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**Innovations Deserving  
Exploratory Analysis Programs**

***Highway IDEA Program***

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## **Algorithm for Using Ultrasound of MHz Frequency for Testing Concrete**

Final Report for Highway IDEA Project 96

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***November 2004***

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## **Algorithm for Using Ultrasound of MHz Frequency for Testing Concrete**

*This report was presented first at the meeting of Committee 228 on Nondestructive Testing of Concrete of the American Concrete Institute Spring Meeting in Washington, D.C. on March 14, 2004, and subsequently to a panel of experts at Drexel University on April 2, 2004. Both presentations received positive responses as Appendices 1 and 2 show.*

### **Abstract**

The specific objective of this Type I research was the development of an algorithm for the rationalization of the Split Spectrum Processing (SSP), an earlier proved computer procedure to make ultrasound of MHz frequency applicable for field testing of concrete structures. This application includes but not restricted to detection and localization of defects and reinforcements as well as thickness determination. SSP is needed to reduce the intensive background noise accompanying high-frequency ultrasound in concrete; that is, to distinguish target signals from noise by enhancing the signal-to-noise ratio. Also, although the spectrum splitting is done by computer, four parameters are needed for the method the optimum values of which are obtained by trial and error in the traditional SSP. This is cumbersome and time consuming, thus its rationalization, that is the elimination of the trial and error, would greatly improve the process for practical application. Such rationalization is achieved by the combination of SSP with Spectral Histogram Technique (SHT). This combination is called Graphical User Interface (GUI) in this report. As the presented results show, the Graphical User Interface does reduce the noise,

thereby improve significantly the interpretation of the received high-frequency ultrasound. Also, its computerized form makes the application simple and quick.

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## Introduction

The general objective of this Type I project was to improve the nondestructive testing of concrete by using high-frequency ultrasound with all its advantages for diagnostic field testing, local and global, of concrete structures. This made necessary the reduction of the high level of background (coherent) noise so typical in the received high-frequency signals. The role model was the medical sciences where the high-frequency method found many different applications in areas of medical diagnostics; except that a different signal processing, the Split Spectrum Processing (SSP) was used in our work for noise reduction. The discussion below concentrates on the simplest application of SSP, that is for thickness determination of a layer, although it is also applicable to more sophisticated nondestructive tasks, such as determination of the thicknesses of individual layers in a layered system (pavements, or asphalt overlay on bridge decks), delamination and debonding detection, and monitoring deterioration within concrete.

## Split Spectrum Processing (SSP)

SSP is a signal processing method that has been successfully used to distinguish meaningful target signals from background microstructure (scatterer) noise in nondestructive

testing of stainless steel and other metals. Its application to concrete, however, is not automatic because the different nature of the internal structure of concrete. Nevertheless, after modification SSP did produce encouraging results with concrete [1].

The most frequently used signal processing method for noise reduction is time averaging but it can reduce only the incoherent content of the signal noise. This is not enough for testing concrete because the remaining noise, which is the coherent (or scattering) noise produced by backscatter of the propagating ultrasound, is still overwhelming. The reduction of the scattering noise requires a more advanced technique and the SSP is such a technique. SSP is based on the observation that a source of scatter in the concrete reflects different echoes from different frequencies in the form of coherent noise; that is, the scattering content is highly sensitive to shifts in the operating frequency, whereas the echoes from defects and boundaries are not. Consequently, when an ultrasonic measurement is repeated in a location with several narrow-band transducers of different frequencies, the combination of these received narrow-band signals suppresses the frequency-dependent noise, whereas the signals reflected by the targets of interest remain unchanged. The net result is an increase in the signal-to-noise ratio for echoes from the targets. Reportedly, arrays of 7, 16 and 19 transducers have been used successfully for such tests by Cambridge Ultrasonics [2].

The fundamental principle of SSP is the same as that of the Cambridge method, namely, reduction of the coherent noise by combining narrow-band signals of different frequencies obtained from the same scatterer(s). The difference is in the production of the narrow-band signals. The Cambridge method uses many transducers with the accompanying experimental complexities whereas SSP achieves the same results with one single broad-band measurement by

splitting the broad-band signal by the computer into narrow-band components of different frequencies.

Details of the split spectrum processing, including the reassembling algorithms (polarity thresholding, minimization, etc.) have been published earlier [1]. The essence is that a broad-band ultrasonic signal, captured after passing through concrete, is submitted to fast Fourier transform and split into an ensemble of narrow-band signal components of differing frequencies by equally spaced Gaussian bandpass filters. When the ensemble of the split narrow-band signals of differing frequencies is reassembled by a suitable algorithm to form a single broad-band output signal (after inverse Fourier transform), the noise cancels out. There are several established reassembling algorithms, any one of these can do the job. Since, however, the computer can perform such calculations without any extra effort, two of these algorithms, the polarity thresholding and the minimization algorithms, were used in our work.. The results they produce differ only in minor details, so to have both is mostly for double checking the procedure. There is a catch, however: the SSP does work but only if its four parameters (the first and last points of the portion to be processed, the bandwidth of the Gaussian filter, and the filter spacing) have specific (optimum) values. In its original form SSP used a more or less haphazard trial-and-error process for the determination of the optimum parameters which made it cumbersome and overly time consuming. Thus, the *specific objective* of this research was to rationalize the process by the development of an algorithm that eliminates the trial-and-error part.

