CALIBRATION STUDIES OF THE HAYES COASTAL ENGINEERING LABORATORY

A Thesis

by

AIMEE REBECCA THURLOW

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2005

Major Subject: Ocean Engineering

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Approved by:

Chair of Committee,	Billy Edge
Committee Members,	Robert Randall
	Douglas Sherman
Head of Department,	David V. Rosowsky

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ABSTRACT

Calibration Studies of the Hayes

Coastal Engineering Laboratory. (December 2005)

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Chair of Advisory Committee: Dr. Billy Edge

The Hayes Coastal Engineering Laboratory is a new laboratory with two water basins: a 45.72-meters long, 3.66 meters wide and 3.06 meters deep Tow Tank with sediment pit for dredging and current flow studies, and a 36.58 meters long, 22.86 meters wide and 1.22 meters deep 3D Wave Basin for coastal wave studies. In order to assess the capabilities of the lab a series of tests were done in both tanks. Hydrodynamic tests in the Tow Tank using a Micro Acoustic Doppler Velociometer measured current flow in the tank and assessed the efficacy of different filters to stabilize flow patterns. A concrete dam structure installed near the reversed diffusers most effectively stabilized flow of all the configurations tested. Wave tests were conducted in the 3D Wave Basin with the newly-installed 48 paddle Rexroth wave generator at 0.5 and 1.0 meter water depths using wired and wireless capacitance wave gauges. These tests measured characteristics of the generated waves and reflection from the rubble-mound beach. In addition, initial testing of the Active Reflection Absorber (ARA) system was done. Correlating the wave data to the theoretical wave being produced showed that with water depth of 0.5 meters the 0.1 meter waves were well-formed, but the 0.2 meter waves

showed energy loss and lower correlation. The results from one meter water depth wave tests showed good formation of 0.2 meter waves. In nearly all wave tests with pool buoys installed the waves were better formed with good correlation and a better fitting power spectrum. The beach reflection was within the expected value range, being ten percent and below for most tests. ARA, while operational, needs to be further tuned to find the settings that will increase its effectiveness.

To my family and most importantly
to my husband Adam.

ACKNOWLEDGEMENTS

I would like thank my advisor and committee chair, Dr. Billy Edge, for the opportunities that he has given me. I have learned a lot and have gained valuable experience that I will carry with me for the rest of my life. Thanks also goes to him and his wife on more personal level for the hospitality they showed me during my time at Texas A&M. I am also grateful to my other committee members, Dr. Robert Randall and Dr. Douglas Sherman, for the help and guidance they have given me.

John Reed is the lab tech for Coastal Engineering and the Coastal Lab, and a good friend of mine now. Your help, guidance and companionship were some of the best things about being here. I will miss working with you.

Finally, I want to thank my husband for all of the love and support he has shown me in the last two years, for proofreading this, and for being another set of hands in the lab when he could, even if it was a dirty job.

TABLE OF CONTENTS

Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE | Page

CHAPTER I

INTRODUCTION

1.1 Background

Hayes Coastal Engineering Laboratory is a new facility that has both a tow tank and 3D wave basin. The facility was built in 2003 and these are the first tests and calibration (Figure 1).

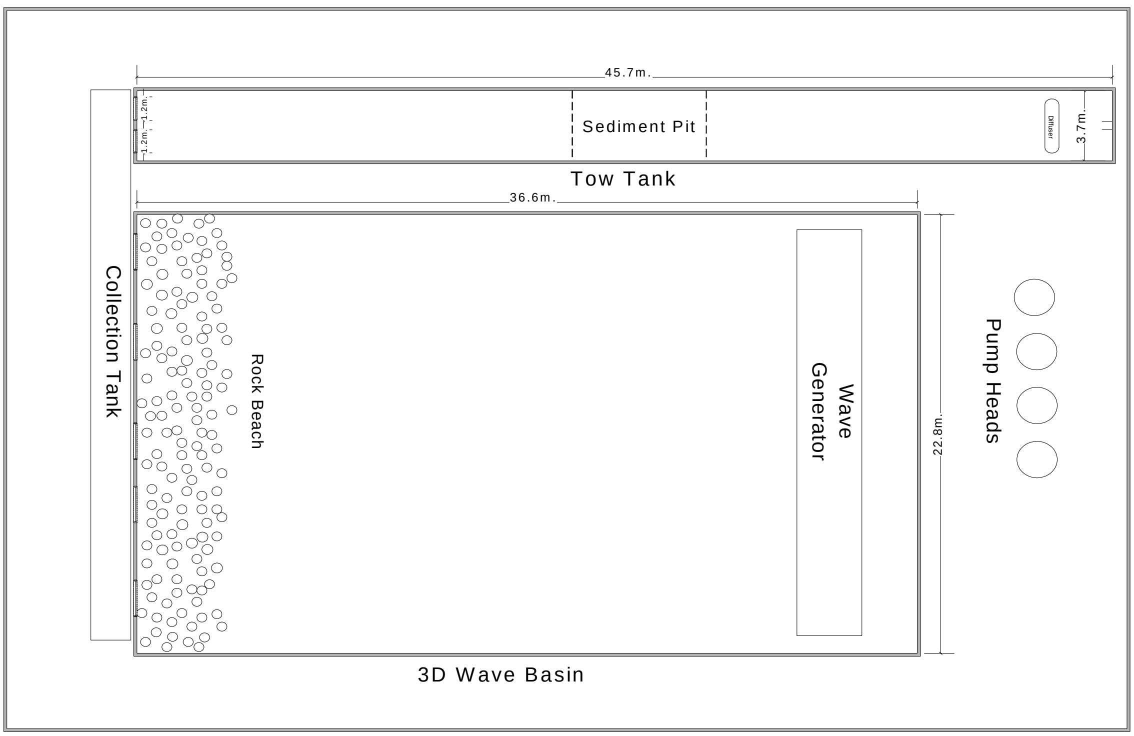

Figure 1. Overall schematic of coastal engineering laboratory

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This thesis follows the style of Coastal Engineering.

The tow tank is 45.72 meters long, 3.66 meters wide and 3.05 meters deep. Water is introduced into the tow tank via a 0.762 meter diffuser. Located 25.91 meters from the diffuser is a sediment pit that is 7.47 meters long, 3.66 meters wide and 1.52 meters deep. The pit has the capability to be covered or uncovered for experiments. At the far end of the tank are two weirs (slide gates), one is located at the floor, 1.22 meters high and 1.52 meters wide, and the second is 1.22 meters above the floor, 2.13 meters high and 1.52 meters wide (Figure 2).

Figure 2. Tow tank weirs

The 3D Wave Basin is 36.58 meters long, 22.86 meters wide and 1.22 meters deep (Figure 3). Water can be circulated into the tank from five different locations under the wave generator. Five weirs, 1.83 meters wide separated by 2.54 meters, are located at the discharge end of the tank. A permeable rock beach is in front of the weirs in a parabolic shape that acts as a wave absorber (Figure 4).

Figure 3. 3D wave basin and wave generator

Figure 4. Parabolic beach and bridge in 3D wave basin

Both the tow tank and 3D wave basin are directly connected to a collection tank. This collection tank is 29.16 meters long, 2.08 meters wide and has variable depth. The four pumps for the laboratory pump water from the collection tank to the tow tank or the wave basin.

Four submersible pumps are available to circulate water through 0.762 meter pipes below the floor into the tow tank and 3D wave basin. Valves may be opened or closed depending on the needed discharge configuration. Control of the facility is through a Siemens control system that allows for: pump operation, movement of weirs, control of valves, recirculation, filtering, etc. from one control computer. This provides an opportunity for teleoperation and teleobservation of the flow conditions.

1.2 Problem Statement

The future use of the laboratory depends upon calibration and documentation of the characteristics and capabilities of the facilities. This study will identify the pertinent and important characteristics that may be used by future researchers. Moreover, in the process of identifying the characteristics, limitations will be noted and corrected where possible. One notable instance is possible improvement in the turbulent nature of the discharge from the diffuser in the tow tank.

1.2.1 Tow Tank

The problems in the tow tank are as follows:

(1) Turbulence occurs through the entire length of the tank

(2) Velocity on one side of the tank is faster than the other

(3) Possible long period oscillation caused by seiching (resonance) in the collection tank.

The asymmetrical configuration of the weirs creates uneven flow in the tank near the weirs (Figure 5). The side of the tank with the lower weir experiences much faster flow than the side with the upper weir. This is a problem because steady state conditions are required in the tank.

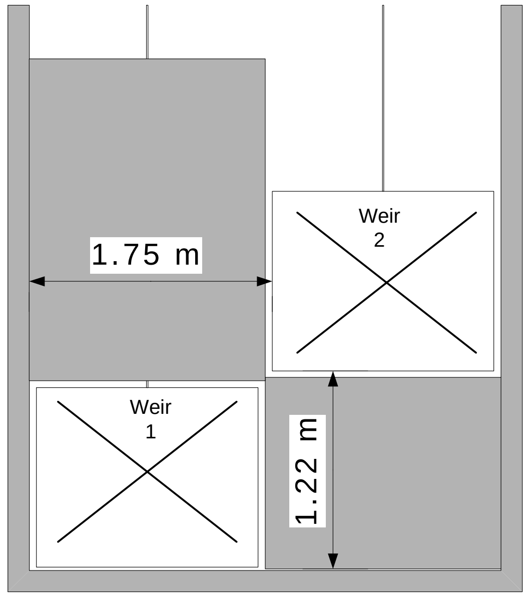

Figure 5. Tow tank weirs

Since the lower weir is in direct connection with the collection tank it has been postulated that oscillation in the collection tank could be contributing to the unsteady flow problem within the tow tank. Due to this variance of velocity and turbulence in the tow tank it is necessary to calculate the seiching in the collection tank, which is connected to the tow tank, to find the frequency of water movement within that tank. Seiching for variable water depths in an enclosed basin has been investigated by many researchers in the past (Wilson, 1972). With this frequency we may be able to identify where potential problems exist to help solve the flow problem.

Pumps

The laboratory utilizes four submersible mixed flow ABS pumps that operate variably up to 60 Hz to circulate water, see Figure 6. The pumps are gravity fed from the collection tank. Each pump has three semi-open impellers with an impeller size of

0.47 meters. Operating at the full 60 Hz the rated speed is 1180 rpm, with the flow rate controlled by varying the frequency driving the pumps. At maximum capacity the pumps can output approximately 9000 gallons per minute.

Figure 6. Four pump heads

The pump system is setup to run via a Siemens control system which allows the user to select which pump(s) to operate and the percentage of speed. The pumps will operate from 30-60Hz, which correlates to the 590-1180 rpm range. Since the Siemens program does not recognize the frequency of the pumps it provides output of flow in percentage of full scale. Therefore, the maximum percentage, 100%, is equivalent to 60 Hz on the pump.

An additional ABS pump is used in the laboratory for recirculation of the water through the sand filter or for draining water out of the system. This submersible wastewater pump is located 9.14 meters below the surface and pulls water through a four-inch pipe located at the bottom of the sump. Unlike the other four pumps, this pump is not variable and has a simple on/off setting.

The four pumps draw water from the sump which is 7.62 meters long and 1.52 meters in diameter. It is connected to the collection tank by a 1.22 meter diameter pipe, which is approximately 39.62 meters long.

1.2.2 Three Dimensional Wave Basin

Each wave basin equipped with a wave generator has its own unique characteristics. To become a fully operational basin one must calibrate the wave basin to better understand how different waves will react within the basin (Li and Williams, 2000). In addition, the responses of the wave generator need to be documented.

Rexroth Wave Generator

The wave generator in the Hayes Coastal Engineering Laboratory was built by Rexroth Hydraudyne B.V. Systems and Engineering, of Boxtel, Netherlands (a subsidiary of the Bosch Group) and installed early 2005. It is a segmented wave generator with 48 electrically-actuated paddles, see (Figure 7). The wave generator is operated by a program called GEDAP[1] from a control computer.

[1] GEDAP is a registered mark of the National Research Council of Canada.

Figure 7. Rexroth wave generator

CHAPTER II

TOW TANK

2.1 Background

2.1.1 Current

A majority of the dynamic forces found in the ocean are produced by atmospheric factors. These factors affect the flow of currents, which respond to the average atmospheric circulation. Also, long term seasonal changes in winds will affect major currents (Duxbury and Duxbury, 1997).

<u>Pure Drift Currents</u>

Waves generated in the ocean are caused by the friction of wind blowing over the ocean; this action also generates pure drift currents.

<u>Wind Gradient Currents</u>

The set-up and set-down of pure drift currents that generate horizontal pressure gradients which produce horizontal variations of ocean level that restructure the density field at all water depths.

<u>Pressure-Gradient Currents</u>

Large variations of atmospheric pressure at the sea surface can create these currents at any depth. Other currents in the ocean are much more significant than this current.

<u>Thermohaline Currents</u>

Changes in temperature and salinity cause a change in density in surface waters. These changes are caused by heat and moisture exchange within the air-sea interface. The unstable density gradient can create mixing which can result in current-like circulation.

<u>River Currents</u>

The Tow Tank is designed so that river flow can be simulated. In rivers, the movement of the water is caused by gravity driving water down a physical elevation gradient. Different river structures are dependent in part on the elevation gradient, with steeper gradients creating straighter rivers, and lower gradients producing meandering rivers (Press, & Siever, 1998). Different river schemes can be constructed in the Tow Tank with the pumps being the source of the water.

2.1.2 Seiching

Seiching is an oscillation within an enclosed basin caused by the reflection of currents and/or waves. This can be quite problematic in a port or harbor because the seiching within the port must be out of the range of natural frequencies of motion of the vessels inside. Consequently much research has been done on the matter (Raichlen, 1966, Wilson, 1972). In the laboratory environment undesirable seiching can occur and if so it must be countered. In the Tow Tank nothing is in place to counter the oscillation. To establish the existence of seiching in the tank an analysis and series of experiments were conducted.

For a basic rectangular basin with constant depth the wave equation is:

$$C^2\left(\frac{\partial^2\eta}{\partial x^2}+\frac{\partial^2\eta}{\partial y^2}\right)=\frac{\partial^2\eta}{\partial t^2} \tag{2.1}$$

and the solution for standing waves is:

$$\eta=\frac{H}{2}\cos(kx)\cos(\sigma t) \tag{2.2}$$

where both k and σ are unknown. Due to the fact that at the ends of the basin the horizontal velocities must be zero this leads to the condition that the antinodes are located at the walls, x=0,l. Thereby, sin kx = 0 for the given condition. Which leads to $kl = n\pi$, where n is the number of oscillations in the basin. Substituting for k:

$$L=\frac{2l}{n} \tag{2.3}$$

Applying the dispersion relationship for shallow water waves to the above equation yields the period of seiching:

$$T=\frac{2l}{n\sqrt{gh}} \tag{2.4}$$

where g is the acceleration due to gravity, h is the water depth and n is the mode. The mode represents each possible type of oscillation, and can be determined by the cause of the oscillation. Higher modes are not as common as lower modes since energy dissipates more rapidly with the higher modes (Dean and Dalrymple, 1991).

For example this would indicate that a fundamental period of oscillation in the tow tank for a 1.22 meter water depth is 26.43 seconds. This method is adequate for rectangular shaped basins with constant depth, but a different method must be employed to calculate the oscillations of complex shaped basins (Raichlen, 1966, Wilson, 1972).

2.2 Methods and Materials

2.2.1 Experimental Setup

<u>The Acoustic Doppler Velociometer (ADV)</u>

In order to obtain velocity data in the tow tank an Acoustic Doppler Velociometer (ADV) system was used, shown in (Figure 8). The specific ADV's used were 16-MHz MicroADV manufactured by SonTek (2001) in San Diego, CA (http://www.sontek.com). The two three-dimensional ADVs were tested side by side to verify the agreement of the readings.

Figure 8. 16-MHz MicroADV

The ADV is used for its high spatial resolution and ability to measure low flow conditions with high accuracy. Not requiring calibration, the ADV can measure water velocities three dimensionally with a range of 1 mm/s to 2.5 m/s and with a sampling rate up to 25 Hz. ADV's consist of three basic elements: the probe, signal conditioning module and the processor.

The probe is side looking which helps lessen the affects of flow interference. The coordinate system is defined by Sontek as follows: Z-axis is along the axis of the acoustic transmitter from the sampling volume towards the ADV sensor; X-axis is vertically down along the axis of the mounting stem; Y-axis gives the right hand coordinate system. The experimental set up had Y-axis oriented along the longitudinal axis of the Tow Tank.

The acoustic sensor has three acoustic receivers and one acoustic transmitter which are attached to a 25 cm rigid stem. The sampling volume of 0.09 cubic centimeters is located five centimeters from the probe head.

The signal conditioning module contains internal receiver electronics which are encased in a black cylindrical Delrin housing to which the probe is permanently attached. An underwater high frequency cable attaches to the module via a 16-pin connector which carries an analog signal to the processing module. This module contains digital processing electronics which convert the analog signal to a digital signal which is then transferred to a computer for analysis. The ADV can be programmed in two different manners depending on which type of processor is used. For this project one ADV operates with the splash proof processing module and uses HorizonADV software as the interface. HorizonADV allows the user to set up the desired data collection settings and view the data in real time. The second ADV uses an integrated circuit mounted on a PC card for processing and interfaces with a DOS based program. The two ADV's were synchronized for data collection purposes via a serial cable connecting the two computers together.

Post-processing of real-time data files (*.*adv* files) taken by the ADV was possible through WinADV, developed for use by the Bureau of Reclamation's Water Resources Research Laboratory and made available to the public for use (Wahl, 2000). This software package allows the user to easily view data, flag any areas of special interest and apply filters to identify and eliminate any anomalies such as low signal to noise ratio or over ranging. A very useful feature of this software is that it allows batch processing of the ADV for easy import into Excel and MATLAB.

