 #510376 (33)

ACOUSTIC PROPERTIES OF SONAR DOME MATERIALS

by

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ABSTRACT

As part of a development project sponsored by DRDM and DMCS on Spectra Fiber composite sonar domes, DREA has been tasked to provide data on the acoustic properties of glass and Spectra Fiber based composite panels in a 2 - 10 kHz range. The low frequency and high level of accuracy desired presented a number of challenges for carrying out insertion loss measurements. This paper introduces the use of parametric arrays to generate broad frequency responses off sonar dome materials. Particular attention is placed on the generation of low kHz signals in a laboratory limited tank setting and the resultant measurements produced.

INTRODUCTION

The two main functions of a sonar dome are to protect hull-mounted sonar equipment from physical damage as a ship moves through the water, and to displace the turbulent boundary layer away from the ship hull to reduce flow noise. Ideally, the dome should have a minimal effect on the propagation of sound from the target to the ship and from the ship to the target. This may be achieved by using materials for dome construction that have a low insertion loss, *IL*, defined as the reduction in sound pressure resulting from insertion of a test panel between a source and a receiver. Unfortunately, materials which have low insertion losses, such as elastomers, are usually not stiff enough to be self-supporting and do not have the required strength for sonar domes. One solution is to use fibre-reinforced plastic (FRP) composite materials with high strength-to-weight ratios, which enable thin panels with relatively low insertion loss to be used. In addition to low insertion loss, FRPs may offer better noise characteristics than metallic structures due to higher internal damping, since the dome itself may contribute to the noise level via flow excitation at resonnances within the structure.

This paper focuses on the acoustic characterization of several candidate materials being considered as sonar dome construction materials. In addition to metallic-based panels and glass-reinforced materials, composites reinforced with Spectra Fiber were examined. Spectra Fiber, from Allied Signal Corporation, is polyethylene prepared in such a manner that it is highly crystalline, with the crystals aligned along the fiber axis. Examination of the acoustic properties of Spectra Fiber panels is part of a larger effort to develop Spectra Fiber sonar domes, sponsored by Chief Research and Development and Director Maritime Combat Systems.

COMPOSITE PANELS

Spectra Fiber composite panels were prepared by Advanced Composite Technology (ACT), Sparks, Nevada using two different resin systems and two different weaves, Table 1. The resin systems used for the prepregs were based either on a cyanate ester (BTCY-3) or an epoxy, Shell EPON 828 (BT250F). The plasma treated Spectra Fiber reinforcing fibres were configured in either a 985-8H satin weave or a 988-4H satin weave, as shown in Table 1. In each case, the panels contained 50% ± 2% by weight resin, and were 1 m x 1 m x 10 mm in size.

Glass reinforced composite panels were fabricated by ACT using the same resin systems (cyanate and epoxy) as the Spectra Fiber panels, using an 8H satin weave.

TABLE 1

SAMPLE IDENTIFICATION			DIMENSION (MM)
__Spectra Fiber Composite Panels__		**Weave**	
985PT/BT250E	(Epoxy-based)	8H	1005 x 1005 x 10
988PT/BT250E	(Epoxy-based)	4H	1005 x 1005 x 10
985PT/BTCY-3	(Cyanate-based)	8H	1005 x 1005 x 10
988PT/BTCY-3	(Cyanate-based)	4H	1005 x 1005 x 10
__GRP Panels__			
7H5100LN016/001	(Epoxy-based)	8H	1020 x 1080 x 10
7H5100LN016/002	(Cyanate-based)	8H	1010 x 1255 x 10
__Standard Calibration Panel__			
Stainless Steel Plate			1219 x 1168 x 0.92

EXPERIMENTAL FACILITY

This investigation required acoustic measurements of sound, propagated at normal incidence to a panel immersed in water. The use of a parametric source was strategic to the study. With conventional sources, measurements on panels of limited size are affected by diffraction from the edges of the test panels. At low frequency ranges, approaching 1 kHz, diffraction is most pronounced, making it difficult to resolve the diffracted signal from the main transmitted signal. To minimize such effects, the energy at the edge must be reduced. With conventional acoustic transmission, it is very difficult to generate small spot insonification at low frequencies; directionality is a function dictated by frequency.

In view of this, a parametric source was designed and developed with a small beam cross-section. The basic principles of a parametric source can be found in Westervelt (1963), Clay and Medwin (1977), Berktay *et al.* (1979) and Humphrey (1985). Briefly, when two intense sound waves of slightly different frequencies are generated coaxially in water, they interact to produce secondary signals that contain a band of frequencies. These include both the sum and difference frequencies. Of particular importance are the low difference frequency signals generated. These signals possess many attractive attributes suited for material testing which include narrow beamwidth, no sidelobes, and broadband capabilities even at the lower kHz range. Therefore, material testing in a small tank is possible with parametric arrays since diffraction and sidelobe interference problems are made negligible. In addition, the broad bandwidth inherent in the parametric source allows material testing over a wide range of frequencies to be executed with a single small transducer.

In the experiments, a process called "self-demodulation" was used to create the secondary signals of the parametric array. In this method, a pulse-modulated carrier wave is radiated from the acoustic transducer with nonlinear interactions occurring in the water between all the frequencies radiated to yield a band of secondary frequencies.

The source for the study involved a wideband transducer resonant at 500 kHz, driven by a modulated carrier waveform obtained from the transmitting electronics. A short carrier pulse with a smooth envelope was transmitted. A "raised cosine bell" was generated as the modulating function. For our application, the parametric source was deliberately truncated within the Rayleigh distance by placing a "low-pass acoustic filter" across the primary beam at one metre from the transducer. This approach attenuated the higher frequency primary waves while transmitting the low-frequency secondary waves without significant loss. The truncator design was not a trivial task, but involved careful matching of characteristics of the primary beam to minimize spreading of the secondary wave after termination. Distances between hydrophones and panels had to be considered in the design of the truncator panel. A plate made of 20 gauge stainless steel was used as truncator.

Newfoundland's Marine Institute's flume laboratory was the site for the tests. Its dimensions consisted of a large, rectangular concrete windowed tank; 21.5 metres long, 8 metres wide and 4 metres deep, ideal for low frequency material evaluation.

The general geometry used in the study is shown in Figure 1A with a time history example of a signal received after the test panel exhibited in Figure 1B.

MEASUREMENTS

The setup for making the loss measurements is shown in Figure 2. A reference signal was first acquired; the transmitted signal was then recorded with the test panel placed between the truncator and hydrophone. The echo reduction measurements utilized a similar experimental setting (see Figure 3). Once a reference signal was recorded without the panel being present, then reflected signals could be captured with the same hydrophone placed in front of the test panel.

The insertion loss of a panel was defined in terms of the complex incident sound pressure and complex transmitted sound pressure:

$$IL = 20\log_{10}\left|\frac{incident\ sound\ pressure\ p_i}{transmittted\ sound\ pressure\ p_t}\right| = 20\log_{10}\left|\frac{1}{T}\right| \tag{1}$$

T is the complex transmission coefficient.

The echo reduction (ER) of a panel was also defined in terms of its complex incident sound pressure and complex reflected sound pressure:

$$ER = 20\log_{10}\left|\frac{incident\ sound\ pressure\ p_i}{reflected\ sound\ pressure\ p_r}\right| = 20\log_{10}\left|\frac{1}{R}\right| \tag{2}$$

R is the complex reflection coefficient and the function $|\bullet|$ represents the magnitude.

