**46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA**

**QNDE2019-1234**

# HANDHELD MICROWAVE IMAGING SYSTEM FOR THE INSPECTION OF NON-METALLIC STRUCTURES

**Mohammad Tayeb Ghasr[1], Yuan Gao, Reza Zoughi**
Applied Microwave Nondestructive Testing Laboratory (*amntl*)
Department of Electrical and Computer Engineering,
Missouri University of Science and Technology
Rolla, MO 65409

## ABSTRACT
*The utilization of non-metallic pipes, primarily fiberglass composites and high density polyethylene (HDPE), is ever expanding due to their corrosion resistance among other benefits. With that in mind, the inspection need for these non-metallic pipes is rapidly growing. However, no viable robust solution currently exists for performing such inspections. Microwave synthetic aperture radar imaging technique has shown tremendous potential for inspection of such structures, in particular for the detection of flaws such as: porosity, voids, delamination and structural erosion. As such, this paper presents a handheld, field deployable, microwave imaging array for the inspection of non-metallic pipes, which consists of an easy to use imaging system for detecting flaws in such pipes in real-time. The design incorporates critically important and practical features, determined essential by potential users, such as: ease-of-use, and being light weight, real-time, and relatively low cost.*

Keywords: Microwave NDT, Non-metallic Pipes, Defect Detection, Microwave SAR Imaging

## 1. INTRODUCTION
The cost of corrosion to the pipeline industry in the United States, according to a report by National Association of Corrosion Engineers (NACE), is as high as US$8.6 Billion/Year [1]. This issue has resulted in a push in the pipeline industry for an ever expanding utilization of non-metallic pipes primarily fiberglass composites and high density polyethylene (HDPE). The global fiberglass and HDPE pipe market is expected to grow with a compound annual growth rate of 5.6% over the period 2016 to 2025. The growth is due to increasing demand from various end-use industries, including: oil & gas, irrigation, chemicals, sewage and others [2]. With an ever-increasing utilization of these pipes, inspecting them becomes critical in order to minimize downtime (for inspection and due to failure) in the aforementioned industries. With these relatively new pipe materials, new testing and inspection techniques are required. In particular, for fiberglass pipes, the traditional testing method of ultrasound (UT) is ineffective due to the nonhomogeneous nature of the fiber layup in their construction. Other methods are not applicable, for example eddy current techniques which is only applied to conductive materials, or have major drawbacks such as the safety hazards of the ionizing X-ray systems [3]. Microwave and millimeter wave imaging techniques have shown great promise for inspecting non-metallic pipes [4]. In particular imaging techniques based on the wideband synthetic aperture radar (SAR) algorithm provide three-dimensional (3D) images that are relatively high resolution and have high signal-to-noise ratio (SNR) [4, 5].

Here, we present a field deployable microwave imaging system in the form of a one-dimensional (1D) array that can be manually scanned (rolled) across the circumference of a pipe for imaging and detection of flaws within the pipe structure. Such a system is capable of imaging a number of flaws such as improper pipe joints, erosion in the internal wall of the pipe, voids, delaminations and cracking.

## 2. IMAGING SYSTEM DESIGN AND RESULTS
The imaging system design is based on a 32-element switched array operating in the frequency range of 20-30 GHz. The radiating elements of the array are open-ended waveguide antennas with an interferometer (receiver) built into the aperture, significantly simplifying the design of the microwave circuitry in the array [5]. Initially a single antenna, built within a three antenna configuration, is tested for its imaging capability in order to test the efficacy of this design. Figure 1 shows a picture of this three-antenna element prototype. This prototype was used to raster scan a 14 mm-thick balsa wood composite with an embedded thin square copper patch with side dimensions of 6 mm. Only one antenna was actively radiating the sample and measuring the reflected waves, while the other two antennas are included to simulate their effect on the active center antenna,

[1] Contact author: mtg7w6@mst.edu

 

similar to the full-length array. At each point in the raster scan grid, 51 measurements across the frequency band of 20-30 GHz were recorded. The obtained wideband raw data was processed using the SAR algorithm outlined in [6]. The resultant SAR image focused at the depth corresponding to the copper patch is shown in Figure 2. The microwave SAR image is represented as a false color image, where red represent a strong amplitude (bright regions) and blue represents a small amplitude (dark regions) of the image. The bright red indication at the center of the image, corresponding to the copper patch, is clearly visible within a uniform and relatively clutter-free (blue) background representing the uniform wood composite.

