Plastics, Rubbers, & Composites

Ultrasonic Analysis of Plastics, Rubbers, & Composites by *Revolutionary* Non-Contact Analyzer-- the NCA 1000

Mahesh C. Bhardwaj
Ultran Laboratories, Inc.
1020 E. Boal Avenue
Boalsburg, PA 16827 USA

Phone: 814.466.6200
Fax: 814.466.6847
email: ultranlabs@aol.com
Web: www.ultranlabs.com

Ian Neeson and Leon Vandervalk
VN Instruments, Ltd.
4501 Furguson Drive, Unit 2
Elizabethtown, Ontario K6T 1A9 Canada

613.342.9182
613.342.0811
techsales@vninstruments.com
www.vninstruments.com

- Background
- Introduction to NCA 1000
- Examples of Transmitted Signals @ 250kHz, 500kHz, 1.0MHz, & 2.0MHz Ultrasound in Ambient Air
- Specific Applications
- Rubber, Insulation, & Composites
- Packaging Polymers & Foams
- Popular Plastics & Photographic Papers

NCA-CC-898

Ultrasonic Analysis of Plastics, Rubbers, & Composites by *Revolutionary* Non-Contact Analyzer—the NCA 1000

Mahesh C. Bhardwaj
Ultran Laboratories, Inc.
1020 E. Boal Avenue
Boalsburg, PA 16827 USA

Phone: 814.466.6200
Fax: 814.466.6847
email: ultranlabs@aol.com
Web: www.ultranlabs.com

Ian Neeson and Leon Vandervalk
VN Instruments, Ltd.
4501 Furguson Drive, Unit 2
Elizabethtown, Ontario K6T 1A9 Canada

613.342.9182
613.342.0811
techsales@vninstruments.com
www.vninstruments.com

BACKGROUND

Conventional wisdom stipulates that ultrasound cannot be propagated through solids or liquids without a physical contact between the transducer and the test medium. Therefore, non-contact ultrasound—i.e., through air coupling—is viewed as impossible. This understandable impossibility is entirely due to the phenomenal acoustic impedance mismatch between the coupling air and the test media. This mismatch can run as high as seven orders of magnitude. On the other hand, common wisdom states that if ultrasound can be propagated through a medium, then the investigation of the transmitted wave can provide significant information about that medium without destroying it. The ultimate task, however, is to accomplish this mission without any contact with the medium.

We been pursuing non-contact ultrasound for a very long time. In 1982 we broke the liquid couplant barrier by introducing dry coupling modality for proper non-destructive analysis of liquid-sensitive materials such as powder compacts, electronic materials, food, and other products. Subsequently, a corollary to this development was our air/gas propagation transducers. Initially treated as an intellectual curiosity, these transducers found distance ranging and limited materials analysis applications without using physical contact.

By 1993, substantial improvements in ultrasound air transduction were observed up to ~2MHz frequency. This development exhibited the feasibility of non-contact ultrasound propagation in a wide variety of materials. In 1997 our transducer designs reached the limits that can only be described in superlative terms. For example, in a frequency range of ~100kHz to ~5MHz, their sensitivity--relative to their contact counterparts--is merely 30dB lower; and the signal-to-noise-ratio as high as 40dB.[1] In practical terms, by

[1] Patents pending and in process.

utilizing these advanced transducers, it is now possible to propagate and analyze any material, including fragile powders, bio-materials, and even extremely high acoustic impedance (>$50 \times 10^6 kg/m^2.s$) metals and ceramics.

This outstanding development was serious for establishing a partnership among ourselves. **VN Instruments also defied the *status quo* with respect to ultrasound instrumentation and signal processing!** We have now fully developed and tested the world's first non-contact ultrasonic analyzer, the NCA 1000—***a dream of materials, biomedical scientists and engineers!***

The NCA 1000 opens new possibilities that are fundamental to materials integrity, process characterization, on-line inspection, and cost-effective production. Its sampling rate is 20/s, time of flight accuracy in a stable air column is +/-1ns (under ambient conditions, +/-20ns) and the dynamic range is at least 140dB. With these unique features in conjunction with the NCA 1000's built-in time, frequency, and phase domain functions, a user can accomplish even more. For example, one can perform routine measurements such as thickness, distance, velocity, defects, etc., as well as complex tasks, such as microstructure, density, attenuation, properties, phase detection, dispersion, and even the compositional analysis of a test medium. In this applications note we provide an introduction to the NCA 1000 and self-explanatory examples for materials characterization.