Computations of the complex reflection and transmission coefficient were performed in the frequency domain via the Fast Fourier Transform (FFT). In each case, the complex Fourier coefficients for each pulse were used in the division. In addition, the Hilbert Transform was employed to better display and calculate changes in the waveform. Such a response analysis involves taking the imaginary part of the signal along with the real part. The resulting analytic signal is displayed as time or frequency envelopes. Such transformed data allows for precise time representation of both the peak values and instantaneous phases of the signal. The Hilbert-transformed series were detrended and the energy envelopes were log transformed (see Figure 1B). (Guigné *et al.* (1991) and Guigné and Chin (1989) provide details on the application of the Hilbert Transform to underwater acoustics).

RESULTS

Ideally, the properties of a sonar dome would be such as to allow the propagation of acoustic radiation through with minimal reflection, absorption, or distortion. Examination of the Hilbert Transforms is one way of determining the amount of distortion due to the panel. The shape of the transmitted waveforms for the cyanate-based Spectra Fiber panels (Figures 4A, 5A and 6A) are very close to those of the Reference waveforms, while the epoxy-based Spectra Fiber and GRP panel waveshapes are slightly more distorted (Figures 7A, 8A and 9A). The Hilbert Transform of a thin (0.92 mm) stainless steel panel is shown for comparison in Figure 10A. Note how the waveshape is altered considerably more than for the composite panels.

The amount of reflection and absorption may be quantified by their echo reduction and insertion loss spectra, shown in Figures 11 and 12 for the panels listed in Table 1. The Spectra Fiber panels had relatively flat insertion loss spectra of less than 1dB up to 35 kHz (Figure 12), whereas the GRP panels had losses that increased more sharply with frequency, with values of 2.5 - 3.5 dB at the higher end of the freuency range examined (40kHz). The cyanate-based panels had slightly better (lower insertion losses) performance than the epoxy-based panels for Spectra Fiber panels, but the opposite was true for the GRPs (i.e. the epoxy resins were superior). The 8H weave was found to have slightly lower insertion losses than the 4H weave for the Spectra Fiber/cyanate resin system. The Spectra Fiber panels also had low reflectivity, or high echo reduction, in the 1 - 40 kHz frequency range (Figure 11). The least reflective panel was the 8H cyanate resin Spectra Fiber panels, which had echo reductions of 15 - 22 dB.

SUMMARY

From the data collected, it is clear that the Spectra Fiber Composite Panels have very low insertion losses compared to the glass fiber composites of the same thickness. In particular, the 988 PT/BT250E epoxy-based panel and 985PT/BTCY3 cyanate-based panel have remarkable responses producing very little waveshape distortion and losses (see Figure 12). The Spectra Fiber echo reduction characteristics also concurred with the goal for the sonar dome material to remain low in reflectivity.

Overall, it would appear that significant gains would be made using Spectra Fiber Composite materials over glass fiber and metallic composite sonar domes. In addition to being non-corroding and having high strength to weight ratio, their acoustic properties appear well-matched in impedance to water, and also appear well suited to low frequency propagation.

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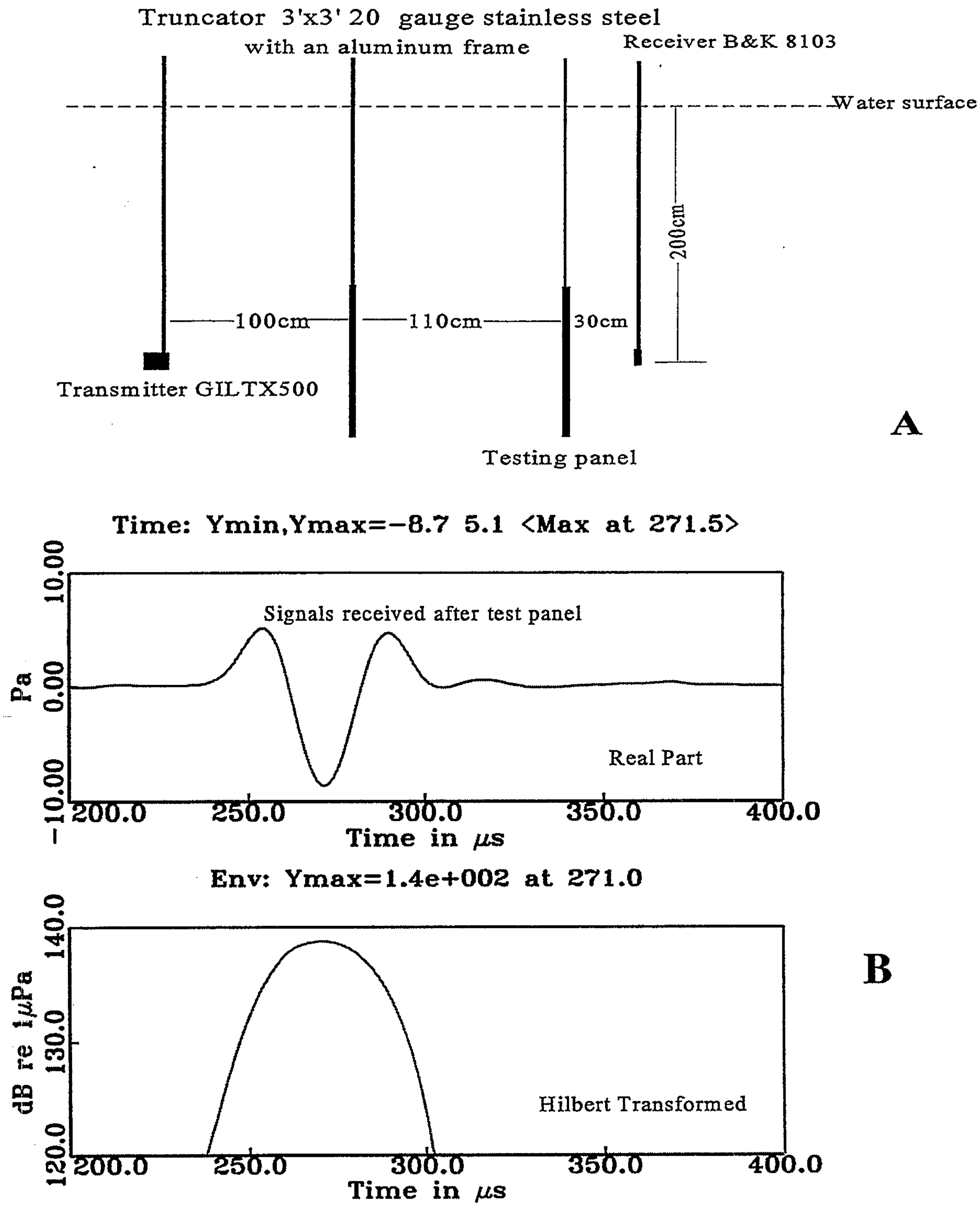


Truncator 3'x3' 20 gauge stainless steel
with an aluminum frame
Receiver B&K 8103
Water surface
200cm
100cm
110cm
30cm
Transmitter GILTX500
Testing panel
A
Time: Ymin,Ymax=-8.7 5.1 <Max at 271.5>
Signals received after test panel
Pa
10.00
0.00
-10.00
Real Part
200.0
250.0
300.0
350.0
400.0
Time in μs
Env: Ymax=1.4e+002 at 271.0
dB re 1μPa
140.0
130.0
120.0
Hilbert Transformed
200.0
250.0
300.0
350.0
400.0
Time in μs
B