<u>Seiching in the Collection Tank</u>

Since the collection tank is not of uniform depth, the basic seiching equation (Equation 2.4) can not be used (Dean and Dalrymple, 1991). To obtain the solution for seiching in the collection tank we must expand the solution for a standing wave and horizontal velocity in a rectangular basin to incorporate the varying water depths in the collection tank:

$$\eta = \frac{H}{2}\cos(kx)\cos(\sigma t) \tag{2.5}$$

$$u = \frac{H}{2}\frac{g}{C}\sin(kx)\cos(\sigma t) \tag{2.6}$$

As seen from Figure 9 there are three different depths in the collection tank, x1, x2 and x3, which must be included in the equation. Substituting the values for x leads to the free surface displacement and horizontal velocity in each basin:

$$\eta_1 = \frac{H_1}{2}\cos(k_1(x - x_1))\cos(\sigma t) \tag{2.7}$$

$$\eta_2 = \frac{H_2}{2}\cos(k_2(x + x_2))\cos(\sigma t) \tag{2.8}$$

$$\eta_3 = \frac{H_3}{2}\cos(k_3(x - x_2 + x_3))\cos(\sigma t) \tag{2.9}$$

$$u_1 = \frac{H_1}{2}\frac{g}{C_1}\sin(k_1(x + x_1))\sin(\sigma t) \tag{2.10}$$

$$u_2 = \frac{H_2}{2}\frac{g}{C_2}\sin(k_2(x - x_2))\sin(\sigma t) \tag{2.11}$$

$$u_3 = \frac{H_3}{2}\frac{g}{C_3}\sin(k_3(x - x_3))\sin(\sigma t) \tag{2.12}$$

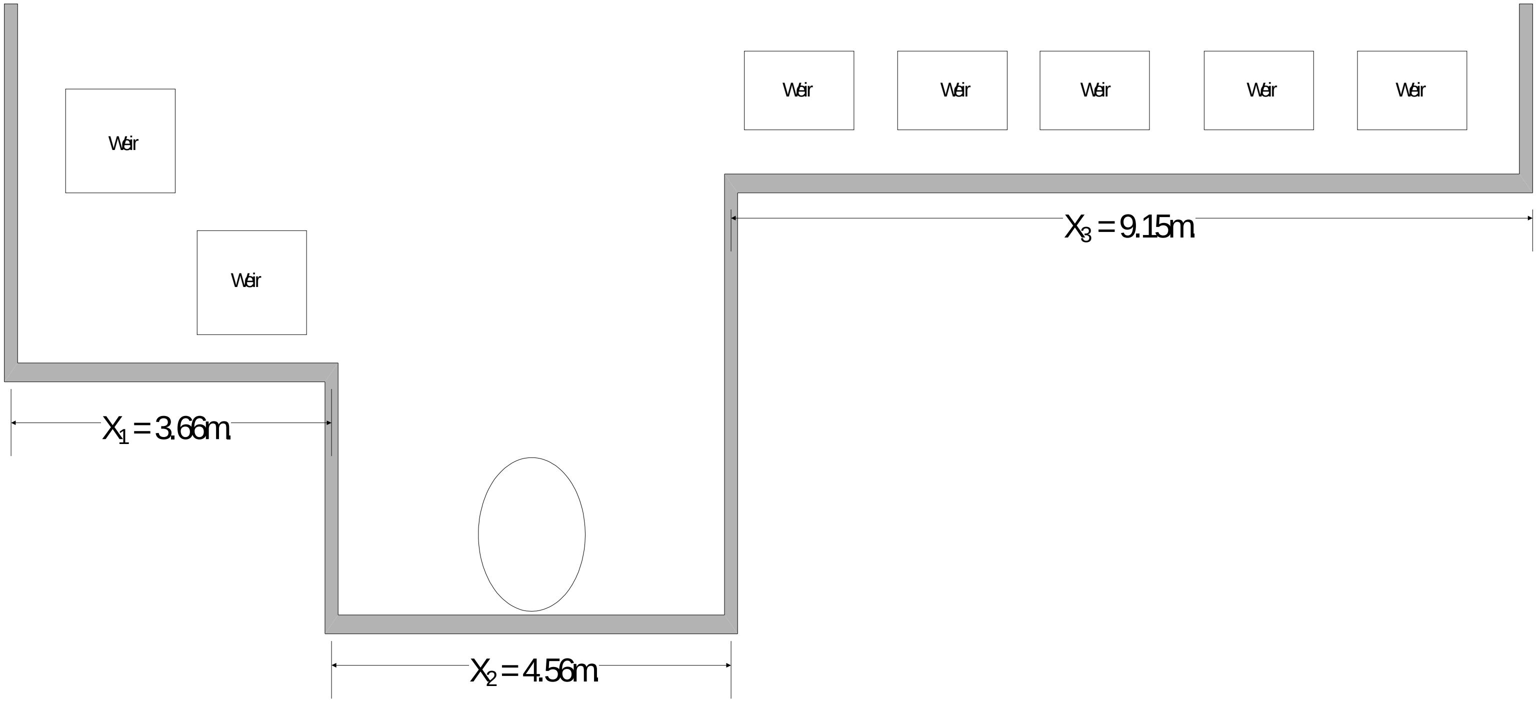

Figure 9. Schematic of collection tank

Since it's known for x = 0 that the free surface elevations and volume flux of water must be equal: $u_1h_1 = u_2h_2 = u_3h_3$. We may find the ratio of wave amplitude and dispersion relation for the seiching frequency in each region, respectively:

$$a_2 = \frac{a_1 \cos(k_1 x_1)}{\cos(k_2 x_2)} \tag{2.13}$$

$$a_3 = \frac{a_1 \cos(k_1 x_1)}{\cos(k_3(-x_2 + x_3))} \tag{2.14}$$

Where $a_n = H_n / 2$.

$$h_1 \frac{ga_1}{C_1} \sin(k_1 x_1) \sin(\sigma t) = h_2 \frac{ga_2}{C_2} \sin(-k_2 x_2) \sin(\sigma t) \tag{2.15}$$

$$h_2 \frac{ga_2}{C_2} \sin(-k_2 x_2) \sin(\sigma t) = h_3 \frac{ga_3}{C_3} \sin(k_3 (x_2 - x_3)) \sin(\sigma t) \tag{2.16}$$

Substituting the amplitude into equation (2.15 and 2.16) leads to the following:

$$C_2 h_1 \tan(\frac{\sigma x_1}{C_1}) + C_1 h_2 \tan(\frac{\sigma x_2}{C_2}) = 0 \tag{2.17}$$

$$C_3 h_2 \tan(\frac{\sigma x_2}{C_2}) + C_2 h_3 \tan(\frac{\sigma (x_3 - x_2)}{C_3}) = 0 \tag{2.18}$$

Therefore,

$$\frac{h_1}{C_1} \tan(\frac{\sigma x_1}{C_1}) + \frac{h_2}{C_2} \tan(\frac{\sigma x_2}{C_2}) + \frac{h_3}{C_3} \tan(\frac{\sigma (x_3 - x_2)}{C_3}) = 0 \tag{2.19}$$

The calculated value for seiching in the collection tank with 1.22 meters of water in the tow tank is 3.85 seconds. Deeper water depths in the tow tank will correspond to shorter period oscillations in the collection tank.

2.2.2 Experimental Procedure

The experiment was designed to test the following aspects of different types of flow filters:

- Ability to create uniform currents across the tank and along its length
- Control of oscillation from seiching
- Understanding of velocity profile in the tank
- Estimation of turbulence at different flow rates

To investigate the effect of filters in the tank three types of filters were utilized: horsehair, expanded metal and concrete blocks were investigated as filter media in varying locations. Four phases were completed, which will be discussed in depth later in the paper.

To install the horsehair and expanded metal in the tank two wooden frames were built that stretched the width of the tank. The horsehair and metal were then attached to the wooden frame. One filter was placed upstream in the tank downstream of the diffusers. The filter was attached to the floor via the metal padeyes on the tank floor with wire cable. The second filter was placed four feet in front of the weirs and was attached in a similar manner.

Concrete blocks taken from the 3D wave basin were originally 4.57 meters long and 0.61 meters wide were cut to fit across the tow tank. These blocks were then placed 3.05 meters from the diffuser. To allow continuous water flow at various water depths each block is separated with four 4X4's placed linearly (Figure 10).

Figure 10. Concrete blocks in front of diffusers

An h-shaped metal frame (Figure 11) was built to handle the supports for the two ADV's. The frame connects to the overhead crane which allows movement in the East and West directions. The black dots represent the connection points. Each ADV was attached to opposite sides of the h-shaped frame and were spaced 3.35 meters apart for the duration of the experiment. The *N, S, E* & W coordinate are the absolute Cardinal coordinate system of the Hayes Coastal Engineering Laboratory and the *X, Y & Z* represent the local coordinates of the sensor itself. The axis of sensor one is aligned in the South direction and the axis of sensor two is oriented in the North direction. Finally, the data was taken after steady flow conditions were met, after about three minutes of running the pumps. In the earlier tests data were taken at 10 Hz and in subsequent tests the sampling rate was increased to 25 Hz in order to increase the quality of the data collected.

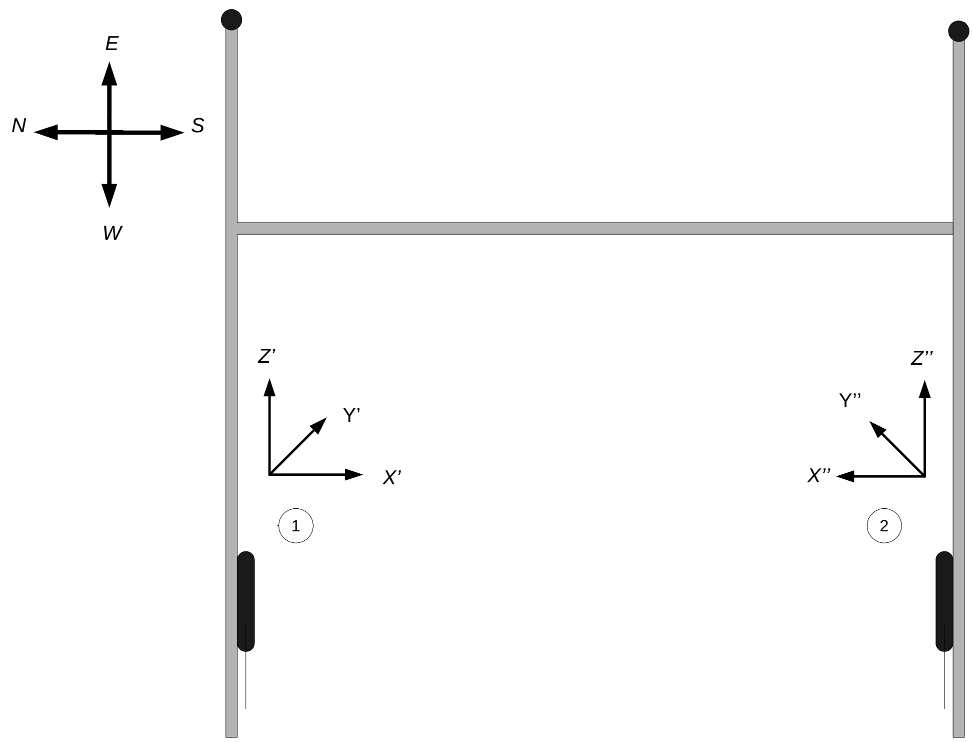

Figure 11. Metal H-frame

The water level for the tests was 1.22 meters and both weirs were fully opened so that water could freely flow into the collection tank. One pump was run at 100% for three minutes before data collection began. Figure 12 shows the ADV locations in the tow tank for testing.

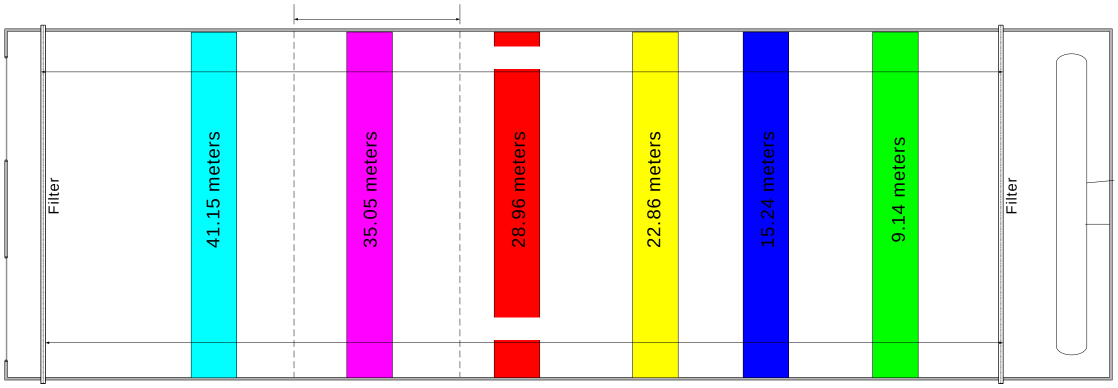

Figure 12. ADV locations in the tow tank

For Phase I, no filters were in the tank and one ADV sensor was located at the 21.34 meters location to establish a base line for future comparisons.

The Phase II tests studied different horsehair and expanded metal configurations attached to the upstream and downstream wooden frames. Both ADV sensors were applied at four different locations within the tow tank.

Next, Phase III tests examined the possibilities to equalize the flow on both sides of the tank. Previously the flow tended to be largest along the northern wall. Initially, one side of the diffuser was re-orientated to face the back wall and later the other side was readjusted in the same manner. The wooden frames had been removed from the tank for these tests. Both ADV sensors took samples in six separate locales.

Finally Phase IV entailed testing the concrete blocks placed just downstream of the re-orientated diffuser. Again both ADV sensors were utilized in the same locations as in Phase III.

Tables 1, 2, 3 and 4 summarize the tests that were performed for each phase.

Table 1: Test plan for Phase I

TEST #	TEST CHARACTERISTICS	SAMPLING RATE (HZ)	SENSOR DEPTH (M)	ARRAY LOCATION (M)
1	No Filters	3	1.07	21.34

Table 2: Test plan for Phase II

TEST #	TEST CHARACTERISTICS	SAMPLING RATE (HZ)	SENSOR DEPTH (M)	ARRAY LOCATION (M)
2	Down stream filter: Expanded metal on both sides of frame. One layer horsehair on lower weir side Upstream filter: Horsehair	10	1.07	16.76 21.34 30.48 42.67
3	Downstream filter: Additional layer of horsehair on lower weir side Upstream filter: Horsehair	10	1.07	16.76 21.34 30.48 42.67
4	Downstream filter: same as Test 3 Upstream filter: Layer of horsehair applied to upstream filter	10	1.07	16.76 21.34 30.48 42.67

Table 3: Test plan for Phase III

TEST #	TEST CHARACTERISTICS	SAMPLING RATE (HZ)	SENSOR DEPTH (M)	ARRAY LOCATION (M)
5	North side of diffuser re-orientated towards the Western Wall	25	0.69	9.14 15.24 22.86 28.96 30.05 41.15
6	Both sides of diffuser re-orientated towards the Western Wall.	25	0.69	9.14 15.24 22.86 28.96 30.05 41.15

Table 4: Test plan for Phase IV

TEST #	TEST CHARACTERISTICS	SAMPLING RATE (HZ)	SENSOR DEPTH (M)	ARRAY LOCATION (M)
7	Four concrete blocks placed downstream of re-orientated diffuser.	25	0.69	9.14 15.24 22.86 28.96 30.05 41.15

2.3 Data Processing

2.3.1 Moving Average Filter

Noise often occurs in current measurement and reduces the accuracy of the measurement. To compensate for the noise, analysis of turbulent flow can be completed by applying a moving average filter to the original data (Yin, Lloyd & Falconer, 2000). The moving average filter, or smoothing filter, is optimal for reducing white noise while maintaining sharp responses (Smith, 1999).

Turbulent fluctuations are considered a random process and may therefore be described with a Gaussian probability distribution, Figure 13. The measured data's Gaussian probability distribution, Figure 14, shows that the noise is far from the local mean velocity and that the velocity is symmetric around the mean velocity. Therefore, the local mean velocities can be calculated from the experimental data.

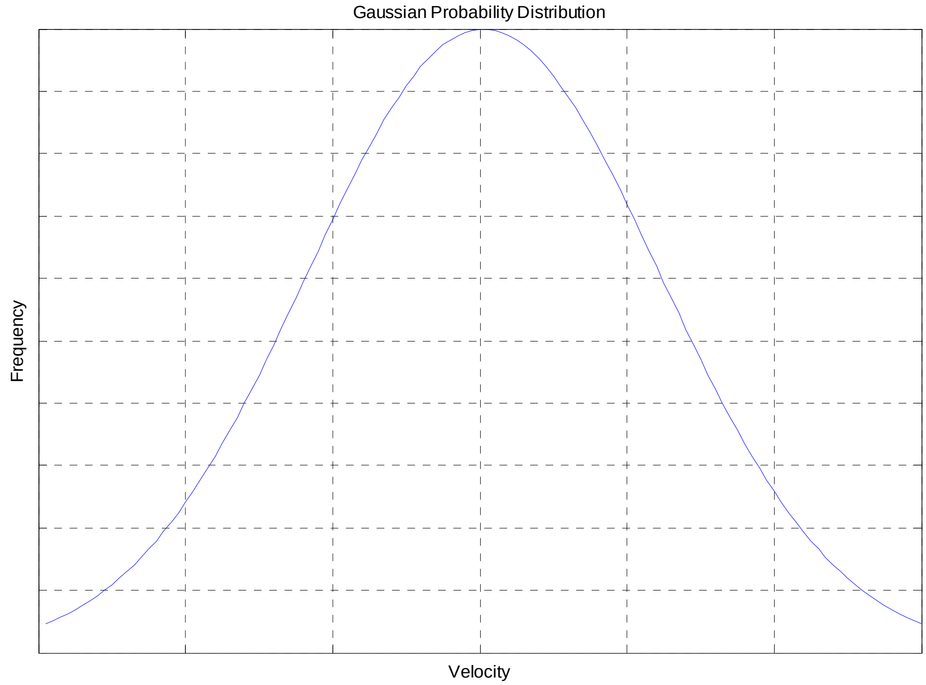

Figure 13. Gaussian probability distribution

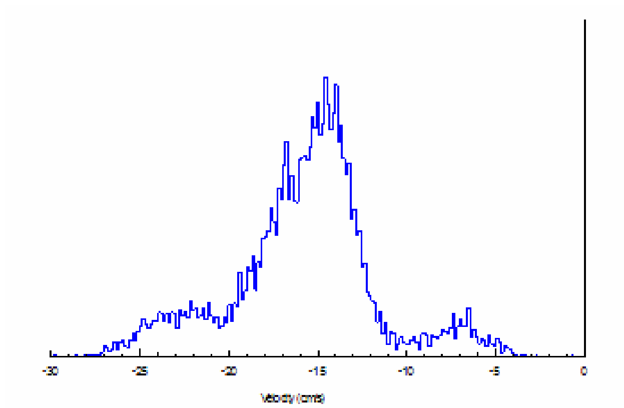

Figure 14. Example of Gaussian probability function of raw ADV data

The moving average filter can now be successfully applied to the experimental data to smooth out local fluctuations and yield a more readable plot (Smith, 1999). This filter works by averaging a predetermined number of points from the input signal which is then used to produce each point in the output signal. The moving average equation is:

$$y(i) = \frac{1}{N}\sum_{j=0}^{N-1} x(i+j) \qquad (2.20)$$

where N is the number of points in the average, $y(i)$ is the output signal and $x(i)$ is the input signal.

In (Figure 15), the top plot shows the time series of raw data taken with the SonTek ADV. The bottom plot is the same time series but with the application of the moving average filter. Notice the noise was removed while maintaining the overall structure of the data set.