INTRODUCTION TO THE NCA 1000

A typical setup of the NCA 1000 in direct transmission mode is shown in Fig. 1. After the non-contact transducers have been aligned and suitably separated from each other—typically, between 20 to 30 wavelengths in air—the transducers' frequency and bandwidth are synthesized with the instrument waveform. Fig. 2 shows the screen of the NCA 1000 when operated in a 4-channel time domain mode. Fig. 3, 4, 5, and 6 respectively show a transmitted signal when two 250kHz, 500kHz, 1.0MHz, and 2.0MHz transmitting and receiving transducers are "talking" to each other in ambient air. Fig. 7 provides an example of transmitted signal through 31mm thick polystyrene sample.

While the NCA 1000 enables relationships of phase, frequency-dependent attenuation, transmission, and dispersion characteristics of the test media, in time domain alone it provides the following significant information:

- **Transmitted signal for defect identification**
- **Time of flight for the test medium thickness and velocity (density, moisture content, viscosity, properties, etc.)**
- **Strength of a transmitted signal for its direct correlation with concentration of phases, viscosity, particulate matter, etc.**

Once the NCA 1000 has been set up in air, then the test medium is inserted between the two transducers in order to make desired measurements. In the on-line version, the test medium moves between the transducers, as the NCA 1000 automatically provides the measured information.

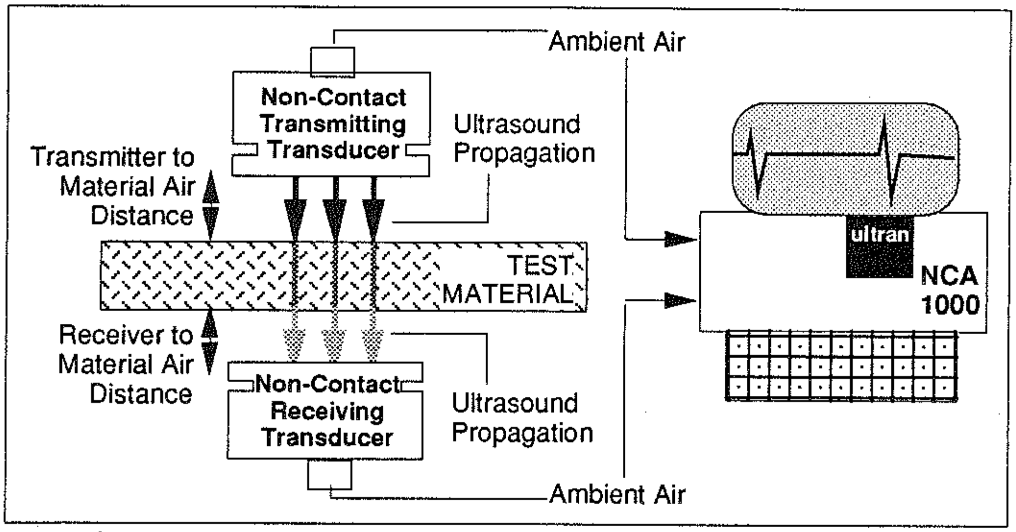


Fig. 1. Schematic setup of the NCA 1000 in direct transmission mode.

