CRITICAL COMPARISON OF CONTACT AND NON-CONTACT ULTRASOUND: Characterization of Transducers and Ultrasound Systems for NDE & Sensing Applications

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After we had created the bread-board science and technology for Non-Contact Transducers (NCT-patents pending and in process) and the Non-Contact Analyzer--NCA-1000--we had anticipated a need for this subject. First of all, since we have been developing air-coupling/Non-Contact Ultrasound (NCU) for more than 15 years (our cataloged air/gas propagation transducers), we had to disqualify our own prior art. Second, since other companies and some research institutes have also made significant advances in NCU, we had to make "bare-bones" comparison with prior-art transducers and associated systems.

All in all such a comparison is highly warranted in light of most extraordinary results that our NCT produce with NCA-1000. We want the reader to know that, our expertise not-with-standing, even we are startled! Read through the following self-explanatory comparisons of ultrasonic transducers, systems, techniques and new modes of testing.

1. TRANSDUCER COMPARISON

For this purpose 1MHz-broadband, 19mm active area diameter transducers belonging to three categories—water immersion, conventional air-scan, and current non-contact—were selected. Mode of testing: Transmission. Excitation of the transmitting transducer: 16V single sine wave pulse. Receiving Transducer: Directly fed into the oscilloscope input. Figures 1, 2, and 3 show time and frequency domain, sensitivity, and Signal to Noise Ratio (SNR) data, respectively, for water immersion, conventional air-scan, and the current non-contact transducers. Salient characteristics of this comparison are summarized in TABLE-I.

2. PERFORMANCE COMPARISON OF CONTACT IMMERSION WITH NON-CONTACT MODE

3. PERFORMANCE COMPARISON OF CONVENTIONAL AIR-SCAN WITH CURRENT NON-CONTACT MODE

In this section we have made a one-to-one comparison of conventional air-scan with our non-contact ultrasound. The key objectives of this comparison are sensitivity, resolution, and signal to noise ratio. The details of transducers, systems, and analyzed materials are given in the following sections.

3.1 Conventional Air-Scan Transducers and Systems

3.1.1 Transducers: These are piezoelectric phenomena-based air/gas propagation transducers characterized by –60dB to –90dB sensitivity, <20dB signal to noise ratio, bandwidths from 30 to 50% of the center frequencies, and frequency range of <100KHz to <2MHz.

3.1.2 Conventional High Power System: It is a combination of burst pulser and broadband receiver with a modern digitizing oscilloscope. The pulser is 400V into 4Ω. We have used 3 pulses per burst and all the available 64dB gain of the receiver, unless noted otherwise.

3.2 Non-contact Transducers and NCA-1000 System.

3.2.1 Transducers: These are also piezoelectric phenomena-based transducers that are characterized by extraordinarily high transduction (section #1) in air or other gases. Typically, their sensitivities are –30dB to -60dB, SNR >30dB, bandwidths from 30 to >100% of the center frequencies, and frequency range of <100KHz to >10MHz.

3.2.2 NCA-1000: This system is based upon the synthesis of computer-generated chirp with the best attributes of broadband NCU transducers. Its dynamic range is >140dB and accuracy of time of flight (tof) measurement better than +/-1ns. NCA-1000 provides on-screen data about thickness, tof, velocity, frequency- and phase-dependent information. Further, provision for the relationship of this information directly to the characteristics/properties of the test medium is also provided. **NCA-1000 is an ANALYZER.**

4 CONDITIONS OF TESTING & TEST MATERIALS

4.1 Conditions of Testing

By purposely selecting **"very-difficult-to-examine" materials,** and that too, at **"high NCU frequencies,"** we first aligned the transducers in ambient air, and then inserted the test material between them. In all following examples the distance from transducers to test materials surfaces are approximately 15mm from each surface.

4.2 Test Materials

4.2.1 25mm Carbon Steel @ @MHz in Transmission Mode. Figures 8 and 9.

4.2.2 25mm Composite-Laminated Kevlar Honey-Comb @ 1MHz. Figures 10 and 11.

4.2.3 Rocket Motor Insulation on Steel @ 1MHz in Transmission Mode. Figures 12 and 13.

4.2.4 9mm Polystyrene @ 1MHz in Transmission Mode. Figures 14 and 15.

4.2.5 **Single 1MHz transducer in Reflection Mode from a Liquid Surface. Figures 16 and 17.**

5. FORMAT OF PRESENTATION

We have presented the actual observations in a way that is familiar--it is simple time-domain format. Note that we are fully aware of the fact that while presenting the data of conventional air-scan, we have not done any signal processing, except signal averaging. On the other hand, with NCA-1000 signal processing is a major issue—it's built into the system. But, we must say that the signal averaging done with NCA-1000 is half that done for the conventional system. For the experts, it may be of further interest to note that when we used our NCU transducers with the conventional system, the results were dramatically better than those produced with old air-scan transducers, but no where near when used with NCA-1000.

