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High Frequency Non-Contact Ultrasonic Analysis: A Practical Reality

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During the last twenty years, both ultrasound and its applications have grown phenomenally. Besides overt defect detection, ultrasound is also used for the characterization of properties, microstructure, anisotropy, chemical corrosion, crystallization, polymerization, viscosity, surface, internal imaging, etc.

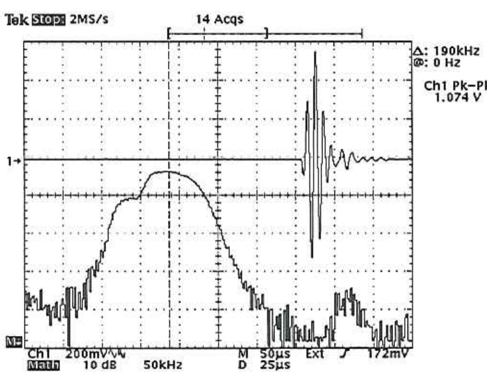
Despite this impressive record, ultrasonic testing is marred by the physical coupling of the transducer to the test material, generally by liquids. If this contact could be eliminated, then we could characterize materials that are porous or hygroscopic, in the early stages of manufacturing (uncured plastics, green ceramics and powder metals), and those that are continuously rolled on a production line (such as plastics, rubber, paper, construction & lumber, etc.) The ultimate aim of non-destructive materials evaluation is to free the test material from touch or contamination. For this the development of Non-Contact Ultrasound (NCU) has been a dream of some.

For NCU to become a reality, we first need the transducers and electronic systems sensitive enough to transmit and detect ultrasound without any contact with the test material. And herein lies a big problem. The phenomenal acoustic impedance mismatch between the coupling air and the test media prevents meaningful NCU transmission in the solids. For practical NCU mode this acoustic impedance barrier must be broken. And for this to happen, it is imperative that ultrasonic transducers be characterized by extremely high sensitivity. Achieving of NCU is analogous to *"throwing a helium-filled rubber balloon so that it can pierce through a stainless steel wall!"*

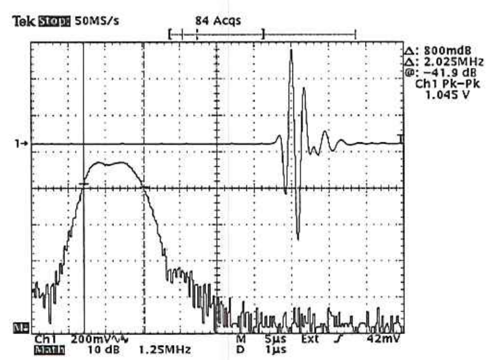
To realize NCU we have been working for a long time. A precursor to high frequency non-contact transducers described in this paper, was our 1982 development of dry coupling longitudinal and shear wave transducers up to 25MHz frequency. An important by-product of this was the air/gas propagation transducers which quickly found applications in aircraft/aerospace industries for imaging and for defect detection in fibrous, low and high density polymers, and composites. Though the sensitivity of these transducers was relatively high, they still required high energy excitation and signal amplification.

In 1995 we finally succeeded in creating perfect acoustic impedance matching of piezoelectric transducers for optimum transduction in air from <100kHz to 5MHz (world-wide patents pending). The sensitivity of these new transducers in air is merely 30dB lower than their conventional contact counterparts. This transducer development was matched by an equally powerful systems development in 1998, that is, the non-contact analyzer -- the NCA 1000 (U.S. patent pending). This system measures thickness, velocity, defects, and frequency-dependent characteristics of materials, and displays them in a simple format. NCA 1000 features over 140dB dynamic range and time-of-flight accuracy of ±1ns (closed condition) and ±20ns (open conditions). In this paper we exhibit NCU transducer characteristics, proof of high frequency NCU, and selected applications.

