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NONCONTACT ULTRASONICS
Summary of Recent Developments and Observations

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1. INTRODUCTION

Dry coupling and air/gas propagation transducers, and techniques are not new to us - they were developed at Ultran in 1982. In the early stage they were extensively used by Brunk[1] for the development of dry coupling techniques for plate thickness measurements and for noncontact profilometry - all by using frequencies between ~1 to >10MHz.

Dry coupling techniques are now state-of-the-art for characterization of green and consolidated, partly sintered and fully sintered, and porous and low density composites, as well as other materials (references available on request).

However, from a practical standpoint, air coupling at high frequencies (200KHz to ~5MHz) is a major challenge. When we superimpose the condition that air coupling must be accomplished under ordinary ambient conditions -- no pressurization of air, or utilization of other gases -- this challenge, obviously becomes indomitable! On the other hand, the significance and need for noncontact propagation through materials are obvious and vital for achieving the goal of Total Materials Quality (from early to final stages of materials manufacture) and major improvements in noninvasive biomedical applications of modern ultrasound.

Notwithstanding apparent difficulties, we experienced significant success with noncontact air propagation through several low Z materials, although analysis of high Z media remained a formidable task. We are pleased to report that this, too, has been overcome recently.

Based upon our proprietary formulations of ferroelectric materials and nonconventional transducer designs, we have developed means for extremely efficient transduction in air without any special provision. Our initial experiments indicate that this efficiency is high enough to overcome several orders of acoustic impedance barrier between air and test materials.

2. OBJECTIVES OF THIS REPORT

In this summary paper we provide an introduction to our experimental setup and observations from our **pre-prototype proof-of-concept transducers** on a wide variety of materials. Our immediate aim is to provoke interest among those who may have a vested interest and the resources for the advancement of this revolutionary development.

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[1]*This work was done from 1983 to 1986 while Brunk was with Allied Corporation, Kansas City Division, Kansas City, MO., and later at Ultran in 1986-87. Presently he is a private consultant.*

3. PRE-PROTOTYPE PROOF-OF-CONCEPT TRANSDUCERS

Nominal Frequency: 250KHz (higher frequencies are currently in progress)
Active Diameter: 19mm
Beam Geometry: Planar

4. EXCITATION AND AMPLIFICATION SYSTEM

Ultran-Ritec: HPN-5000
Pulser Settings:
- Pulse Repetition Frequency: 200Hz
- Pulse Width: 2,500ns
- Pulse Separation: 4,700ns
- Pulses per Burst: 6
- Pulse Out: 400V into 4Ω

Receiver Settings:
- Gain: 76dB
- Low Pass Filter: 10MHz
- High Pass Filter: 10KHz
- Input Impedance: High

5. EXPERIMENTAL SETUP

Technique: Direct Transmission with 0° and Oblique Incident Ultrasound
Separation between Transmitter and Receiver: 43mm in air
Ambient Temperature: 22°C
Ambient Relative Humidity: 60%
Details: Fig. 1.

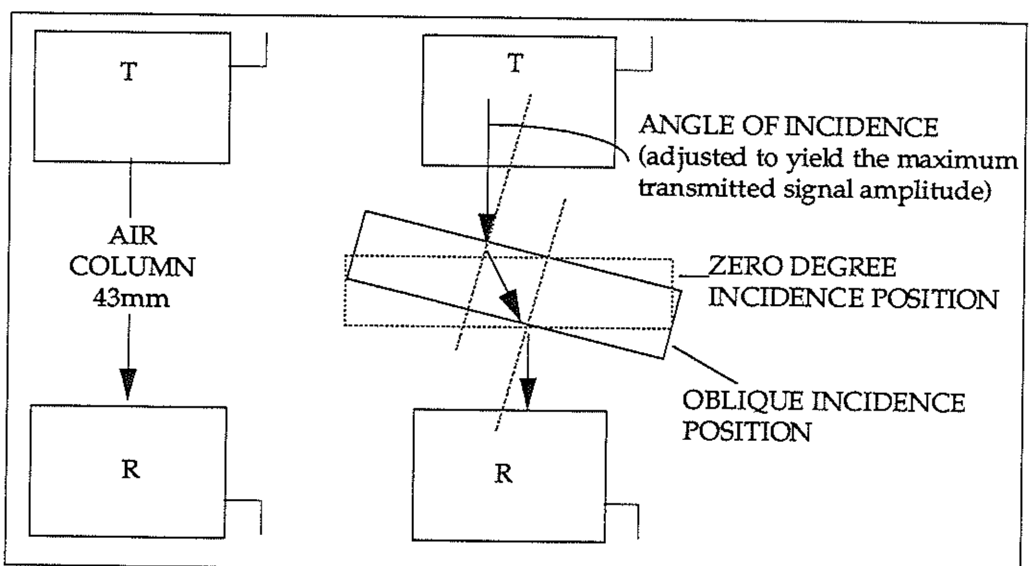

Fig. 1. Schematic of the transducers and test material configuration

6. OBSERVATIONS

Observations from a wide variety of materials in the form of realtime rf oscilloscope traces are shown in figures 2 through 11. Fig. 12 is a special case of aluminum analysis.

