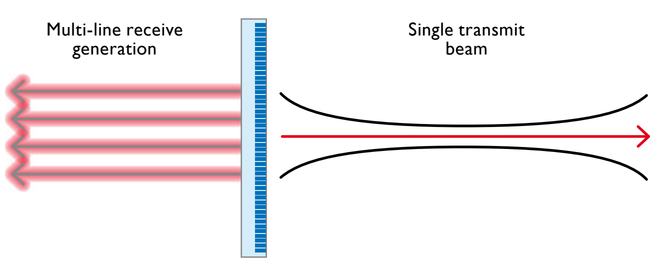


Figure 3 Multi-line beamforming

The transmit beam was even less focused than in the past, leading to the development of image artifacts. However, even with artifacts, multi-line beam formation was an important step in improving frame rate.

Synthetic focus beamforming

More recently, synthetic focus beamforming (also known as zonal focusing or plane wave imaging) has been available commercially. Synthetic focus beamforming has been known since the mid-1970s, but remained only of academic interest until recent years when higher density data storage and increased computational capability of microprocessors enabled the development of practical implementations. Synthetic focusing attempts to overcome some of the limitations of conventional beamforming by insonifying all or most of the image field during each transmit event – essentially reducing the influence of transmit focusing on the final image **(Figure 4)**.

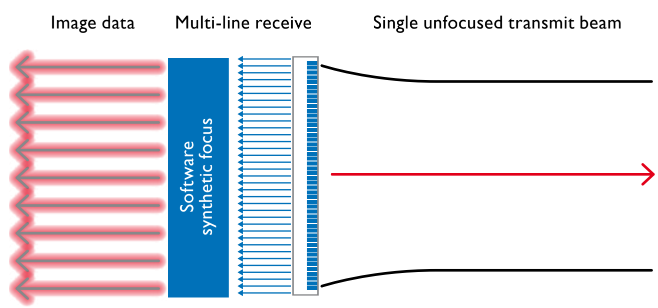


Figure 4 Synthetic focus/plane wave beamforming

This allows each transducer element to receive energy from most of the target region, so that all of the round-trip focusing required to generate an image can be performed on receive – thus allowing for the possibility of much higher frame rates, with reasonable spatial resolution.

However, synthetic focus beamformers have limitations of their own. Since synthetic focusing uses low intensity, unfocused plane waves on transmit, focusing occurs only on receive. The low transmit intensity results in poor signal to noise and a loss in penetration. If one attempts to recover signal to noise by averaging images from multiple transmit events, it reduces the frame rate, making it poorly suited for cardiac imaging other scenarios involving motion. Tissue harmonic imaging in particular requires higher amplitude ultrasound waves to be generated, and this normally requires some amount of transmit focusing – which is again incompatible with synthetic focusing.

Figure 5
Conventional focused transmit beam

Breaking the rules of conventional ultrasound

Through all of these incremental improvements in beam focusing, image resolution, and frame rate, the transmit beam has remained the same. It was still focused only at its programmed transmit focal point and its profile is still that of an hourglass **(Figure 5)**.

With conventional beamforming, imaging attributes such as spatial resolution, temporal resolution and tissue uniformity are linked – meaning if one attribute is improved another attribute is adversely affected **(Figure 6)**. One must always compromise one or more of the imaging attributes to achieve performance gains for another. For example, when users want to image with high frame rates – perhaps to visualize a rapidly moving structure or to allow the transducer to be swept across the patient when searching for pathology – they must accept a compromise in image quality, typically spatial resolution.

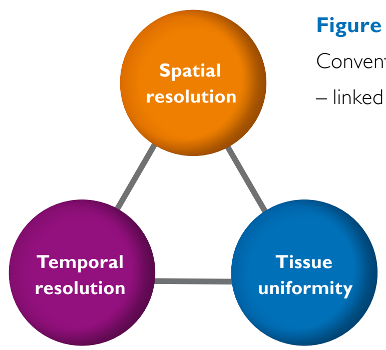


Figure 6
Conventional architecture – linked imaging attributes

This conventional wisdom has now been dashed by Philips ***n***SIGHT Imaging – a totally new way to form images without the compromise of conventional architectures. ***n***SIGHT Imaging reconstructs virtually perfect transmit beams throughout the depth of field. The round-trip beam profile is now no longer the product of an hourglass shape on transmit and a pencil shape on receive, but the product of two sharply defined pencil profiles **(Figure 7)**.