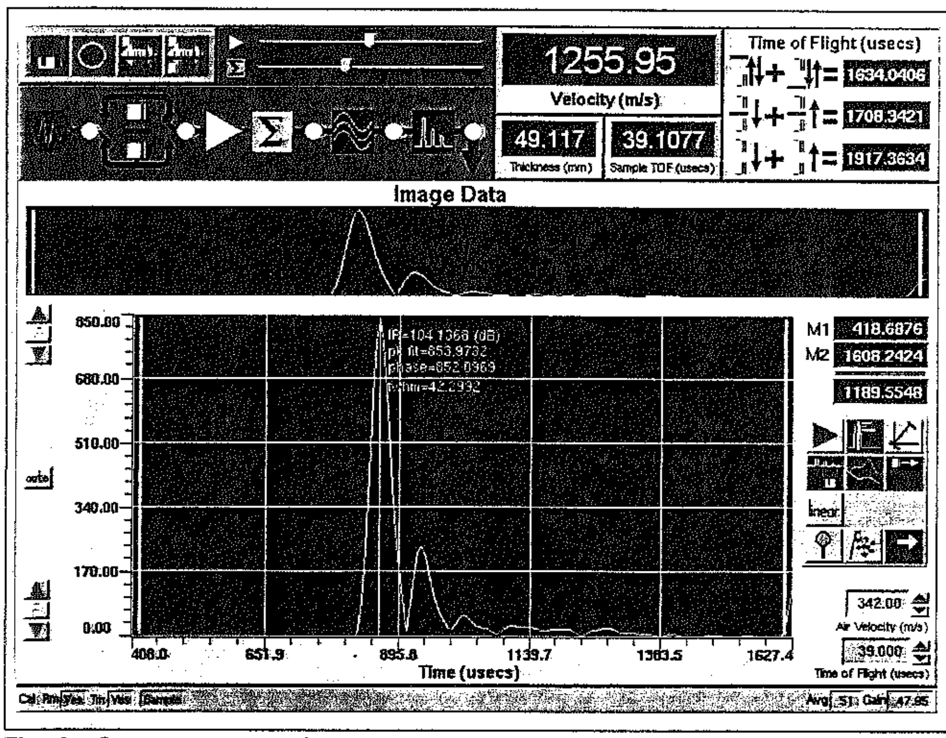


Fig. 2. Screen of the NCA 1000. The screen is divided into three basic regions. The upper left-hand corner is for the calibration and configuration of the system. The upper right-hand corner displays thickness, time of flight, and velocity of the test medium. The lower

(dark) region shows the 1D image data. Note that the peak displays its integrated area in dBs, its location in time, and its half full width.

Transmitted Signals in Ambient Air at 250kHz and 500kHz.

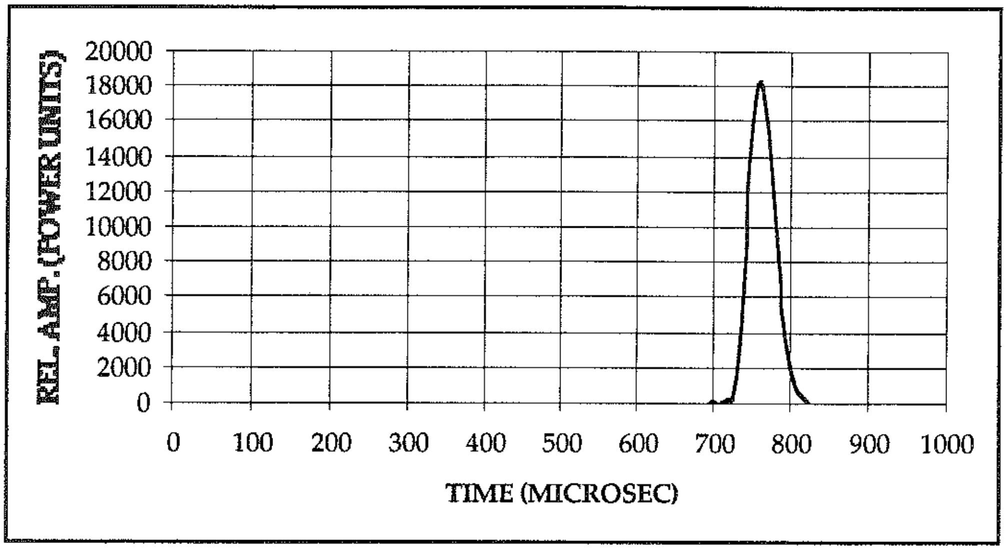


Fig. 3. Transmitted signal from 250kHz transmitting and receiving transducers separated by 26cm in ambient air.

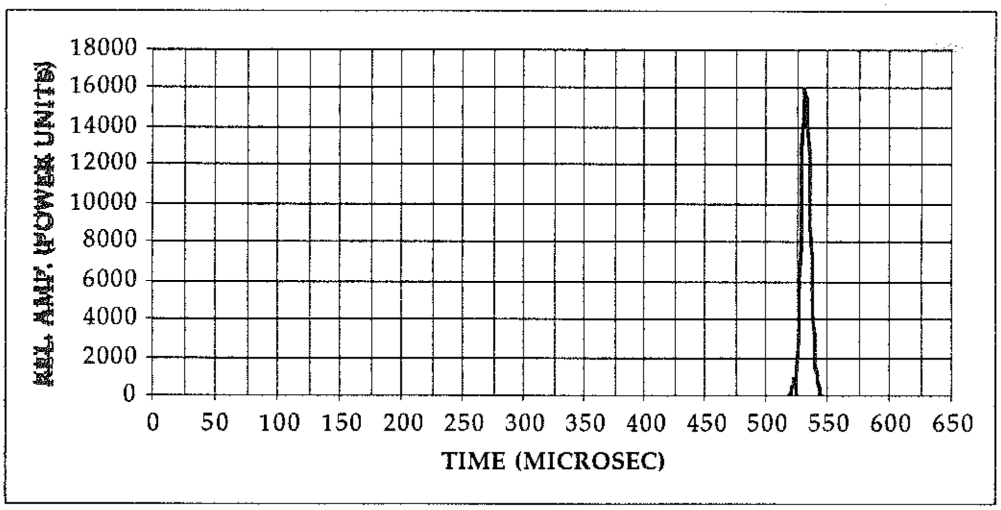


Fig. 4. Transmitted signal from 500kHz transmitting and receiving transducers separated by 18cm in ambient air.