Green Ceramics

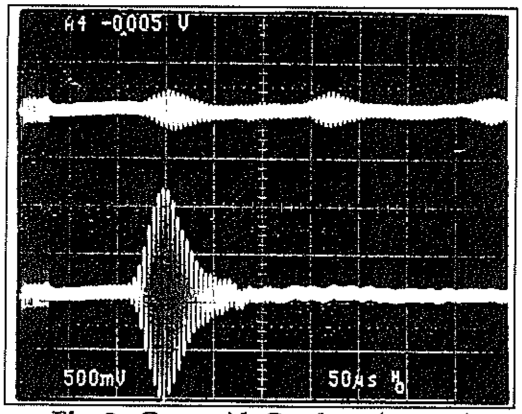

Fig. 2. Green Al_2O_3 sheet (0.3mm).
Top: 0° incidence. Bottom: Oblique Incidence.

Sintered Ceramics

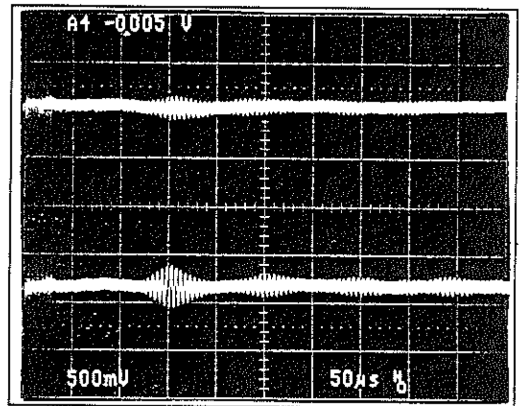

Fig. 3. Sintered Al_2O_3 sheet (0.3mm).
Top: 0° incidence. Bottom: Oblique Incidence.

Plastics and Composites

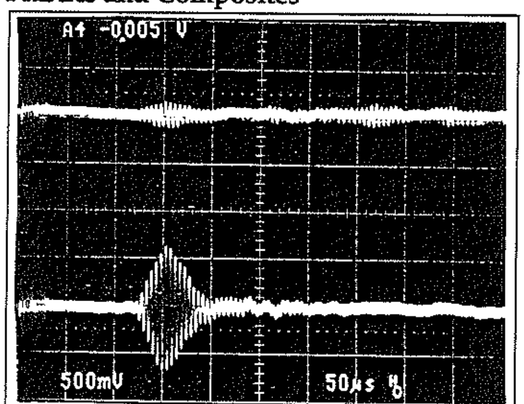

Fig. 4. Polyurethane sheet (1.3mm)
Top: 0° incidence. Bottom: Oblique Incidence.

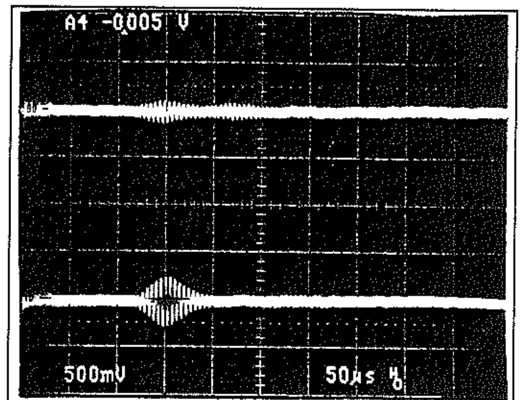

Fig. 5. PMMA sheet (3.8mm)
Top: 0° incidence. Bottom: Oblique Incidence.