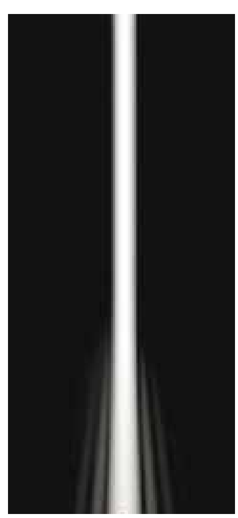


Figure 7
nSIGHT Imaging transmit beam reconstruction

As a result, dramatic improvements in contrast resolution, anatomical detail resolution and depth of field are realized, particularly in the very near and very far fields. With ***n***SIGHT Imaging spatial resolution, temporal resolution and tissue uniformity are unlinked, allowing the user to improve all aspects of imaging performance without compromising each other **(Figure 8)**.

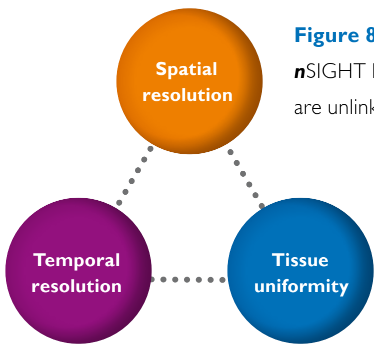


Figure 8
nSIGHT Imaging attributes are unlinked

Exploring *n*SIGHT Imaging

nSIGHT Imaging is a unique combination of a new precision beamformer and massive parallel processing. This innovative architecture allows coherent beam reconstruction in real time, incorporating the best features of multi-line beamforming with synthetic focusing techniques **(Figure 9)**.

nSIGHT Imaging supports a much higher degree of parallel beamforming than conventional multi-line approaches, allowing a much higher opportunity for frame rate improvements. The technique of combining multiple receive beams with other receive beams obtained from different transmit events – essentially a form of inverse filtering – automatically corrects for broadened transmit beam profiles and eliminates multi-line artifacts. Inverse filtering also continuously adjusts with depth as the transmit beam profile changes (due to transmit focusing), thus increasing the depth of field of each transmit focus.

Since multiple transmit beams are combined to generate each round-trip beam, and each transmit beam has a different noise pattern, the noise sums incoherently while the signal sums coherently, thus improving the signal-to-noise ratio and hence penetration.

To understand the details of ***n***SIGHT Imaging further, let's dissect the ultrasound beams of a conventional transmit-receive cycle **(Figure 10)**. The red focus line is the transmit beam center and the blue line is the aligned receive beam focus. When the transmit beam is launched from the transducer array, it is timed to have a curved wave front which will cause it to converge at a predetermined focal point.