Non-contact Transducer Characteristics in Ambient Air by Pulse Excitation Transmission Mode

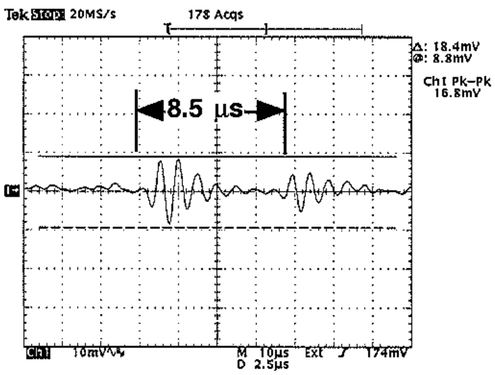


200kHz, 50mm active area transducers. T-R air separation: 100mm. Bandwidth Center Frequency: 200kHz. Bandwidth @ -6dB: 100kHz (50%). Pulse Width: <20µs. Sensitivity: -46dB. SNR: 46dB.

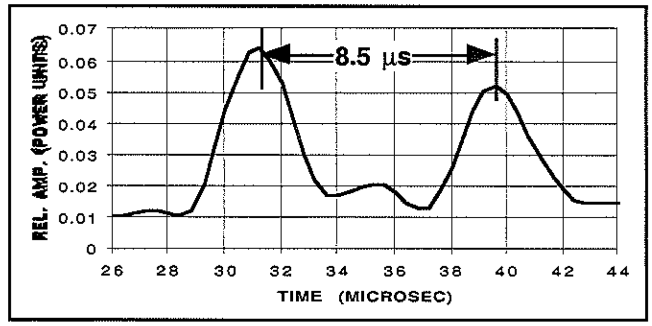


3MHz, 12mm active area diameter transducers. T-R air separation: 10mm. Bandwidth Center Frequency: 2.6MHz. Bandwidth @ -6dB: 2.0MHz (75%). Pulse Width: <700ns. Sensitivity: -64dB. SNR: 30dB.

Practical Evidence of High Frequency NCU – Propagation of 1 and 2MHz ultrasound in steel (Z = 51Mrayl).

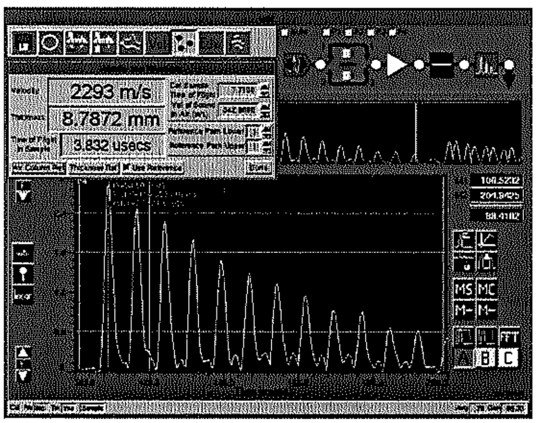


A 1MHz non-contact transmitted signal through 25mm carbon steel. T & R are 10mm away from the material surfaces. Excitation: 400V square wave into 4Ω. Amplification: 64dB. Left indication: directly transmission signal. Right: First thickness reflection. Amplitude of transmitted signal: ~20mV.

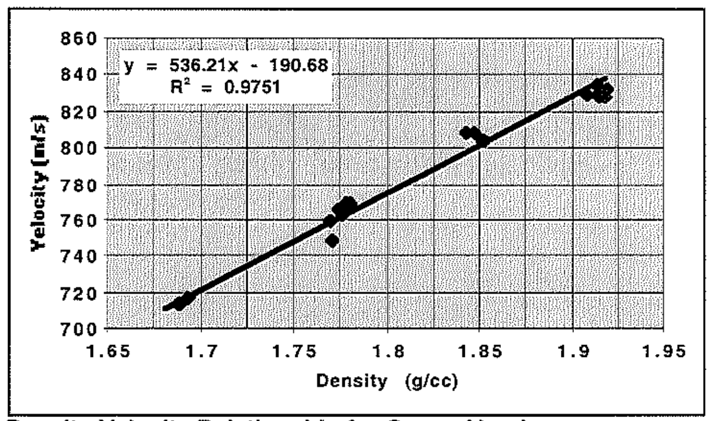


A 2MHz non-contact transmitted signal through 25mm carbon steel. T & R are 5mm away from the material surfaces. Excitation & signal processing: NCA 1000. Left indication: directly transmitted signal. Right: First thickness reflection.