ANOTHER OBSERVATION/THOUGHT: *We would like the reader to note that under some conditions, which we cannot reveal yet, the observations reported here by our transducers and system can improve 100 times!*

NON-CONTACT ULTRASOUND BASED IMAGING

The NCA-1000 can be retrofited with the existing conventional C-scanning systems, but there is more. Work is currently in progress for 2D and 3D synthetic aperture imaging in conjunction with more advanced NCU transducers in both transmission and reflection modes. Initial results of this trial are extremely encouraging. From the user's standpoint we expect indexing between <10mm to >50mm, and detectabilities ranging from <100µm to 20µm. Besides the popular defect-oriented imaging, our new system will also generate image data as functions of tof, velocity, frequency- and phase-dependent ultrasound. Therefore, our imaging system, too, will be an image analysis system with direct relevance to the characteristics of the test materials.

Epilogue

First of all, it should be amply clear from this work that we have not only defied the so-called air-scan and like transducers and systems (including our own prior art), but we have also dared to compare our non-contact ultrasound with the traditional contact method, in use for more than 70 years. This is by no means an ordinary feat in ultrasound or in the annals of materials characterization and analysis. Therefore, should our statements sound self-serving or pompus, we offer no apology. Bear in mind that our approach in ultrasound is not a panacea, yet. But it has a greater possibility than any other characterizing or sensing method. Individually and collectively we are proud to have made a contribution of this magnitude, as we now take this technology in the service of our complex society.

It is to the reader's advantage to underscore the contents of this report, should she/he be pursuing the objectives of pure non-destructive testing for any purpose what-so-ever! If anyone has any question, we are ready to answer.

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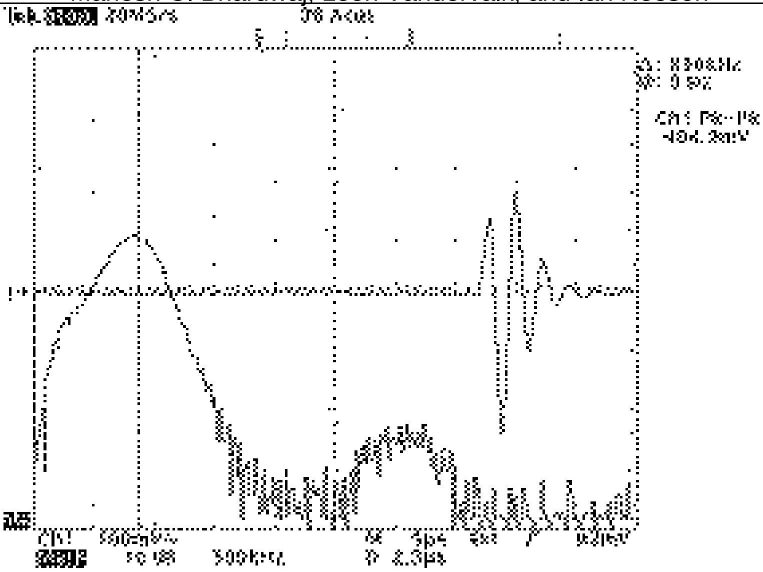

Fig. 1. Time and frequency domain of 1MHz, 19mm diameter water immersion transducers in transmission mode, with transmitting and receiving transducers separated by 10mm water. Peak Frequency: 0.89MHz. Bandwidth @ -6dB: 0.6MHz. Received signal amplitude: 0.405V. Sensitivity: -32dB. SNR: ~40dB.

TABLE-I. Salient characteristics of 1MHz, 19mm active area diameter water immersion, conventional air-scan, and current non-contact transducers.

TRANSDUCER TYPE	PEAK FREQUENCY (MHz)	BANDWIDTH (MHz), %	SNR (dB)	SENSITIVITY (dB)	SENSITIVITY Relative to Water (dB)
Water Immersion	0.89	0.6, 65%	40	-32	---
Conventional Air-scan	0.93	0.3, 32%	<20	-67	Below 35dB
Current Non-Contact	**0.89**	**0.6, 65%**	**36**	**-50**	**Below 18dB**