As shown in this Final Report, this objective was fulfilled: a fast and simple algorithm was developed successfully that did reduce the coherent noise significantly without the trial-and-error procedure. As was indicated in our Stage Report, there were several promising approaches



for this elimination. Out of these, the method called Spectral Histogram Technique (SHT), proved to be the best for the direct calculation of the optimum or near optimum parameters for SSP. The peak of this histogram represents the frequency where the signal-to-noise ratio is maximum, thus the adjacent peaks are selected by the computer as two of the parameters, the starting and final frequencies for SSP in Table 1. This is marked with red arrow in Figure 4b. So, we supplemented the SSP with SHT under one interface, called the Graphical User Interface (GUI) in Matlab that is a commercially available mathematical software. This not only reduces the time of noise reduction to minutes but also makes it so simple that a technician with elementary knowledge of Matlab can do it.

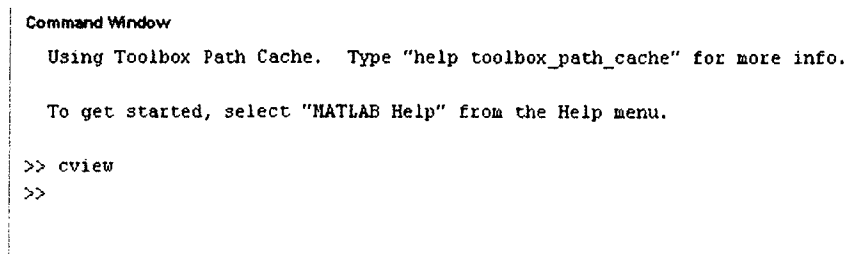
Details of the GUI and its application for noise reduction are presented below. The construction of a prototype for field use is left for a future Type II project.

### **Application of the Graphical User Interface (GUI)**

The results of the ultrasonic measurements are time averaged and stored in the same computer where the GUI is. The GUI can be activated by typing “*cview*” in the Matlab Command Window under the specified directory, as shown in Figure 1. This will open up an initial View command window under the specified directory, as shown in Figure 2. This command window includes the descriptions and the command buttons to initialize or terminate the software. The user can initialize the program by hitting the “*Enter*” button on the Main Menu window (Fig. 2). This window consists of two main sections: the Graphical Display and the Control Panel. Hitting the “*Close*” window terminates the software.

The Graphical Display window includes four plotting sections, as illustrated in Figure 3. An example for application is given in Figure 4 showing the test results obtained on a concrete slab with steel reinforcement. (This case will be discussed further later.) The first window displays ultrasonic signals in time domain received after passing through the slab after time averaging but otherwise unprocessed. The red section indicates the portion of the data that will be submitted to SSP. This is selected by the user as shown in Table 1 and described below. The second window presents the Spectral Histogram which is the distribution of the frequencies in the signal. This is calculated automatically by the computer from the experimental data. The third window presents the graph showing the ultrasonic data after processing with polarity thresholding, and the forth one the same with minimization. These are also determined by the computer automatically. (See also Example 1.)

The control panel includes ten push buttons (four hidden which are displayed after processing) and five entry field controls in terms of the number of data points. The functionality of these buttons is described in Tables 1 and 2.



```

Command Window
Using Toolbox Path Cache. Type "help toolbox_path_cache" for more info.

To get started, select "MATLAB Help" from the Help menu.

>> cview
>>

```

**Figure 1. Matlab Command window**

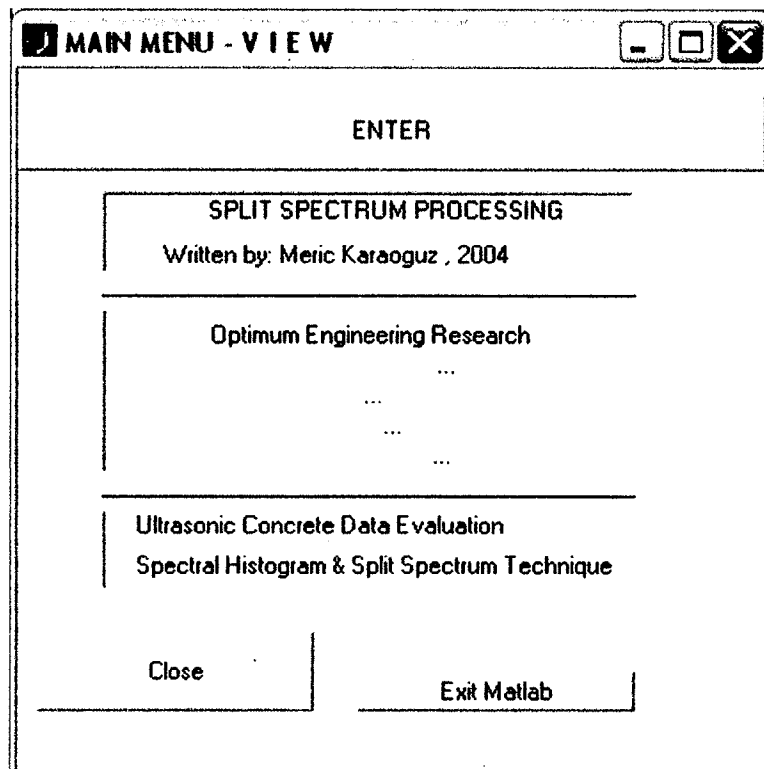


Figure 2. Initial Command Window.