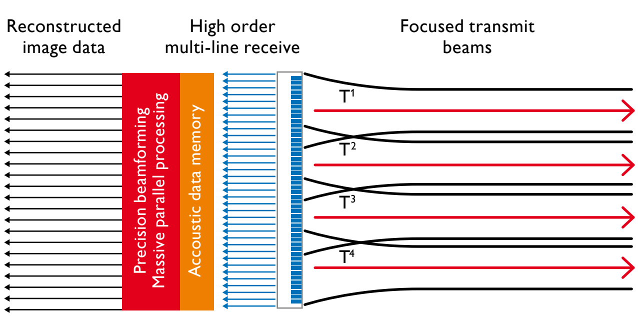


Figure 9 Philips ***n***SIGHT Imaging

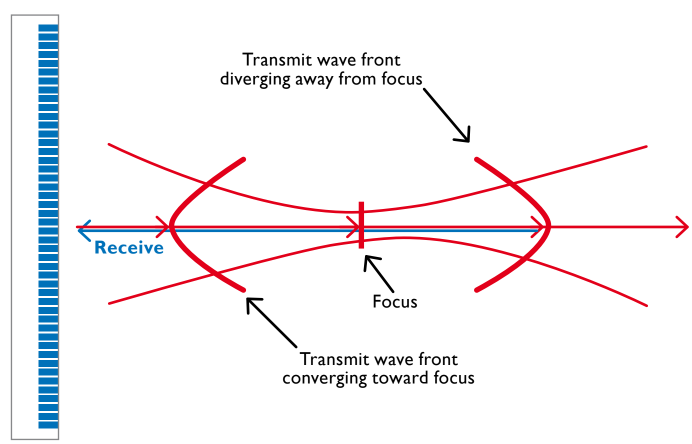


Figure 10 Conventional transmit beam

As the drawing shows, the transmitted converging wave front appears convex when viewed from the array. After the wave front converges at the focus it begins to diverge, with a concave appearance as viewed from the array. This process of convergence, focus, and divergence gives the beam the classic hourglass beam profile shown on either side of the beam center. The receive beam, being continually focused as it is received, has a narrow, pencil-like beam profile. The resultant round-trip beam profile (that defines the lateral resolution) is the product of both transmit and receive beam profiles. So even if the transmit beam is not as well focused as the receive beam, the round-trip beam profile should still be sharper (narrower). However, if both beams are pencil thin, then the product of the two would give us the sharpest round-trip beam possible, especially away from the original transmit focus. This is the promise of ***n***SIGHT Imaging.

Multiple transmit-receive cycles

nSIGHT Imaging technology applies multiple transmit-receive cycles with spatially different transmit beam profiles. For example, **Figure 11** illustrates three spatially adjacent transmit beams, T1, T2, and T3. All three transmit beams have the same converging and diverging wave fronts as shown in the drawing and all three are focused at the same depth as indicated by the vertical red line in the center. On receive, a beam is formed in response to each transmit beam which is at the same spatial location indicated by the blue receive beam R. In each case, the receive beamforming is the same, so three dynamically focused receive beams are received along the blue arrow R. While the three transmit beams are all tightly focused at the focal depth, it is seen that their wave fronts are out of phase both before and after focal convergence.

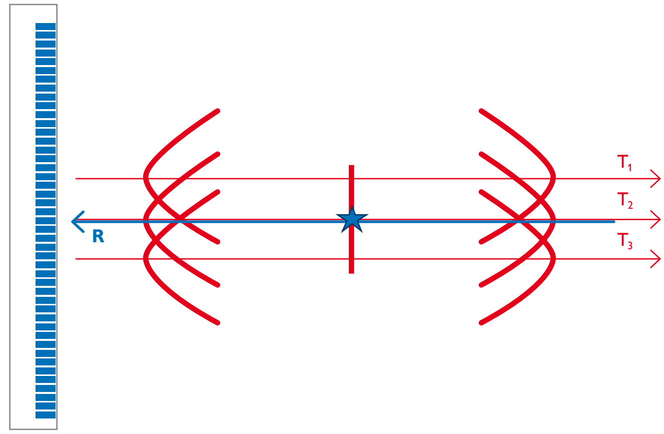


Figure 11 Multiple transmit-receive cycles

Consider just the near field shown in **Figure 12**. The "single" center beam has the correct phase location, yet the outer two beams (top and bottom) have the incorrect phase, and that ***n***SIGHT will align them with the center beam reference.

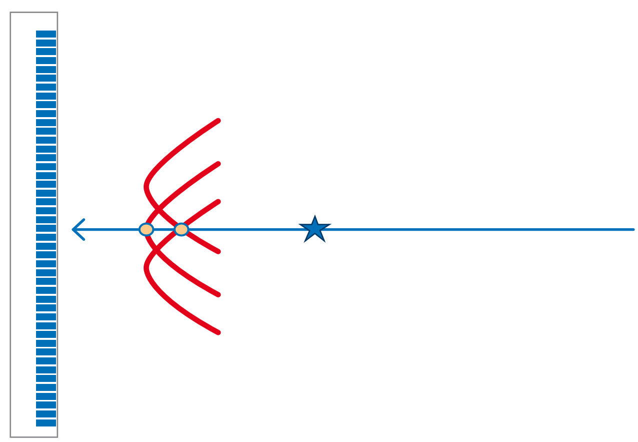


Figure 12 Near field wave fronts

***n*SIGHT Imaging adjusts for this phase misalignment by bringing the out-of-phase wave front into alignment with the center wave fronts, as shown in **Figure 13**.