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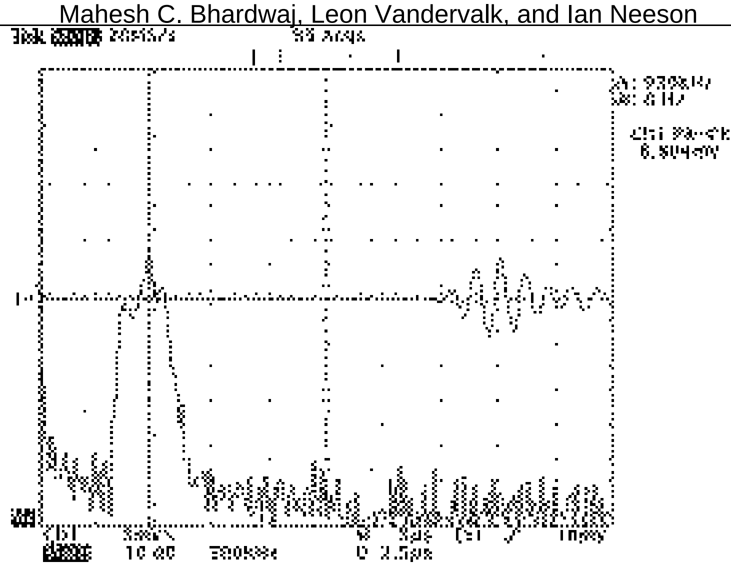

Fig. 2. Time and frequency domain of 1MHz, 19mm diameter conventional air-scan transducers in transmission mode, with transmitting and receiving transducers separated by 10mm ambient air. Peak Frequency: 0.93MHz. Bandwidth @ -6dB: ~0.3MHz. Received signal amplitude: 6.8mV. Sensitivity: -67dB. SNR: <20dB.

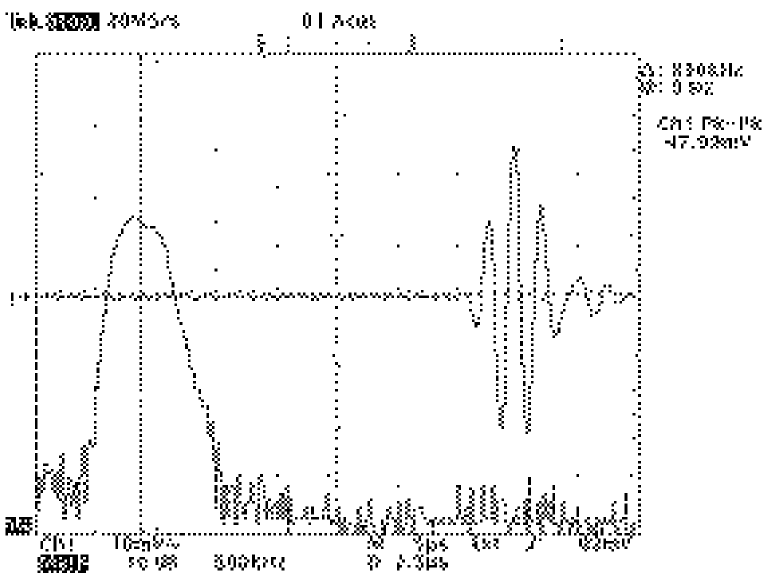

Fig. 3. Time and frequency domain of 1MHz, 19mm diameter current non-contact transducers in transmission mode, with transmitting and receiving transducers separated by 10mm ambient air. Peak Frequency: 0.89MHz. Bandwidth @ -6dB: ~0.6MHz. Received signal amplitude: 48mV. Sensitivity: -50dB. SNR: 36dB.

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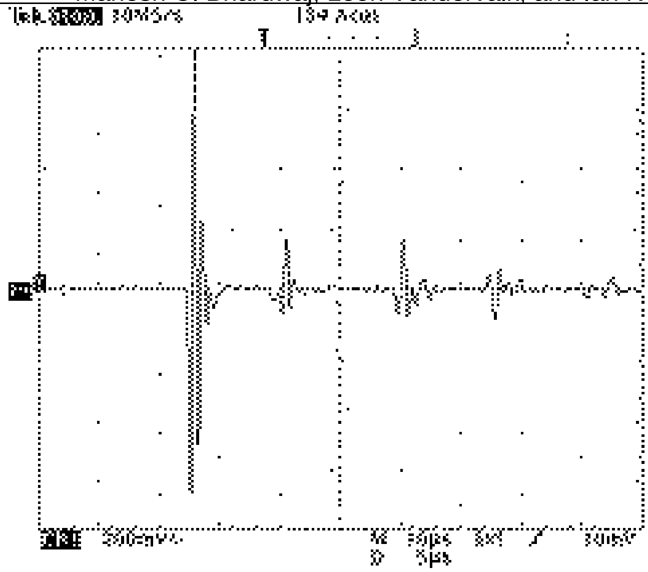

Fig. 4. Transmitted signal through 9mm thick polystyrene generated by water immersion @ 2MHz with a commercial short pulse ultrasonic pulser-receiver. First peak is directly transmitted through the material. Rest of the peaks correspond to reflections from two sides of the material. Compare with Fig. 5.