Transmitted Signals in Ambient Air at 1.0 and 2.0MHz.

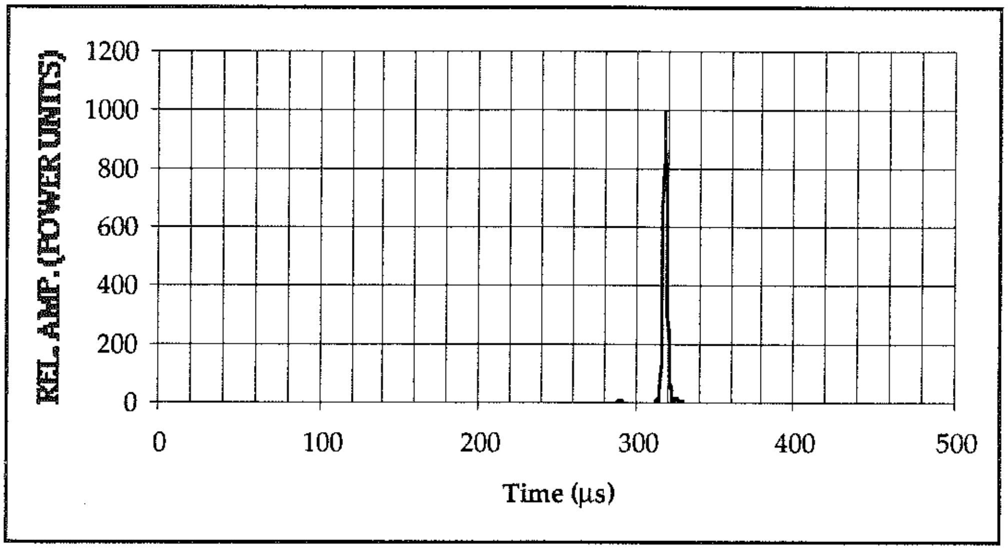


Fig. 5. Transmitted signal from 1.0MHz transmitting and receiving transducers separated by 11cm ambient air.

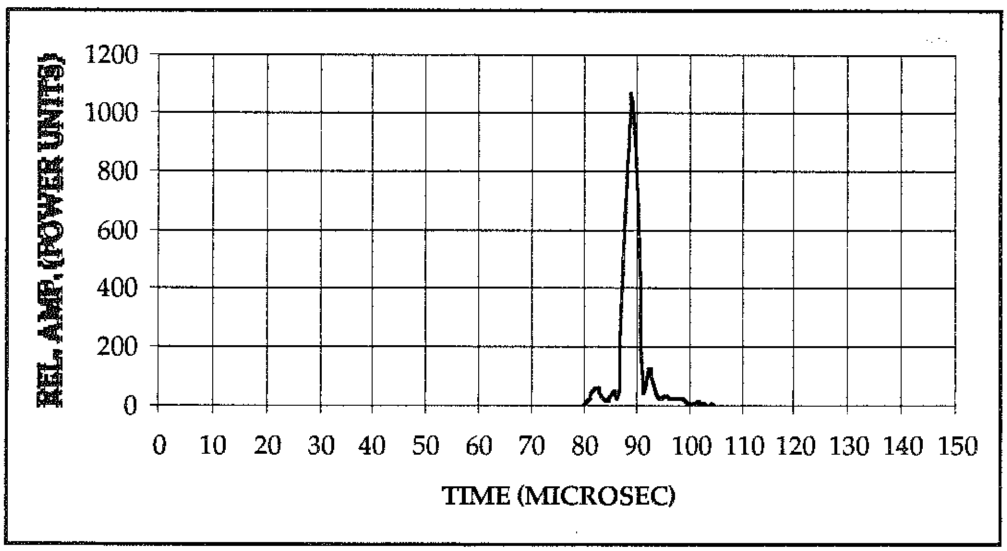


Fig. 6. Transmitted signal from 2.0MHz transmitting and receiving transducers separated by 3cm ambient air.