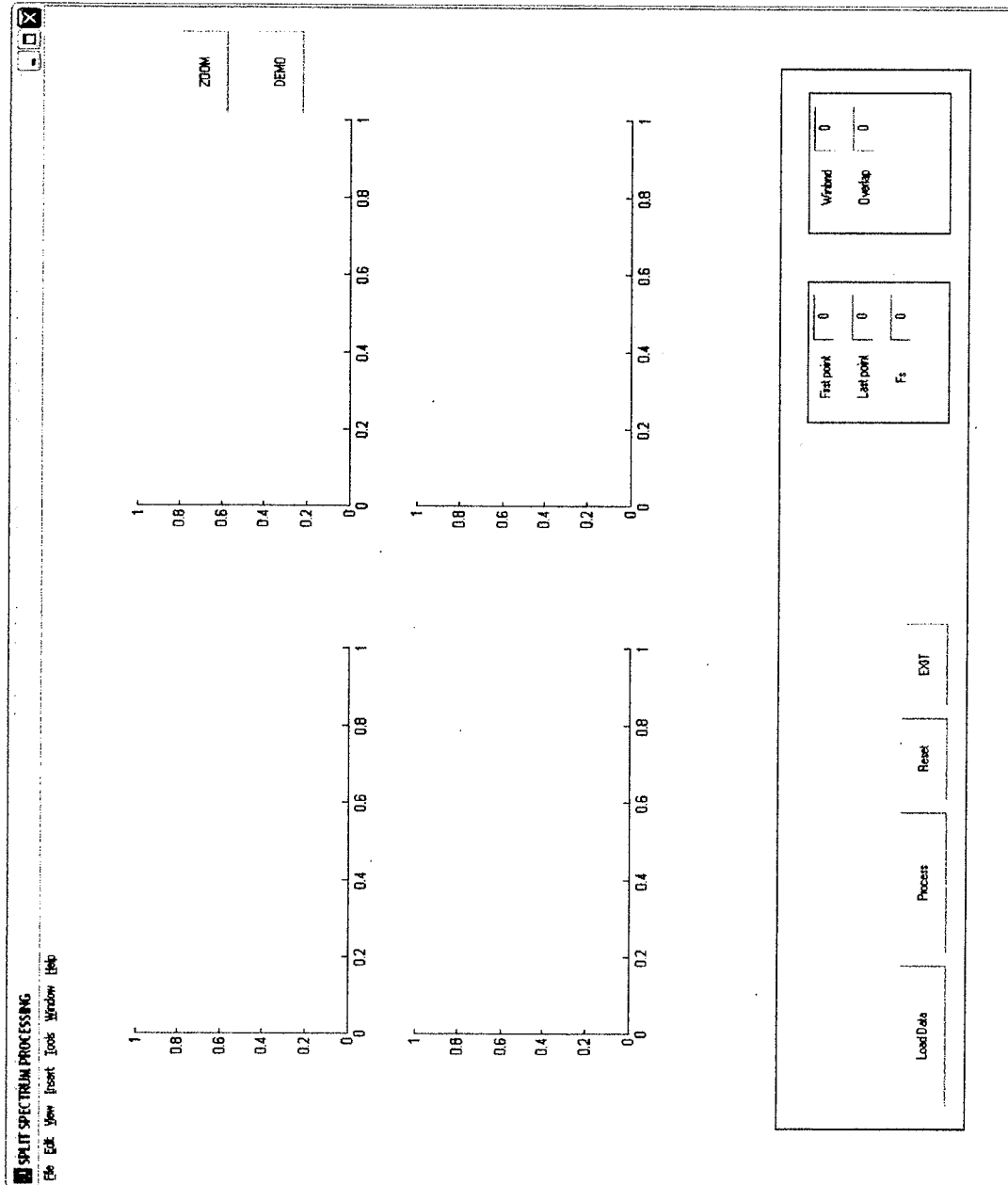


Figure 3. Graphical User Interface (GUI) Processing Window.