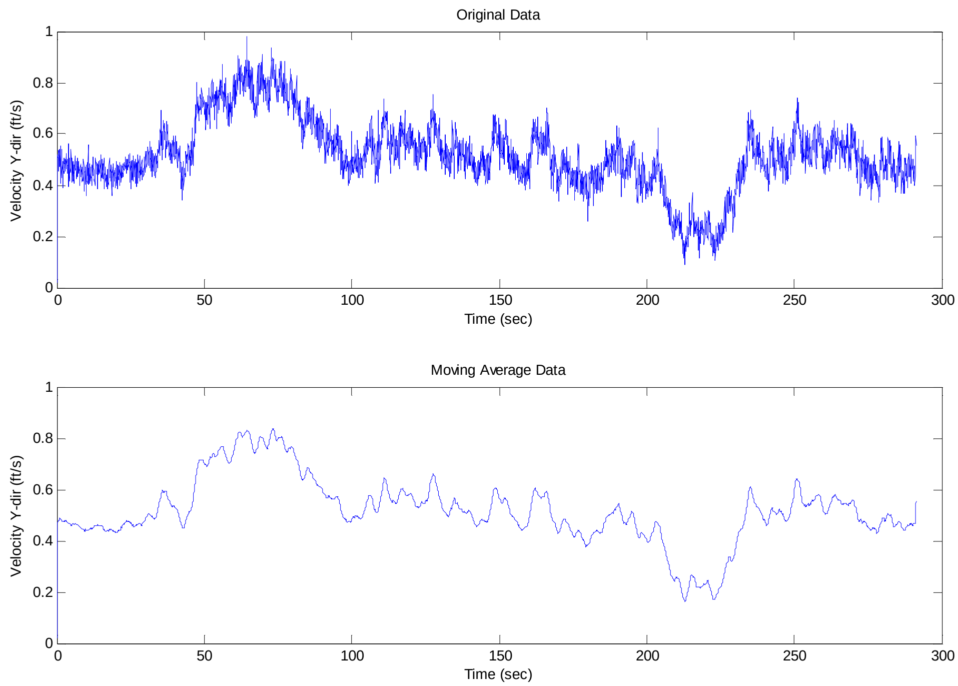

Figure 15. Velocity plots of original data and moving average data

2.3.2 Spectral Analysis

Fourier analysis is commonly used to define the energy spectrum based on a time series *f* (*t*) by decomposing the signal into many sinusoids. This energy spectrum describes how much signal, or amplitude, is present per unit bandwidth (Smith, 1999). The time series is defined as:

$$f(t) = \sum_{n=0}^{\infty} (a_n \cos(n\sigma t) + b_n \sin(n\sigma t)) \tag{2.21}$$

where a_n and b_n are the real and imaginary parts of the frequency spectrum. The coefficients can be obtained by using the orthogonal properties of *sin* and *cos* functions:

$$\int_t^{t+T} \sin(n\sigma t)\cos(m\sigma t)dt = 0 \tag{2.22}$$

$$\int_{t}^{t+T} \cos(n\sigma t)\cos(m\sigma t)dt = \begin{cases} T & m = n = 0 \\ \frac{T}{2} & m = n \neq 0 \\ 0 & m \neq 0 \end{cases} \tag{2.23}$$

$$\int_{t}^{t+T} \sin(n\sigma t)\sin(m\sigma t)dt = \begin{cases} \frac{T}{2} & m = n \neq 0 \\ 0 & m \neq 0 \end{cases} \tag{2.24}$$

The Fourier coefficients may then be defined as:

$$a_o = \frac{1}{T}\int_{t}^{t+T} f(t)dt \tag{2.25}$$

$$a_n = \frac{2}{T}\int_{t}^{t+T} f(t)\cos(n\sigma t)dt \tag{2.26}$$

$$b_o = 0 \tag{2.27}$$

$$b_n = \frac{2}{T}\int_{t}^{t+T} f(t)\sin(n\sigma t)dt \tag{2.28}$$

where a_o is the average of the signal over a period T and b_o will always be zero a sine wave of zero frequency has a constant value of zero. The mean square value of the function is related to the coefficients by using Parseval's theorem (Smith, 1999):

$$\frac{1}{T}\int_{t}^{t+T} f^2(t)dt = a_0^{\ 2} + \frac{1}{2}\sum_{n=1}^{N}(a_n^{\ 2} + b_n^{\ 2}) \tag{2.29}$$

Since we have a sampling period of T with N_s samples per second, we can define N as the number of points used in the FFT. The Fourier series can then be represented, using the complex series, in the following form

$$f(t) = \sum_{n=-N}^{N} F(n) e^{in\sigma t} \tag{2.30}$$

where
$$\begin{cases} F(n) = |F(n)| e^{i\varepsilon_n} \\ |F(n)| = \dfrac{1}{2}\sqrt{a_n{}^2 + b_n{}^2} = |F^*(-n)| \\ \varepsilon_n = \tan^{-1}\left(\dfrac{b_n}{a_n}\right) \end{cases}$$

Applying the FFT to the original noisy ADV data results in a power spectrum that is hard to read and yields very little useful information. To solve this problem the input signal may be broken up into many 512 point segments and run through a 512 point FFT. This results in many frequency spectra which are then averaged to produce a 256 point frequency spectrum (Smith, 1999). Figure 16 shows an example of averaging the frequency spectra to remove noise. Notice the marked improvement in (b); the noise was reduced enough that any remarkable feature may now be identified.

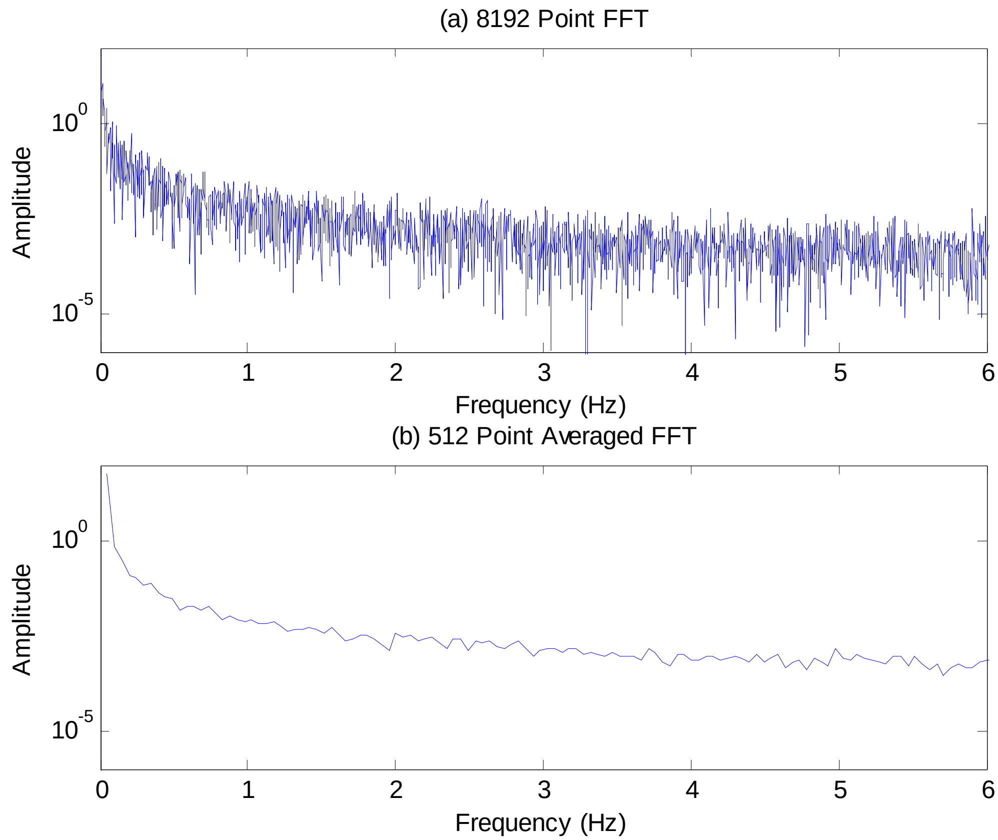

Figure 16. Power spectrum

2.4 Results

Velocity data for the tow tank tests was processed and plotted as velocity profiles over time and power spectra were generated. Utilizing these plots allowed the characteristics of the flow in the tank to be examined. Velocity profiles show how the flow differs from one side of the tank to the other at the same distance from the diffuser, and also how velocities vary between locations along the tank. The power spectrum for a test can be used to detect if there is a regular oscillation occurring in the tank. All of the velocity profiles and power spectra plots are located in Appendix A and Appendix B, respectively.

2.4.1 Velocity Profiles

Figure 17 shows the data for each test from Station 1, at the 21.34 meter location (Tests 1-4) and 22.86 meters (Tests 5-7), overlaid. These seven plots were overlaid because they were the closest locations for comparison between all seven tests. This figure shows that the velocity is fairly stable at Station 1 and within a close range, approximately 0.1 m/s. Test 4, while having a similar average to the other tests and low standard deviation, 0.0606, showed more variation within the range of speeds than tests 1-3 and 7. Compared to the other tests, Test 5 and 6 both have double the standard deviation than the other tests, being 0.1494 and 0.1293 respectively. Test 5 shows the flow increasing throughout most of the test. While Test 6 has a much higher flow rate through the middle part of the tests, it is comparable at the beginning and end to the other tests.

Station 3 showed similar results to Station 1. There was more variation between tests evident at Station 3, as can be seen in Figure 18. The average velocity of all tests except Test 3 and 5 are within approximately 0.03 m/s.

Some things become evident viewing these two figures, such as the large variation in velocity between the two stations in Test 5, see Table 5. The increase in Station 1 for Test 5 seems to correspond to the decrease in Station 3. Evidently the water from the South side of the tank, with the diffuser in the original position, flowed to the North side of the tank. This may explain the low and negative flow rates observed at Station 3. In addition, Test 6 showed alternating velocities between sides of the tank.

Table 5: Average velocities for Stations 1 and 3 at 21.34 and 22.86 meters

	STATION 1 (m/s)	STATION 3 (m/s)
Test 1	0.180	0.151
Test 2	0.143	0.178
Test 3	0.286	0.179
Test 4	0.162	0.176
Test 5	0.233	0.0675
Test 6	0.158	0.171
Test 7	0.165	0.149
Average	**0.190**	**0.153**

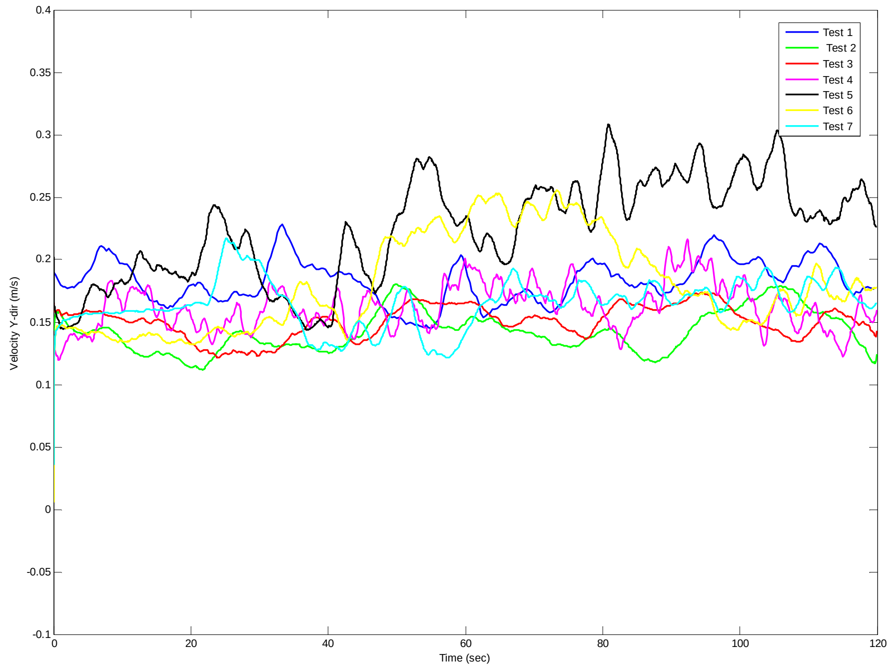

Figure 17. Velocity plot of Station 1 at the 21.34 meter location

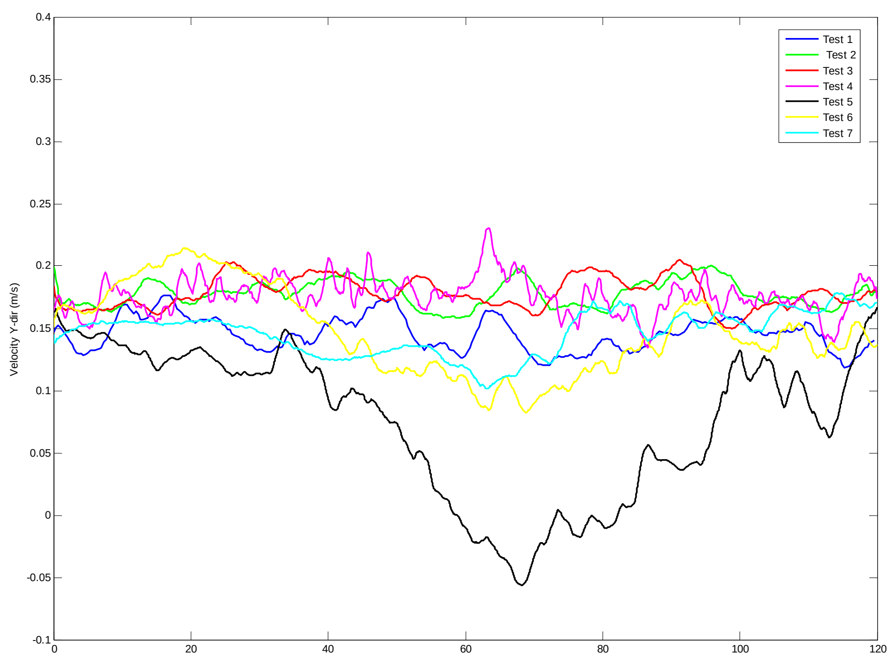

Figure 18. Velocity plot of Station 3 at the 21.34 meter location

Table 6: Average velocities for all testing locations

LOCATIONS	9.14 (m)		15.24-16.76 (m)		21.34-22.86 (m)		28.96-30.48 (m)		35.05 (m)		41.15-42.67 (m)	
	Sta1 (m/s)	Sta3 (m/s)	Sta1 (m/s)	Sta3 (m/s)	Sta1 (m/s)	Sta3 (m/s)	Sta1 (m/s)	Sta3 (m/s)	Sta1 (m/s)	Sta3 (m/s)	Sta1 (m/s)	Sta3 (m/s)
Test 1	-	-	-	-	0.180	0.152	-	-	-	-	-	-
Test 2	-	-	0.146	0.160	0.143	0.178	0.157	0.168	-	-	0.149	0.168
Test 3	-	-	0.152	0.180	0.151	0.179	0.157	0.172	-	-	0.164	0.166
Test 4	-	-	0.140	0.169	0.162	0.176	0.162	0.164	-	-	0.169	0.157
Test 5	0.315	-0.032	0.315	0.009	0.233	0.070	0.177	0.126	0.162	0.141	0.135	0.156
Test 6	0.083	0.242	0.133	0.197	0.158	0.171	0.158	0.167	0.160	0.163	0.123	0.188
Test 7	0.101	0.119	0.134	0.138	0.165	0.149	0.165	0.150	0.163	0.155	0.144	0.163

For locations closest to the diffuser, 9.14 – 16.76 meters, there is a greater variance of averages velocities between the two stations than experienced in locations farther down the tank, see Table 6. This most likely indicates a turbulent environment caused be water entering the tank via the diffuser. Further down the tank, around 21.0 – 28 meters this turbulent structure seems to dissipate. Test 7 though shows most similar averages for both stations close to the diffuser. The concrete structure near the diffuser seems to attenuate the fluctuation occurring between the stations

At the 41.15 and 42.67 meter location Station 3 is slightly faster for all tests, although Tests 3 and 4 are very close to each other. Those tests both have the horsehair filter installed near the weirs which probably contributes to stabilizing the flow further down the tank. The horsehair impedes the water on the South side of the tank from rushing to the North side where the weir is. It was also noticed that an increase in Station 1 coincides to a decrease in Station 3 for all testing locations. In some cases, such as Test 5, this is a predominant feature. Yet in the other tests the changes are evident but with much smaller amplitudes.

2.4.2 Power Spectrum

When starting to analyze the power spectra, a cleaning process was attempted to amplify the information in the plots. Initially a low pass filter, the Hamming window, was applied to smooth the power spectrum. The Hamming window filter, (Figure 19), is good for smoothing a spectrum by reducing the level of noise and allowing pertinent features to be displayed (Smith, 1999). It allows the tail of peaks to be reduced and broadens the peaks without covering important features.

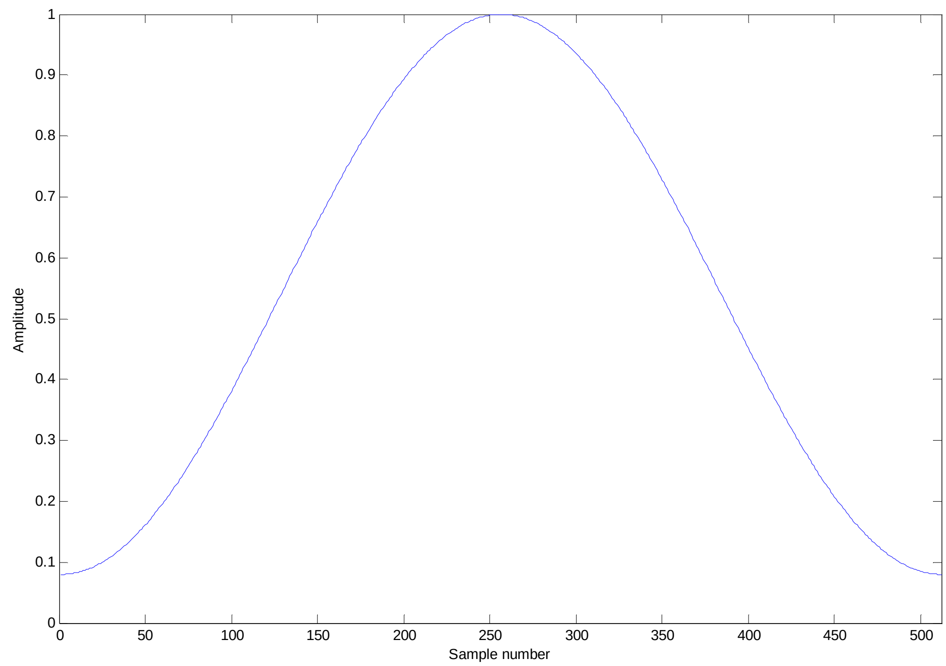

Figure 19. Hamming window filter

Recall that the raw data was broken into many 512 point segments. The Hamming window filter is applied to each segment of raw data then run through 512 point discrete Fourier transform (DFT). The resulting frequency spectra are then averaged to create a 256 point frequency spectrum. The results of using the Hamming window filter were disappointing, see Figure 20. The only noticeable difference between the power spectrum with the Hamming window filter applied and the power spectrum without was that the Hamming window spectrum had less energy and the peaks and troughs were slightly more defined. So the filter did work as it was supposed to, but the lack of any extreme difference made it redundant to apply the filter to the raw data set, so it was not used.