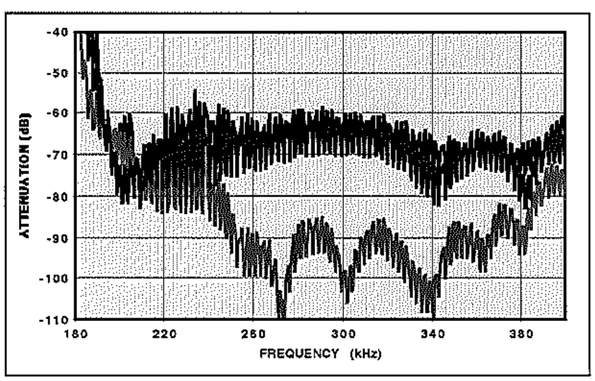
Some Industrial, Food, and Bio-medical Applications



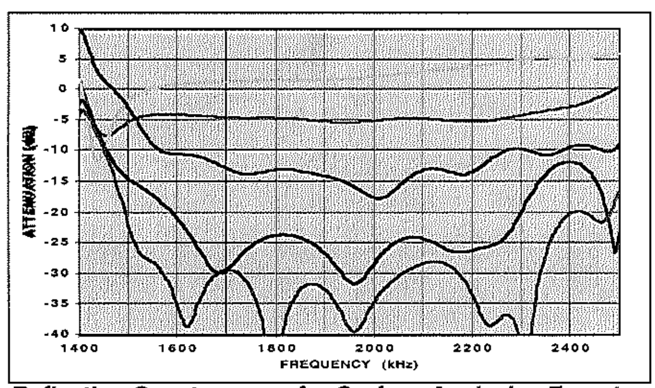
The NCA 1000 screen displaying velocity and thickness of a material. The test material in this case is a 8.8mm polystyrene. NCU frequency: 1MHz.



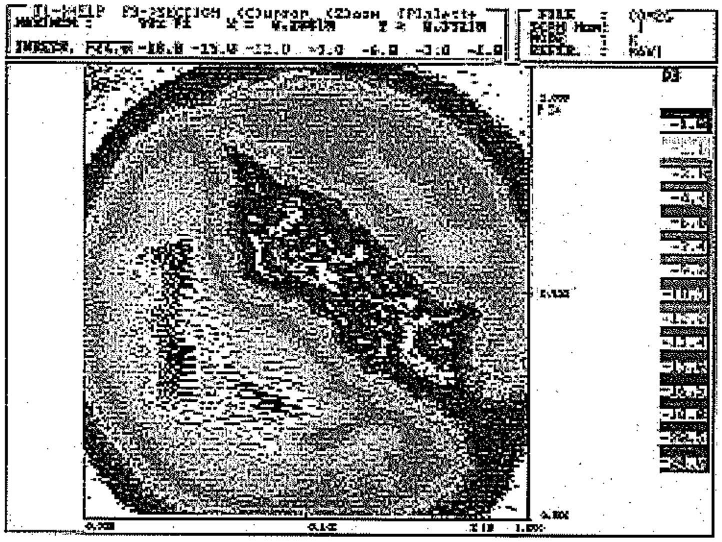
Density-Velocity Relationship for Green Alumina. NCU frequency: 1.0MHz with NCA 1000.



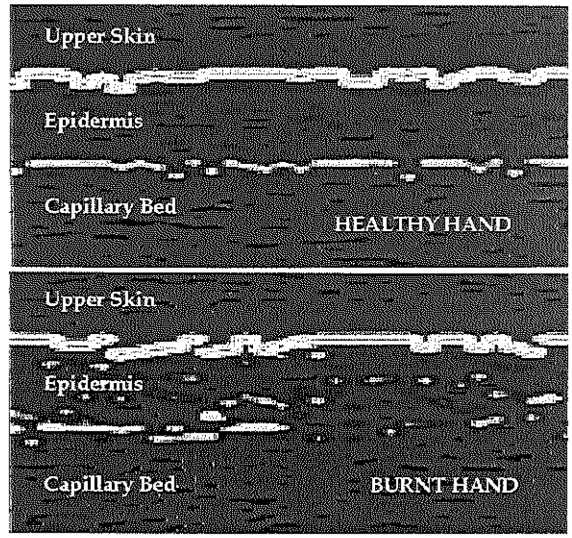
Transmission Spectroscopy of Porous Materials – Space Shuttle Tiles. Top: 0.38g/cc. Middle: 0.28g/cc, Bottom: 0.1g/cc. NCU Frequency: 350kHz.