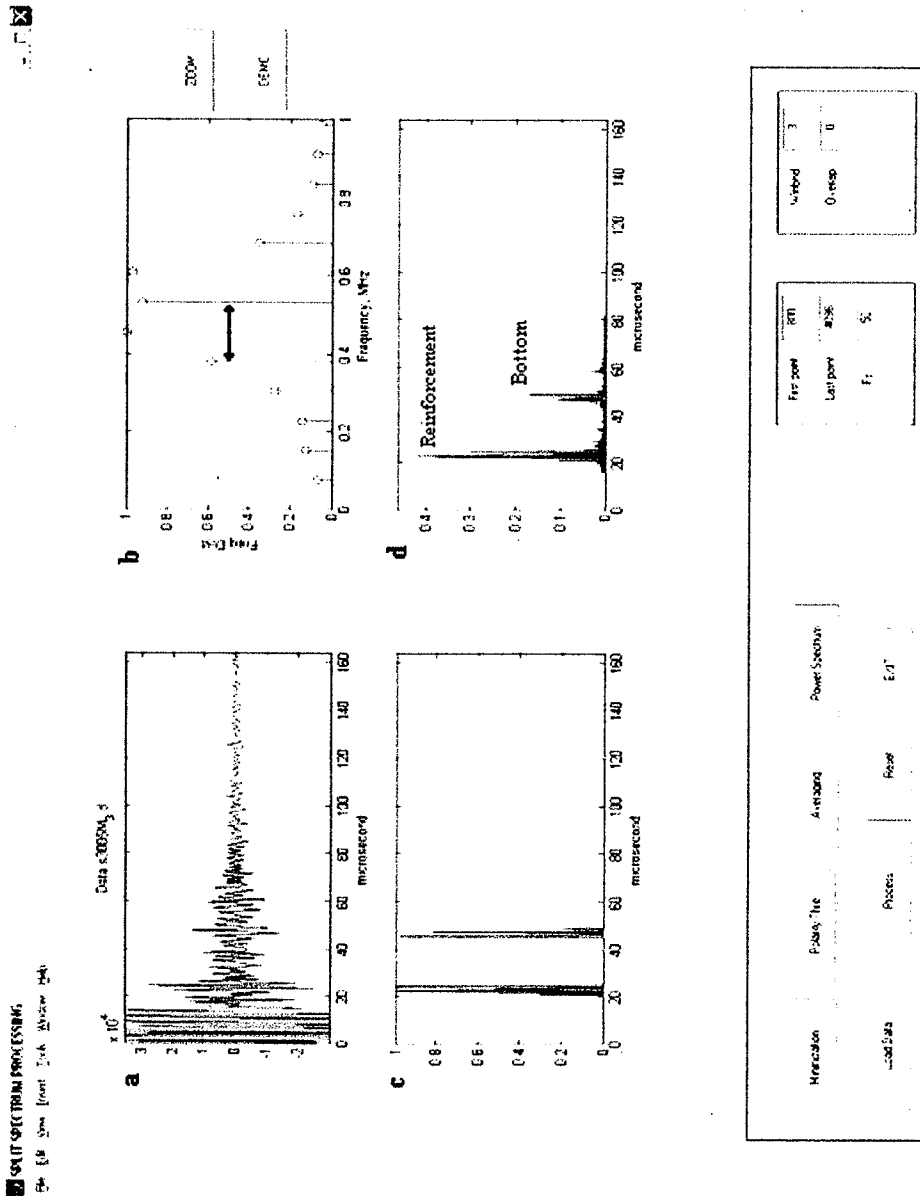


Figure 4. GUI-processed results of a test on a reinforced concrete slab with 0.5 MHz transducer. (a) signals of the longitudinal waves before SSP; (b) spectral histogram of (a); (c) the signals in (a) after SSP and polarity thresholding; (d) the signals in (a) after SSP and minimization.

**Table 1. Description for Entry Field Controls**

<b>Entry Field Controls</b>	
<b>First Point</b>	Indication of starting frequency for the dataset for processing
<b>Last Point</b>	Last frequency for processing
<b>F<sub>s</sub></b>	Sampling frequency of the data
<b>Winbnd</b>	Window bandwidth for SSP filtering
<b>OverLap</b>	The spacing between the adjacent filters for SSP

**Table 2. Descriptions for Push Button Controls**

<b>Push Button Controls</b>	
<b>Load Data</b>	Opens up a dialogue; user selects the data set to be processed
<b>Process</b>	Performs initial processing & produces Spectral Histogram results
<b>Reset</b>	Clears out the graph fields, and entry fields are set to zero
<b>Exit</b>	Closes the main window and opens up the view window
<b>Minimization</b>	Produces noise reduction with Minimization method
<b>Polarity Threshold</b>	Produces noise reduction with Polarity Thresholding method
<b>Averaging</b>	Produces noise reduction with Averaging algorithm
<b>Power Spectrum</b>	Displays the Power Spectrum of the ultrasound data
<b>Zoom</b>	Enables/Disables the zoom feature
<b>Demo</b>	Previously saved processing can be selected and displayed

## Processing Algorithms

The collected experimental data are time averaged, then processed first by the Spectral Histogram Technique to calculate two of the optimum or near optimum parameters for SSP. The software then calculates the frequencies corresponding to this selected region for final processing. The third parameter, the Gaussian filter bandwidth is selected usually as  $\frac{1}{4}$  of the

estimated range for the minimization algorithm, and  $1/7$  for the polarity thresholding. The spacing between the filters for both algorithms is the minimum available spacing which is determined by the number of data collected and the sampling frequency.

## Steps of Processing

This illustration of noise reduction uses the previously mentioned reinforced concrete slab. A portion of the related experimental data set, “*s3005M\_3.d*”, to be processed is shown in Figure 5. The parameters for other data sets will, of course, be different. The steps of the GUI are given below.

- i. Open Matlab.
- ii. Type “*cview*” in the Matlab command window as shown in Figure 1. This will run the VIEW window shown in Figure 2.
- iii. Click **ENTER**. This will open up the main Processing Window shown in Figure 3.
- iv. Enter the First Point field, e.g. “*800*”.
- v. Enter the Last Point field, e.g. “*4096*”.
- vi. Enter the Sampling Frequency, e.g. “*50*”.
- vii. Enter Winbnd, e.g. “*5*”.
- viii. Enter OverLap, e.g. “*1*”.
- ix. Click on **LOAD DATA**. This will bring up a dialog box presenting data sets for processing.

The data sets are usually saved in a text file with a “.d” extension. Select the data set to be processed, for instance *s3005M\_3.d*., then click on **OK**.