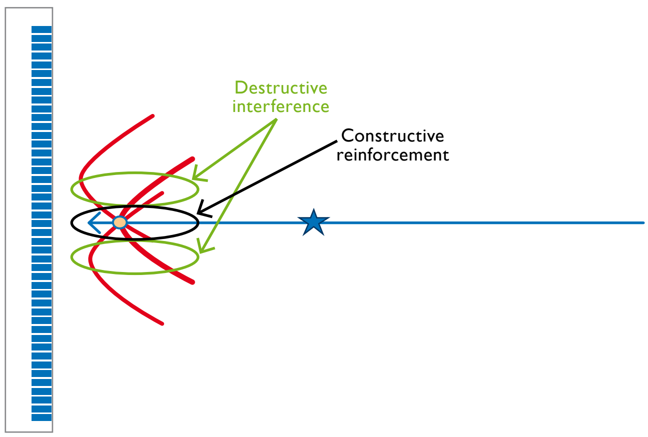


Figure 13 Alignment of wave fronts

It does not do this by any adjustment of the transmit waveform itself because, as stated above, once the transmit wave front is launched into the body it cannot be altered by the ultrasound system. The phase alignment is done by operating on the stored received signals which are affected by the round-trip beam profile and system delays, which causes the round-trip signals to appear as if they experienced dynamic transmit focusing.

Multiple improvements in resolution and detail

It is seen in **Figure 13** that several beneficial effects are produced by ***n*SIGHT Imaging. First, the three transmit wave fronts are all in phase on the scanline as shown by the yellow circle. Thus, the signals from all three beams constructively reinforce each other and will additively combine, producing a clearer, stronger signal precisely on the scanline being formed by the beamformer. On either side of the scanline it is seen that the three wave fronts are out of phase with each other. Consequently they will destructively interfere with each other away from the scanline axis. As a result, the desired scanline signals will be enhanced by the positive reinforcement while unwanted adjacent signals and noise experience cancellation. This is akin to the principle of frame averaging in ultrasound. But instead of combining one entire frame image with another, the signals received from an image field are adjusted and combined individually, point-by-point, throughout the entire image field. As a result, images are clearer and sharper than ever before. In the near field example of **Figure 13**, this means that detailed near field structures like muscular striations, highly superficial breast lesions, and liver capsule nodules can be resolved and viewed like never seen before.

Penetration also improves

***n*SIGHT Imaging brings improvement in penetration in the far field as shown in **Figure 14**. In the far field, the diverging wave fronts are similarly brought into phase coherence at the point indicated by the yellow circle. Since the signals from three transmit-receive events are being combined, there is inherent pulse averaging. Weak signals from the far field are enhanced multiple times when the signals are combined, providing increased clarity and resolution at the greater depths of field. As in the near field example, off-axis signals are out of phase which results in cancellation. Noise is averaged out and greater penetration with improved resolution results. A consequence of this far field performance is that far field artifacts common with previous ultrasound such as ventricular clutter are greatly diminished with ***n*SIGHT Technology.