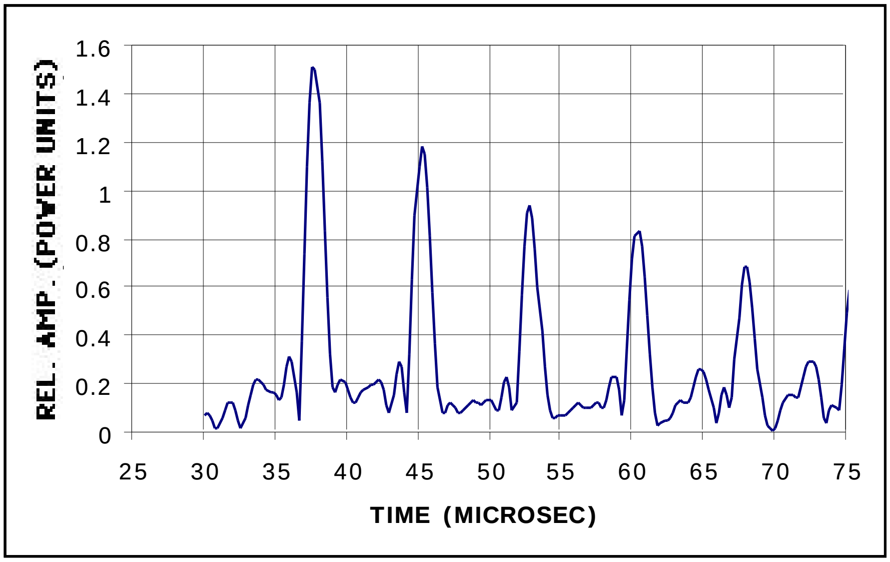

Fig. 5. Transmitted signal through 9mm thick polystyrene generated by non-contact technique in ambient air @ 2MHz with NCA-1000. First peak is directly transmitted through the material. Rest of the peaks correspond to reflections from two sides of the material. Compare with Fig. 4.

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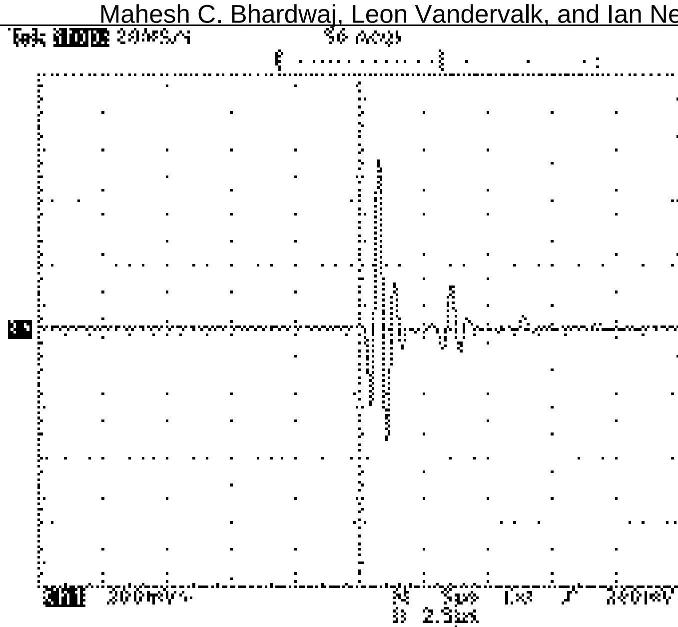

Fig. 6. Transmitted signal through 4.7mm thick multi-layer graphite fiber plastic composite generated by water immersion technique @ 2MHz with a commercial short pulse ultrasonic pulser-receiver. First peak is directly transmitted through the material, while the nest small peak corresponds to reflection from the material thickness. Compare with Fig. 7.

