Corrosion is a common problem in most of the industrial segments like Oil & Gas, Power, Transportation and Aviation etc. Ultrasonic testing is the most prevalent technique to measure the corrosion or thickness loss. As of now lot of thickness gauges are widely used to measure the thickness loss or corrosion or erosion damages. The conventional ultrasound will provide the measurement at the spot, hence its time taking process and no imaging capabilities for easy interpretation. Another constraint with ultrasound transducer is the near surface resolution especially to measure the corrosion or erosion on thinner thickness part. Small corrosion echoes are difficult to detect the front surface.

Though Dual Element probes improves signal to noise ratio and enable detection of thinner part it is used in thickness gauges. Finding the minimum thickness on large area coverage is a huge time taking process with thickness gauges. This paper elaborates about the use of Phased Array Ultrasound technology helps to overcome the productivity issues with thickness gauges and how the Dual Array transducer (DM Array probe) increases the near surface resolution which is equivalent to thickness gauge. It also shares the results of DM array probes versus high resolution standard phased array transducers on the corrosion specimens.

Keywords: Phased Array UT, Thickness Gauge, Corrosion Inspection, DM Array, Delay Line Transducer, Corrosion UT

Introduction
The corrosion of steel is inevitable in industries like power plant, oil and gas refineries, transportation etc. At atmospheric condition oxygen provides the necessary ingredient to form the iron oxide and the transformation is very slow. But if water is also present the transformation is rapid and the iron turns to rust. This shows that the corrosion in steel is a universal widespread problem. As per “CC Technologies & NACE International” the study shows the cost of corrosion in the USA is $276 Billion per Year. Corrosion costs 2 lakh crore rupees per year in India. This emphasizes the importance of identifying the corrosion damage and prevention.

Non Destructive Testing is heavily involved in the battle of corrosion world to play a major part in identifying the extent of corrosion damage. In corrosion evaluation various NDT techniques are used to identify the corrosion. In the early years, radiography has the very important feature of giving the corrosion engineer a general impression of the nature and the extent of corrosion. But it has limitation to access both sides and in addition, X-rays and Gamma Rays are inherently dangerous. Hence it is a time taking process. The other conventional techniques like Eddy Current, Magnetic particle and Dye Penetrant are limited to surface and subsurface inspection.
In corrosion evaluation, ultrasonics has the important advantage that access to only side of component is needed. So ultrasound has the main stay in the NDT field for corrosion detection. The ultrasonic method normally utilized is the pulse-echo technique. The distance between the surface and the interface or backwall is detected by time in microseconds.

**Ultrasound Thickness Gauges**

With the conventional ultrasound technique it has some limitation of near zone and dead zone which has huge impact on corrosion evaluation. The challenge in technique of ultrasound is detection of thinnest spot in the pipe or ship or boiler etc. It needs high amplification to see small targets and it needs the UT probe with greater near surface resolution.

To improve the near surface resolution, delay line can be used and hence the near zone will be within the delay. When using the delay line pulse echo technique, small corrosion echoes are still difficult to detect the near surface. Dual Element ultrasound probes improve the signal to noise ratio and hence enabled the detection and measurement of $T_{\text{Min}}$.

With the past recent years Dual Element Ultrasound probes are designed which has significantly improved by almost nullifying the near zone effects. And hence lots of thickness gauges are evolved to measure the thickness loss. Thickness Gauges is one of the most commonly used instrument to efficiently detect and measure corrosion pits, thin spots, erosion damage etc. Thickness gauges provide data to mitigate the risks and manage the assets to ensure safety.

**Challenges with Thickness Gauges**

Thickness Gauges is the most appropriate technical solution for efficiently detecting thickness loss and corrosion. But while covering large areas, searching for $T_{\text{Min}}$ the most critical spot is equivalent to searching the needle in haystack. Thickness Gauges can provide only the spot evaluation and hence there is a high chance of manual error and less productivity to cover the large area by collecting data with small spots.

Phased Array Ultrasound is emerging as the powerful ultrasound technology in lot of applications which plays major role in productivity. In the large coverage areas, the use of
electronic scanning with multi-element phased array probes will improve the coverage and the volumetric image like radiography. Now a days Phased Array instrument revolutionized with software and provide lots of intuitive image with tools to assist in locating the corroded areas.

Fig. 3: Single Point Inspection on large areas

Fig 4: Electronic Scanning with Phased Array UT

**Challenges in Phased Array UT for Corrosion**

Phased Array ultrasound technology is proven for various major applications like Weld Inspection, Inspection of complex components where the conventional A-scan is not possible to access those areas etc., However Phased Array Ultrasound has changed lot of conventional method of A-scan UT with the modern trend of electronic steering and focusing, but it is still challenging for corrosion application to resolve the thickness loss. Phased Array transducers also have the same constraint of physics with near surface resolution. Hence the challenge is same as conventional UT even though Phased Array has huge advantage of line scanning. High resolution phased array contact and delay line probes didn’t have the adequate Signal to Noise ratio to resolve small corrosion.
Fig. 5: ASTM #4 – 1.5 mm (0.062") FBH @ 2.25 mm (0.09") deep

Fig. 6: PAUT probe Backwall echo without FBH

Fig. 7: PAUT probe with FBH
Figure 6 shows a nice back wall echo with very good signal to noise ratio when the probe is placed on the region of no FBH. But when placed the probe on the region of FBH, it has resolved the back wall echo and the surface above back wall echo. But it has missed to resolve the 1.5 mm FBH and 2.25 mm deep hole. This is mainly due to the dead zone of probe is > 2 mm and hence it is not able to resolve the 2.25 mm FBH. This shows that special Phased Array probes are needed to preform something equivalent to Dual Element Probe used in Thickness Gauges.