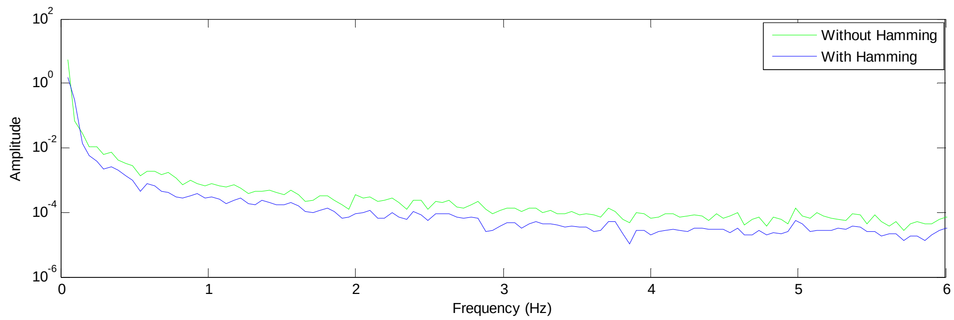

Figure 20. Power spectrum plot comparing ADV data with and without the applied Hamming window filter

Figure 21 compares all seven tests at the 21.34 and 22.86 meter locations for Station 1, which is the side of the tank with the lower weir. As you can notice in the first test without filters, there is a lot of oscillation across the frequency band but much less energy in the spectrum than compared to the other tests. Comparing just the spectrum without filters to those with filters you may notice that some form of filter in the tow tank does help to eliminate the number and severity of oscillations occurring. Test 5 has more energy than the other spectra and a well defined albeit small, peak around 1.8 seconds that also occurs with Test 1 and Test 3 but with more energy. This coincides with the results from the velocity profile at the same location. Test 7 shows the least amount of oscillations compared to prior tests.

At the same location on the other side of the tow tank, Station 3, the results (Figure 22) are more spread out than those of Station 1. Test 1 has larger amplitude peaks at Station 3 than at Station 1, which was probably caused by reflection off the wall from the upper weir side. In Test 5, Station 3 has nine times more energy than Station 1 and over double the energy of the other locations. In addition, two defined peaks, instead of just the one evident at Station 1, occur at 1.58 and 2.28 seconds. Tests 2 – 4 are in similar ranges of the power spectrum while Tests 5 – 7 are slightly higher with Test 5 again having the most energy.

For the 9.14 – 15.24 meter locations there is more energy than those locations farther down the tank. Test 5 has considerably more energy in Station 3 than in Station 1, while Station 1 in Test 6 has more energy than Station 3. This difference is most likely caused by the flipping the diffusers to both face the wall. Overall, early tests demonstrated more noise and energy than later tests. This could be attributed to less turbulence in the water column from the various filters used in the later tests.

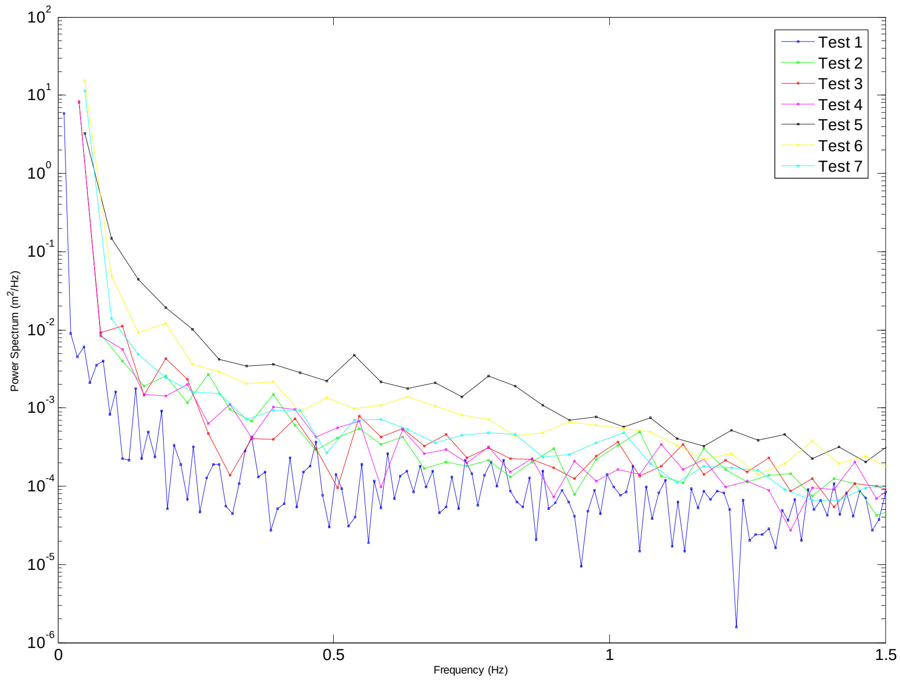

Figure 21. Power spectrum plot for Station 1 of all seven tests at the 21.34 meter location

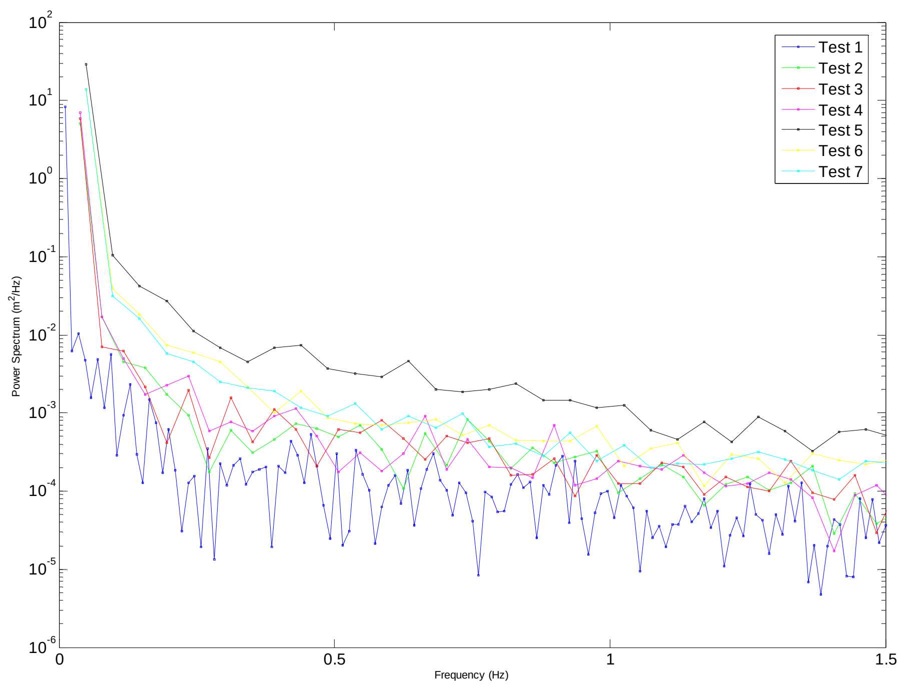

Figure 22. Power spectrum plot for Station 3 of all seven tests at the 21.34 meter location

CHAPTER III

WAVE TANK

3.1 Background

To be able to develop accurate physical models one must first understand the environment they are trying to duplicate. The sea is mainly comprised of winds, currents and waves. Waves can have varying wave heights and lengths depending on the forces acting on the water. The predominant force that creates many different kinds of waves is wind.

3.1.1 Wind Waves

Wind generated waves, the most common type, are created by the transfer of energy from the wind to the water. As wind blows across the water's surface, friction transfers energy to the water creating waves. As the wind blows at various rates over large areas for varying lengths of time the water surface becomes rough and larger waves form. Any wave's energy is proportional to the square of its height. As waves become larger the restoring force changes from surface tension to gravity. The actual height of waves is controlled by the interaction of several factors; wind speed, duration and fetch (Duxbury and Duxbury, 1997). Depending on the duration and fetch the wave heights will increase quadratically until a maximum is reached, which is known as a fully developed sea. In this state energy is dissipated by viscous forces such as waves breaking as well as bottom friction. As waves develop, their speed and wavelength increases and the waves become more rounded.

3.1.2 Wave Modeling

As waves propagate towards the shoreline they transform. This makes it necessary in the coastal regime to be able to understand these transformations and be able to predict the velocity, changes in wave height with water depth and direction, decrease in wave length, and the power and energy spectrum. As deep water waves enter shallow water they transform, becoming dependent on water depth. As the depth decreases their velocity decreases and the wave steepness increases until the wave becomes unstable and breaks. Shallow water is approximated to be when the water depth, h, is less than 1/20th the deep water wave length.

To begin, one must recall governing equations for potential free surface flow, as given by Dean and Dalrymple (1991):

$$\begin{cases} \nabla^2\phi = 0 & \text{in the fluid} \\ p = -\rho\frac{\partial\phi}{\partial t} - \frac{1}{2}\rho\left(\vec{\nabla}\phi\right)^2 - \rho g z + C(t) & \text{along the streamline} \\ \frac{\partial\eta}{\partial t} + \vec{\nabla}\phi\vec{\nabla}\eta = 0 & \text{at } z = \eta \\ \frac{\partial\phi}{\partial t} + \frac{1}{2}\left(\vec{\nabla}\phi\right)^2 + g\eta = 0 & \text{at } z = \eta \\ -\frac{\partial\phi}{\partial z} = 0 & \text{at } z = -h \\ \phi(\mathrm{x,t}) = \phi(x+L,t) & \\ \phi(x,t) = \phi(x,t+T) & \end{cases} \qquad (3.1)$$

$$\text{where } \begin{cases} \phi = \text{fluid potential} \\ \text{p} = \text{pressure} \\ \eta = \text{free surface elevation} \\ \rho = \text{density of fluid} \\ \text{L} = \text{wave length} \\ \text{T} = \text{wave period} \end{cases}$$

3.1.3 Linear Airy-Wave Theory

The simplest wave theory, linear Airy-wave theory, assumes that the wave height is much smaller than the wave length and water depth (kh<<1) [2] and is only valid for low wave steepness (Dean & Dalrymple, 1991). Due to this assumption, as the wave enters intermediate and shallow water depths, the theory is unable to accurately describe particle motion.

The linearization of the previous boundary conditions is the basis for Linear Wave Theory (Dean and Dalrymple, 1991) which requires the solution of the Laplace equations with the expressed boundary conditions. The linearized equations are:

$$\begin{cases} \nabla^2 \phi = 0 & \text{in the fluid} \\ \dfrac{\partial \phi}{\partial z} - \dfrac{\partial \eta}{\partial t} = 0 & \text{at z = 0} \\ \dfrac{\partial \phi}{\partial t} + g\eta = 0 & \text{at z = 0} \\ -\dfrac{\partial \phi}{\partial z} = 0 & \text{at z = -h} \\ \phi(x,t) = \phi(x+L,t) & \\ \phi(x,t) = \phi(x,t+T) & \end{cases} \qquad (3.2)$$

---

[2] k=wave steepness, h=water depth

By separating the variables the velocity potential for a monochromatic wave train may be derived by using the above set of equations:

$$\phi(x,y,z,t) = A\cosh\left[k(z+h)\right]\sin(kx-\sigma t) \tag{3.3}$$

where A is a constant.

Applying the dynamic free surface boundary condition to the velocity potential, the free surface water elevation is given by:

$$\eta = \frac{1}{g}\frac{\partial\phi}{\partial t} = \frac{A\sigma}{g}\cosh(kh)\cos(kx-\sigma t) \tag{3.4}$$

Since we know from comparing the physical models of η to the analytical representation that η is given as:

$$\eta = \frac{H}{2}\cos(kx-\sigma t) \tag{3.5}$$

(Dean and Dalyrmple, 1991)

Therefore, by substitution we can solve for A:

$$A = \frac{Hg}{2\sigma}\frac{1}{\cosh(kh)} \tag{3.6}$$

Substituting A back into the velocity potential for a monochromatic wave yields the following:

$$\phi(x,y,z,t) = \frac{Hg}{2\sigma}\frac{\cosh\left[k(z+h)\right]}{\cosh(kh)}\sin(k_x x + k_y y - \sigma t) \tag{3.7}$$

The linearized expressions for velocity potential and water surface elevation may be substituted into the kinematic boundary condition to establish the dispersion relationship, which correlates the frequency and wavelength of a wave.

$$\sigma^2 = gk\tanh(kh) \tag{3.8}$$

The celerity of the wave $C = \frac{L}{T} = \frac{\sigma}{k}$ is:

$$C = \sqrt{\frac{g}{k}\tanh(kh)} \tag{3.9}$$

<u>Shallow Water Simplifications</u>

When waves enter shallow water, the water depth is less than one-twentieth the wavelength (h < L/20). Relating the wavelength to wave number gives you $L = 2\pi / k$. Therefore the shallow water assumption is $kh < \frac{\pi}{10}$. Likewise, since the asymptotic form of the hyperbolic tangent for small <u>*kh*</u> is equivalent to *kh* the dispersion relationship and celerity reduces to the following:

$$\sigma^2 = gk^2h \tag{3.10}$$

$$C = \sqrt{gh} \tag{3.11}$$

<u>Water Particle Kinematics</u>

The horizontal and vertical velocities are derived from the velocity potential:

$$u = -\frac{\partial\phi}{\partial x} = \frac{H\sigma}{2}\frac{\cosh\left[k(h+z)\right]}{\sinh(kh)}\cos(kx-\sigma t) \tag{3.12}$$

$$v = -\frac{\partial\phi}{\partial y} = \frac{H\sigma}{2}\frac{\cosh\left[k(h+z)\right]}{\cosh(kh)}\cos(kx-\sigma t) \tag{3.13}$$

$$w = -\frac{\partial\phi}{\partial z} = \frac{H\sigma}{2}\frac{\sinh\left[k(h+z)\right]}{\sin(kh)}\sin(kx-\sigma t) \tag{3.14}$$

Pressure

To find the pressure of a monochromatic wave the unsteady Bernoulli equation is utilized:

$$p = -\rho \frac{\partial \phi}{\partial t} - \frac{1}{2}\rho\left(\bar{\nabla}\phi\right)^2 - \rho g z + C(t) \tag{3.15}$$

Linearizing the above equation yields:

$$p = \rho g \frac{H}{2} \frac{\cosh\left[k(h+z)\right]}{\cosh(kh)} \cos(kx - \sigma t) \tag{3.16}$$

In addition the static pressure is $p = -\rho g z$.

3.1.4 Non-Linear Wave Theory

Much more complex Stokes theory picks up where Airy-wave theory is no longer satisfactory. Stokes wave theory does not assume that wave heights are negligible and is therefore better able to describe wave motion. Characterized by narrow crests and broad flat troughs, Stokes wave theory better predicts waves profile because it takes into account non-linear effects. (Dean and Dalrymple, 1991)

Stokes wave solution to second order and the associated wave velocities, respectively are:

$$\begin{aligned}\phi = \frac{Ag}{\sigma} \frac{\cosh\left[k(z+h)\right]}{\cosh(kh)} \sin(kx - \sigma t) \\ + \frac{3}{8} A^2 \sigma \frac{\cosh\left[2k(z+h)\right]}{\sinh^4(kh)} \sin\left[2(kx - \sigma t)\right]\end{aligned} \tag{3.17}$$

$$\eta = \underbrace{A\cos(kx - \sigma t)}_{linear} + \frac{A^2 k}{4} \frac{\cosh(kh)}{\sinh^3(kh)} \left[2 + \cos(2kh)\cos\left[2(kx - \sigma t)\right]\right] \tag{3.18}$$

$$u = \frac{Agk}{\sigma}\frac{\cosh\left[k\left(z+h\right)\right]}{\cos\left(kh\right)}\cos\left(kx-\sigma t\right) + \frac{3}{4}A^2\sigma k\frac{\cosh\left[2k\left(z+h\right)\right]}{\sinh^4\left(kh\right)}\cos\left[2\left(kx-\sigma t\right)\right] \tag{3.19}$$

$$w = \frac{Agk}{\sigma}\frac{\sinh\left[k\left(z+h\right)\right]}{\cos\left(kh\right)}\sin\left(kx-\sigma t\right) + \frac{3}{4}A^2\sigma k\frac{\sinh\left[2k\left(z+h\right)\right]}{\sinh^4\left(kh\right)}\sin\left[2\left(kx-\sigma t\right)\right] \tag{3.20}$$

The maximum horizontal velocity and wave elevation are as follows:

$$u_{\max}\left(z\right) = \frac{Agk}{\sigma}\frac{\cos\left[k\left(z+h\right)\right]}{\cos\left(kh\right)} + \frac{3}{4}A^2\sigma k\frac{\cosh\left[2k\left(z+h\right)\right]}{\sinh^4\left(kh\right)} \tag{3.21}$$

$$\eta_{\max} = A + \frac{A^2k}{4}\frac{\cosh\left(kh\right)}{\sinh^3\left(kh\right)}\left[2+\cosh\left(kh\right)\right] \tag{3.22}$$

Comparing linear and non-linear wave theories it can be seen that the second order velocity is very small, therefore negligible. Nevertheless, the nonlinear theory is quite important to accurately predict water surface elevation because linear wave theory will over-predict the amplitude.

3.1.5 Wave Spectra

Irregular waves are essentially the superposition of many sine waves with varying range of frequencies. There are many different types of spectra, but the ones we focused on for the study are JONSWAP, Pierson & Moskowitz and TMA. For more information on other spectra refer to Khandekar (1989).

JONSWAP (Joint North Sea Wave Project), 1973

$$S_{\eta\eta}(f) = \frac{\alpha g^2}{2\pi^4 f^5} e^{\left[-\frac{5}{4}\left(\frac{f_p}{f}\right)^4 + \ln \gamma e^{\left(\frac{(f-f_p)^2}{2\sigma^2 f_p^2} \right)} \right]} \tag{3.23}$$

Where

$$\begin{cases} f_p = \text{ Peak frequency} = 2.84\left(\dfrac{9F}{U^2}\right)^{-0.33} \\ F = \text{Fetch length} \\ \alpha = \text{Philip's Constant} = 8.1\text{x}10^{-3} \\ \gamma = \text{Peak enhancement factor: range 1-10} \begin{cases} 3.3 & \text{typical seas} \\ 9\text{-}10 & \text{long period swell} \\ <3.3 & \text{wave grouping} \end{cases} \\ \sigma = \begin{cases} \sigma_a = 0.07 & \text{for } f \le f_p \\ \sigma_b = 0.09 & \text{for } f \ge f_p \end{cases} \end{cases}$$

Defined by Hasselmann et al. (In Chiswell and Kibblewhite, 1981), it was initially designed for storm conditions in the North Sea but has since grown to be used globally as a good approximation for storm conditions. Observations made during the project revealed that the wind-sea spectrum has a narrower, sharper peak during the growing phase than the Pierson & Moskowitz spectra.

The form for JONSWAP developed by Goda in (1978) is now more commonly utilized:

$$S_{\eta\eta}(f) = 2\pi\alpha\gamma e^{\left[\frac{(f-f_p)^2}{2\sigma^2 f_p^2} \right]} \frac{H_s^{\,2}}{f_p} \frac{1}{\left(\dfrac{f}{f_p}\right)^5} e^{\left[-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4} \right]} \tag{3.24}$$

where $\alpha = \dfrac{0.0624}{0.230 + 0.0336\gamma - \dfrac{0.185}{1.9 + \gamma}}$

Pierson & Moskowitz (P-M Spectra), 1964

$$S_{\eta\eta}(f) = \frac{\alpha g^2}{2\pi^4 f^5} e^{\left(-\beta\left(\frac{g}{Uf}\right)^4\right)} \tag{3.25}$$

This spectra is used for the case of fully developed wind waves in the open ocean and agrees closely with observed wind speeds in the 10-40 knot range (Khandekar, 1989). The parameters are as follows: wind speed U taken at an elevation of 19.5 meters, and the Philips Constant α = 8.1x10^{-3} and β = 0.74. In addition, the following is true for this spectrum:

$$\int_0^\infty S_{\eta\eta}(f)\,df = \left(\frac{H_s}{4}\right)^2 \tag{3.26}$$

where H_s = significant wave height.