Command Window

&gt;&gt; xn

xn =

1.0e+003 \*

2.5627	3.1767	-1.5613	-5.2213	-3.5153	3.7207	-0.6113	0.1227	-5.0013	1.6587
2.3287	2.8247	-1.5613	-4.9893	-3.4563	3.5487	-0.3903	-0.0403	-4.9203	1.5517
2.0937	2.4737	-1.5623	-4.7563	-3.3973	3.3757	-0.1693	-0.2033	-4.8403	1.4437
1.8597	2.1217	-1.5623	-4.5243	-3.3393	3.2037	0.0517	-0.3663	-4.7593	1.3367
1.6247	1.7707	-1.5633	-4.2923	-3.2803	3.0317	0.2727	-0.5293	-4.6783	1.2297
1.3907	1.4187	-1.5633	-4.0593	-3.2213	2.8597	0.4937	-0.6923	-4.5983	1.1217
1.1557	1.0677	-1.5643	-3.8273	-3.1623	2.6867	0.7147	-0.8553	-4.5173	1.0147
0.9217	0.7157	-1.5643	-3.5953	-3.1043	2.5147	0.9357	-1.0183	-4.4363	0.9067
0.6867	0.3647	-1.5653	-3.3623	-3.0453	2.3427	1.1567	-1.1813	-4.3563	0.7997
0.4527	0.0127	-1.5653	-3.1303	-2.9863	2.1707	1.3777	-1.3443	-4.2753	0.6927
0.2187	-0.3383	-1.5663	-2.8983	-2.9273	1.9977	1.5977	-1.5073	-4.1943	0.5847
-0.0163	-0.6903	-1.5663	-2.6653	-2.8683	1.8257	1.8187	-1.6703	-4.1143	0.4777
-0.2503	-1.0413	-1.5673	-2.4333	-2.8103	1.6537	2.0397	-1.8333	-4.0333	0.3707
-0.4853	-1.3933	-1.5673	-2.2013	-2.7513	1.4817	2.2607	-1.9953	-3.9523	0.2627
-0.7193	-1.7443	-1.5683	-1.9683	-2.6923	1.3087	2.4817	-2.1583	-3.8713	0.1557
-0.9543	-2.0963	-1.5683	-1.7363	-2.6333	1.1367	2.7027	-2.3213	-3.7913	0.0477
-1.1883	-2.4473	-1.5693	-1.5043	-2.5743	0.9647	2.9237	-2.4843	-3.7103	-0.0593
-1.4233	-2.7993	-1.5693	-1.2713	-2.5163	0.7927	3.1447	-2.6473	-3.6293	-0.1663
-1.6573	-3.1503	-1.5703	-1.0393	-2.4573	0.6197	3.3657	-2.8103	-3.5493	-0.2743
-1.8913	-3.5023	-1.5703	-0.8063	-2.3983	0.4477	3.5867	-2.9733	-3.4683	-0.3813
-2.1273	-3.8553	-1.5713	-0.5733	-2.3393	0.2747	3.8087	-3.1373	-3.3873	-0.4893
-1.8623	-3.7403	-1.7533	-0.7203	-2.0363	0.2307	3.6247	-3.2303	-3.1353	-0.5613
-1.5973	-3.6263	-1.9363	-0.8673	-1.7333	0.1857	3.4397	-3.3233	-2.8833	-0.6323
-1.3323	-3.5113	-2.1183	-1.0143	-1.4303	0.1417	3.2557	-3.4173	-2.6303	-0.7043
-1.0663	-3.3963	-2.3013	-1.1613	-1.1273	0.0977	3.0717	-3.5103	-2.3783	-0.7763
-0.8013	-3.2823	-2.4833	-1.3083	-0.8243	0.0537	2.8877	-3.6033	-2.1263	-0.8473
-0.5363	-3.1673	-2.6663	-1.4553	-0.5213	0.0087	2.7027	-3.6963	-1.8743	-0.9193
-0.2713	-3.0523	-2.8483	-1.6023	-0.2193	-0.0353	2.5187	-3.7893	-1.6213	-0.9913
-0.0063	-2.9383	-3.0313	-1.7503	0.0837	-0.0793	2.3347	-3.8823	-1.3693	-1.0623
0.2587	-2.8233	-3.2133	-1.8973	0.3867	-0.1243	2.1507	-3.9763	-1.1173	-1.1343
0.5237	-2.7083	-3.3963	-2.0443	0.6897	-0.1683	1.9657	-4.0693	-0.8653	-1.2063
0.7887	-2.5943	-3.5783	-2.1913	0.9927	-0.2123	1.7817	-4.1623	-0.6123	-1.2783
1.0547	-2.4793	-3.7603	-2.3383	1.2957	-0.2563	1.5977	-4.2553	-0.3603	-1.3493
1.3197	-2.3643	-3.9433	-2.4853	1.5987	-0.3013	1.4137	-4.3483	-0.1083	-1.4213
1.5847	-2.2503	-4.1253	-2.6323	1.9017	-0.3453	1.2287	-4.4413	0.1437	-1.4933
1.8497	-2.1353	-4.3083	-2.7793	2.2047	-0.3893	1.0447	-4.5353	0.3967	-1.5643
2.1147	-2.0203	-4.4903	-2.9263	2.5077	-0.4343	0.8607	-4.6283	0.6487	-1.6363
2.3797	-1.9063	-4.6733	-3.0733	2.8107	-0.4783	0.6767	-4.7213	0.9007	-1.7083
2.6447	-1.7913	-4.8553	-3.2203	3.1137	-0.5223	0.4917	-4.8143	1.1527	-1.7793
2.9107	-1.6763	-5.0383	-3.3673	3.4167	-0.5663	0.3077	-4.9073	1.4057	-1.8513

&gt;&gt;

Figure 5. A portion of the data set s3005M\_3.d for Figure 4.



- x. Click on **PROCESS**. This will run the Spectral Histogram Algorithm which will display the data in time domain and the spectral histogram (Figs. 4a and 4b). Moreover, Minimization, Polarity Thresholding, Averaging and Power Spectrum control buttons will appear on the control panel (Table 2).
- xi. The user can chose one of the available reassembling algorithms, such as the polarity thresholding algorithm or the minimization algorithm or preferably both for processing by clicking on the corresponding button. The result is shown in Figures 4c and 4d. This is either the end of SSP or the user can go to step xii.
- xii. To repeat the processing with another data set, clear the graph windows as well as the control fields by clicking on the **RESET** button.
- xiii. The **ZOOM** control will let the user focus on particular locations on the graph windows.
- xiv. Demo button can be used in order to display the previously processed and saved data files.
- xv. **EXIT** will terminate the software.

Additional examples are shown in the next section.

## Examples for the Use of the Rationalized SSP

1. Reinforcement detection and thickness determination. This is the same case the steps of which are discussed above. The specimen was a concrete prism with a 90x103 mm<sup>2</sup> cross section in which a reinforcing bar 12.7 mm in diameter was embedded. The concrete cover was 46 mm. The test was performed in a pulse-echo setup with a transducer of 0.5 MHz central frequency. The pre-established pulse velocity was 4.1 km/s. The pre-SSP signals are shown in Figure 4a. As Figures 4c and 4d show, the rationalized SSP eliminated practically all the

coherent noise; thus, both the reinforcing bar and the bottom surface are identified at 22 and 49  $\mu\text{s}$ , respectively.