Figure 1

Setup for Insertion Loss Measurements

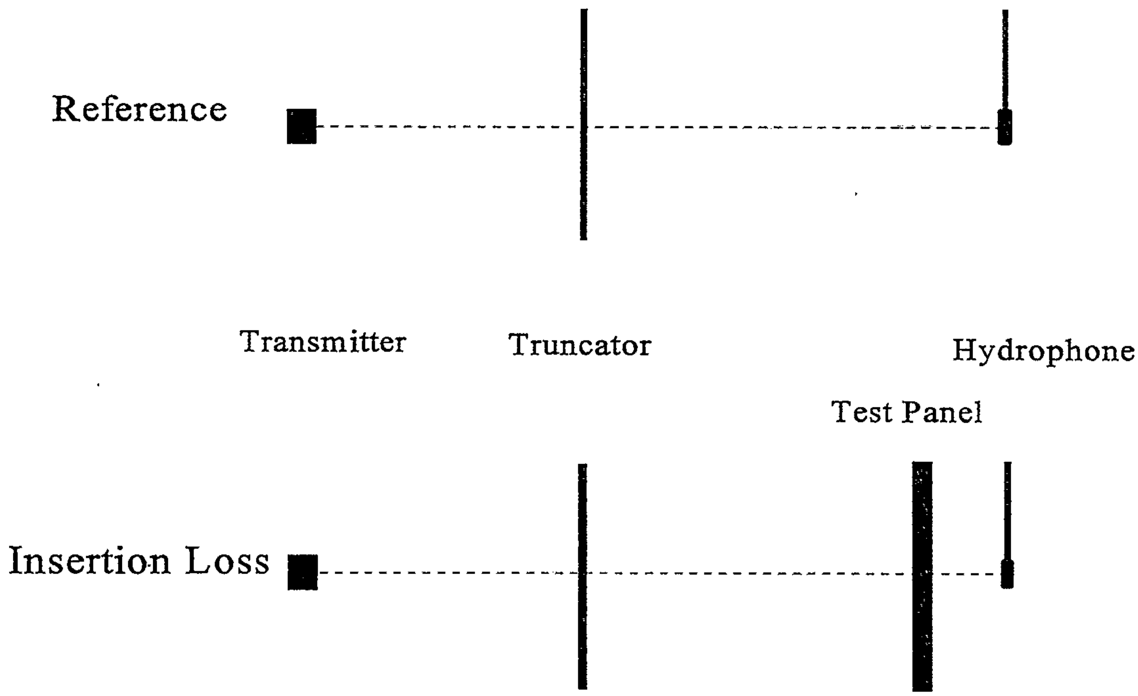


Figure 2

Setup for Reflection Loss Measurements

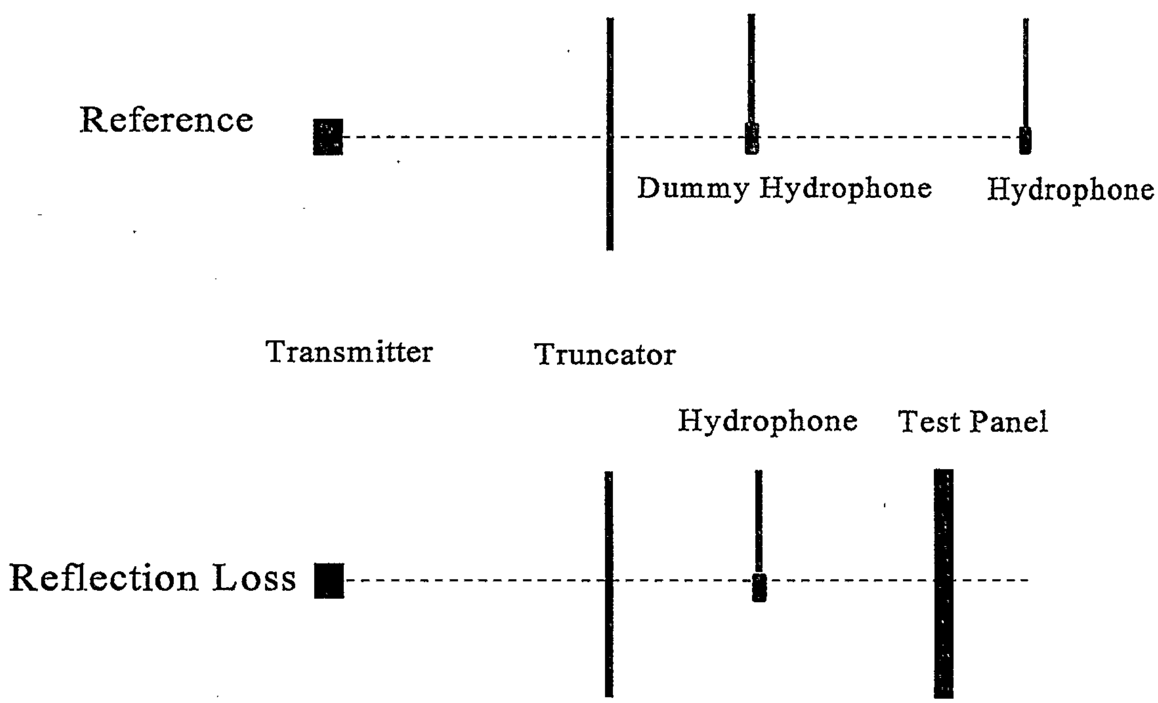
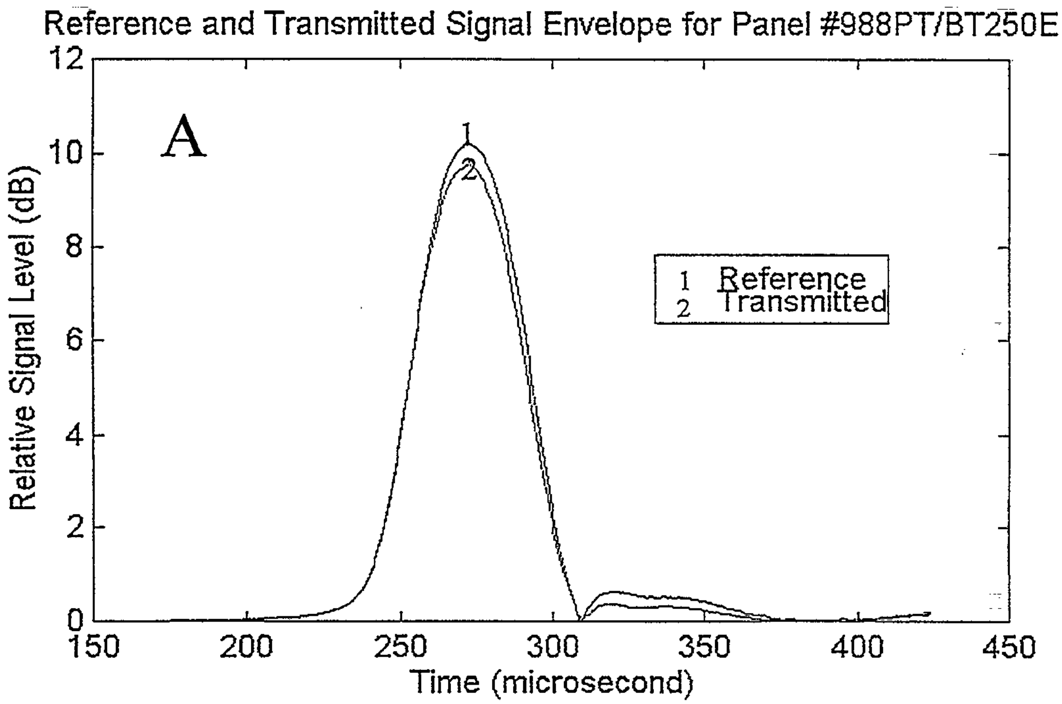