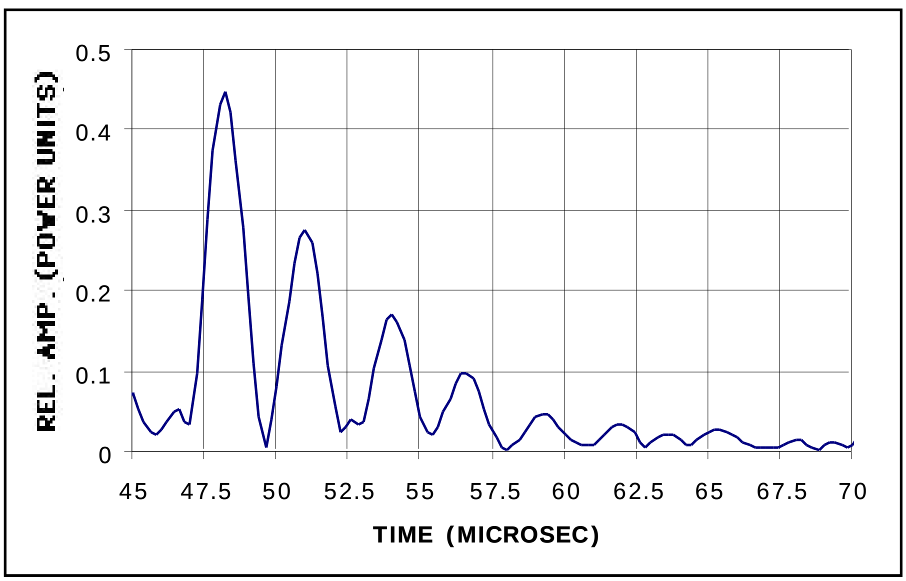

Fig. 7. Transmitted signal through 4.7mm thick multi-layer graphite fiber plastic composite generated by non-contact technique in ambient air @ 2MHz with NCA-1000. First peak is directly transmitted through the material. Rest of the peaks correspond to reflections from two sides of the material. Compare with Fig. 6.

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COMPARISON OF 2MHz ULTRASOUND THROUGH 25mm STEEL

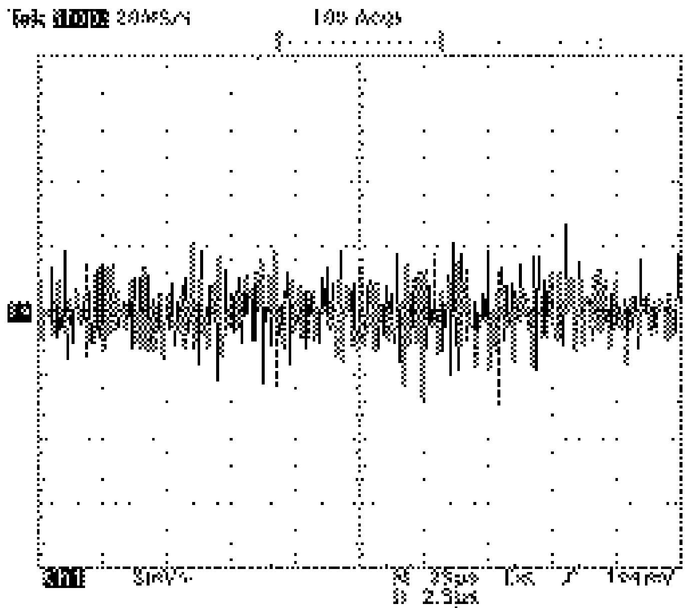

Fig. 8. High Power Conventional System (400V into 4Ω, 3 pulses, 64dB gain MAX) With Air-Scan 2MHz Transducers. Transmission signal through 25mm Carbon Steel.

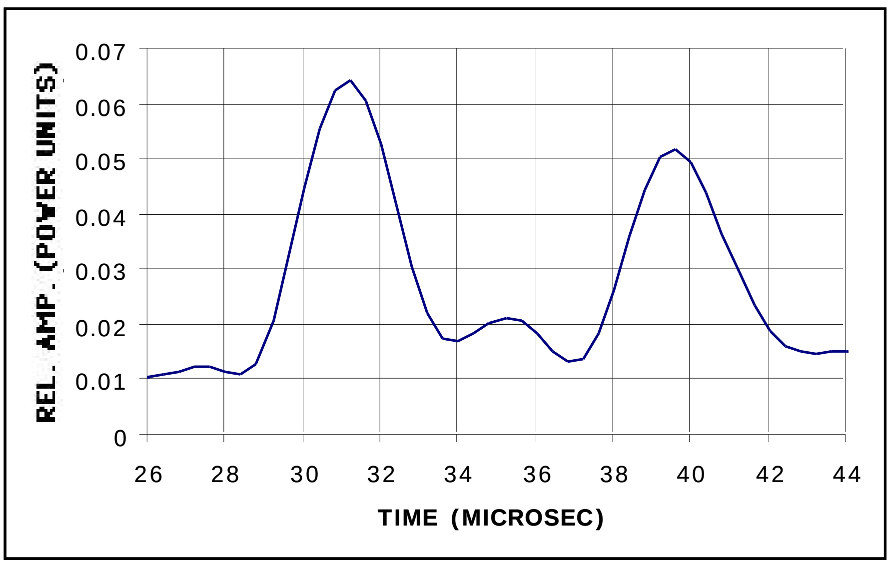

Fig. 9. NCA-1000 With 2MHz Non-Contact Transducers. Transmission signal through 25mm Carbon Steel. First peak, directly transmitted through the material, the next one corresponds to reflection through its thickness.