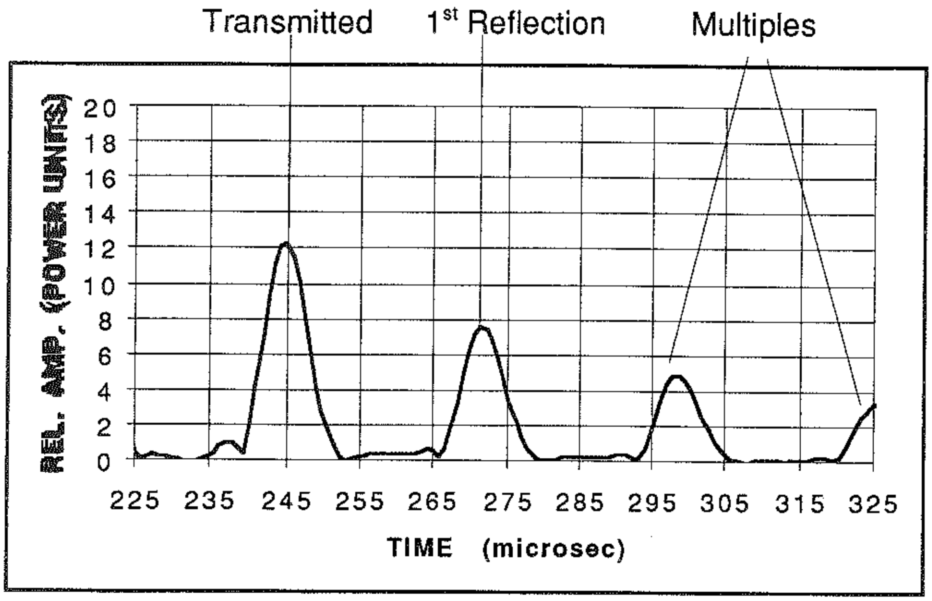


Fig. 7. Typical signal from a 31.5mm thick polystyrene reference sample at 1.0Mhz frequency.

In the accompanying figures, we provide self-explanatory examples of analysis of selected materials performed by NCA 1000 system. We encourage the interested persons to contact any one of us.

For further information about our work into non-contact ultrasound, please refer to the following publications:

1. M.C. Bhardwaj, "Innovation in Non-Contact Ultrasonic Analysis: Applications for Hidden Objects Detection," Mat Res Innovat (1997) 1: 188-196
2. J.P. Jones, D. Lee, M. Bhardwaj, V. Vanderkam, and B. Achauer, "Non-Contact Ultrasonic Imaging for the Evaluation of Burn-Depth and Other Biomedical Applications, Acoust. Imaging, V. 23 (1997).
3. M.C. Bhardwaj, "Non-Contact Ultrasonic Characterization of Ceramics and Composites," Cer. Trans. #89, Am. Cer. Soc., Westerville, OH (1997).
4. T. Soltesz, D.J. Green, and M.C. Bhardwaj, "Ultrasonic Non-Contact Analysis of Ceramics: A Systematic Study," in preparation.
5. B.R. Tittmann, M.C. Bhardwaj, L. Vandervalk, and I. Neeson, "Non-Contact Ultrasonic NDE of Carbon Composites," in preparation.

ENCLOSURES: Plastics + Rubbers + Composites EXAMPLES.

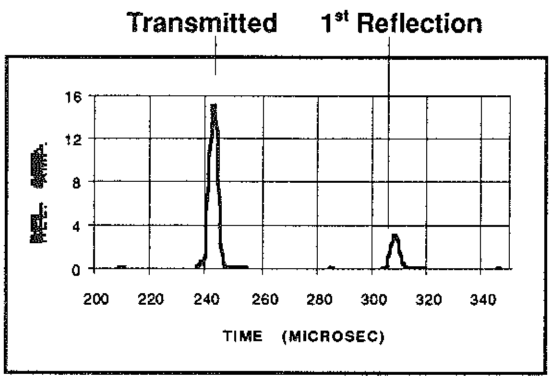
MCB, IN, VN: cbm

Ultran
Phone: 814.466.6200
Fax: 814.466.6847
Email: ultranlabs@aol.com
Web: www.ultranlabs.com