Figure 3


Reference and Transmitted Signal Envelope for Panel #988PT/BT250E
A
Relative Signal Level (dB)
Time (microsecond)
1 Reference
2 Transmitted
0
2
4
6
8
10
12
150
200
250
300
350
400
450

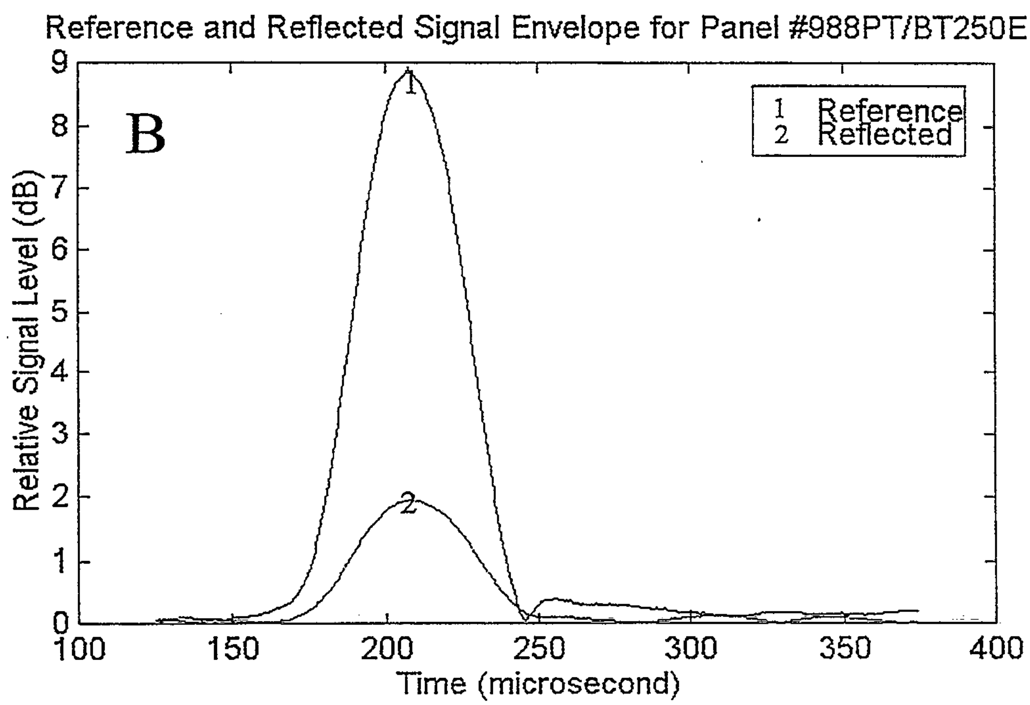

Reference and Reflected Signal Envelope for Panel #988PT/BT250E
B
Relative Signal Level (dB)
Time (microsecond)
1 Reference
2 Reflected
0
1
2
3
4
5
6
7
8
9
100
150
200
250
300
350
400

Figure 4

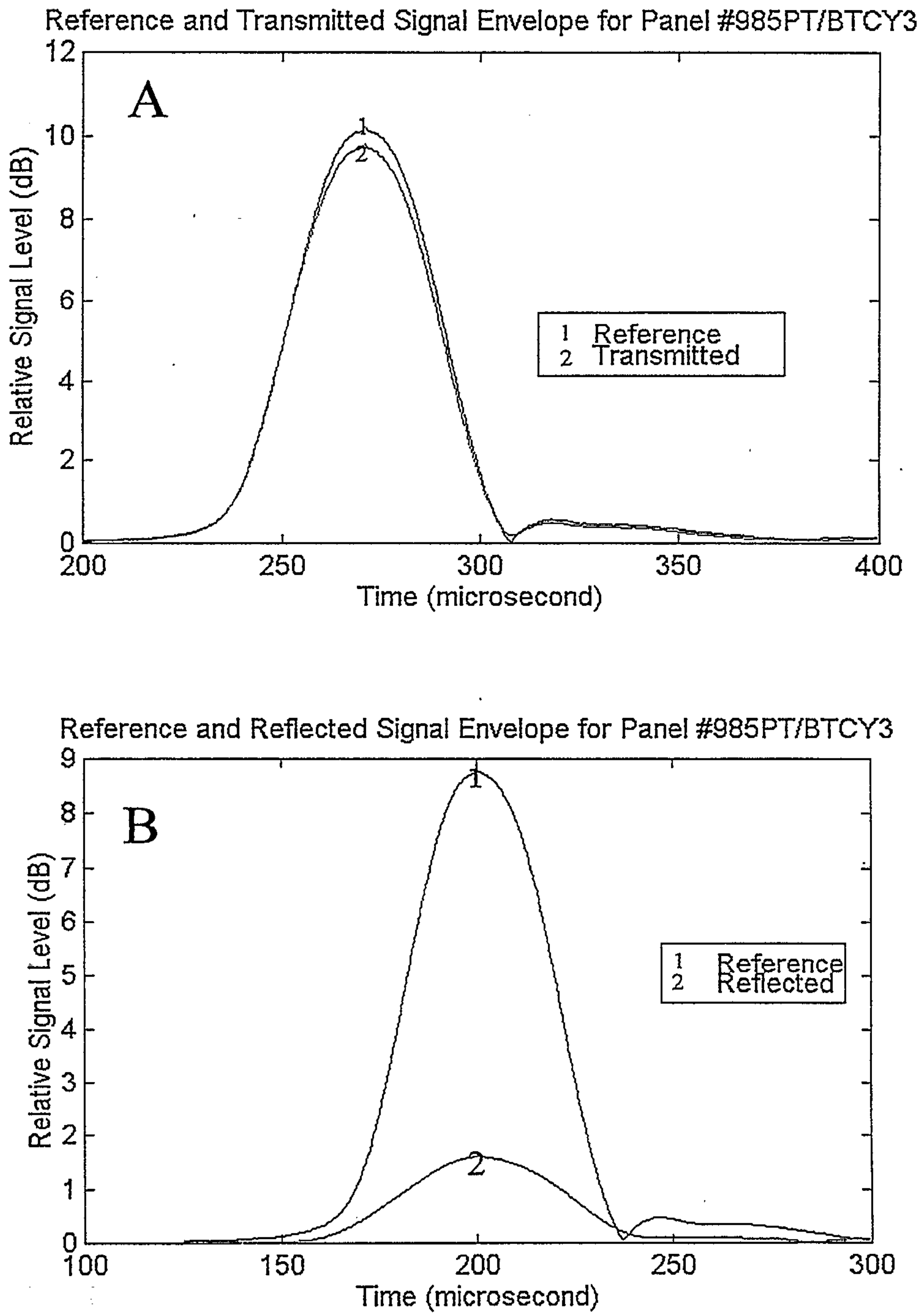

Reference and Transmitted Signal Envelope for Panel #985PT/BTCY3
A
Relative Signal Level (dB)
Time (microsecond)
1 Reference
2 Transmitted
0
2
4
6
8
10
12
200
250
300
350
400
Reference and Reflected Signal Envelope for Panel #985PT/BTCY3
B
Relative Signal Level (dB)
Time (microsecond)
1 Reference
2 Reflected
0
1
2
3
4
5
6
7
8
9
100
150
200
250
300