2. Void detection. The specimen was a mortar prism  $175 \times 97 \times 97 \text{ mm}^3$  which had a hole of 15 mm in diameter located at 130 mm depth, another one at 81 mm, and a third one at 35 mm. The transducer had a 1 MHz nominal central frequency. The pre-established pulse velocity was 3.5 km/s. The results are presented in Figure 6. The ultrasonic signals reflected from the two holes and the bottom, respectively, can be identified at 47, 74 and 98  $\mu\text{s}$ . The peaks around 60  $\mu\text{s}$  are likely from a large aggregate.

3. Interface and Thickness determinations. The specimen consisted of two layers. The top layer, 153 mm in thickness, was concrete, the bottom layer was mortar of 100 mm thick. The transducer had 0.25 MHz nominal center frequency. The pre-established pulse velocity in the concrete was 5.4 km/s and 3.6 km/s in the mortar. The results are shown in Figure 7. The interface is identified at 56  $\mu\text{s}$ , and the bottom at 112  $\mu\text{s}$ .

4. Thickness determination. The specimen was a mortar prism of  $203 \times 203 \times 95 \text{ mm}^3$  dimension. The transducer had a nominal central frequency of 1 MHz. The results are shown in Figure 8. The signal reflected from the bottom surface has a time of flight of 125  $\mu\text{s}$ . It is interesting though that the polarity thresholding graph shows a second reflection at 250  $\mu\text{s}$  which is the second reflection by the bottom. This is advantageous because it confirms the first reflection.

— -- —

The total processing time for the four data sets was approximately 120 s. The optimum parameters of SSP for the 1 MHz, 0.5 MHz and 0.25 MHz center frequency transducers are presented in Table 3.

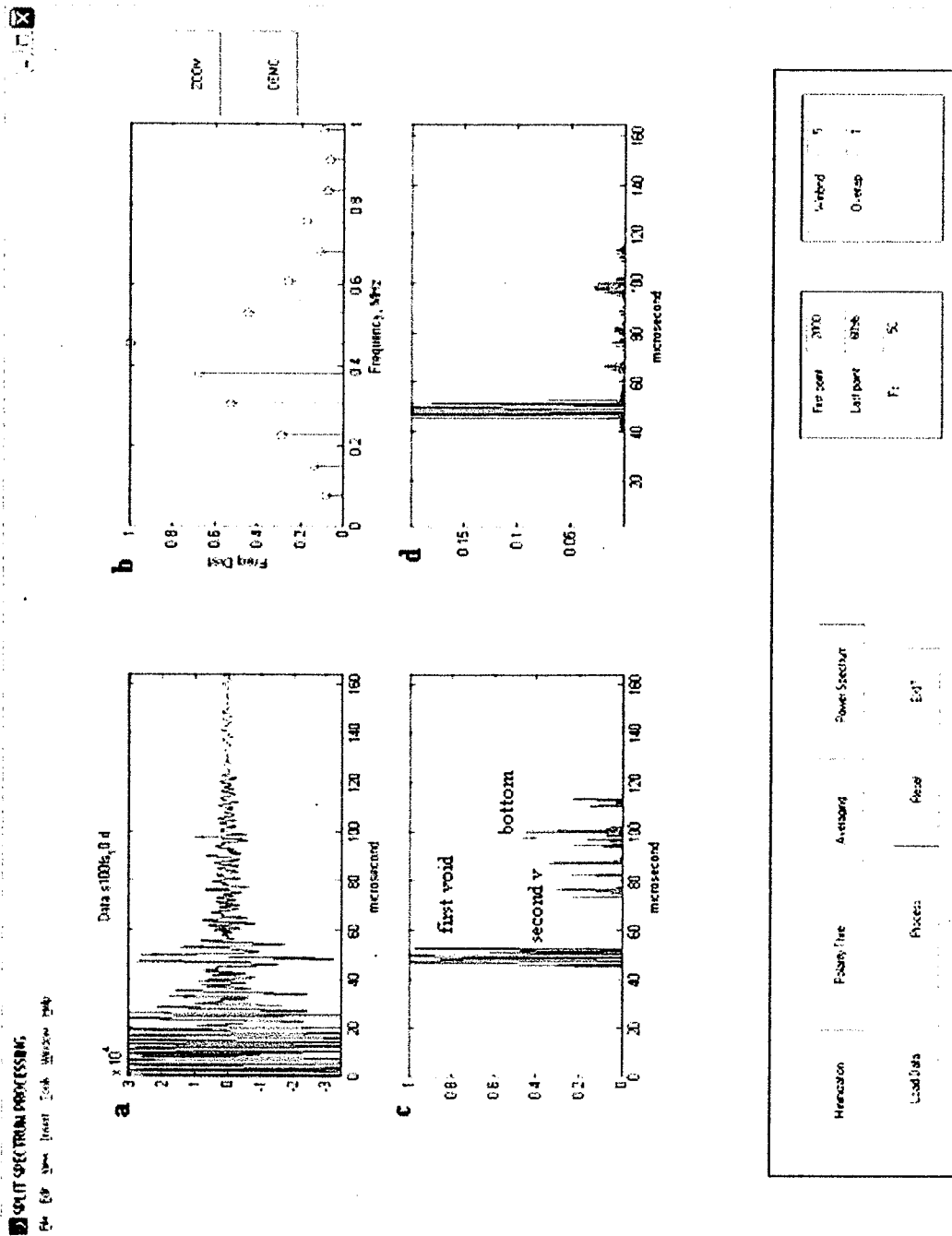


Figure 6. Detection of voids with 0.5 MHz transducer. (a) through (d) are the same as in Figure 4.