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COMPARISON OF 1MHz ULTRASOUND THROUGH 25mm HONEY-COMB COMPOSITE

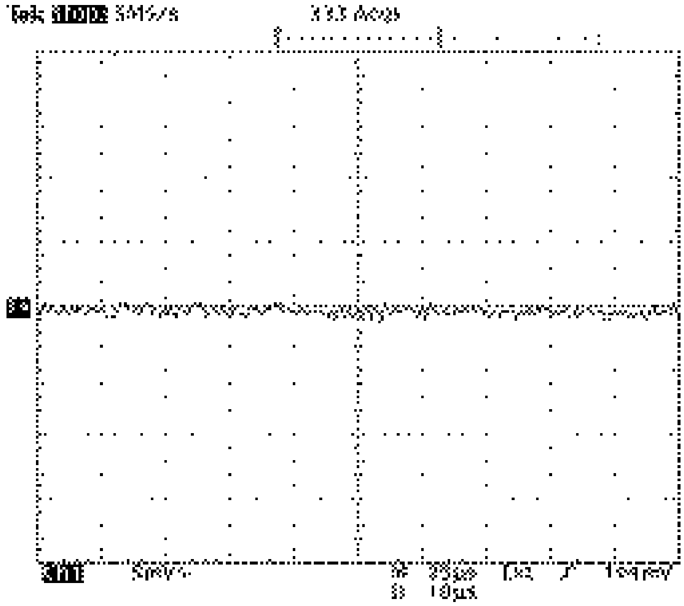

Fig. 10. High Power Conventional System (400V into 4Ω, 3 pulses, 64dB gain MAX) With Air-Scan 1MHz Transducers. Transmission signal through 25mm Composite-Laminated Kevlar

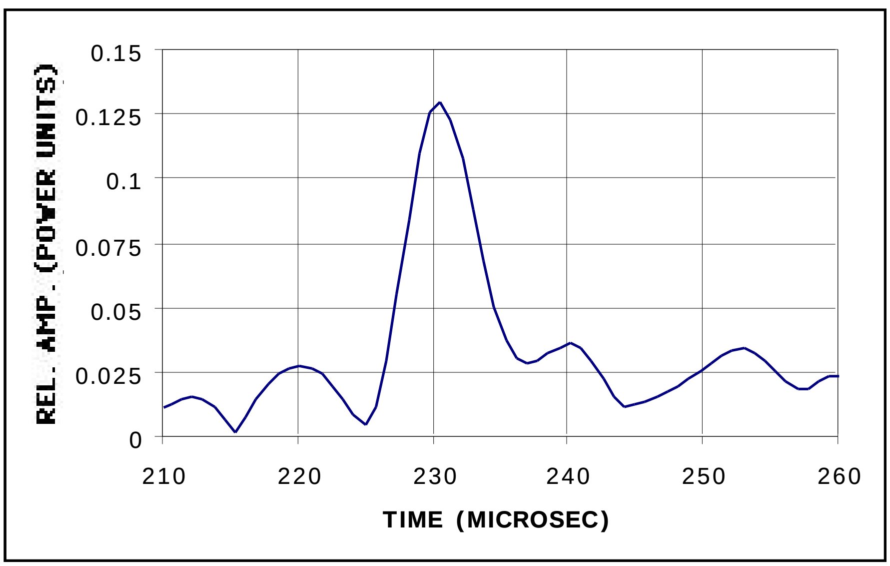

Fig. 11. NCA-1000 With 1MHz Non-Contact Transducers.
Transmission signal through 25mm Composite-Laminated Kevlar Honey-Comb Composite.

COMPARISON OF 1MHz ULTRASOUND THROUGH ROCKET MOTOR CASING

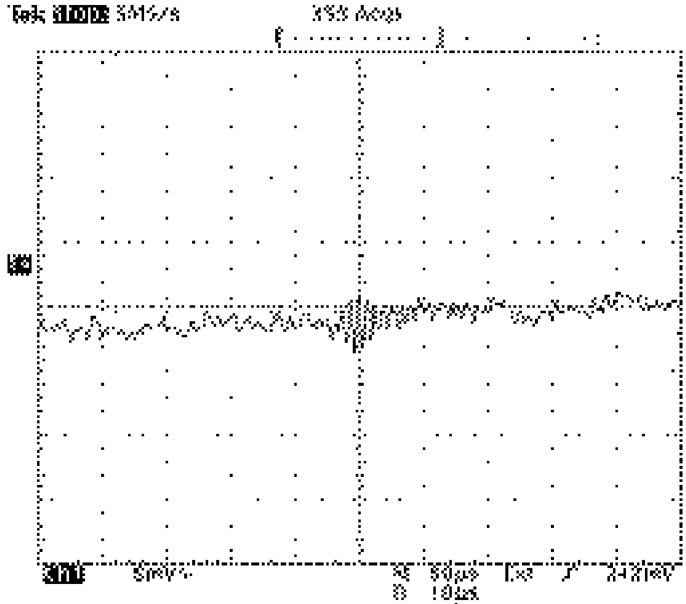

Fig. 12. High Power Conventional System (400V into 4Ω, 3 pulses, 64dB gain MAX) With Air-Scan 1MHz Transducers. Transmission signal through 3mm Rocket Motor Insulation Bonded to 12mm Steel.