Figure 5

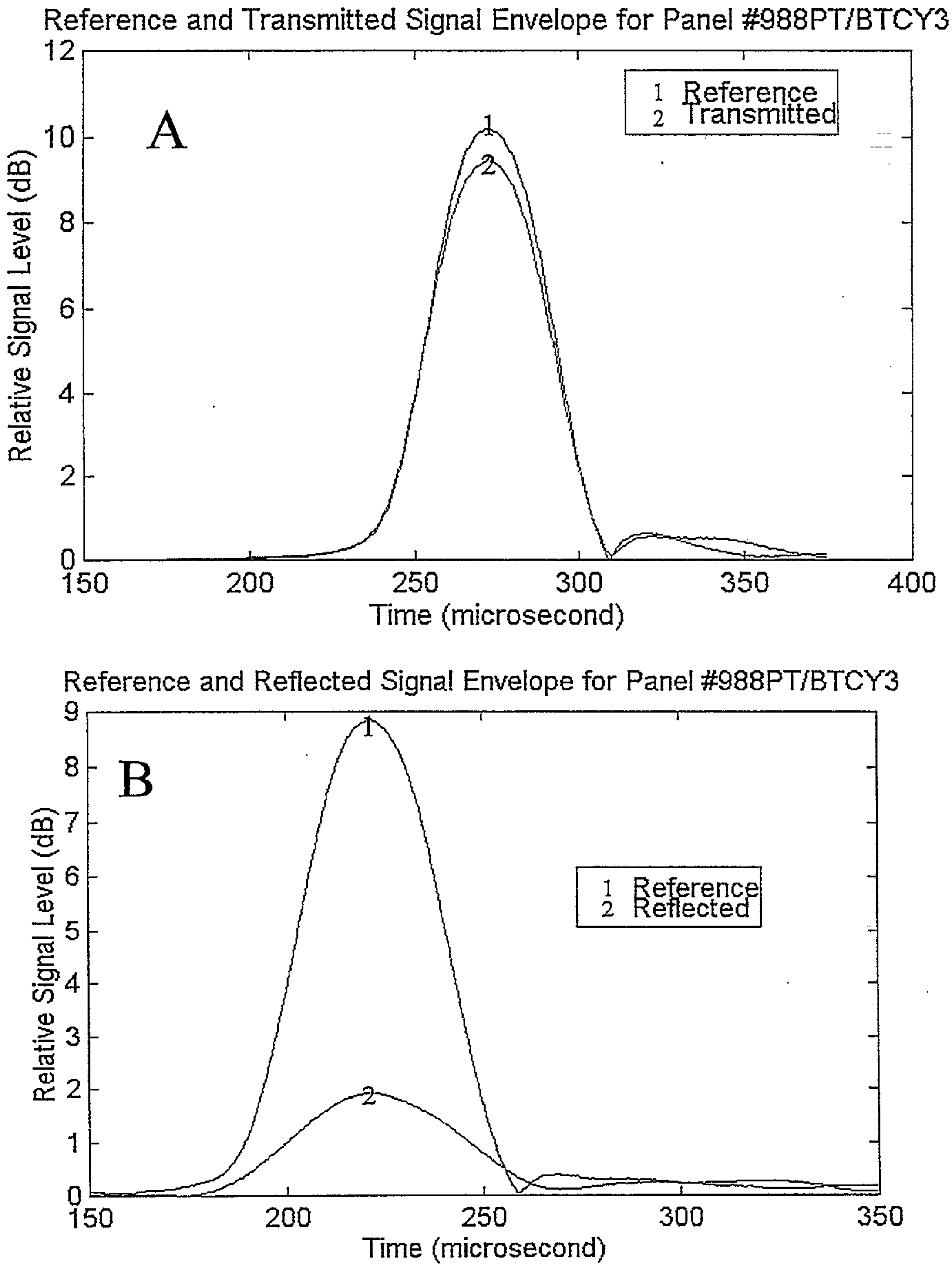

Reference and Transmitted Signal Envelope for Panel #988PT/BTCY3
A
1 Reference
2 Transmitted
Relative Signal Level (dB)
Time (microsecond)
0
2
4
6
8
10
12
150
200
250
300
350
400
Reference and Reflected Signal Envelope for Panel #988PT/BTCY3
B
1 Reference
2 Reflected
Relative Signal Level (dB)
Time (microsecond)
0
1
2
3
4
5
6
7
8
9
150
200
250
300
350