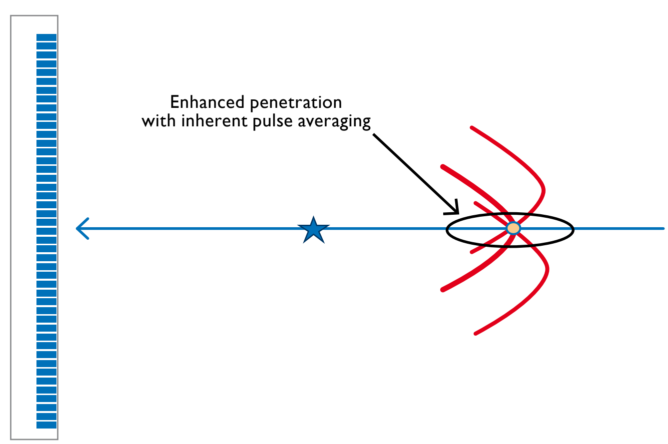


Figure 14 Enhanced penetration with pulse averaging

The dynamically refocused reconstructed transmit beam is now precisely focused throughout the full depth of field and has the same narrow, uniform beam pattern exhibited by dynamically focused receive beams. The product of the two beam profiles is an expected pencil-like round-trip beam profile as shown in **Figure 7**. Another benefit of ***n***SIGHT Imaging is that critical placement of a transmit focal depth is no longer required. The image will be more fully focused over the entire depth of field and less dependent on the set focal point. Complete image focusing attained in the past with multiple focal zones in zone focusing is achieved automatically with ***n***SIGHT Imaging without suffering the significant drop in frame rate experienced by multiple transmit zone focusing techniques. The concerns involved in focal zone setting are now relegated to the prior history of conventional diagnostic ultrasound.

No loss in temporal resolution

If the previous processing were done with three conventional transmit-receive cycles as **Figure 11** illustrates, frame rate would decrease by a factor of three. This deleterious effect does not occur with ***n***SIGHT Imaging through its use of high-order multi-line transmission and reception as illustrated by **Figure 15**. This example shows four transmit-receive cycles with four transmit beams T1, T2, T3, and T4. The transmit beam centers are shifted along the array from one event to another as shown in the drawing.