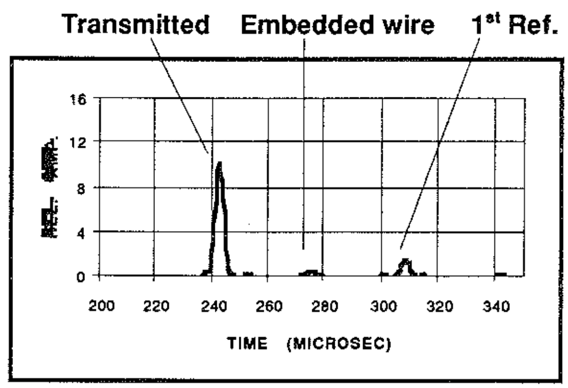
VN INSTRUMENTS
613.342.9182
613.342.0811
techsales@vninstruments.com
www.vninstruments.com

NCA 1000 Applications:
Ultrasonic Non-Contact Analysis

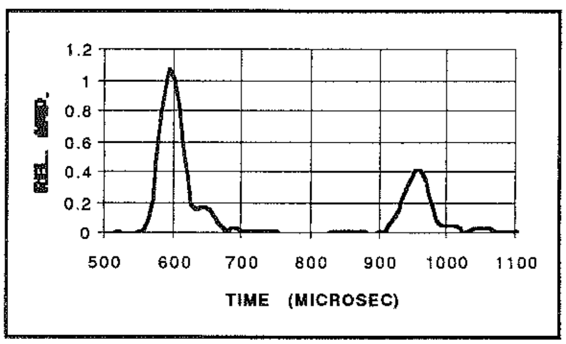
Rubber, Insulation, & Composites



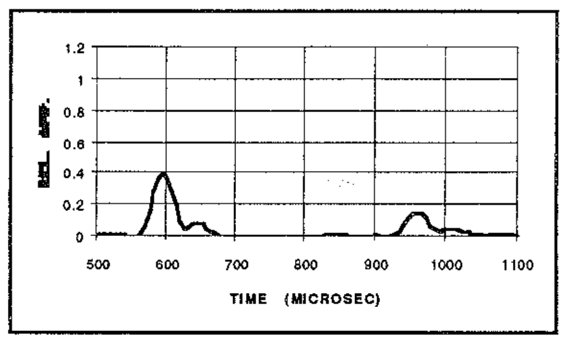
51mm Diene Rubber @ 1MHz.
Defect Free



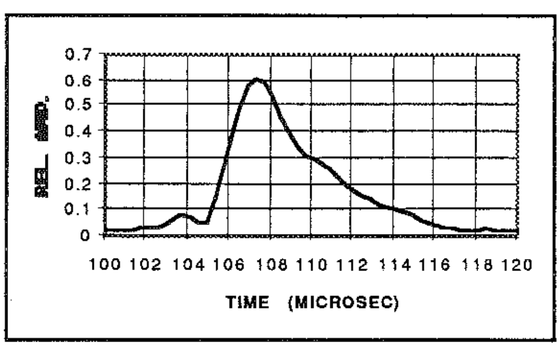
51mm Diene Rubber @ 1MHz.
With 2mm steel wire in the center.



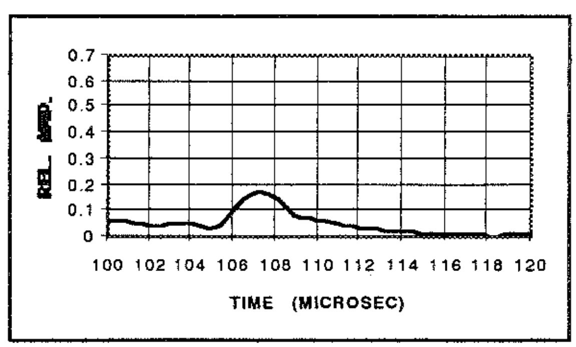
51 mm Rocket Motor Insulation @ 250kHz.
Defect Free.



51mm Rocket Motor Insulation @ 250kHz.
With an embedded defect.



1.7mm Circuit Board Composite @ 2.0MHz.
Good region.



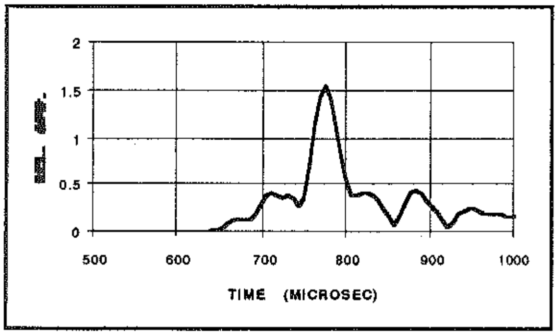
1.7mm Circuit Board Composite @ 2.0MHz. Disbonded region.