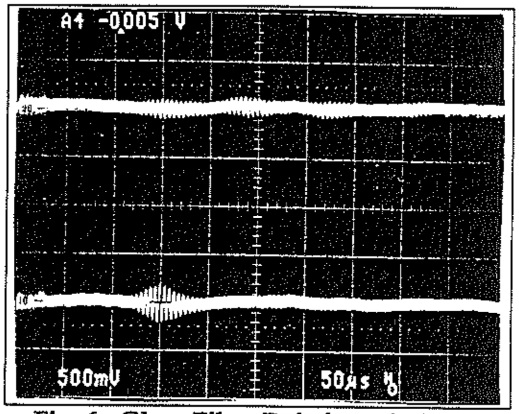

Fig. 6. Glass Fiber Reinforced Plastic
Composite (1.6mm). Top: 0° incidence. Bottom: Oblique Incidence.

Paper Products

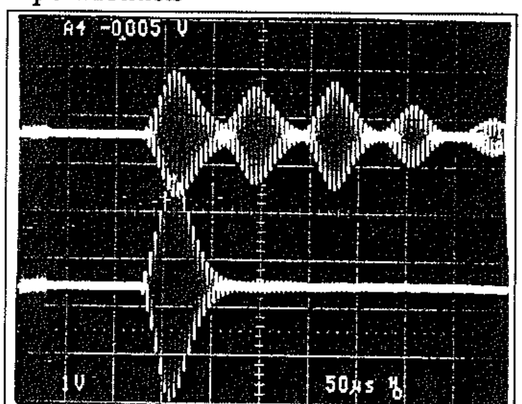

Fig. 7. Cardboard sheet (1.1mm)
Top: 0° incidence. Bottom: Oblique Incidence.

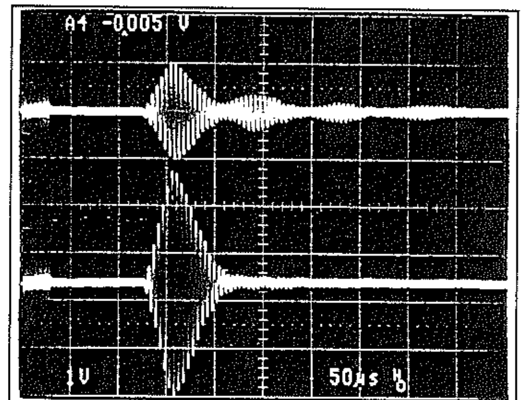

Fig. 8. Bond Paper (0.13mm)
Top: 0° incidence. Bottom: Oblique Incidence.

Wood and Lumber

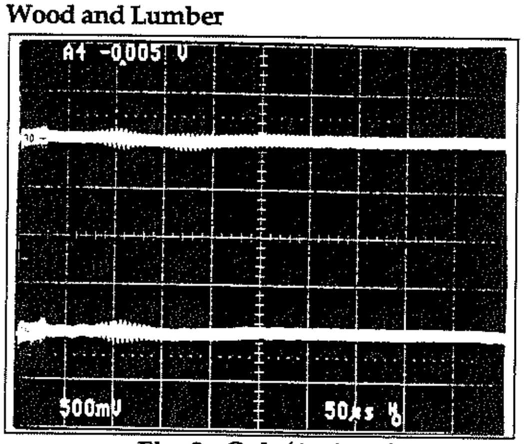

Fig. 9. Oak (12.6mm)
Top: 0° incidence. Bottom: Oblique Incidence.

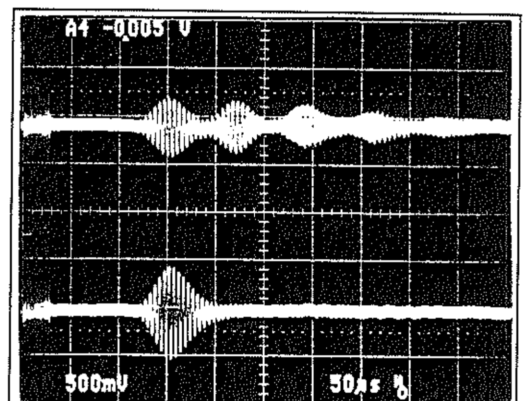

Fig. 10. Particle Board (2.9mm)
Top: 0° incidence. Bottom: Oblique Incidence.