TMA (Textel[3], MARSEN[4], ARSLOE[5]), 1985

$$S_{\eta\eta}(f) = jonswap 2\pi f \sqrt{\frac{h}{g}} \tag{3.27}$$

Defined by Bouws et al. (1985), it was intended to account for the similarity of wind wave spectra in finite water depths. Having shown to compare accurately to measured values of shallow water spectra it is a useful tool to extend deep water spectra

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[3] Lightship located in the southern North Sea
[4] Marine Remote Sensing Experiment at the North Sea
[5] Atlantic Remote Sensing Land and Ocean Experiment

models into shallow water domain. In addition, when accounting for water depth, the TMA spectra changes to JONSWAP spectra with increasing water depth.

3.1.6 Wave Reflection

In the coastal and laboratory environments waves are reflecting off coastal structures, floating or submerged objects and beaches. This reflected wave interlocks with the incident wave and affects the general wave characteristics. In the laboratory it is important to be able to separate the incident and reflected waves to accurately asses the model's response to the incident waves. According to Hughes (1993), the best method for analysis of both regular and irregular waves is a three or five probe-fixed array of wave gages which measures wave heights and phase angles. This method uses the Mansard Funke (1980) least square method for analysis that decomposes the measured spectra into incident and reflected spectra.

<u>Regular Waves</u>

The partially reflected incident wave has a water surface elevation:

$$\eta(t) = \underbrace{a_I \cos(kx - \sigma t + \varepsilon)}_{\text{Incident Wave}} + \underbrace{a_I K_R \cos(kx + \sigma t + \varepsilon + \phi)}_{\text{Reflected Wave}} \tag{3.28}$$

$$\text{where} \begin{cases} a_I = \text{Incident wave amplitude} \\ a_R = \text{Reflected wave amplitude} \\ k = \text{Wave number} \\ \sigma = \text{Angular wave frequency} \\ \varepsilon = \text{Arbitrary incident wave phase angle} \\ K_R = \text{Reflection coefficient} = \left(\dfrac{a_R}{a_I}\right) \\ \phi = \text{Phase shift} \end{cases}$$

The interaction of the waves causes standing waves with node and antinode points at L/4. Using trigonometric functions the above equation can be simplified:

$$\begin{aligned}\eta(t) &= a_I\left[\cos(kx+\varepsilon)+K_R\cos(kx+\varepsilon+\phi)\right]\cos(\sigma t)\\ &+a_I\left[\sin(kx+\varepsilon)-K_R\sin(kx+\varepsilon+\phi)\right]\sin(\sigma t)\end{aligned} \tag{3.29}$$

Let

$$\begin{aligned}A\cos\beta &= \left[\cos(kx+\varepsilon)+K_R\cos(kx+\varepsilon+\phi)\right]\\ A\sin\beta &= \left[\sin(kx+\varepsilon)-K_R\sin(kx+\varepsilon+\phi)\right]\end{aligned} \tag{3.30}$$

Which allows equation () to be simplified to:

$$\eta(t) = a_I A\cos(\sigma t-\beta) \tag{3.31}$$

Solving for A and substituting back into the equation yields:

$$\eta(t) = a_I\sqrt{1+K_R{}^2+2K_R\cos\left[2(kx+\varepsilon)+\phi\right]}\cos(\sigma t-\beta) \tag{3.32}$$

Due to the maximum wave height occurring at the antinode when $\cos\left[2(kx+\varepsilon)+\phi\right]=1$ and the minimum wave height occurring at the nodal point $\cos\left[2(kx+\varepsilon)+\phi\right]=-1$, we are able to ascertain that:

$$\begin{aligned}H_{\max} &= 2a_I\sqrt{1+2K_R+K_R{}^2} \quad \text{or} \quad H_{\max}=H_I(1+K_R)\\ H_{\min} &= 2a_I\sqrt{1-2K_R+K_R{}^2} \quad \text{or} \quad H_{\min}=H_I(1-K_R)\end{aligned} \tag{3.33}$$

Where $H_I = 2a_I$. This leads to the incident wave height and reflection coefficient respectively:

$$H_I = \frac{H_{\max}+H_{\min}}{2} \tag{3.34}$$

$$K_R = \frac{H_{\max} - H_{\min}}{H_{\max} + H_{\min}} \tag{3.35}$$

The reflection coefficient is numerically valued from 0.0-1.0 with $K_R = 1$ the incident wave is completely reflected and $K_R < 1$ partially reflected.

<u>Irregular Waves</u>

The elevation for a partially reflected irregular wave is:

$$\begin{aligned}\eta(x_m,t) &= a_I^{(1)}\cos\left(kx_m - \sigma t + \phi_I^{(1)}\right) + a_R^{(1)}\cos\left(kx_m + \sigma t + \phi_R^{(1)}\right)\\ &+ \sum_{n=1}^{\infty} a^{(n)}{}_{I,B}\cos\left[n\left(kx_m - \sigma t\right) + \phi^{(n)}{}_{I,B}\right]\\ &+ \sum_{n=1}^{\infty} a^{(n)}{}_{R,B}\cos\left[n\left(kx_m + \sigma t\right) + \phi^{(n)}{}_{R,B}\right]\\ &+ \sum_{n=1}^{\infty} a^{(n)}{}_{I,F}\cos\left[\left(k^{(n)}x_m - n\sigma t\right) + \phi^{(n)}{}_{I,F}\right]\\ &+ \sum_{n=1}^{\infty} a^{(n)}{}_{R,F}\cos\left[\left(k^{(n)}x_m + n\sigma t\right) + \phi^{(n)}{}_{R,F}\right] + \varepsilon_m^{(t)}\end{aligned} \tag{3.36}$$

where
$$\begin{cases} n = n^{\text{th}} \text{ wave component} = 1,2,3... \\ x_m = \text{ distance between probe 1 and probe m} \\ \text{B} = \text{bound wave} \\ \text{F} = \text{free wave} \\ \varepsilon_{\text{m}}^{(t)} = \text{error from the signal noise in measurement} \end{cases}$$

From the water surface elevation the transformed waves may be divided into incident and reflected waves in terms of the first harmonic and the n$^{\text{th}}$ harmonic of the bound and free waves. The bound waves are attached to the first harmonic waves and propagate at the same phase velocity (Mansard and Funke, 1980). The free waves propagate at their own respective velocities which can be described by the dispersion relationship.

The Fourier transformation:

$$\hat{\eta}^{(n)}\left(x_m\right)=\frac{\sigma}{2\pi}\int_{0}^{(2\pi/\sigma)}\eta\left(x_m,t\right)e^{(-in\sigma t)}dt \tag{3.37}$$

is applied to equation (3.36) to decompose the wave field into individual frequencies by using the known orthogonal properties of trigonometric functions. This consequently yields the following:

$$\hat{\eta}^{(1)}\left(x_m\right)=C_I^{(1)}X_I^{(1)}+C_R^{(1)}X_R^{(1)}+\Omega_m^{(1)} \tag{3.38}$$

where

$$\begin{cases} X_I^{(1)} = a_I^{(1)}e\left[-i\left(kx_1+\phi_I^{(1)}\right)\right] \\ X_R^{(1)} = a_R^{(1)}e\left[i\left(kx_1+\phi_R^{(1)}\right)\right] \\ C_I^{(1)} = \dfrac{e\left(-ik\Delta x_m\right)}{2} \\ C_R^{(1)} = \dfrac{e\left(ik\Delta x_m\right)}{2} \\ \Omega_m = \text{ fast Fourier transform of } \varepsilon_{\mathrm{m}}^{(t)} \text{ at n} = 1 \end{cases}$$

To solve for the unknowns X_I and X_R we must apply the least squares method proposed by Mansard and Funke (1980). To do this one must find values for X_I and X_R for which the sum of squares of $\Omega_m^{(1)}$ for any location *m* is a minimum.

$$\sum_m\left(\Omega_m^{(1)}\right)^2=\sum_m\left(\hat{\eta}^{(1)}\left(x_m\right)-C_I^{(1)}X_I^{(1)}-C_R^{(1)}X_R^{(1)}\right)^2=\text{ minimum} \tag{3.39}$$

To help minimize errors the minimum is assumed to be reached when the following occurs:

$$\frac{\partial}{\partial X_I^{(1)}}\sum_m\left(\Omega_m^{(1)}\right)^2=\frac{\partial}{\partial X_R^{(1)}}\sum_m\left(\Omega_m^{(1)}\right)^2=0 \tag{3.40}$$

The algebraic equation for solving X_I and X_R is:

$$\begin{bmatrix} \sum_m \left(C_I^{(1)}\right)^2 & \sum_m \left(C_I^{(1)} C_R^{(1)}\right) \\ \sum_m \left(C_I^{(1)} C_R^{(1)}\right) & \sum_m \left(C_R^{(1)}\right)^2 \end{bmatrix} \begin{bmatrix} X_I^{(1)} \\ X_R^{(1)} \end{bmatrix} = \begin{bmatrix} \sum_m \left(\hat{\eta}^{(1)}(x_m) C_I^{(1)}\right) \\ \sum_m \left(\hat{\eta}^{(1)}(x_m) C_R^{(1)}\right) \end{bmatrix} \tag{3.41}$$

Upon solving equation (3.41) for X_I and X_R the amplitudes of the first harmonic components may be determined; $a_I^{(1)} = abs\left(A_I^{(1)}\right)$, $a_R^{(1)} = abs\left(A_R^{(1)}\right)$.

One must avoid spacing the wave probes so that the solution to equation 3.41 is equal to zero. This occurs when $X_{12} = L_p/2$ and $X_{13} = L_p/5$ and $3L_p/10$, where L_p is the peak wave length. Ideally the wave probes should be placed a minimum of one wave length away from the reflecting structure. Mansard and Funke (1980) recommended that the distance between probes be the following:

$$X_{12} = \frac{L_p}{10} \tag{3.42}$$

$$\frac{L_p}{6} < X_{13} < \frac{L_p}{3} \text{ and } X_{13} \neq \frac{L_P}{5} \neq \frac{3L_P}{10} \tag{3.43}$$

The reflection coefficient for each harmonic can be expressed as:

$$K_R = \sqrt{\frac{\left(a_R^{(1)}\right)^2 + \sum_{N=1}\left[\left(a_{R,B}^{(n)}\right)^2 + \left(a_{R,F}^{(n)}\right)^2\right]}{\left(a_I^{(1)}\right)^2 + \sum_{N=1}\left[\left(a_{I,B}^{(n)}\right)^2 + \left(a_{I,F}^{(n)}\right)^2\right]}} \tag{3.44}$$

3.2 Methods and Materials

3.2.1 Experimental Setup

Rexroth Wave Generator

The following technical specifications of the wave generator come from the Wave Generator Manual (Rexroth Bosch Group, 2004). The wave generator is located on the west wall of the three-dimensional basin. It has 48 waveboards; each is driven by a ball spindle and nut which are in turn driven by a digital AC-servomotor, or actuator. By converting the rotary motion of the actuator, the ball spindle is able to move in a linear motion guided by two guide rails. Each actuator contains feedback of the position and velocity of the waveboard and is controlled by the Motor Controller which is mounted inside the Motor Control Cabinet (MCC). Each MCC contains eight actuators and is controlled by a Serial Real-time Communication System (SERCOS) interface via fiber-optic cable from its respective Control Computer. The SERCOS interface provides control parameters and set points for segment positions to the Motor Control and the actual position and torque of the waveboards is retrieved from the Motor Controller. In addition the Motor Controller is able to limit the maximum velocities and torque so that if the motor should travel beyond these limits the system will perform an emergency stop.

The Operator Station is where the waves are calculated, generated and the system is monitored. The Operator Station is networked to the Control Computer Cabinet (CCC), which consists of three Control Computers. Each Control Computer controls 16 wave boards through two MCCs. The first computer, the master computer, controls the first 16 paddles. The second and third Control Computers control paddles 17-32 and 33-48 respectively. The Control Computers receives data and commands from the Operator Station and then distributes segment set points to their respective MCC via the SERCOS interface. All three computers are synchronized which allows smooth start-up and shutdown of the waveboards. They also monitor that wave generator's behavior.

The software utilized to compute the wave signal is GEDAP, developed by the Canadian Hydraulics Centre (CHC). GEDAP information comes from the GEDAP User's Guide for Windows NT, written by Miles (1997). The user is able to enter the wave properties into the system, which then creates a set point file. This is then checked to ensure it is not exceeding the system's operational limits. If it is exceeded then LIMITING software is used. The set point file is then sent to the master Control Computer which then distributes the set points locally and to the slave computers.

In all enclosed basins a certain amount of reflection will occur, even with a wave absorber located at the opposite end of the tank. This reflection causes degradation of the wave field which limits the duration of wave testing. It can also develop long period seiching. To compensate for this oscillation technology called Active Reflection Absorption, ARA, is applied with its inputs coming through GEDAP. This works by having wave height meters installed on each wave board that measures the actual water level in front of the wave board. The measurements are done by measuring the capacitance between two conductors and are sensitive to local variations in the water. The signal produced by the wave height meters is then processed by ARA algorithms which through GEDAP also know the required water surface elevation. ARA then allows the paddles to move in such a manner that the reflected waves will be reduced while still allowing the generation of the desired wave. In addition, the usage of ARA allows for fast decay of waves following testing which cuts time between testing. (Rexroth Bosch Group, 2004)

Wave Gauges

To properly measure the wave field within the wave tank one must use wave gauges. Two different types were utilized for testing, wired and wireless. Both gauge types are capacitance wave gauges which mean they measure the voltage potential which occurs across the two rods that extend into the water. Capacitance varies linearly along a wire of uniform thickness, allowing the surface elevation of the water to be measured (Hughes, 1993).

The wired wave gages are approximately 0.61 meters long and attach to an amplifier via two-wire cable. Three wired wave gauges were attached to long square poles which in turn were attached to the bridge with c-clamps. The center wave gauge was located midway on the bridge span with the other two wave gauges located 4.88 meters on either side of the center wave gauge, see Figure 23.

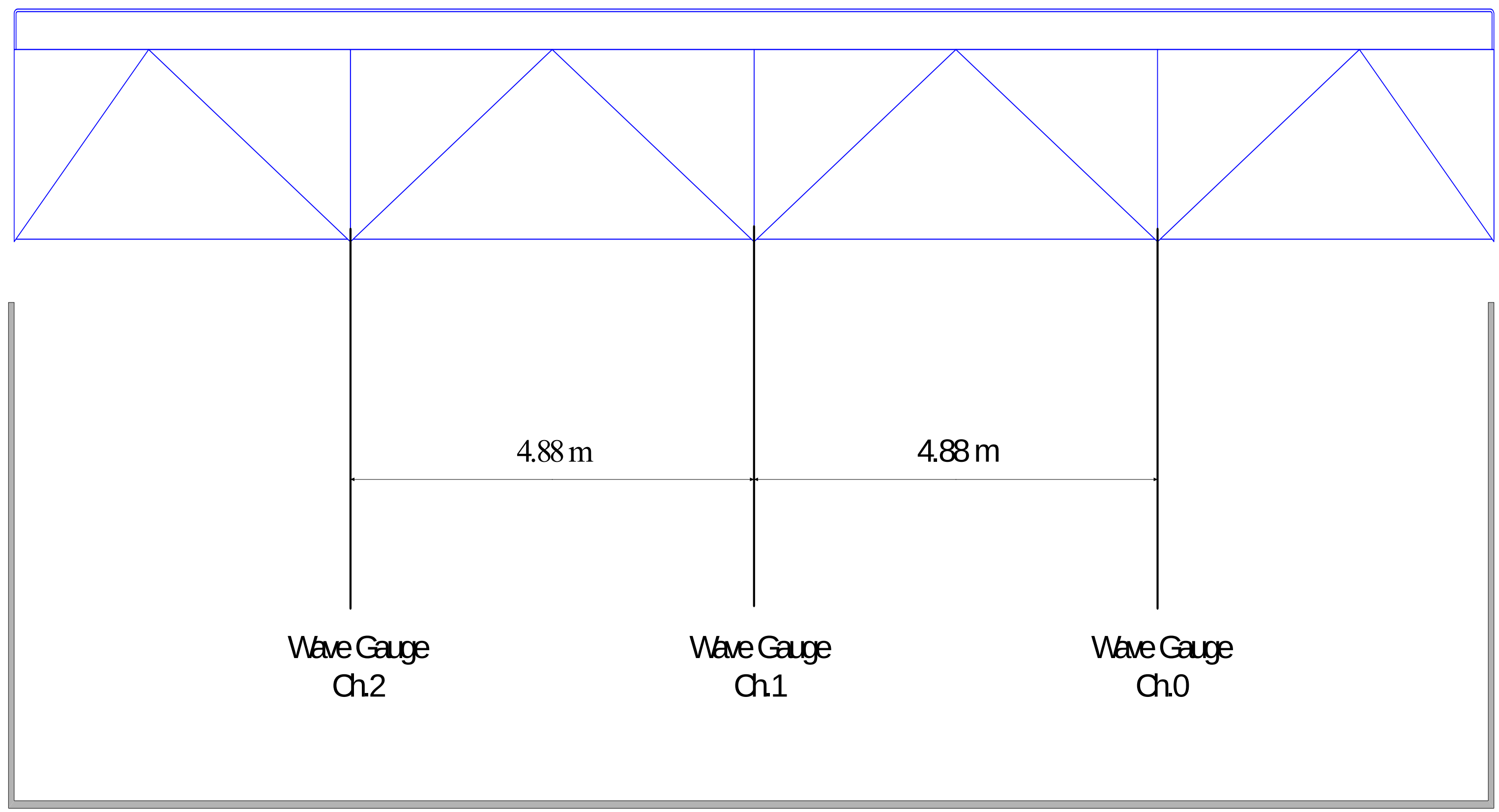

Figure 23. Three wired wave gauges attached to the bridge

A new addition to the wave gauge market is wireless wave gauges. The gauges themselves are 0.49 meters long. Unlike their predecessors which have long wires running to an amplifier, these have a short coaxial cable which attaches to the wave gauge and to the cylindrical shaped transmitter. The transmitter contains an antenna, a transmitter, and circuitry to drive it, and is powered with a rechargeable AA battery pack. The wireless wave gauge control box allows eight gauges to be used in the tank simultaneously.

3.2.2 Experimental Procedure

The experimental program was designed to test the following aspects of the Rexroth Wave Generator:

- Ability to duplicate the calculated theoretical wave
- Response of the wave tank to the created waves
- The effectiveness of ARA

It is also essential to understand the effectiveness of the rubble beach as a wave absorber and of the pool buoys' ability to reduce reflection and remove unwanted high-frequency noise. In additional the effectiveness and ease of operations of the wireless wave gauges in the wave basin was researched. Five phases of testing were completed which will be discussed later in the paper.