Ultran
Phone: 814.466.6200
Fax: 814.466.6847
Email: ultranlabs@aol.com
Web: www.ultranlabs.com

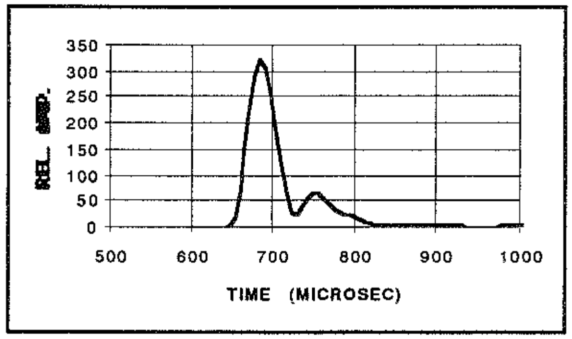
VN INSTRUMENTS
613.342.9182
613.342.0811
techsales@vninstruments.com
www.vninstruments.com

NCA 1000 Applications:
Ultrasonic Non-Contact Analysis

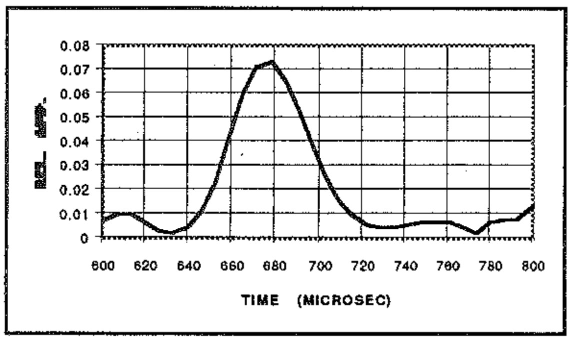
Packaging Polymers & Foams



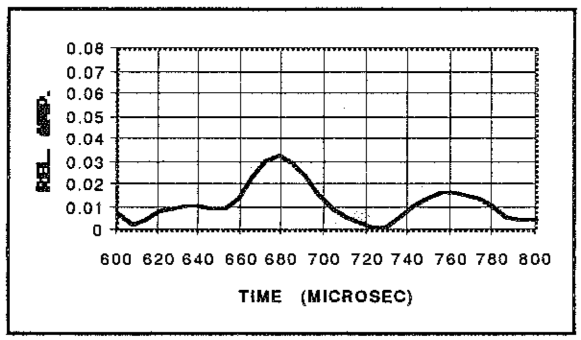
30mm Large Cell Packaging Foam @ 250kHz. V: 550m/s.



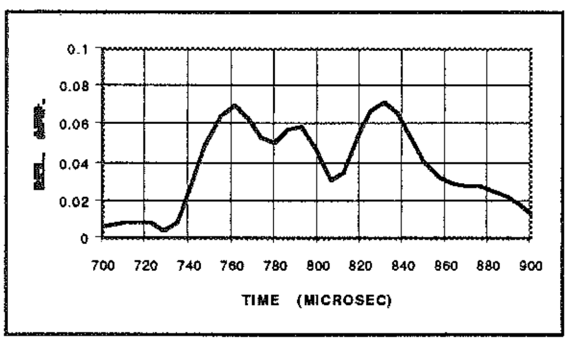
26mm Small Cell Polystyrene Foam @ 250kHz. V: 740m/s



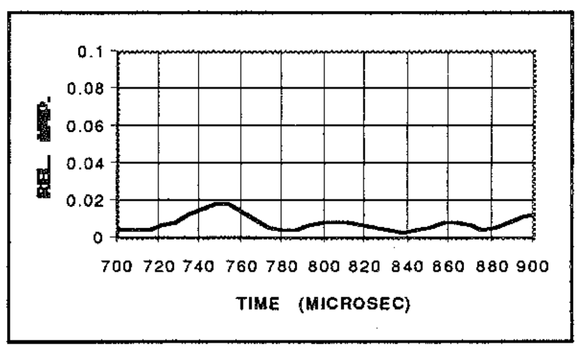
22.2mm FRP Sandwiched Polymer Foam @ 250kHz. Good bond region.



22.2mm FRP Sandwiched Polymer Foam @ 250kHz. Disbond region.



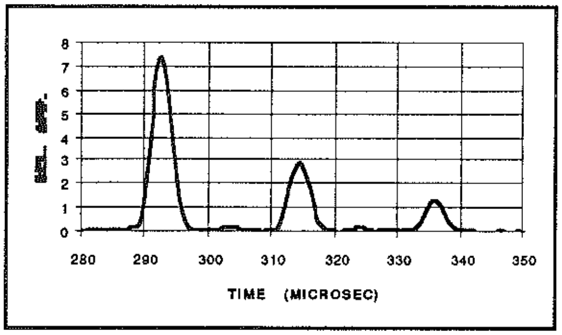
51mm Multi-layer (4) Polymer Foam @ 250kHz. Good bond region.