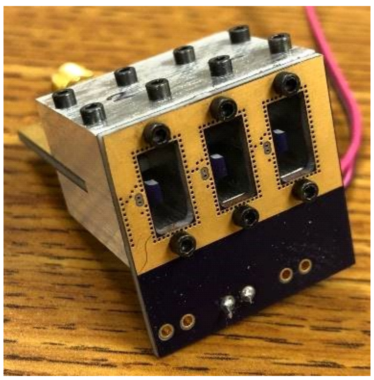

**FIGURE 1:** PICTURE OF A 3 ANTENNA ARRAY PROTOTYPE.

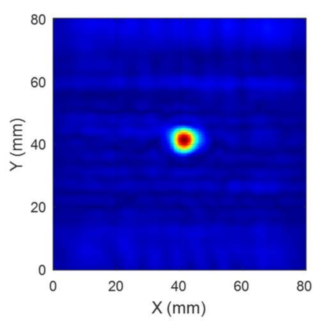


**FIGURE 2:** MICROWAVE SAR IMAGE OF A THIN COPPER PATCH INSIDE A BALSA WOOD COMPOSITE.

Similarly, a 20 mm thick and relatively flat fiberglass sample containing a flat bottom hole with a dimeter of 12 mm and depth of 6 mm was raster scanned. Specifically, the flat bottom hole which was on the bottom side of the sample, was 14 mm deep from the inspected top surface. The flat bottom hole represents a void inside or erosion (i.e., wall thinning) to the inner lining of a fiberglass pipe or tank. Figure 3 shows a SAR image focused at the depth corresponding to the bottom surface of the sample which shows a pair of bright (red) indication merged into an elongated (along the *y*-axis) indication. The pair of indications (or elongation) are due to the scattering from two opposite edges of the hole which primarily occurs along the electromagnetic wave polarization (direction of electric field vector) which is in the *y*-direction in this case. The background in this image is more cluttered than the image in Figure 2 due to the inhomogeneity of fiberglass.

As mentioned above, wideband SAR imaging can produce 3D images. Figure 4 shows the 3D image produced of the fiberglass sample with the flat bottom hole. Here, the colorbar represents the distance of the image voxels from the antenna aperture, where red indications are the deepest points corresponding to the bottom surface of the fiberglass sample and blue indications are the shallowest point corresponding to the top surface of the sample. In this 3D image of Figure 4, the red indications at the bottom surface of the sample are due to the scattering from two opposite edges of flat bottom hole along the wave polarization as mentioned previously. The other shallow (blue) indications are due to surface roughness and small voids located near the surface of the sample. Conversely, without 3D SAR imaging, it is difficult to distinguish critical defects (such as those internal to the structure) from non-critical defects such as those due to surface roughness.