Wave gauges were located in the 3D wave tank as shown in Figure 24 to record data at a 25-Hz sampling rate on the waves being produced by the wave generator. Initially three wired wave gages were used for testing. The gauges were attached to the bridge with clamps at the locations given earlier.

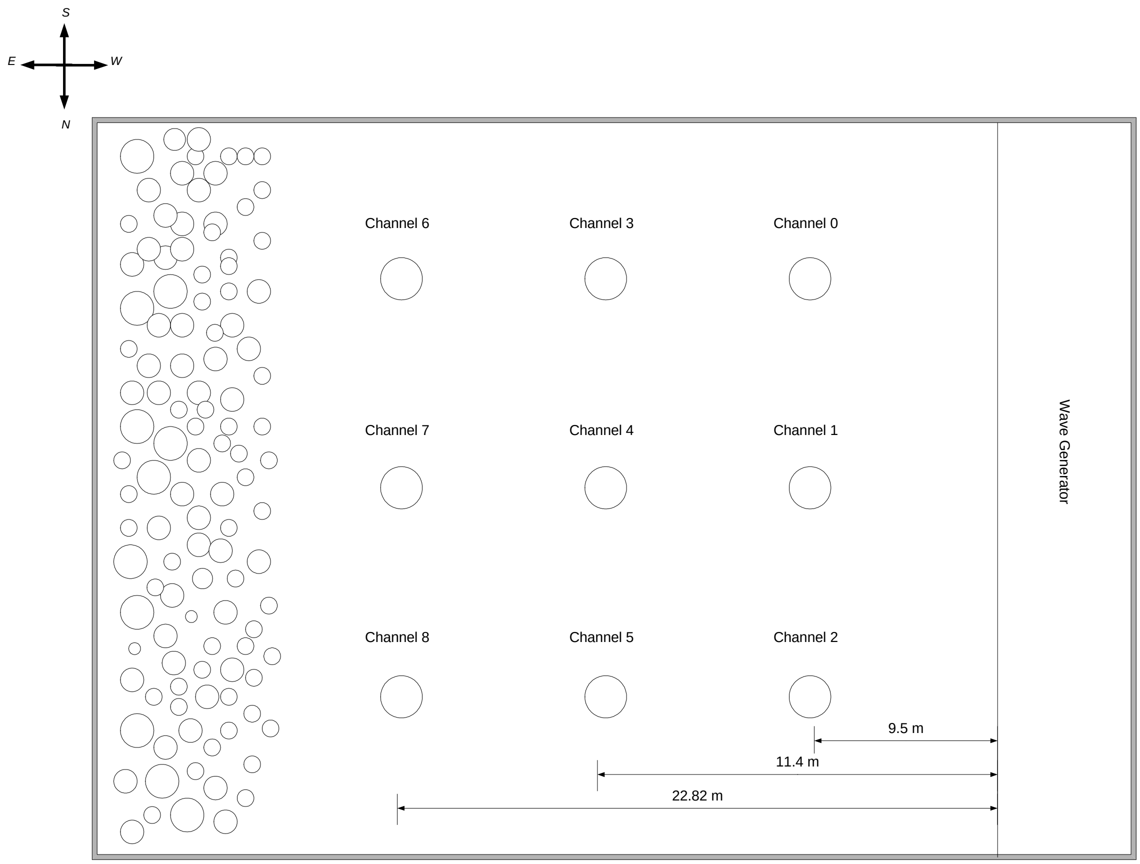

Figure 24. Location of wave gauges in 3D wave basin

For Phase V a side by side comparison was completed of the wired and wireless wave gauges. One wired wave gauge was attached to the bridge and one wireless wave gauge was located slightly to the North of the wired wave gauge (Figure 25). Both wave gauges were situated at the same height in 0.5 meters of water.

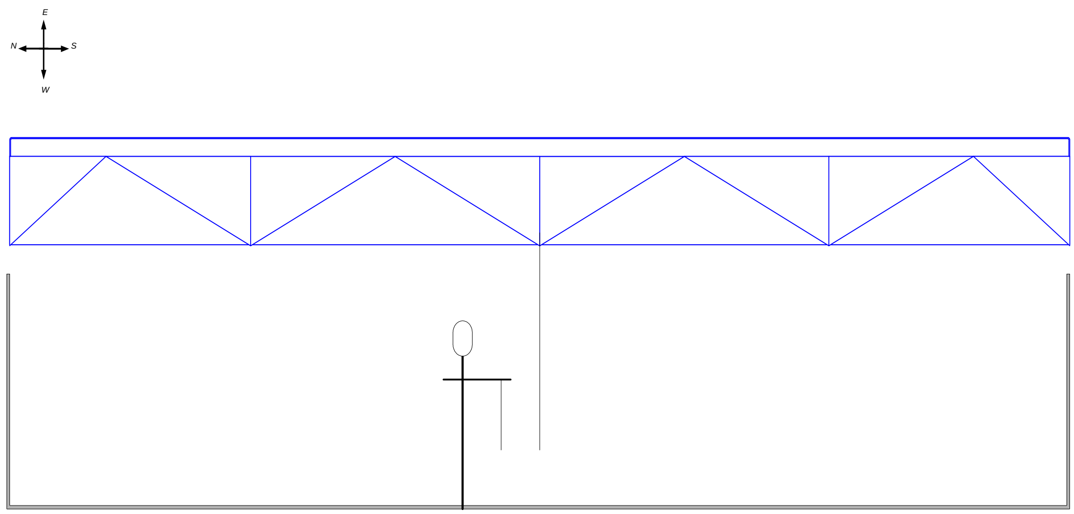

Figure 25. Comparison of wired and wireless wave gauges

The Phase VI tests examined and compared monochromatic and irregular wave trains at 0.5 and 1.0 meter water depths. Wave gauges were placed throughout the tank.

Next, Phase VII investigated the difference in the wave field with the addition of round plastic pool buoys, like those used as lane dividers in lap pools, located three meters from the wave generator. The same waves from Phase VI were used at 0.5 and 1.0 meter water depths. The wave gauges were located in the same positions in the tank as in Phase VI.

For Phase VIII three wave gauges were located by the beach to assess the amount of reflected wave from the rock beach. Waves were run three times each with and without ARA engaged. Gain settings for ARA for the test duration were local = 0.1 (each paddle), and overall = 1.0 (whole wave generator).

Finally, Phase IX tested the effectiveness of ARA. Three 4.57 meter wide concrete blocks were placed 8.23 meters in front of the wave generator (Figure 26). In front of the concrete blocks three wave gauges were placed to obtain reflection data. Waves were run with and without ARA for comparison.

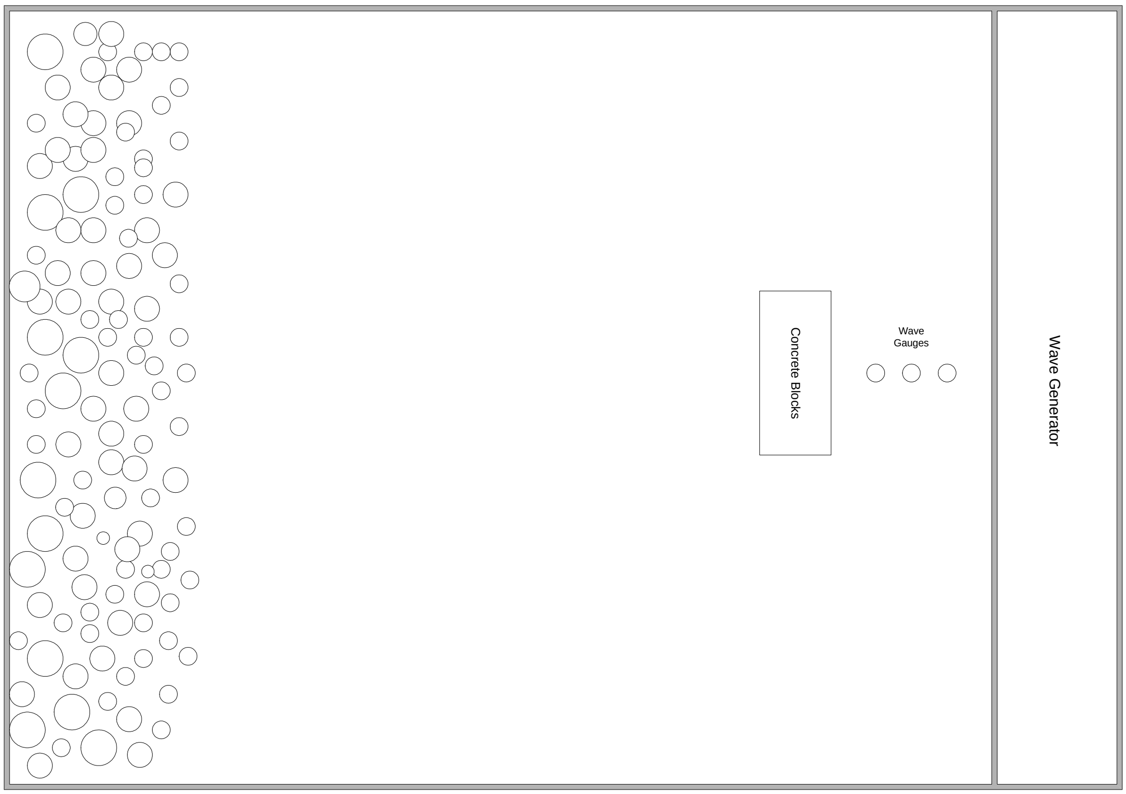

Figure 26. Wave gauge location for ARA testing

Tables 7 – 15 summarize the tests that were completed for each phase of the wave testing.

Table 7: Test plan for Phase VI – 0.5 meter water depth

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQUENCY (HZ)	GAMMA
1	Monochromatic	0.1	1.0	1.0000	-
2	Monochromatic	0.1	1.25	0.8000	-
3	Monochromatic	0.1	1.5	0.6667	-
4	Monochromatic	0.1	2.0	0.5000	-
5	Monochromatic	0.1	2.5	0.4000	-
6	JONSWAP	0.1	1.0	1.0000	3.3
7	JONSWAP	0.1	1.5	0.6667	3.3
8	JONSWAP	0.1	2.0	0.5000	3.3
9	PM-Fp	-	1.0	1.0000	-
10	PM-Fp	-	1.5	0.6667	-
11	PM-Fp	-	2.0	0.5000	-
12	PM-Tp	0.1	-		-
13	TMA	0.1	1.0	1.0000	3.3
14	TMA	0.1	1.5	0.6667	3.3
15	TMA	0.1	2.0	0.5000	3.3

Table 8: Test plan for Phase VI - 1.0 meter water depth

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQUENCY (HZ)	GAMMA
16	Monochromatic	0.2	1.0	1.0000	-
17	Monochromatic	0.2	1.25	0.8000	-
18	Monochromatic	0.2	1.5	0.6667	-
19	Monochromatic	0.2	2.0	0.5000	-
20	Monochromatic	0.2	2.5	0.4000	-
21	JONSWAP	0.2	1.0	1.0000	3.3
22	JONSWAP	0.2	1.5	0.6667	3.3
23	JONSWAP	0.2	2.0	0.5000	3.3
24	PM-Fp	-	1.0	1.0000	-
25	PM-Fp	-	1.5	0.6667	-
26	PM-Fp	-	2.0	0.5000	-
27	PM-Tp	0.2	-		-
28	TMA	0.2	1.0	1.0000	3.3
29	TMA	0.2	1.5	0.6667	3.3

Table 8 cont.

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQUENCY (HZ)	GAMMA
30	TMA	0.2	2.0	0.5000	3.3
31	Monochromatic	0.2	1.25	0.8000	-
32	Monochromatic	0.2	1.5	0.6667	-
33	Monochromatic	0.2	2.0	0.5000	-
34	Monochromatic	0.2	2.5	0.4000	-
35	Monochromatic	0.3			
37	JONSWAP	0.2	1.5	0.6667	3.3
38	JONSWAP	0.2	2.0	0.5000	3.3
40	PM-Fp	-	1.5	0.6667	-
41	PM-Fp	-	2.0	0.5000	-
42	PM-Tp	0.2	-		-
44	TMA	0.2	1.5	0.6667	3.3
45	TMA	0.2	2.0	0.5000	3.3

Table 9: Test plan for Phase VII – 0.5 meter water depth

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQUENCY (HZ)	GAMMA
1B	Monochromatic	0.1	1.0	1.0000	-
2B	Monochromatic	0.1	1.25	0.8000	-
3B	Monochromatic	0.1	1.5	0.6667	-
4B	Monochromatic	0.1	2.0	0.5000	-
5B	Monochromatic	0.1	2.5	0.4000	-
6B	JONSWAP	0.1	1.0	1.0000	3.3
7B	JONSWAP	0.1	1.5	0.6667	3.3
8B	JONSWAP	0.1	2.0	0.5000	3.3
9B	PM-Fp	-	1.0	1.0000	-
10B	PM-Fp	-	1.5	0.6667	-
11B	PM-Fp	-	2.0	0.5	-
12B	PM-Tp	0.1	-		-
13B	TMA	0.1	1.0	1.0000	3.3
14B	TMA	0.1	1.5	0.6667	3.3
15B	TMA	0.1	2.0	0.5000	3.3

Table 10: Test plan for Phase VII – 1.0 meter water depth

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQUENCY (HZ)	GAMMA
31B	Monochromatic	0.2	1.25	0.8000	-
32B	Monochromatic	0.2	1.5	0.6667	-
33B	Monochromatic	0.2	2.0	0.5000	-
34B	Monochromatic	0.2	2.5	0.4000	-
35B	JONSWAP	0.2	1.5	0.6667	3.3
36B	JONSWAP	0.2	2.0	0.5000	3.3
37B	PM-Fp	-	1.5	0.6667	-
38B	PM-Fp	-	2.0	0.5000	-
39B	PM-Tp	0.2	-		-
40B	TMA	0.2	1.5	0.6667	3.3
41B	TMA	0.2	2.0	0.5000	3.3

Table 11: Test plan for Phase VIII – 0.5 meter water depth, without ARA

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQ (HZ)	WAVE LENGTH (METERS)	PROBE SPACING (METERS)		DISTANCE TO BEACH (METERS)
						X12	X13	
1	Monochromatic	0.1	1.0	1.0000	1.5	0.15	0.5	4.6
2	Monochromatic	0.1	1.25	0.8000	2.2	0.22	0.5	4.6
3	Monochromatic	0.1	1.5	0.6667	2.8	0.28	0.5	4.6
4	Monochromatic	0.1	2.0	0.5000	4.0	0.40	0.95	5.5
5	Monochromatic	0.1	2.5	0.4000	5.237	0.52	0.95	5.5
6	JONSWAP	0.1	1.0	1.0000	1.5	0.15	0.5	5.5
7	JONSWAP	0.1	1.5	0.6667	2.8	0.28	0.5	5.5
8	JONSWAP	0.1	2.0	0.5000	4.0	0.40	0.95	5.5
9	PM	-	1.0	1.0000	1.5	0.15	0.5	5.5
10	PM	-	1.5	0.6667	2.8	0.28	0.5	5.5
11	PM	-	2.0	0.5000	4.0	0.40	0.95	5.5
12	TMA	0.1	1.0	1.0000	1.5	0.15	0.5	5.5
13	TMA	0.1	1.5	0.6667	2.8	0.28	0.5	5.5
14	TMA	0.1	2.0	0.5000	4.0	0.40	0.95	5.5
15	Monochromatic	0.2	1.0	1.0000	1.5	0.15	0.5	4.6
16	Monochromatic	0.2	1.25	0.8000	2.2	0.22	0.5	4.6
17	Monochromatic	0.2	1.5	0.6667	2.8	0.28	0.5	4.6
18	Monochromatic	0.2	2.0	0.5000	4.0	0.40	0.95	5.5
19	Monochromatic	0.2	2.5	0.4000	5.237	0.52	0.95	5.5
20	JONSWAP	0.2	1.0	1.0000	1.5	0.15	0.5	5.5
21	JONSWAP	0.2	1.5	0.6667	2.8	0.28	0.5	5.5
22	JONSWAP	0.2	2.0	0.5000	4.0	0.40	0.95	5.5
23	PM	-	1.0	1.0000	1.5	0.15	0.5	5.5
24	PM	-	1.5	0.6667	2.8	0.28	0.5	5.5

Table 11 cont.

Test #	Wave Type	Wave Height (meters)	period (sec)	fReq (Hz)	Wave length (meters)	Probe Spacing (meters)		Distance to beach (meters)
						X12	X13	
25	PM	-	2.0	0.5000	4.0	0.40	0.95	5.5
26	TMA	0.2	1.0	1.0000	1.5	0.15	0.5	5.5
27	TMA	0.2	1.5	0.6667	2.8	0.28	0.5	5.5
28	TMA	0.2	2.0	0.5000	4.0	0.40	0.95	5.5

Table 12: Test plan for Phase VIII – 0.5 meter water depth, with ARA

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQ (HZ)	WAVE LENGTH (METERS)	PROBE SPACING (METERS)		DISTANCE TO BEACH (METERS)
						X12	X13	
1A	Monochromatic	0.1	1.0	1.0000	1.5	0.15	0.5	4.6
2A	Monochromatic	0.1	1.25	0.8000	2.2	0.22	0.5	4.6
3A	Monochromatic	0.1	1.5	0.6667	2.8	0.28	0.5	4.6
4A	Monochromatic	0.1	2.0	0.5000	4.0	0.40	0.95	5.5
5A	Monochromatic	0.1	2.5	0.4000	5.237	0.52	0.95	5.5
6A	JONSWAP	0.1	1.0	1.0000	1.5	0.15	0.5	5.5
7A	JONSWAP	0.1	1.5	0.6667	2.8	0.28	0.5	5.5
8A	JONSWAP	0.1	2.0	0.5000	4.0	0.40	0.95	5.5
9A	PM	-	1.0	1.0000	1.5	0.15	0.5	5.5
10A	PM	-	1.5	0.6667	2.8	0.28	0.5	5.5
11A	PM	-	2.0	0.5000	4.0	0.40	0.95	5.5
12A	TMA	0.1	1.0	1.0000	1.5	0.15	0.5	5.5

Table 12 cont.