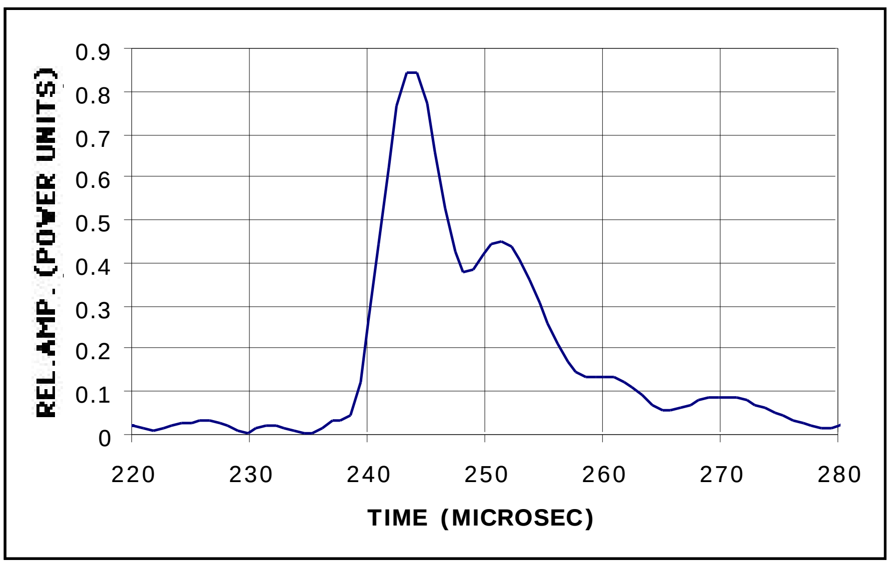

Fig. 13. NCA-1000 With 1MHz Non-Contact Transducers.
Transmission signal through 3mm Rocket Motor Insulation Bonded to 12mm Steel.

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COMPARISON OF 1MHz ULTRASOUND THROUGH 9mm POLYSTYRENE

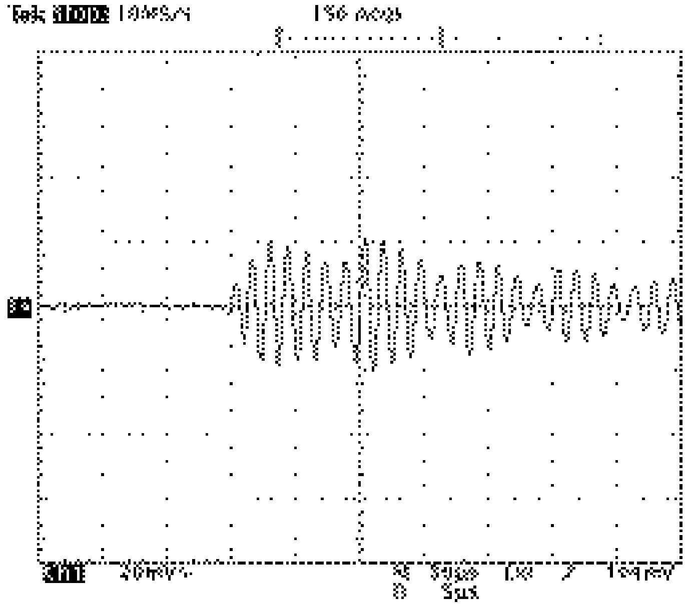

Fig. 14. High Power Conventional System (400V into 4Ω, 3 pulses, 64dB gain MAX) With Air-Scan 1MHz Transducers. Transmission signal through 9mm Polystyrene Sheet.