Liquids

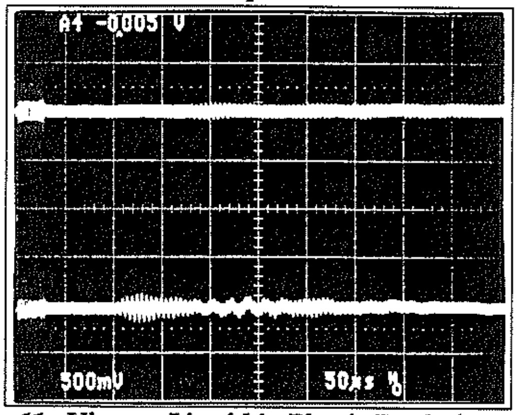

**Fig. 11. Viscous Liquid in Plastic Bottle (38mm)
Top: 0° incidence. Bottom: Oblique Incidence.**

Metals - a special case

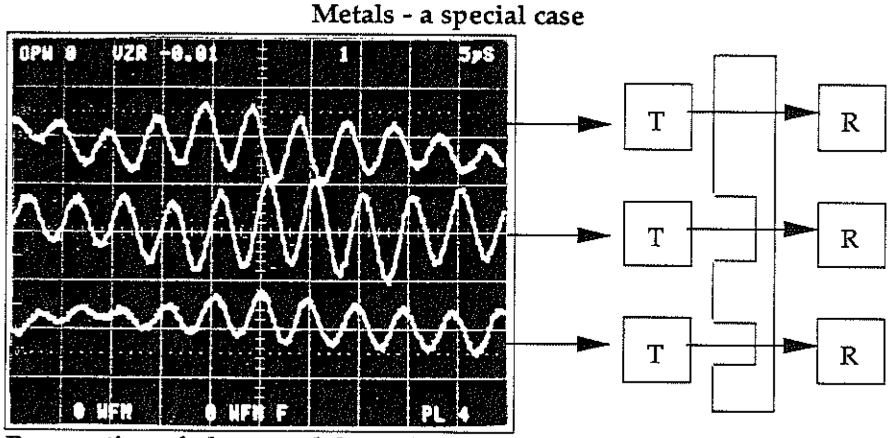

Fig. 12. Propagation of ultrasound through 6065 aluminum by noncontact air propagation technique. The distance between two transducers in air is ~25mm and aluminum is 1.5mm thick.

Top Trace: Propagation through a solid section of 1.5mm thick 6065 aluminum sheet.

Middle trace: Propagation through 13mm diameter flat bottom hole, ~1mm deep. The reason the transmitted amplitude here is higher than in the top trace is because the size of FBH and the ultrasound diameter are within proximity of each other, therefore, a larger volume of ultrasound is passing though a thinner, 0.5mm section of aluminum. Slthough it is not quite clear from the picture, there is actually a transit time differential (relative to top trace) indicating the thinness (0.5mm) of aluminum.

Bottom Trace: Propagation through 6mm diameter flat bottom hole, ~1mm deep. Here the reduction in transmitted amplitude is due to a "shadow" effect. It is not clear from the photograph, but in terms of transit time between this and the middle trace, there is no difference since the thinness of aluminum through which ultrasound is propagating, the same, in both cases, i.e., 0.5mm.

Table-I is a comprehensive summary of noncontact ultrasonic observations from these materials described in figures 2 through 12, as well as others. Fig. 13 shows the relationship between acoustic impedance and received signal voltage differential between oblique and 0° incidence transmission, normalized to 1cm.

TABLE-I. Preliminary NON-CONTACT ultrasonic observations from a variety of materials by utilizing pre-prototype "extremely high efficiency" ultrasonic transducers for propagation in air/gases. (All numbers are approximate).

MATERIALS	THICKNESS (mm)	VELOCITY (m/s)	1 Z (MRayl)	2 INCIDENT ANGLE (°)	3 RECEIVED SIGNAL (V)	4 ΔV/cm (V)
Green Ceramics						
Al_2O_3 (green)	0.3	1,600	0.25	0 43	0.4 2.2	0.054
Al_2O_3 (white)	0.7	2,000	0.35	0 50	0.2 0.7	0.035
Sintered Ceramics & Glasses						
Al_2O_3	0.38	12,000	4.7	0 17	0.2 0.5	0.011
ZrO_2 Refractory (Very Porous)	6.5	3,250	2.5	Immeasurable		
Glass	3mm	5,800	1.5	0 9	0.1 0.2	0.03
Metals						
Aluminum	1.6	6,320	1.7	0 13	0.1 0.2	0.016
Stainless Steel	1.5	5,970	4.8	0 12	<0.1 <0.2	0.015
Plastics & Fiber Composites						
PMMA	3.8	2,740	0.33	0 12	0.2 0.5	0.114
PMMA	24	2,740	0.33	0 9	0.15 0.3	0.36
Polyurethane	1.3	1,600	0.18	0 46	0.25 1.4	0.149
Graphite FRP (8 ply)	1.35	2,900	0.5	0 16	0.15 0.4	0.033
Glass FRP (~20 ply)	6.2	3,180	0.6	0 12	0.15 0.3	0.093
Graphite FRP (~16 ply)	4.0	2,860	0.5	0 8	0.2 0.3	0.04

Table-I continued.