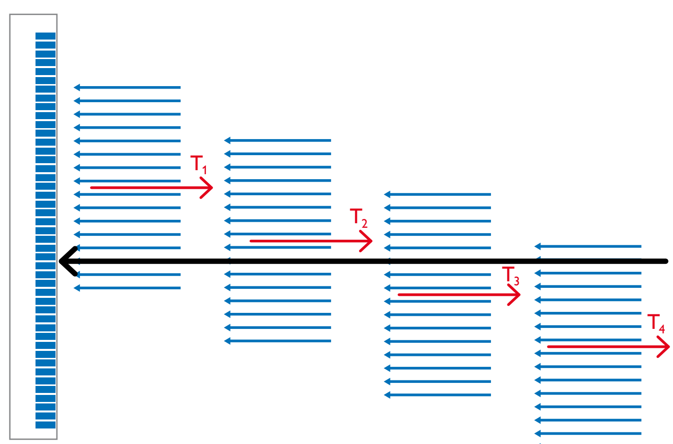


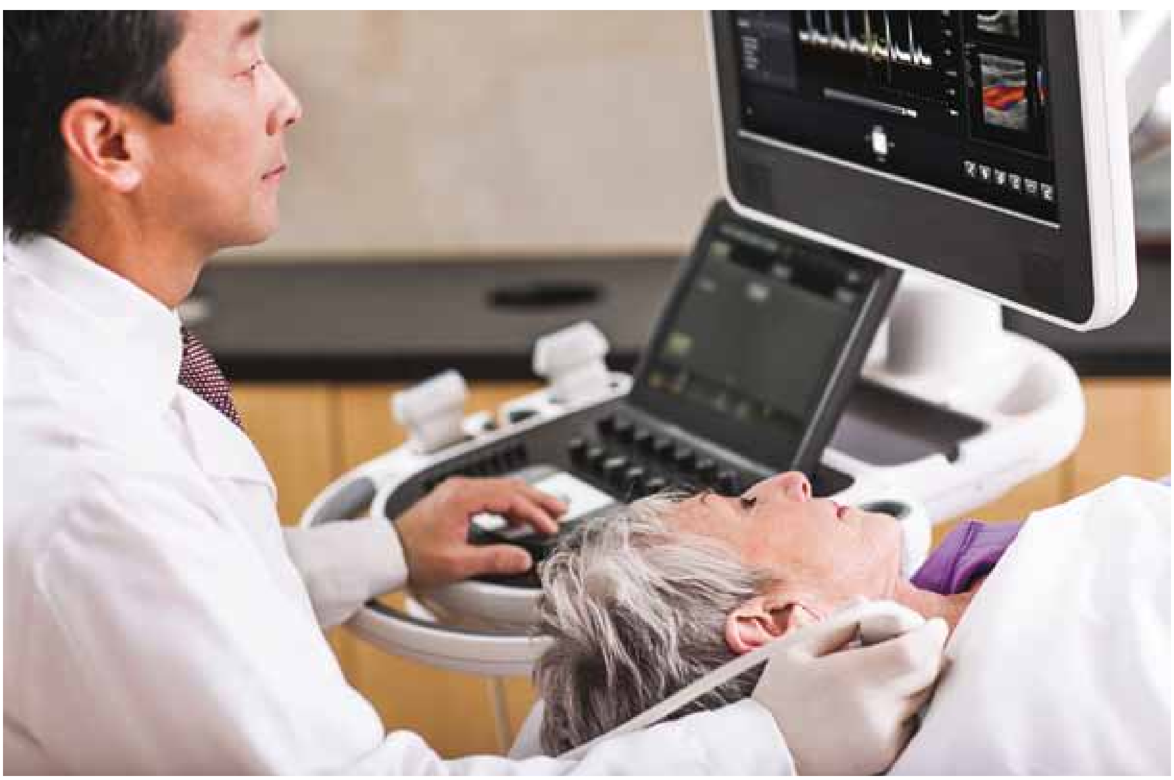
Figure 15 High order multi-line

Instead of receiving a single receive beam as in **Figure 11**, sixteen (or more) receive beams are acquired in response to each transmit beam. The black arrow shows that these four transmit-receive events will result in a scanline formed from four transmit-receive events, which is both transmit-focused and receive-focused. It can also be seen in **Figure 15** that three other fully focused beams can also be formed at this time, one in the scanline position above the black arrow and the two below. Thus, for each incremental transmit event, four fully focused scanlines will be formed with significantly faster frame rates than conventional single beam acquisition and with significantly greater resolution and detail than that provided by the three-cycle example of **Figures 11-14**. This means that frame rate and temporal resolution are improved four-fold over the conventional approach. The need to trade off temporal resolution for spatial resolution and image detail is relegated to the past with Philips patented ***n***SIGHT Imaging.

Massive parallel processing comes to ultrasound

The precision beam reconstruction method of ***n***SIGHT Imaging also requires the addition of powerful processing. In order to perform virtually instantaneous beam reconstruction, a new architecture needed to be developed. The result is proprietary hardware and software able to perform massive parallel processing of data. The unique ***n***SIGHT Imaging architecture is able to perform 450 x 10^9 40-bit multiply-accumulates per second. To put this into perspective, this would equate to:

- ~5000x Cray-1 supercomputers working in unison ($5-8M each in 1980)
- ~75x high-end multicore DSPs working in unison (3 cores, 2 32-bit MACs per core, 1 GHz)
- ~25x high-end gamer desktop PCs working in unison (dual socket, 8 cores per socket, 2 GHz)