Test #	Wave Type	Wave Height (meters)	period (sec)	fReq (Hz)	Wave length (meters)	Probe Spacing (meters)		Distance to beach (meters)
						X12	X13	
13A	TMA	0.1	1.5	0.6667	2.8	0.28	0.5	5.5
14A	TMA	0.1	2.0	0.5000	4.0	0.40	0.95	5.5

Table 13: Test plan for Phase VIII – 1.0 meter water depth, without ARA

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQ (HZ)	WAVE LENGTH (METERS)	PROBE SPACING (METERS)		DISTANCE TO BEACH (METERS)
						X12	X13	
1	Monochromatic	0.2	1.25	0.8000	2.41	0.241	0.6	7.32
2	Monochromatic	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
3	Monochromatic	0.2	2.0	0.5000	5.21	0.521	1.65	7.32
4	Monochromatic	0.2	2.5	0.4000	6.99	0.699	1.65	7.32
5	JONSWAP	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
6	JONSWAP	0.2	2.0	0.5000	5.21	0.521	1.65	7.32
7	PM	-	1.5	0.6667	3.35	0.335	0.6	7.32
8	PM	-	2.0	0.5000	5.21	0.521	1.65	7.32
9	TMA	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
10	TMA	0.2	2.0	0.5000	5.21	0.521	1.65	7.32

Table 14: Test plan for Phase VIII – 1.0 meter water depth, with ARA

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQ (HZ)	WAVE LENGTH (METERS)	PROBE SPACING (METERS)		DISTANCE TO BEACH (METERS)
						X12	X13	
1A	Monochromatic	0.2	1.25	0.8000	2.41	0.241	0.6	7.32
2A	Monochromatic	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
3A	Monochromatic	0.2	2.0	0.5000	5.21	0.521	1.65	7.32
4A	Monochromatic	0.2	2.5	0.4000	6.99	0.699	1.65	7.32
5A	JONSWAP	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
6A	JONSWAP	0.2	2.0	0.5000	5.21	0.521	1.65	7.32
7A	PM	-	1.5	0.6667	3.35	0.335	0.6	7.32
8A	PM	-	2.0	0.5000	5.21	0.521	1.65	7.32
9A	TMA	0.2	1.5	0.6667	3.35	0.335	0.6	7.32
10A	TMA	0.2	2.0	0.5000	5.21	0.521	1.65	7.32

Table 15: Test plan for Phase IX

TEST #	WAVE TYPE	WAVE HEIGHT (METERS)	PERIOD (SEC)	FREQ (HZ)	ARA		DIST WAVE GENERATOR (METERS)
					local	overall	
A1	Mono	0.1	1.5	0.6667	0.1	1.0	4.57
A2	Mono	0.1	1.5	0.6667	-	-	4.57
A3	Mono	0.1	2.0	0.5000	0.1	1.0	4.57
A4	Mono	0.1	2.0	0.5000	-	-	4.57

3.3 Data Processing

3.3.1 Zero-Crossing Analysis

In the time domain certain physical characteristics, such as maximum wave height, mean period, significant wave height etc., may be obtained by performing a zero crossing analysis on a time series. According to this method, waves are defined as a portion of the wave record with two successive zero up or two successive down crossings, see Figure 27. This is the method GEDAP uses to define waves in the time domain.

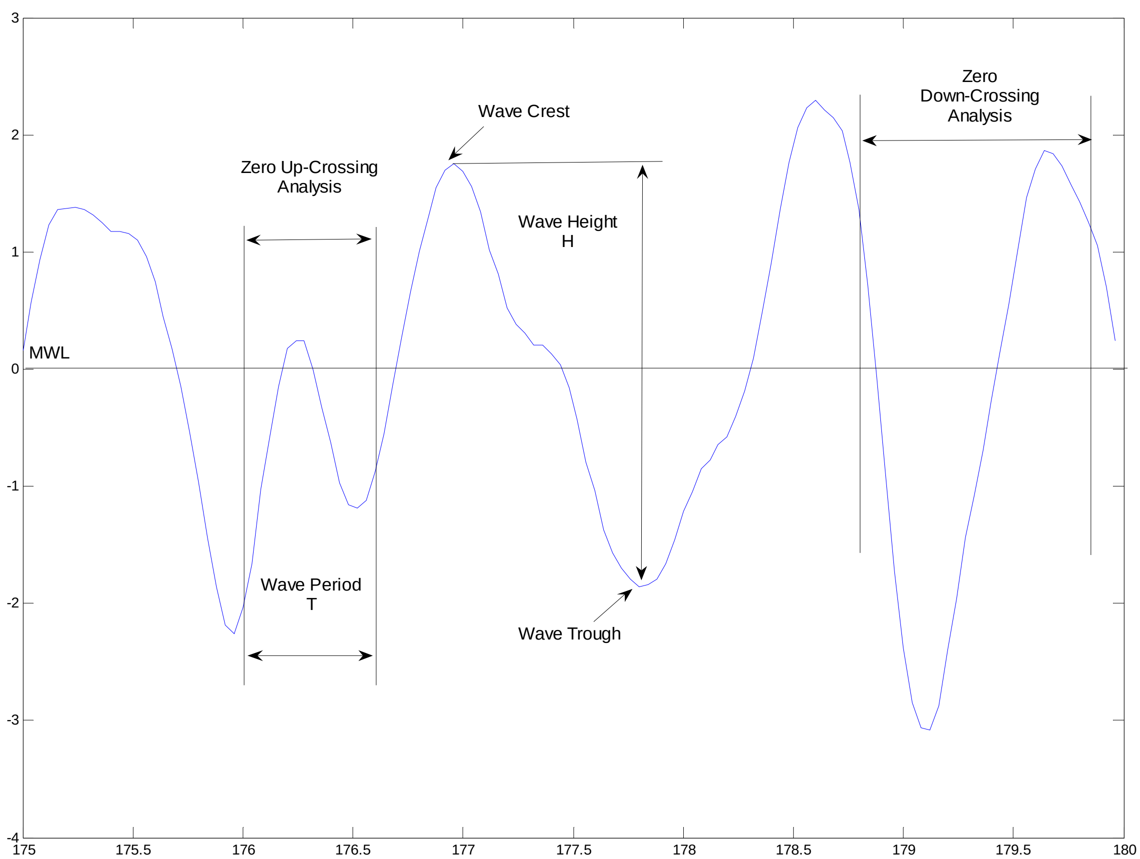

Figure 27. Zero cross analysis diagram

3.3.2 Cross-Correlation

Since there is a time lag between the generated target wave trace and the recorded wave elevation data the two data sets must be synchronized in order to compare for similarities. The time lag (τ) is calculated between the two signals and locates when Rxy (τ), the cross correlation function, is maximum. This time shift is then applied to the recorded wave trace and a new signal is generated, which now has maximum correlation with the target wave trace. The cross correlation function is defined as:

$$Rxy(\tau) = \frac{Cxy(\tau)}{(sigma\_x * sigma\_y)} \tag{3.45}$$

where Cxy (τ) is the cross covariance function between x(t) and y(t), sigma_x the standard deviation of x(t) and sigma_y the standard deviation of y(t). When the two signals are identical Rxy (τ) is equal to 1.0 at (τ) = 0. The cross covariance function, Cxy (τ), is defined as:

$$Cxy(\tau) = E\left[\left(x(t) - x_{mean}\right) * \left(y(t+\tau) - y_{mean}\right)\right] \tag{3.46}$$

where E[z] is the expected value of z, x_{mean} is the mean value of x(t) and y_{mean} is the mean value of y(t). The cross covariance is calculated using FFT which is much faster than computing the cross covariance in the time domain. To avoid Gibbs oscillation, which is an oscillation in the frequency domain that is caused by truncation of the signal in the time domain, in the cross covariance a linear taper is applied to the first and last five percent of the x(t) and y(t) signals (Miles, 1997). The signal is resampled using cubic spline interpolation to N2 points where N2 is the integer power of 2 that is required for FFT.

3.3.3 Variance Spectral Density Analysis

The spectral analysis was completed in the same manner as it was performed with the ADV data, see Section 2.3.2 Spectral Analysis.

3.3.4 Signal Restoration

Occasionally measured signals may contain some errors, such as glitches that must be cleaned up before analysis may occur. These errors are typically caused by sensor saturation or exceeding the voltage of the converter. The wireless wave gauges were sometimes subject to data drop outs, reducing the quality of the data. Several approaches using the GEDAP program were used depending on the severity of the errors.

For minor errors, such as a few clipped peaks or troughs, the signal was restored by applying a cubic spline interpolation to the data set to estimate the original shape of the wave data. The user identifies a valid range for the peaks and troughs within the data set which allows the program to identify the valid parts of the signal. This approach was best used for monochromatic waves. (Miles, 1997)

For irregular waves a different approach is needed that will accurately identify the errors within the data set. By first calculating the first derivation of the signal any point that exceeds alpha (α) * sigma (σ) where sigma is the standard deviation of the first derivative and alpha is the nondimensional glitch detection level selected by the user, typical values are 3.5 for a Gaussian distributed signal. For signals with abundant errors selecting a lower value of alpha will increase the number of detected glitches. Consequently good segments of the signal may be identified as glitches. Upon detection of the glitch the seven points by the glitch were removed and replaced by using cubic spline interpolation. (Miles, 1997)

Another approach to fix irregular waves when the previous approach doesn't work is to use a minimum sigma search method. Initially the user identifies a length of time in the record that has no glitches in which the mean and standard deviation can be calculated to determine the upper and lower limits of the wave data. These limits are identified as the following:

$$Y_1 = Y_{mean} - (\alpha * \sigma) \tag{3.47}$$

$$Y_2 = Y_{mean} + (\alpha * \sigma) \tag{3.48}$$

The data is then searched to identify all valid data points which fall within the time span and are checked against the limits. Any point identified that is considered invalid is discarded. For each valid point identified the mean, sigma, Y_1 and Y_2 are recomputed. The valid points are then sorted into increasing order by time and linear interpolation is applied to fill in the gaps from the discarded data points. (Miles, 1997)

Finally, for those data records in which there are errors that can not be removed, the user can identify the beginning and end time for the glitch. The glitch can then be removed and cubic spline interpolation is applied to fill in the gaps.

3.4 Results

3.4.1 Waves

In the configuration the wave generator was tested in, the generated waves will be most like the target wave in the middle of the tank. For that reason, these results will focus on the data collected in the middle of the tank. Appendix C and E contain the correlation and power spectrum plots for all data collected within the wave basin. In Appendix E, it will be noticed that there are some spikes outside of the areas they should be, see figure E-50 as an example. The results are good for those channels numerically, but due to the data having to be processed extensively to clean it the data plots in the wrong place. Appendix D contains numerical wave characteristics and correlation values for the wave tests.

Tests for half meter water depth were run with 0.1 and 0.2 meter wave heights for regular and irregular spectra. For regular wave tests the 0.1 meter waves were close to the target wave trace. Some energy loss and crest flattening was evident, especially with the 2.0 and 2.5 second period waves, but the shorter period waves looked good, see Figure 28. However, periods of 0.75 and in some cases 1.0 second can not be used in the tank. These periods generate a cross oscillation within the tank. One second period waves can be used if the water in the tank is completely still before running, otherwise the oscillation will occur.

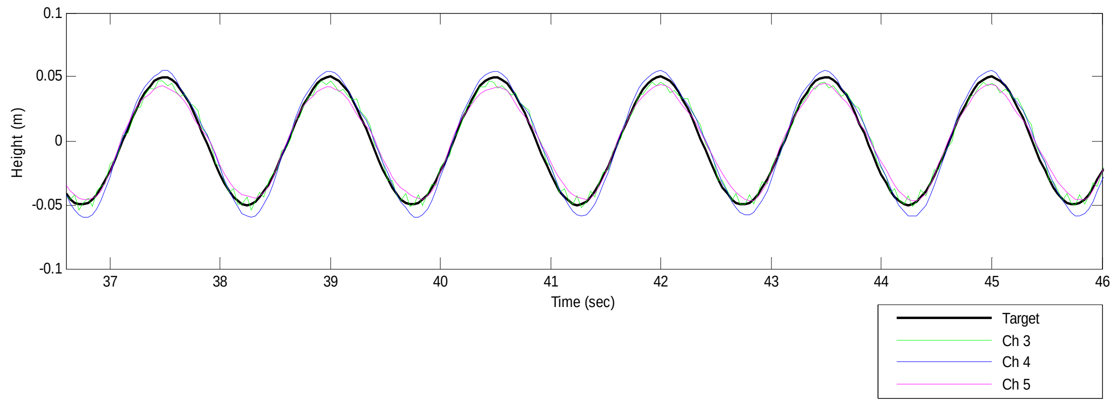

Figure 28: Test 1, monochromatic, h = 0.5 m, H = 0.1 m, T = 1. 5 sec, Ch 3 - 5

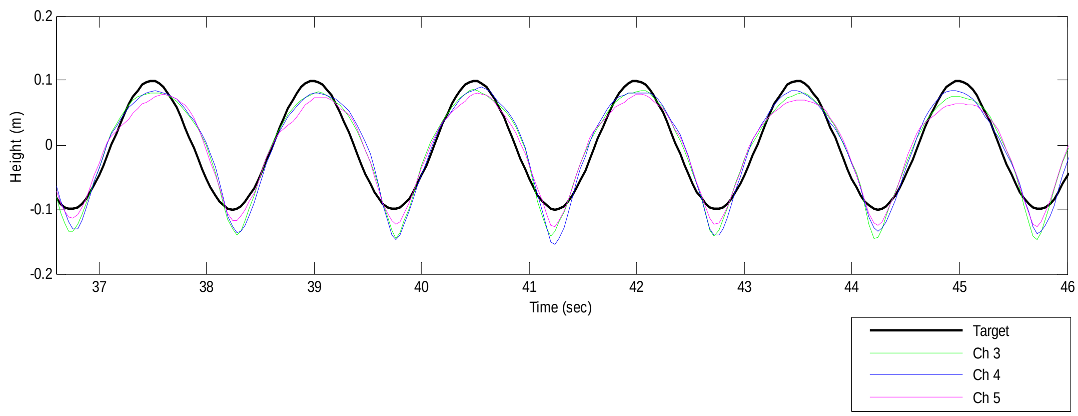

Figure 29: Test 18, monochromatic, h = 0.5 m, H = 0.2 m, T = 1.5 sec, Ch 3 – 5

Comparing the tests without buoys to the same tests completed with buoys in place showed an improvement. With buoys in place high frequency noise was reduced and crest shape was much closer to ideal. Power spectrum plots were generated for each wave test as well. These power spectra confirmed the results of the correlation plots. In these it was quite evident that buoys improved the characteristics of nearly all of the waves.

For example a 1.5 second period JONSWAP wave, see Figure 30 and Figure 31, shows a double peaked spectrum for wave gauge number four, which is in the center of the tank, in the test without buoys. The test with buoys shows channel four being closer to the target spectrum and without the second peak.

The 0.2 meter waves had high energy loss, sharpening of the troughs and broadening of peaks, see Figure 29. While running tests this was visually evident because of some wave breaking occurring in the tank. Viewing a power spectrum of a 0.2 meter wave height JONSWAP wave confirms the loss of energy, see Figure 32. Due to the inability to generate the target wave trace these tests were not repeated with buoys. Overall the 0.1 meter waves were close to ideal, especially with buoys in place, and the 0.2 meter waves may not be adequate for all experimental purposes because of the energy loss.

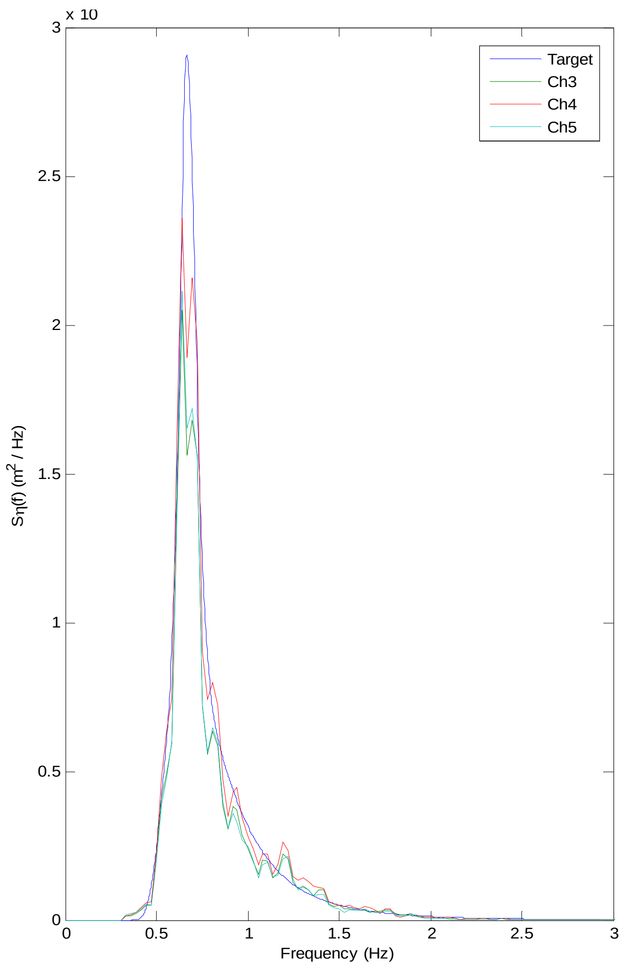

Figure 30: Power spectrum plot of JONSWAP wave, h = 0.5 m, H = 0.1 m, T = 1.5 sec

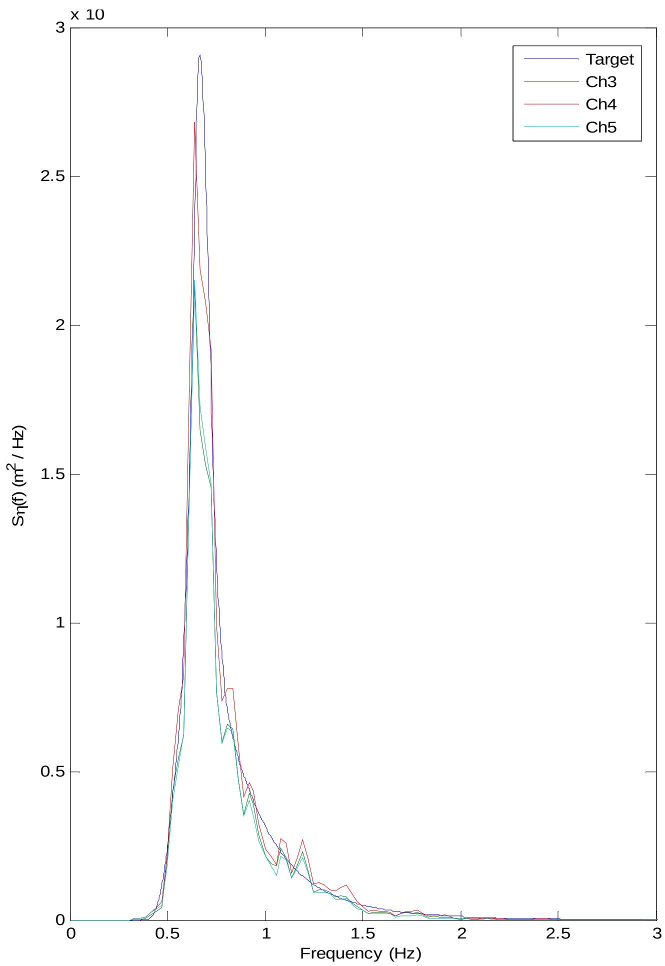

Figure 31: Power spectrum plot of JONSWAP wave with buoys , h = 0.5 m, H = 0.1 m, T = 1.5 sec

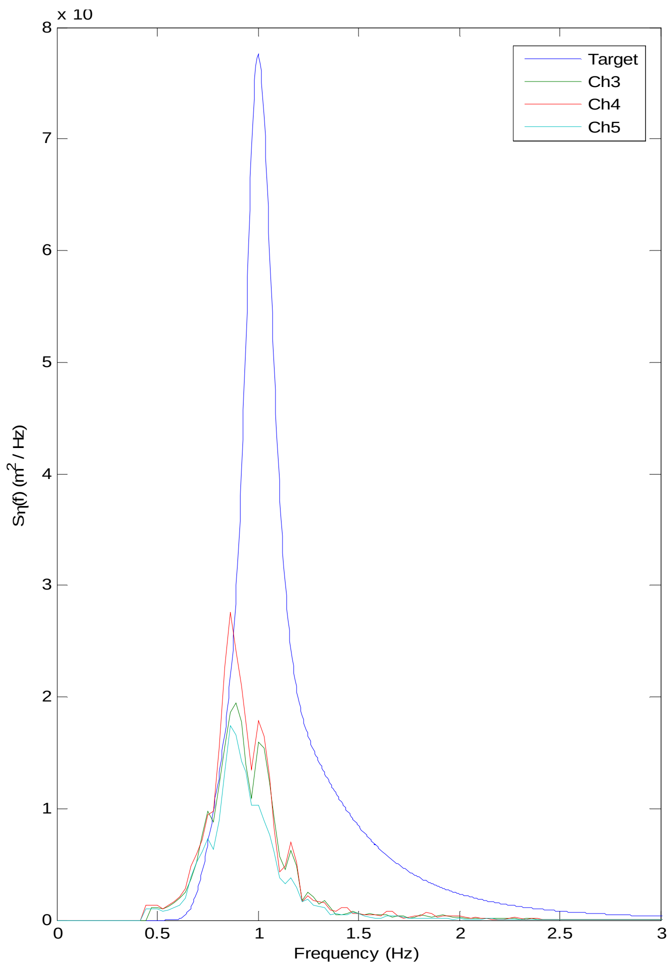

Figure 32: Power spectrum plot of JONSWAP wave, h = 0.5 m, H = 0.2 m, T = 1.0 sec

It was apparent that correlation was low for 1.0 second period waves in all three irregular wave spectra; see Figure 33 for an example. Periods of 1.5 second correlated much better, see Figure 34. For 2.0 second waves the front three channels (0 – 2) and the rear three channels (6 – 8) correlated better than the middle channels (3 – 5). The center of the tank seemed to have more reflected energy in it. In the PM spectra tests the larger features correlated much better than the small ones, this may be due to reflected energy from the beach. Like with the monochromatic waves, the 0.2 meter waves did not correlate as well to the target spectra. Energy loss was apparent in places with flattened crests and narrow troughs. Power spectra, like Figure 32, corroborate the visual impression. Overall the JONSWAP spectra correlated the best throughout all tests, while TMA waves were the worst; see Figure 35 and Figure 36.