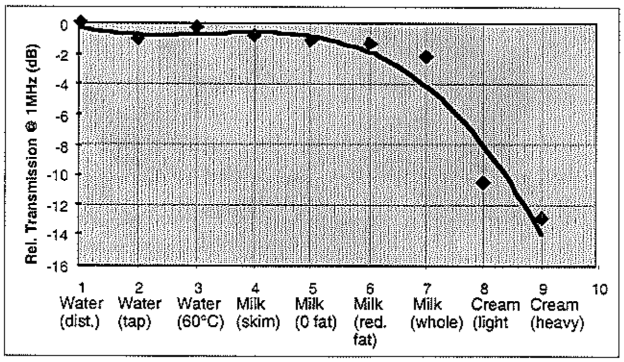
Reflection Spectroscopy for Surface Analysis. From top to bottom: 20µm, 35µm, 50µm, 75µm, and 125µm. NCU Frequency: 2.0MHz.



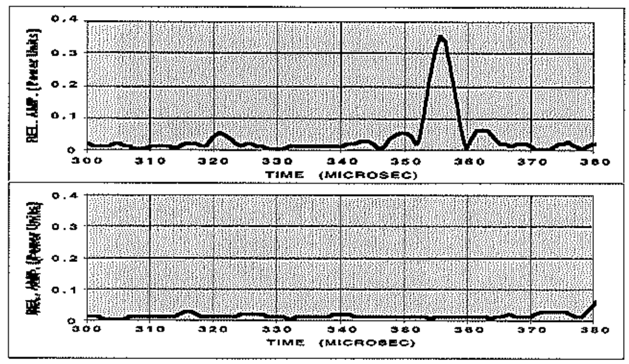
Impact-damaged GFRP Composite: 1.5mm 8 layers.
NCU Frequency: 2MHz.



Healthy & Burnt Human Hand. Note damage between epidermis & capillary bed. NCU Frequency: 2MHz. ***Courtesy, J.P. Jones, University of California, Irvine, CA.***



Fat Content in Milk Products in Containers.
NCU Frequency: 1MHz.



Milk Chocolate. Top without nuts. Bottom: with nuts.
NCU Frequency: 1MHz.

CONCLUSIONS

Air-coupled transducers in less than MHz range have been known for some time. However, non-contact transducers up to 5MHz with sensitivity only 30dB lower than conventional contact transducers described here, open new possibilities for industrial and bio-medical applications. In comparison the NCU mode rivals the contact liquid-coupling mode of ultrasound. This development in conjunction with the NCA 1000 now allows execution of routine NDE tasks plus analysis equivalent to materials characterization methods based upon other wave phenomena. By documentary evidence we have shown the transducer characteristics, proof of very high sensitivity, and a few applications of interest to industry and health care. The NCA 1000 is a sophisticated laboratory tool that can be easily adapted to on-line applications. It should be of interest to note that this system and transducers have been successfully integrated into factories and laboratories worldwide. For further information about our work into non-contact ultrasound, please see the following:

1 Bhardwaj, M.C., "Innovation in Non-Contact Ultrasonic Analysis: Applications for Hidden Objects Detection," Mat. Res. Innovat. (1997) 1:188-196.
2 Jones, J.P, Lee, D., Bhardwaj, M., Vanderkam, V., and Achauer, B., "Non-Contact Ultrasonic Imaging for the Evaluation of Burn-Depth and for Other Biomedical Applications," Acoust. Imaging, V. 23 (1997).
3 Bhardwaj, M.C., "Non-Contact Ultrasonic Characterization of Ceramics and Composites," Proceedings Am.Cer.Soc., V 89 (1998).
4 T. Carneim, D.J. Green & M.C. Bhardwaj, "Non-Contact Ultrasonic Characterization of Green Bodies," Cer. Bull., April 1999.
5 Bhardwaj, M.C., "High Transduction Piezoelectric Transducers and Introduction of Non-Contact Analysis," a chapter submitted for the Encyclopedia of Smart Materials, ed. J.A. Harvey, Wiley, New York (2000).