MATERIALS	THICKNESS (mm)	VELOCITY (m/s)	1 Z (MRayl)	2 INCIDENT ANGLE (°)	3 RECEIVED SIGNAL (V)	4 ΔV/cm (V)
Rubbers						
Poly-butadiene	51.4	1,600	0.16	0 >55	0.25 0.35	0.514
Diene	26.6	1,560	0.16	0 >55	0.1 0.4	0.798
Clear Solid Propellant Fuel						
	10mm	1,800	0.2	0 70	0.15 1.2	1.05
Papers & Similar Materials						
Copy paper	0.1	220	<0.01	0 >55	2.6 5.6	0.03
Bond Paper	0.13	300	<0.01	0 >55	2.0 4.6	0.034
Cover Stock	0.22	370	<0.01	0 55	1.2 4.0	0.061
Cardboard	1.1	400	<0.01	0 55	2.7 5.0	0.253
Manila Folder	0.28	320	<0.01	0 55	1.0 3.3	0.064
Glossy Plotter	0.12	500	0.01	0 55	1.3 4.5	0.038
Wood and Lumber						
Oak	20.6	2,000	<0.2	0 6	0.2 0.35	0.309
Oak	12.6	2,250	<0.2	0 9	0.2 0.4	0.252
Particle board	2.9	1,500	<0.2	0 15	0.6 1.0	0.12

1. *Acoustic Impedance.*
2. *Oblique incidence was adjusted to yield the highest transmitted signal.*
3. *Directly measured on the oscilloscope*
4. *Difference between oblique and 0° incidence transmitted signals, normalized to 1cm. The oblique incidence (critical angle) phenomenon and its significance is described in detail by Dr. Bernard Hosten, Université Bordeaux I, Talence, France.*

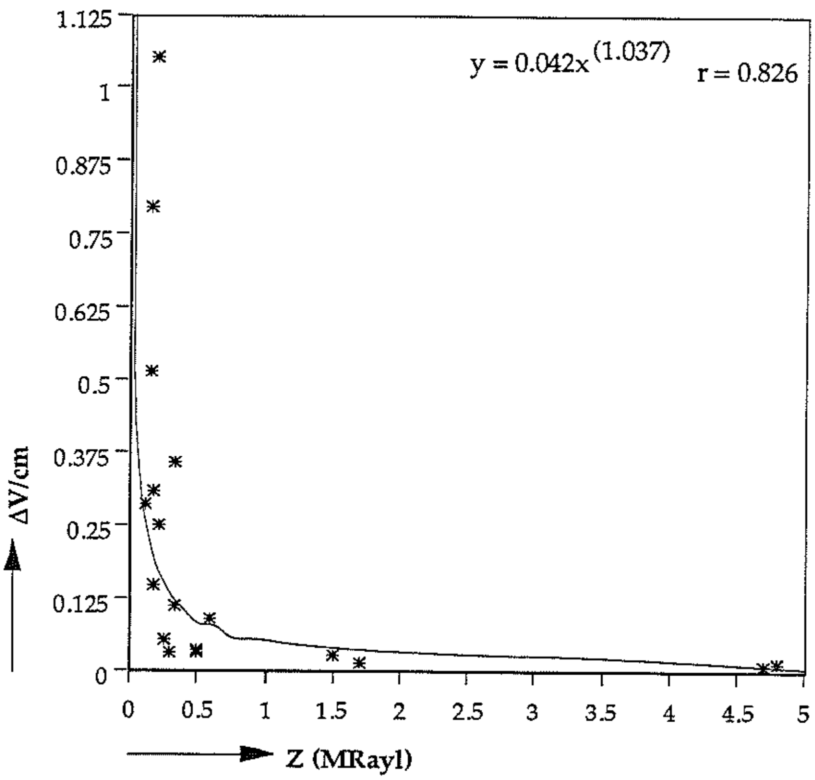

Fig. 13. Relationship between acoustic impedance, Z, and difference between received voltages from 0° and oblique incidence, normalized to 1cm.

NOTE

Note that these are only the first attempts of this kind. Although these observations are spectacular, we request you not to consider them as final because they have been generated by our "pre-prototype proof-of-concept transducers." Obviously, we will be going farther with this approach as we attract the attention of serious customers and promoters of this development.

MCB, RLB: cbm