Figure 6

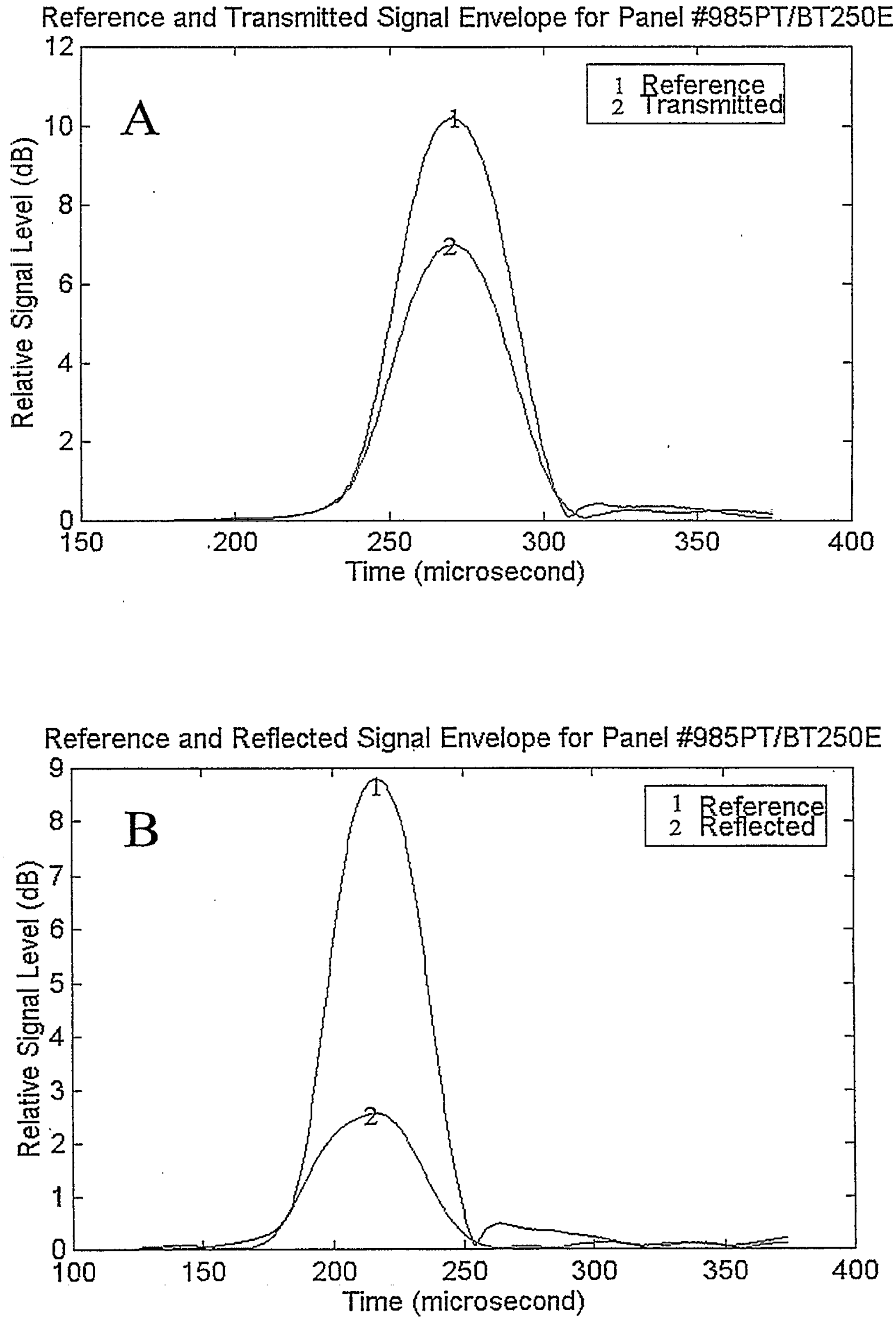
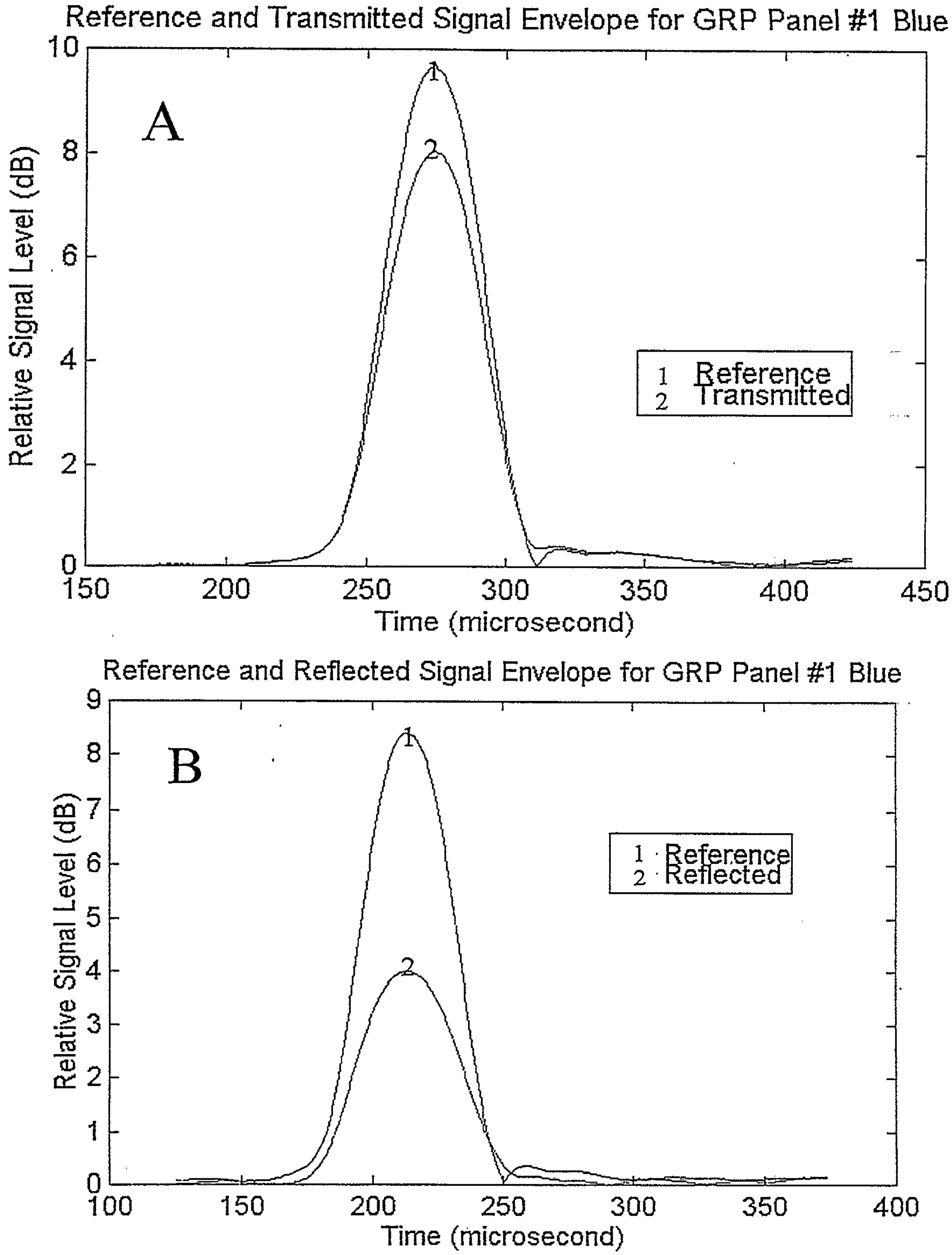
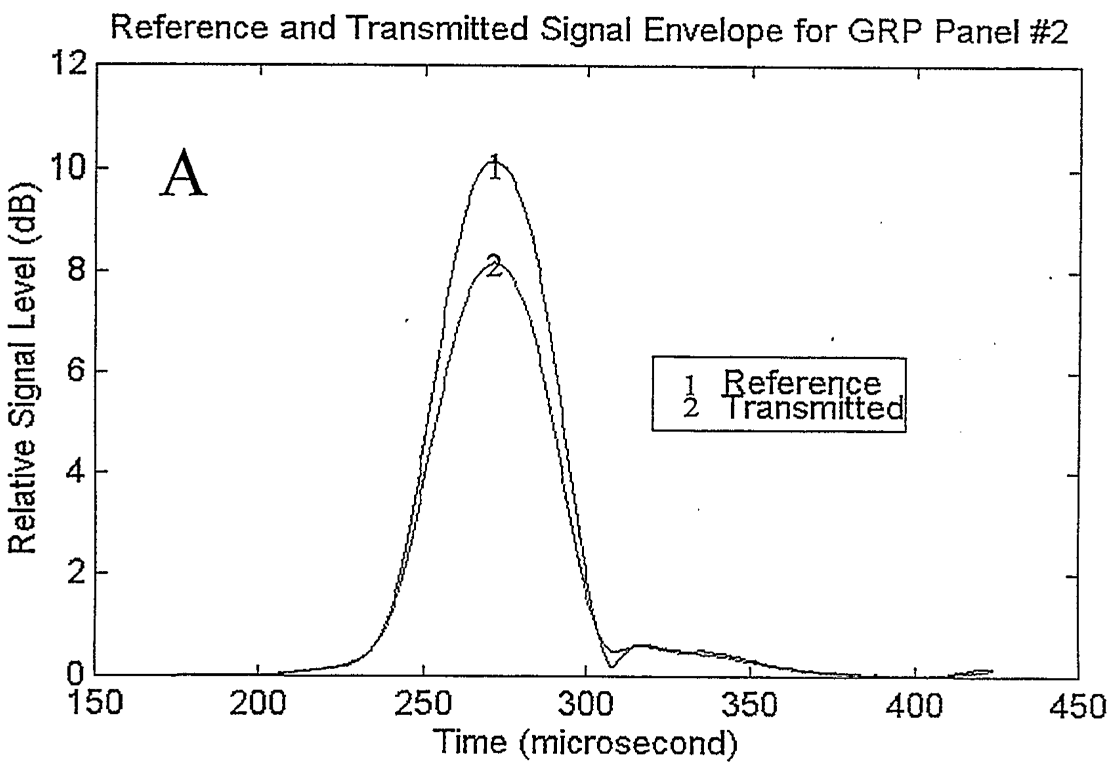