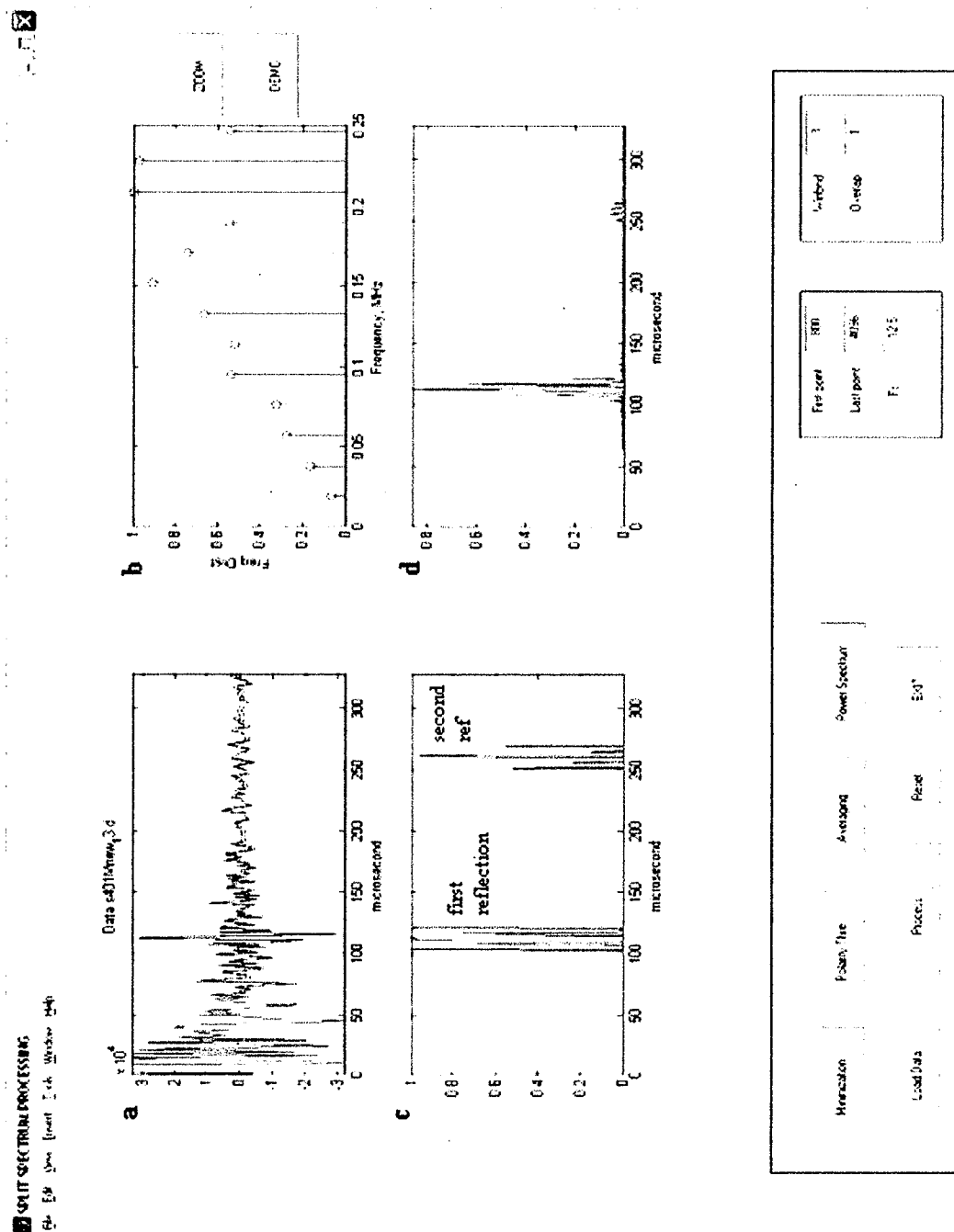


Figure 8. Double reflection from the bottom of a slab indicating the thickness with 1 MHz transducer.

(a) through (d) are the same as in Figure 4.

**Table 3. The Optimum Split Spectrum Parameters for 1MHz, 0.5MHz and 0.25MHz transducers**

<b>F<sub>c</sub></b>	<b>F<sub>1</sub></b>	<b>F<sub>N</sub></b>	<b>B<sub>M</sub></b>	<b>B<sub>PT</sub></b>	<b>Shift</b>
<b>1MHz</b>	<b>0.182 MHz</b>	<b>0.250 MHz</b>	<b>0.009 MHz</b>	<b>0.005 MHz</b>	<b>0.002 MHz</b>
<b>0.5MHz</b>	<b>0.36 MHz</b>	<b>0.53 MHz</b>	<b>0.037 MHz</b>	<b>0.022 MHz</b>	<b>0.007 MHz</b>
<b>0.25MHz</b>	<b>0.14 MHz</b>	<b>0.21 MHz</b>	<b>0.024 MHz</b>	<b>0.015 MHz</b>	<b>0.003 MHz</b>

**F<sub>c</sub>**: Transducer Center Frequency

**F<sub>1</sub>**: Starting Frequency for SSP Filtering

**F<sub>N</sub>**: Final Frequency for SSP Filtering

**B<sub>M</sub>**: Filter Bandwidth for Minimization Algorithm

**B<sub>PT</sub>**: Filter Bandwidth for Polarity Thresholding Algorithm

**Shift**: Filter Spacing

## Future Work

The extension of the reported research will focus on the production of two-dimensional ultrasonic images (B scan) of the internal structure of concrete. Whereas the one-dimensional graphs with SSP in this report show more clearly than before the existence and location of a target, (crack, hole, rebar, boundary, etc.), it cannot usually identify what the target is. In contradistinction, a B scan can identify not only whether it is a crack or boundary or rebar but also it can show the shape, size and orientation of the target. In other words, the high-frequency ultrasound image of a concrete specimen could give diagnostic information about the inside of a piece of concrete. This is particularly important in defect characterization, and identification of multiple reinforcement.