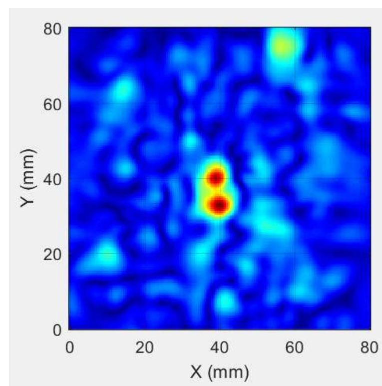


**FIGURE 3:** MICROWAVE SAR IMAGE OF A FLAT BOTTOM HOLE INSIDE A FIBERGLASS SAMPLE.

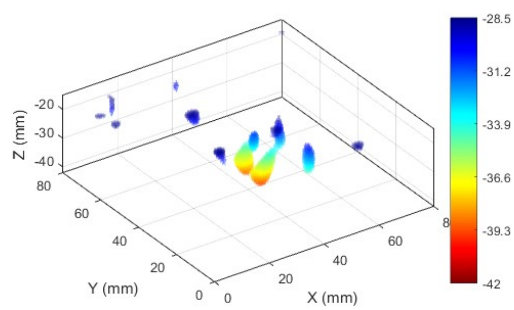


**FIGURE 4:** 3D MICROWAVE SAR IMAGE OF A FLAT BOTTOM HOLE INSIDE A FIBERGLASS SAMPLE.

Figure 5 shows the rendering of the entire imaging system array. The design of the system is based on the innovative and recently developed microwave camera [5, 7]. The imaging system is based on a 32-element array and covers a length of about 250 mm. the microwave circuitry is housed within a lightweight aluminum housing that serves as shielding against interference, provide protection to the circuitry and also form the radiating waveguide antenna apertures. The system incorporates wheels on both ends with positioning encoders that track the manual movement of the user. Subsequently, using the developed SAR techniques in [7], the acquired spatially-random data are processed for error-free images.

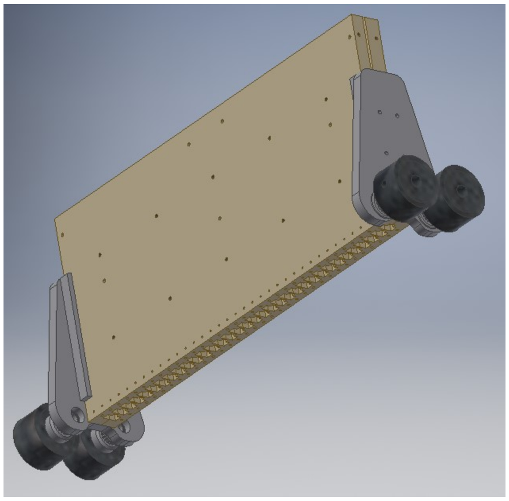

**FIGURE 5:** RENDER OF THE IMAGING SYSTEM 1D ARRAY.

## 3. CONCLUSION

A handheld portable and real-time microwave imaging system is presented for the inspection of non-metallic pipes and structures. The system operates in the frequency range of 20-30 GHz and designed to produce 3D SAR images. The imaging results illustrate the efficacy of this design in detecting small flaws within thick structures and producing high SNR images. The relatively high resolution offered by the SAR algorithm provide for a quantitative assessment of the flaw size and location. The ability to produce 3D images help in isolating non-critical surface flaws from the more critical subsurface flaws.


## ACKNOWLEDGEMENT

This work was supported by the Missouri University of Science and Technology (Missouri S&T), Technology Acceleration Grant.


## REFERENCES


[1] IPL Technologies, "What is Corrosion Costing the pipeline industry?" last accessed March 29, 2019, www.ipltec.com/news/articles/what-is-corrosion-costing-the-pipeline-industry/.

[2] Grand View Research, "Fiberglass Pipe Market Analysis" August 2017 https://www.grandviewresearch.com/industry-analysis/fiberglass-pipe-market.

[3] Ghasr, M. T., Horst, M. J., Lechuga, M., Rapoza, R., Renoud, C. J. and Zoughi, R., 2015, "Accurate One-Sided Microwave Thickness Evaluation of Lined-Fiberglass Composites," IEEE Trans. Instr. Meas., vol. 64, no. 10, pp. 2802-2812.

[4] Laviada, J., Wu, B., Ghasr, M. T. and Zoughi, R. 2019, "Nondestructive Evaluation of Microwave-Penetrable Pipes by Synthetic Aperture Imaging Enhanced by Full-Wave Field Propagation Model," IEEE Trans. Instr. Meas., vol. 68, no. 4, pp. 1112-1119.

[5] Ghasr, M.T., Case, J.T., and Zoughi, R., "Novel Reflectometer for Millimeter Wave 3D Holographic Imaging", IEEE Trans. Instr. Meas., vol. 63, no. 5, pp. 1328-1336, May 2014.

[6] Case, J. T., Ghasr, M. T., and Zoughi, R., 2013 "Nonuniform Manual Scanning for Microwave Nondestructive Evaluation Imaging" IEEE Trans. Instr. Meas., vol. 62, no. 5, pp. 1250-1258.

[7] Ghasr, M. T., Horst, M. J., Dvorsky, M. R., and Zoughi, R., 2017, "Wideband Microwave Camera for Real-Time 3D Imaging," IEEE Trans. Ant. Prop., vol. 65, no. 1, pp. 258-268.


 