**Dual Element Array (DM) Probes**

To overcome the challenges with standard Phased Array probes has lead us to develop a technology in probe as exactly same as Dual Element Probes which is very well accepted in the corrosion detection. We have developed the TR Dual array probe which will give the performance like conventional TR Dual Array probe.

Dual Element Array (DM) probe is designed with the array of elements which is used for transmission and another set of elements which is used for receive. The required effective area of virtual probe can be configured by grouping the array of elements as it is inevitable with Phased Array UT. The probe is designed to mount on a fixed wedge with roof angle. The basic concept is taken from conventional Dual element TR probes which will create the V-path for transmission and receiving the ultrasound. V-path is converted into corrected depth to show the accurate reading. V-path correction is done as same as conventional ultrasound TR probe. By changing the Virtual Probe size will help to achieve the sensitivity for different range of thickness.

Figure 8 shows the development of probe technology which is using the conventional Dual TR probe concept with Array probe design. With this concept the flexibility of electronic scanning and virtual probe can be done with high signal to noise ratio. Transformation of bringing the conventional value on array probe technology is a challenge on probe design to achieve the same result of the probes used in conventional thickness gauges. From GE Inspection technologies we have developed this probe by overcoming the challenge which is compatible with GE phased array UT product Phasor XS.

**Experimental Results of DM Array probe**

The setup is done as shown in the figure 9 by connecting the DM probe with portable phased array instrument Phasor XS. The efficiency of DM array probe is measured by placing the
probe on FBH #5 of ASTM block with multiple Soundpath distance and measure the amplitude variation in dB.

Figure 10 shows the graph of measuring the amplitude for different Soundpath having the FBH #5 for 2 different apertures. Blue line shows the aperture with 3-elements and pink line shows the aperture with 5-elements. 3-element and 5-element have more or less same amplitude until 6.25 mm (0.25”).

The amplitude with 3-element is relatively lower than 5-elements aperture with increase in Soundpath distance for the same reflector size. This shows the flexibility and importance of Phased Array technology by changing the aperture size based on thickness to be inspected, which is not possible with conventional UT.
Figure 11 shows the graph of performance of the Dual Array probe with the conventional FH2E probe with the same effective aperture on Phased Array DM probe. The graph shows the relatively same amplitude until 7.5 mm (0.3”) and then Dual Array probe shows better performance than conventional TR probe and the slope is same. This clearly shows that with the Dual Array DM probe can achieve the same result of conventional TR probes which is used for thickness gauging.

**Performance Comparison of DM array probe**

The same experiment which was done with high resolution standard phased array probe is repeated with DM array probe on ASTM block and 0.09” (2.25 mm) hole to compare the performance of DM array probe with Standard phased array probe.

Setup shows the DM array probe is placed on the same ASTM block with FBH 0.06” (1.25 mm) at 0.09” (2.25 mm).
The images show the improvement in detection of FBH @ 2.25 mm depth and the clear resolution between the backwall echo and the surface above the backwall. The images clearly proved that thickness loss and near surface corrosion can be achieved with DM array probe which can resolve the thickness variation with 1 mm and the defects located at 2mm. The below figure shows the comparison of high resolution PA pulse echo probe with Dual Array TR probe shows the improvement in resolution and Signal to Noise ratio that can be achieved with DM probe.
The probe is designed for accurate digital thickness measurement with V-path correction gives the huge advantage of using the phased array technology for corrosion application. The approach of using the traditional conventional concept on advanced phased array imaging will surely improve the productivity of scanning and easily locating the $T_{Min}$ with the images. The imaging will increase operator confidence and POD.
Data Recording with C-scan

With the support of C-scan imaging it is very easy to produce the image something equivalent to radiography. One pass of scan can cover upto 45 mm (1.8”) with the linear scan of grouping 8 elements as active aperture.

Fig. 18: Area scanning of PA Linear Probe for better coverage and productivity

C-scan can be obtained with timed or encoded mode. The C-scan can be displayed as per amplitude and as per Depth. With different color mapping as per depth and as per amplitude will help the inspector to have multiple perspective as per the need.
In addition to advantage of better probe, imaging, productivity & POD, the dedicated thickness measurement capability will assist the analyzer to make decision on Risk Bases Assessment. Displaying the readings like:

- Thinnest reading experienced in a SCAN from all beams since last reset
- Thinnest from any beam in the current probe position
- Thickness reading for selected beam in current probe position

To adapt with the curved surfaces like pipes and tubes, we have designed footprints with different radius of curvature.

**Conclusion**
With the design of new phased array TR probe has made the progress to move from conventional thickness gauges to phased array imaging with very simple steps. Phased Array DM probe has improved manual inspection productivity; improve the minimum wall probability of detection (POD), improved area of coverage. With the phased array imaging visualization and measurement simplifies the detection and interpretation. Detection characteristics beyond those of a thickness gauge probe are possible with the combination of the A-scan and Phased Array Image with Dual Array Probe design.

**References**