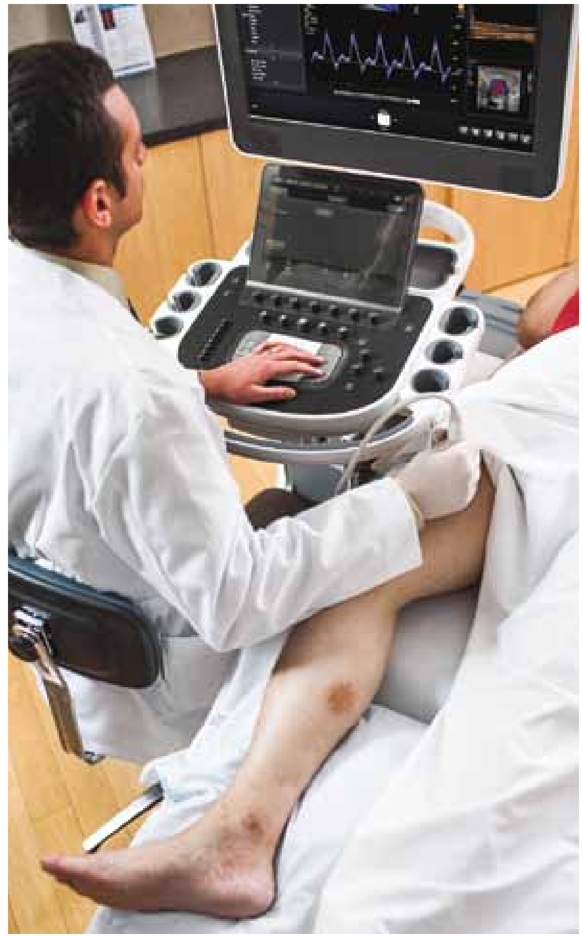


Reaching its full potential

A powerful new beamformer architecture capable of resolving fine detail throughout an entire image field cannot realize its full potential unless the system signal path preceding the beamformer delivers the highest quality signal information. Hence, Philips has designed the front end of the EPIQ system to enable the reception and delivery of signals with greater image information content than in the past. The initial acquisition signal path has been redesigned with new front-end analog circuitry to provide increased acoustic signal bandwidth, which is especially important for maximizing sensitivity and penetration at the highest imaging frequencies. This signal path has also been redesigned with increased dynamic range, which enables detection of a wider range of acoustic signal amplitudes without distortion for greater resolution of fine detail. With a new signal path providing signals of increased signal bandwidth and dynamic range, ***n***SIGHT Imaging attains unrivaled levels of performance.

Clinical breakthroughs

Philips ***n***SIGHT Imaging produces truly extraordinary clinical results across multiple applications. Improvements in all aspects of imaging can be realized as seen in the table below.



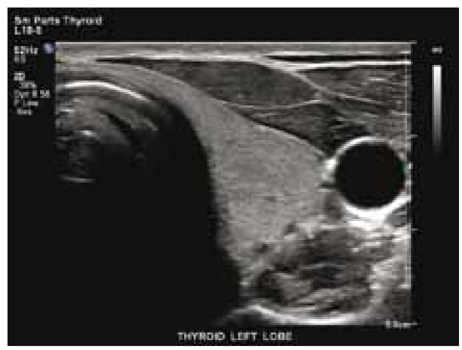
Technical feature	Clinical impact
Precision real time beam reconstruction	• Superb spatial resolution • Enhanced contrast resolution • Outstanding tissue uniformity • Fewer artifacts and reduced image clutter
Fewer transmit operations with increased frame rate	• Facilitates 2D survey scan with less artifacts • Excellent B-mode IQ in color flow modes • Enhanced SonoCT and harmonic modes • Outstanding CEUS performance • Superb 3D/4D IQ and frame rate
Ultra-wide system bandwidth and exceptional signal-to-noise ratio	• Outstanding CEUS performance • Superb Doppler performance • Exceptional high frequency performance • Enhanced penetration and contrast resolution

*n*SIGHT Imaging – seeing is believing

Philips EPIQ ultrasound system with ***n***SIGHT Imaging truly represents the next era in premium ultrasound with a new level of diagnostic certainty and clinical confidence. Along with the introduction of the most powerful architecture ever created for ultrasound, Philips EPIQ overshadows every premium ultrasound system that has come before with exceptional image quality, an unmatched user experience, and unheard of levels of adaptive intelligence.

C9-2 imaging of a 14-week fetus reveals superb contrast resolution and delineation of structural detail.

Outstanding spatial resolution and stunning uniformity seen with the C9-2 PureWave curved array transducer.



High frequency imaging of the thyroid gland with the L18-5 linear array demonstrates superb detail and contrast resolution.

This image of the carotid artery reveals a subtle dissection abnormality.

Breast imaging with the L18-5 linear array transducer shows a small cyst with microcalcification.

PureWave C10-3v transducer demonstrates excellent detail and contrast resolution with superb frame rate.

X5-1 xMATRIX transducer shows superb myocardial and valve definition.

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