The next steps in the continuation of the work will be:

1. Development of a software for the production of two-dimensional ultrasonic images (B scan) of the internal structure of concrete.
2. Laboratory instrumentation for the B scan.
3. Preparation of concrete specimens for ultrasonic determination and/or identification of crack, hole, rebar, boundary, etc. with B scan.
4. Laboratory tests to establish the applicability and limits of validity of the method.
5. A complete software and a laboratory prototype will be the end product of the work.

## **Conclusions**

Although it has been established earlier that Split Spectrum Processing (SSP) can greatly reduce the background (coherent) noise in high-frequency ultrasound in concrete, it was overly complicated and time consuming. Thus, further research was needed to make the process practical for field application. This was achieved by the creation of the Graphical User Interface, a software that consists of the combination of SSP with a statistical method, the Spectral Histogram Technique. As the presented examples illustrate, this combination eliminated the cumbersome and lengthy trial-and-error portion of the traditional SSP. Thus, the noise reduction became so simple and fast that a trained technician can perform the defect detection, thickness determination, and reinforcement location. The improved process seems to be applicable for the future production of two-dimensional images for improved diagnosis of concrete in structures.

## References

[1] S. Popovics, N. M. Bilgutay, M. Karaoguz, and T. Akgul, "High-Frequency Ultrasound Technique for Testing Concrete," *ACI Materials Journal*, V. 97, No. 1, January - February 2000. pp. 58 – 65.

[2] Cambridge Ultrasonics, "High-Performance Transducers for Concrete," *Innovation News*, Issue 3, September 1997.



COMMITTEE CORRESPONDENCE

Reply to:  
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26 March 2004

MEMORANDUM FOR: Members of ACI 228

FROM: Bernard Hertlein, Secretary, ACI Committee 228  
Stephen Pessiki, Chairman, ACI Committee 228

SUBJECT: Minutes of ACI 228 Meeting and 228.2R Task Group list.

Attached please find the following two documents:

1. Minutes of the meeting held in Washington, D.C. on 14 March 2004;
2. List of Task Group members working on the Revision of 228.2R.

Please review the minutes for accuracy, and bring any urgent corrections to my attention. Non-urgent corrections can wait until the meeting.

If you wish to be added to a particular Section of the Task Group working in 228.2R, please let Aldo Delahaza know as soon as possible. Thanks all.

copy: TAC Contact  
Todd Watson, Deputy Manager Engineering, ACI

## MINUTES

ACI Committee 228, Nondestructive Testing of Concrete  
Washington Hilton and Towers, Washington, District of Columbia  
Sunday, March 14, 2004

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### 9. Informal Presentations and Open Discussion

#### 9.1 Presentations

Sandor Popovics of Drexel University introduced a current research project that was aimed at reducing the noise inherent in high-frequency ultrasound in concrete, with a view to investigating the feasibility of examining the interior structure of concrete with ultrasonic imaging techniques similar to those used for medical ultrasound imaging. Meric Karaoguz, a graduate student at Drexel then demonstrated the present state of the proposed measurement, noise reduction, and analysis techniques.

The committee was impressed with the potential demonstrated at the meeting, and agreed that the proposed imaging method, if successful, would be an important and valuable tool. The committee expressed its unanimous support for the continuation of this research.

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COMMONWEALTH OF PENNSYLVANIA  
DEPARTMENT OF TRANSPORTATIONwww.dot.state.pa.us  
April 20, 2004

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Inam Jawed, Ph.D., Program Officer  
National Cooperative Highway Research Program  
500 Fifth Street, N.W.  
Washington, DC 20001

**APPENDIX 2**

Dear Dr. Jawed:

The purpose of this letter is to inform you that on April 2, 2004 a subject matter expert team met with researchers based at Drexel University in Philadelphia for a demonstration and briefing on a very promising concrete diagnostic tool. Members of this team included George Alexandridis, Chief Engineer of the Delaware River Joint Toll Bridge Commission; Patrick McCollough, Senior Engineer with the Delaware River Port Authority; Harold Rogers, PennDOT's Senior Bridge Engineer; and Charles Davies, PennDOT's District 6-0 Bridge Engineer. The team members were unanimous in their opinion that the research that is being led by Dr. Sandor Popovics is worthy of support into subsequent phases.

The demonstration showed that the tool that has been developed has promising applications to detecting aggregate problems, voids and de-laminations using non-destructive means. The importance of having access to this type of diagnostic tool cannot be overstated. The two-dimensional images that the expert team viewed of concrete aggregate characteristics was very impressive and demonstrated that with further development a tool could be deployed that would support field-level decisions that currently are made without high quality information.

Please know that the development of the type of field-deployable tool that was demonstrated by the Drexel researchers has a top priority with PennDOT's concrete experts and is strongly supported. Based on the encouraging results of the preliminary development, the team members consider it very likely that the proposed additional work will be completed successfully.

In the case that live testing will be needed the Pennsylvania Department of Transportation will seriously consider the support of the continuation of the developmental stages of this project, followed by deployment in live field trials. To clarify, please let me reiterate the critical importance for PennDOT, as well as the Delaware River Joint Toll Bridge Commission and the Delaware River Port Authority, to have a tool available for the estimation of the strength potential and failures of concrete for the better, faster and more economical construction and maintenance of concrete structures.

Sincerely,

A handwritten signature in black ink, appearing to read "Bob Garrett".

Bob Garrett, Research Manager  
Bureau of Planning and Research

Cc: George Alexandridis  
Charles Davies  
Patrick McCullough  
Sandor Popovics  
Harold Rogers