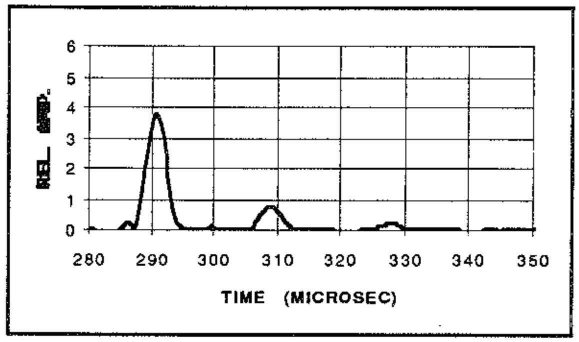
51mm Multi-layer (4) Polymer Foam @ 250kHz. Disbond region.

NCA 1000 Applications:
Ultrasonic Non-Contact Analysis

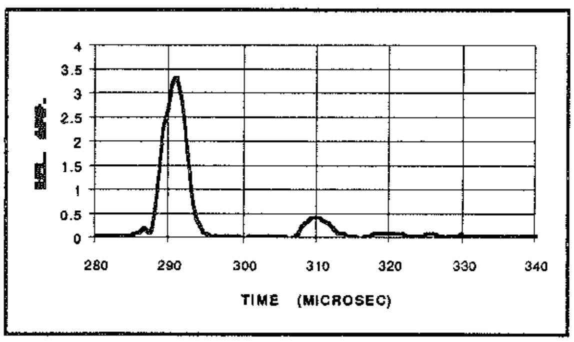
Popular Plastics & Photographic Papers



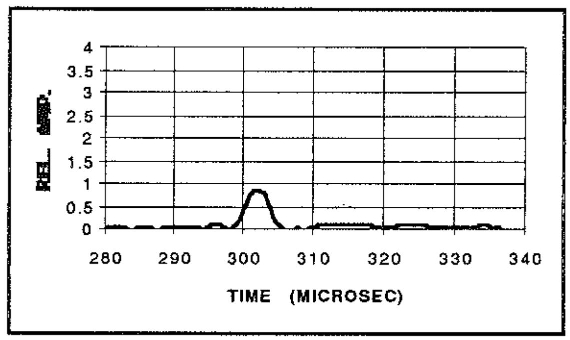
25.4mm polystyrene @ 1.0MHz.
V = 2,180m/s.



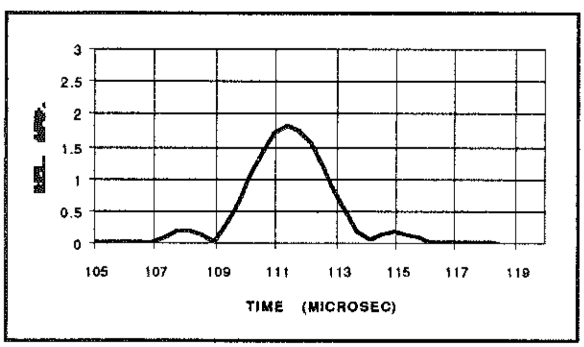
25.4mm Acrylic (PMMA) @1.0MHz.
V = 2,750m/s



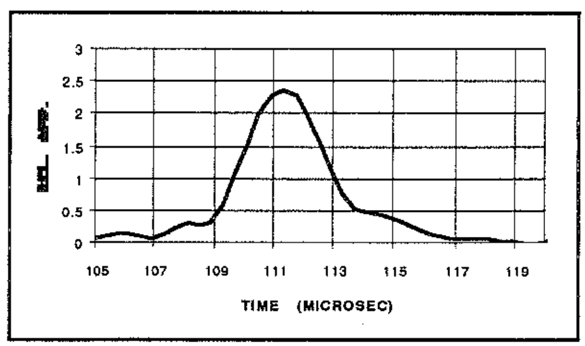
25.4mm Nylon @ 1.0MHz.
V = 2,500m/s.



25.4mm Teflon @ 1.0MHz.
V: 2,300m/s



0.26mm Kodak Photographic Paper @ 2.0MHz.
V = 560m/s.



0.22mm Polaroid Photographic Paper @ 2.0MHz. V = 640m/s.