Reference and Transmitted Signal Envelope for Panel #985PT/BT250E
A
1 Reference
2 Transmitted
Relative Signal Level (dB)
Time (microsecond)
0
2
4
6
8
10
12
150
200
250
300
350
400
Reference and Reflected Signal Envelope for Panel #985PT/BT250E
B
1 Reference
2 Reflected
Relative Signal Level (dB)
Time (microsecond)
0
1
2
3
4
5
6
7
8
9
100
150
200
250
300
350
400

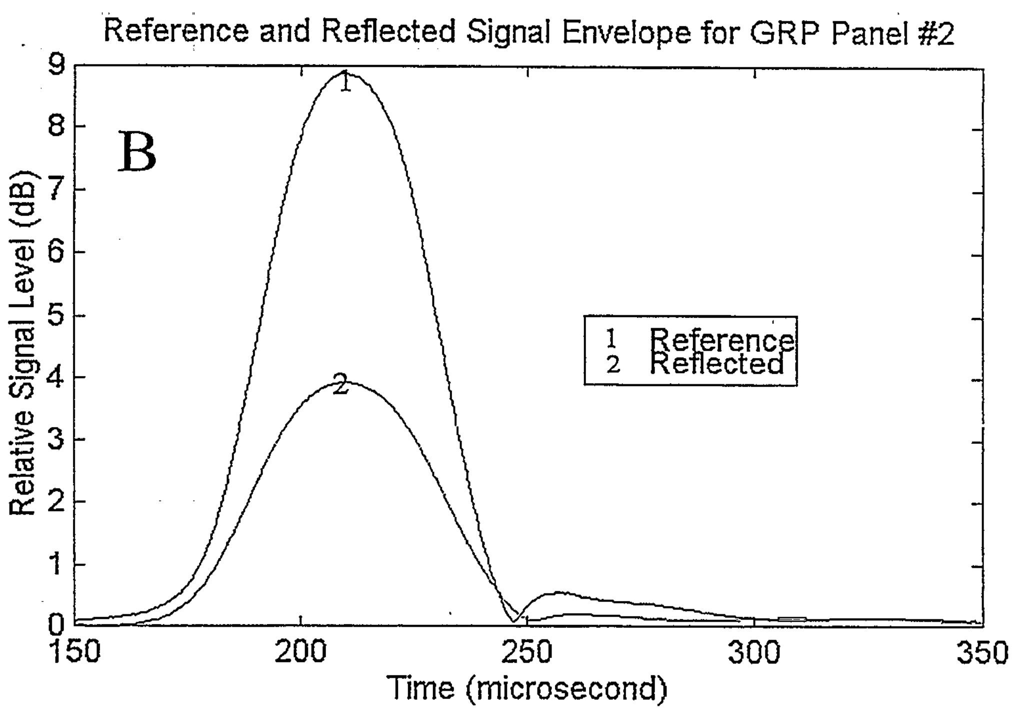
Figure 7



Blue - Epoxy

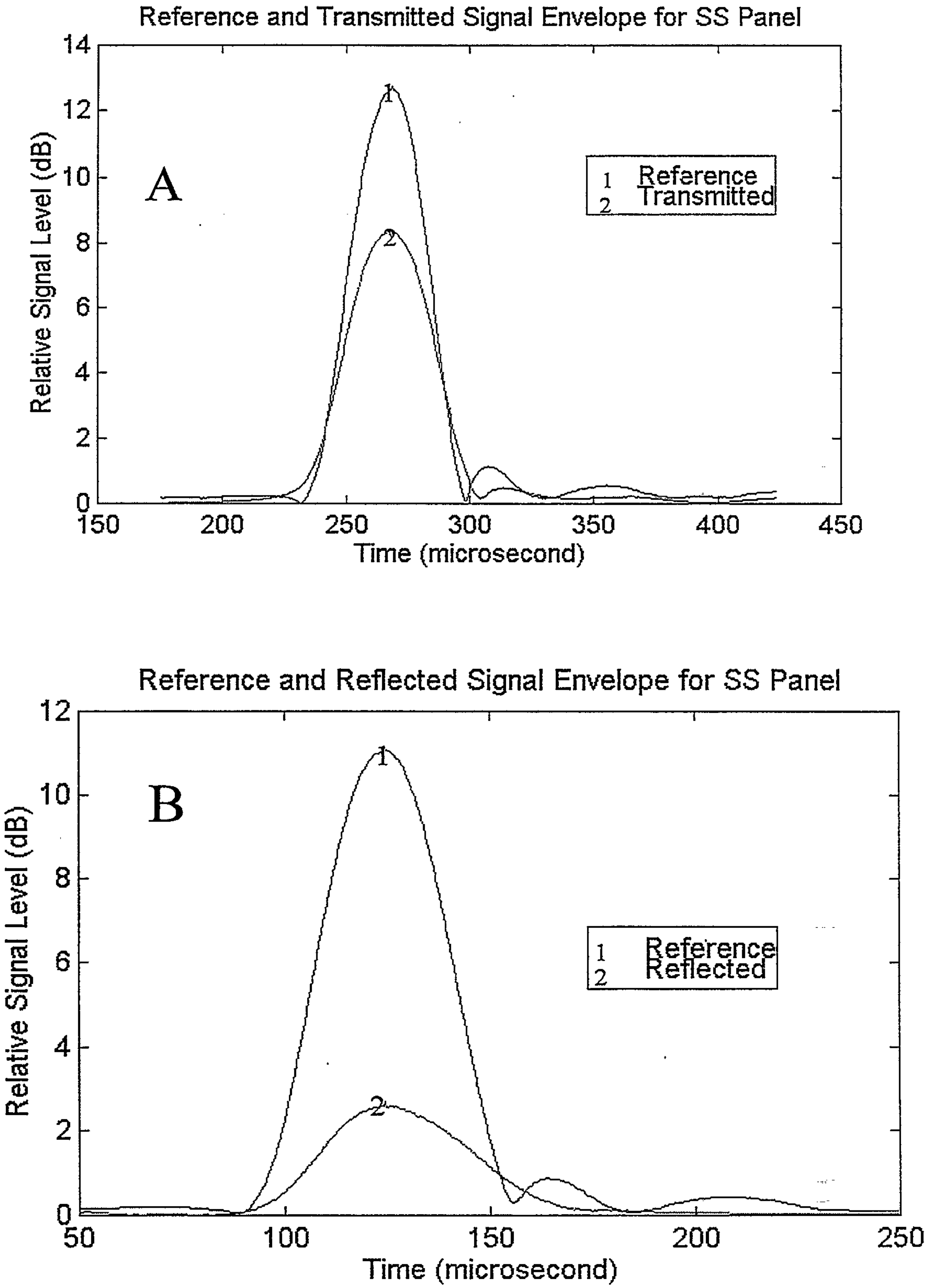
Figure 8





Brown - Cyanate

Figure 9



SS - Stainless Steel

Figure 10

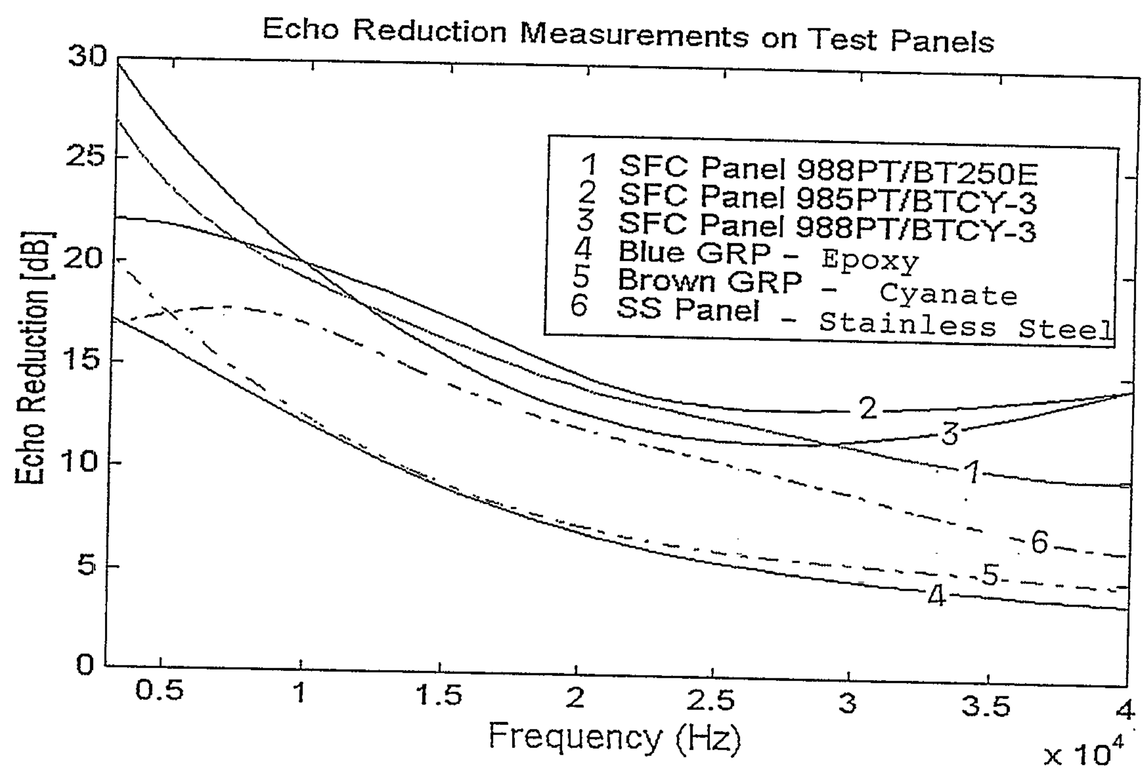

Echo Reduction Measurements on Test Panels