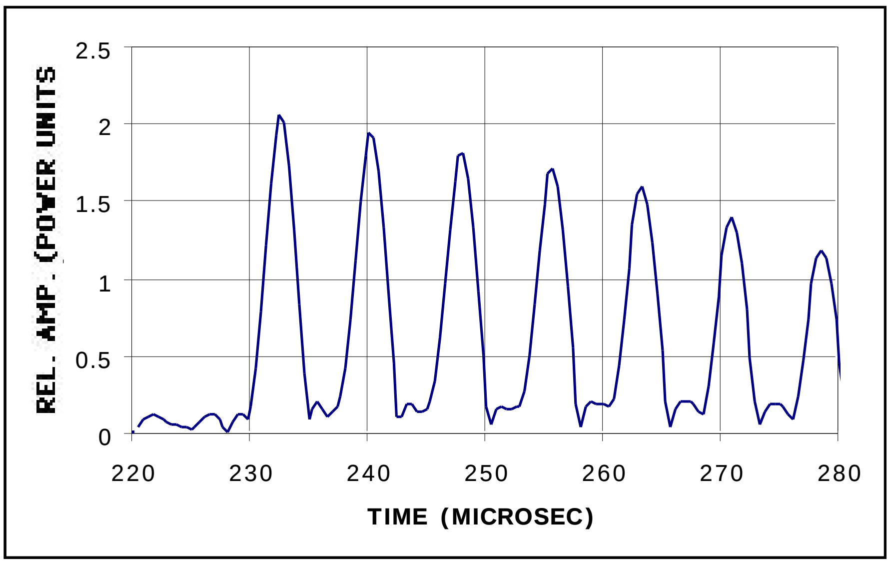

Fig. 15. NCA-1000 With 1MHz Non-Contact Transducers. Transmission signal through 9mm Polystyrene Sheet.

COMPARISON OF 1MHz ULTRASOUND REFLECTION FROM LIQUID SURFACE

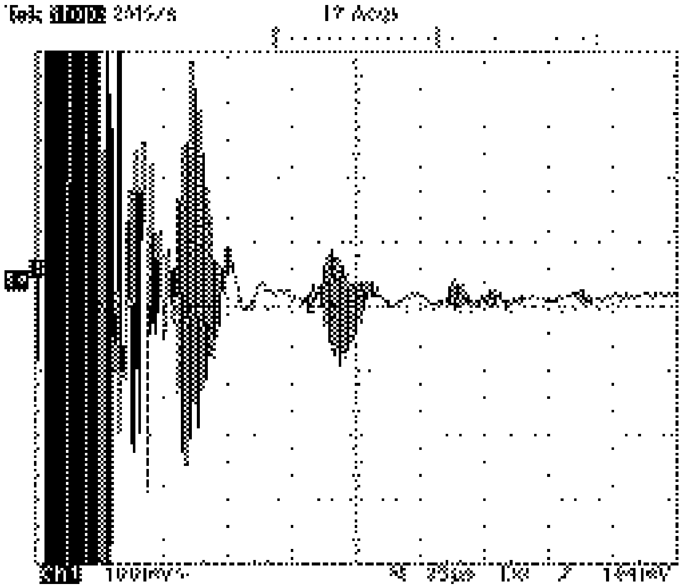

Fig. 16. High Power Conventional System (400V into 4Ω, 2 pulses, 52dB gain) With Air-Scan 1MHz Transducers. Reflection signal from a liquid surface separated by 9.26mm air from the transducer.

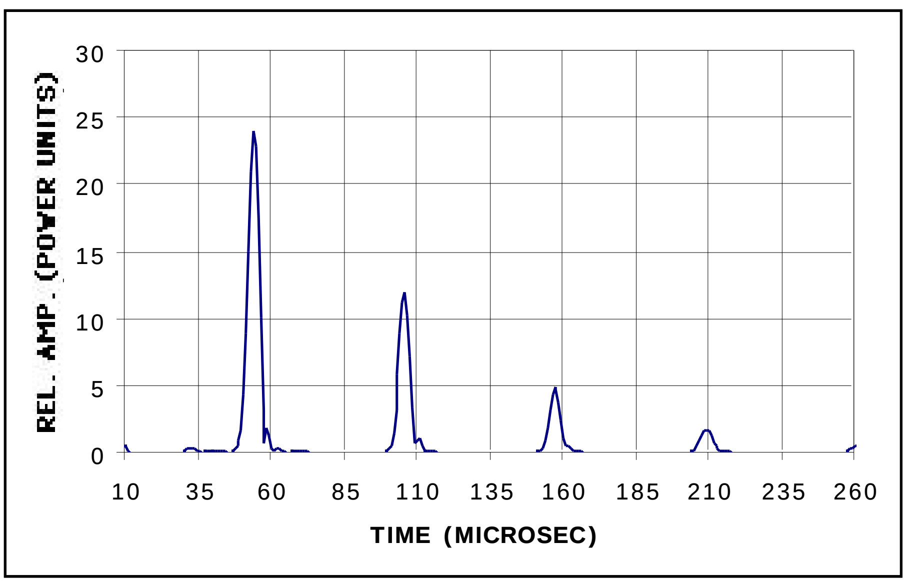

Fig. 17. NCA-1000 With 1MHz Non-Contact Transducers.
Reflection signal from a liquid surface separated by 9.26mm air from the transducer.

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