Echo Reduction [dB]
Frequency (Hz)
x 10^4
0
5
10
15
20
25
30
0.5
1
1.5
2
2.5
3
3.5
4
1 SFC Panel 988PT/BT250E
2 SFC Panel 985PT/BTCY-3
3 SFC Panel 988PT/BTCY-3
4 Blue GRP - Epoxy
5 Brown GRP - Cyanate
6 SS Panel - Stainless Steel
1
2
3
4
5
6

Figure 11

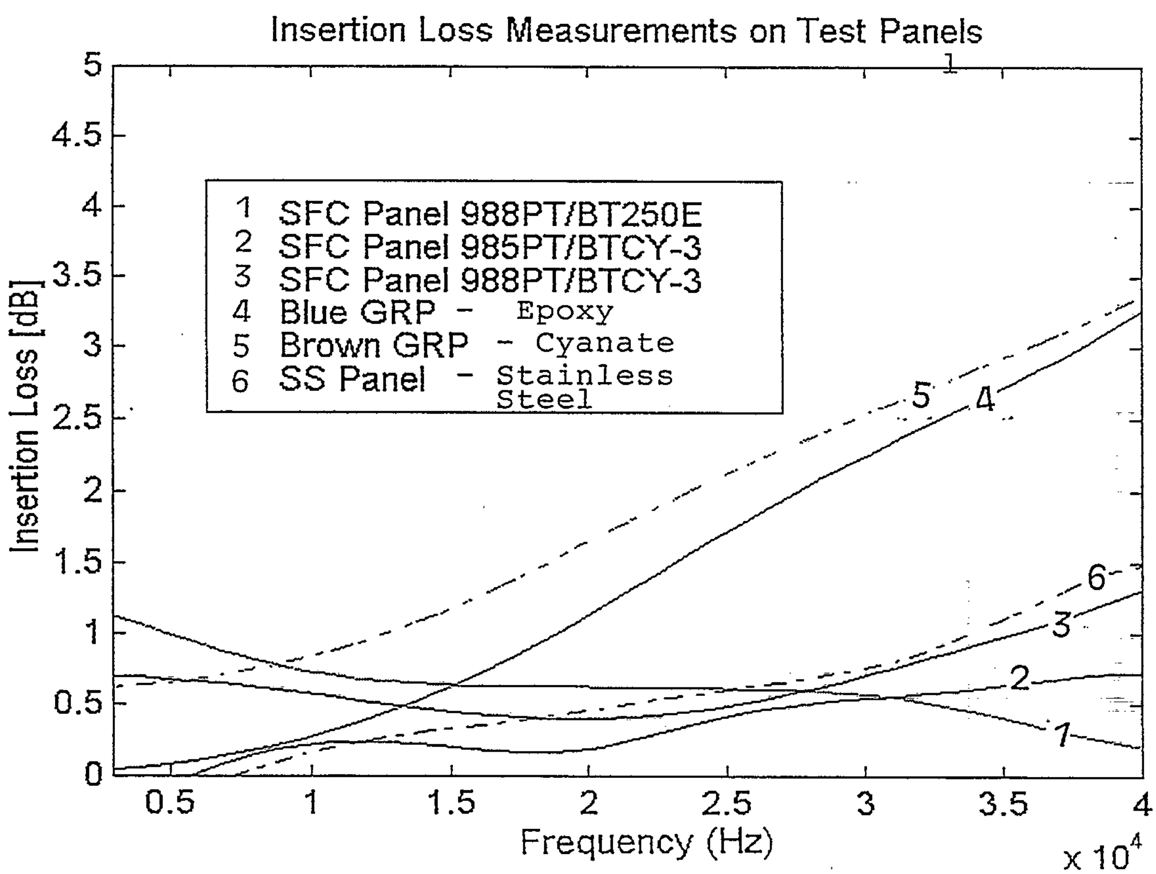

Insertion Loss Measurements on Test Panels
Insertion Loss [dB]
Frequency (Hz)
x 10^4
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1 SFC Panel 988PT/BT250E
2 SFC Panel 985PT/BTCY-3
3 SFC Panel 988PT/BTCY-3
4 Blue GRP - Epoxy
5 Brown GRP - Cyanate
6 SS Panel - Stainless Steel

Figure 12

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