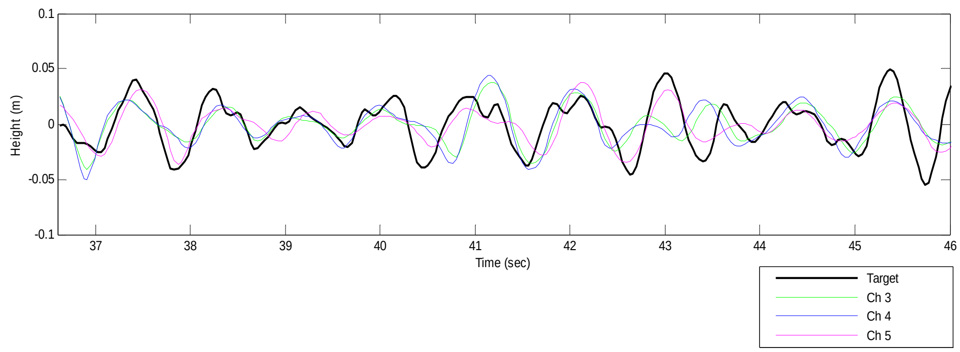

Figure 33: Test 13, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 3 – 5

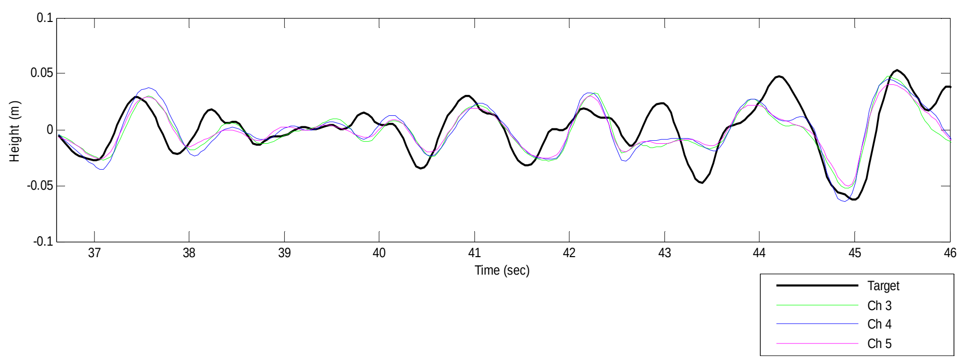

Figure 34: Test 14, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 3 – 5

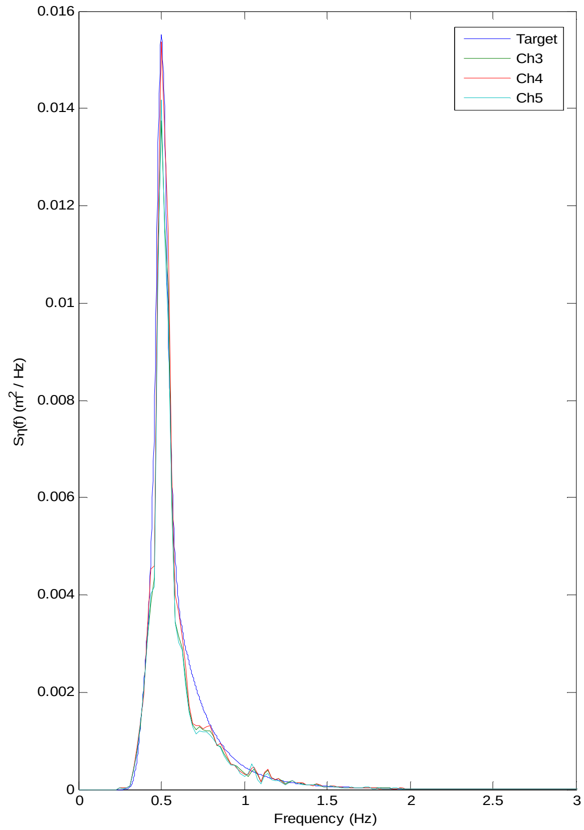

Figure 35: Test 36, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec

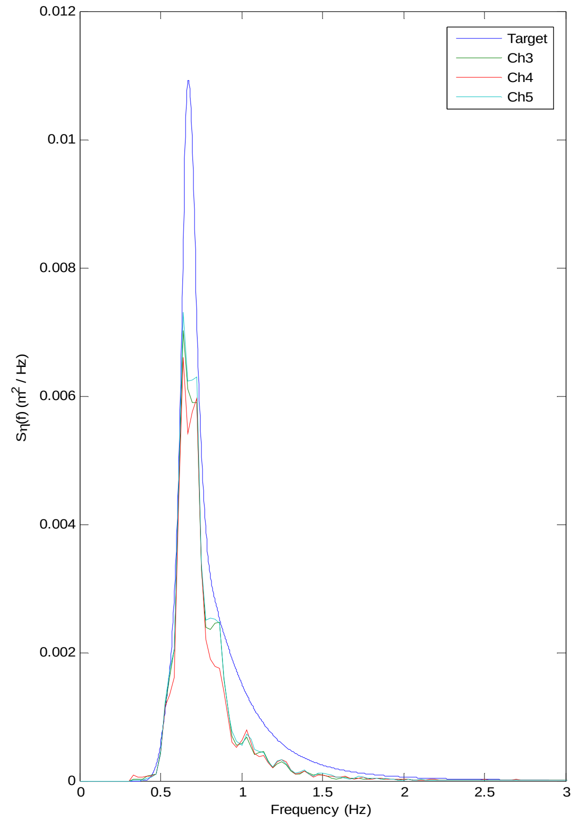

Figure 36: Test 40 with buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec

The tests with buoys in place correlated much better than those tests run without buoys, see Figure 37 and Figure 38. Another recurrent feature in the data is the effect the buoys had on the entire front channel (0 – 2) data. The wave heights at the three locations were somewhat different from each other, whereas the data grouped well in the other channels.

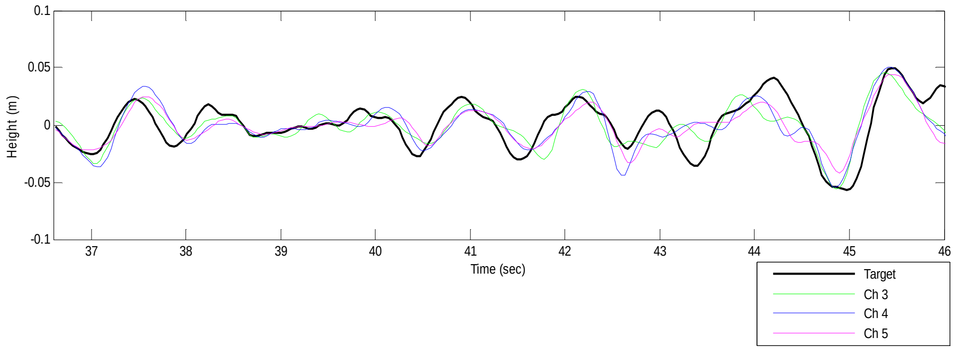

Figure 37: Test 10, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

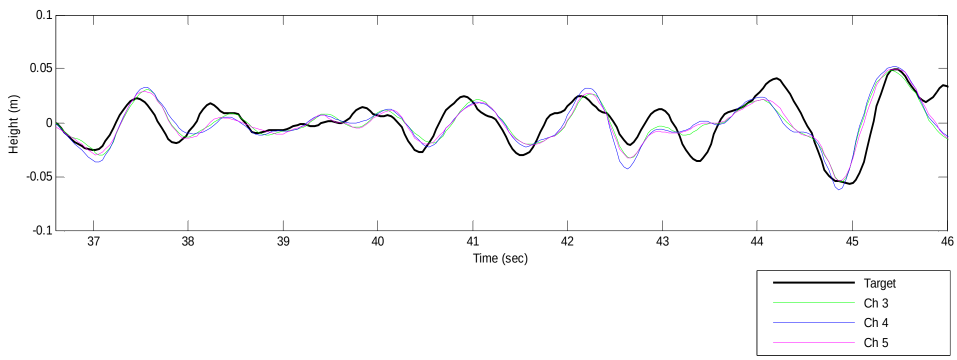

Figure 38: Test 10 with buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

A series of wave tests was run with h = 1.0 meter. Monochromatic and irregular wave spectra were tested with H = 0.2 meters. Each test was also repeated with the buoys in place. The test results with one meter of water showed similar wave generation and propagation behavior in the tank. Results for 0.2 meter waves in one meter water depth were much better than those produced with one-half meter water depth. Some energy loss did occur in the tests run without buoys. Once again, the tests run with buoys in place were closer to the target wave trace. Correlation and power spectrum plots both show that wave characteristics are superior with the buoys in the tank.

3.4.2 Reflection

Any wave basin with a wave absorber needs to have the reflection measured to understand how models will react to the system. A typical reflection value for a rubble-mound beach is around 10 percent. The first set of tests was done with a water depth of 0.5 meters. Initial testing of 0.1 meter monochromatic waves produced reflection values ranging from 6.85 – 16.51 percent, see Table 16. The 0.2 meter monochromatic waves had somewhat higher reflection values, which are expected due to the larger energy waves, see Table 18. Data for the 0.1 and 0.2 meter monochromatic waves without ARA engaged was collected using the wired wave gauges. The tests that had ARA active and the irregular wave tests were completed using the wireless wave gauges. The data dropouts that occurred frequently from the wireless wave gauges seemed to have adversely affected the reflection analysis, see Table 17, Table 18, Table 19 and Table 20. The data was unable to be adequately cleaned and this is the reason for such high reflection values.

For irregular waves, very little was able to be determined because of wave gauge problems. The 1.5 second period tests did seemingly provide good information, all being below 10 percent, see Table 19 and Table 20. The wave gauge problems seem to be amplified with 1.0 and 2.0 second periods, but the problems were virtually non-existent with a 1.5 second period. The reason for this is unknown, but the fact that 1.5 second period data is clean means that there are good reflection values for each irregular wave spectra.

Table 16: Beach reflection, monochromatic wave, h= 0.5 m, H = 0.1 m

Test #	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm)		Reflection	Average
				X12	X13		
1	1.00	0.10	1.50	0.15	0.50	3.78%	7.75%
1a	1.00	0.10	1.50	0.15	0.50	8.94%	
1b	1.00	0.10	1.50	0.15	0.50	10.54%	
3	1.25	0.10	2.20	0.20	0.50	14.62%	15.09%
3a	1.25	0.10	2.20	0.20	0.50	15.14%	
3b	1.25	0.10	2.20	0.20	0.50	15.51%	
5	1.50	0.10	2.80	0.28	0.50	8.64%	8.33%
5a	1.50	0.10	2.80	0.28	0.50	8.42%	
5b	1.50	0.10	2.80	0.28	0.50	7.92%	
7	2.00	0.10	4.00	0.40	0.95	16.50%	16.51%
7a	2.00	0.10	4.00	0.40	0.95	16.49%	
7b	2.00	0.10	4.00	0.40	0.95	16.55%	
9	2.50	0.10	5.24	0.52	0.95	6.65%	6.85%
9a	2.50	0.10	5.24	0.52	0.95	6.91%	
9b	2.50	0.10	5.24	0.52	0.95	6.98%	

Table 17: Beach reflection, monochromatic wave with ARA, h = 0.5 m, H = 0.1 m

Test #	Period	Wave Ht	Calc L	Wave Probe Spacing (cm)		ARA		Reflection	Average
	(sec)	(m)	(m)	X12	X13	overall	local		
15a	1.00	0.10	1.50	0.15	0.50	1.00	0.10	45.14%	
15b	1.00	0.10	1.50	0.15	0.50	1.00	0.10	5.92%	30.37%
15c	1.00	0.10	1.50	0.15	0.50	1.00	0.10	40.04%	
14a	1.25	0.10	2.20	0.20	0.50	1.00	0.10	4.78%	
14b	1.25	0.10	2.20	0.20	0.50	1.00	0.10	4.55%	4.49%
14c	1.25	0.10	2.20	0.20	0.50	1.00	0.10	4.14%	
13a	1.50	0.10	2.80	0.28	0.50	1.00	0.10	32.74%	
13b	1.50	0.10	2.80	0.28	0.50	1.00	0.10	31.37%	32.13%
13c	1.50	0.10	2.80	0.28	0.50	1.00	0.10	32.29%	
11a	2.00	0.10	4.00	0.40	0.95	1.00	0.10	38.00%	
11b	2.00	0.10	4.00	0.40	0.95	1.00	0.10	37.40%	37.38%
11c	2.00	0.10	4.00	0.40	0.95	1.00	0.10	36.75%	
12a	2.50	0.10	5.24	0.52	0.95	1.00	0.10	10.43%	
12b	2.50	0.10	5.24	0.52	0.95	1.00	0.10	9.95%	10.18%
12c	2.50	0.10	5.24	0.52	0.95	1.00	0.10	10.17%	

Table 18: Beach reflection, monochromatic wave, h = 0.5 m, H = 0.2 m

Test #	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm) X12	X13	Reflection	Average
2	1.00	0.20	1.50	0.15	0.50	14.52%	
2a	1.00	0.20	1.50	0.15	0.50	12.12%	14.62%
2b	1.00	0.20	1.50	0.15	0.50	17.23%	
4	1.25	0.20	2.20	0.20	0.50	15.91%	
4a	1.25	0.20	2.20	0.20	0.50	16.81%	16.74%
4b	1.25	0.20	2.20	0.20	0.50	17.51%	
6	1.50	0.20	2.80	0.28	0.50	4.81%	
6a	1.50	0.20	2.80	0.28	0.50	6.75%	5.96%
6b	1.50	0.20	2.80	0.28	0.50	6.32%	
8	2.00	0.20	4.00	0.40	0.95	30.71%	
8a	2.00	0.20	4.00	0.40	0.95	22.14%	24.80%
8b	2.00	0.20	4.00	0.40	0.95	21.56%	
10	2.50	0.20	5.24	0.52	0.95	5.99%	
10a	2.50	0.20	5.24	0.52	0.95	6.04%	5.78%
10b	2.50	0.20	5.24	0.52	0.95	5.31%	

Table 19: Beach reflection, irregular waves, h = 0.5 m, H = 0.1 m

Test #	Spectrum	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm) X12	Wave Probe Spacing (cm) X13	Reflection	Average
1a	JONSWAP	1.00	0.10	1.50	0.15	0.50	11.61%	13.23%
1b		1.00	0.10	1.50	0.15	0.50	13.78%	
1c		1.00	0.10	1.50	0.15	0.50	14.29%	
3a		1.50	0.10	2.20	0.28	0.50	9.28%	6.57%
3b		1.50	0.10	2.20	0.28	0.50	4.04%	
3c		1.50	0.10	2.20	0.28	0.50	6.38%	
13a		2.00	0.10	2.80	0.40	0.95	47.90%	51.59%
13b		2.00	0.10	2.80	0.40	0.95	49.92%	
13c		2.00	0.10	2.80	0.40	0.95	56.94%	
9a	PM	1.00	0.10	1.50	0.15	0.50	70.24%	69.87%
9b		1.00	0.10	1.50	0.15	0.50	69.86%	
9c		1.00	0.10	1.50	0.15	0.50	69.51%	
5a		1.50	0.10	2.20	0.28	0.50	7.12%	6.24%
5b		1.50	0.10	2.20	0.28	0.50	6.85%	
5c		1.50	0.10	2.20	0.28	0.50	4.76%	
15a		2.00	0.10	2.80	0.40	0.95	69.63%	69.34%
15b		2.00	0.10	2.80	0.40	0.95	68.61%	
15c		2.00	0.10	2.80	0.40	0.95	69.77%	

Table 19 cont.

Test #	Spectrum	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm) X12	Wave Probe Spacing (cm) X13	Reflection	Average
11a	TMA	1.00	0.10	1.50	0.15	0.50	66.13%	65.58%
11b		1.00	0.10	1.50	0.15	0.50	65.38%	
11c		1.00	0.10	1.50	0.15	0.50	65.23%	
7a		1.50	0.10	2.20	0.28	0.50	6.42%	5.71%
7b		1.50	0.10	2.20	0.28	0.50	5.08%	
7c		1.50	0.10	2.20	0.28	0.50	5.63%	
17a		2.00	0.10	2.80	0.40	0.95	53.41%	53.52%
17b		2.00	0.10	2.80	0.40	0.95	53.61%	
17c		2.00	0.10	2.80	0.40	0.95	53.54%	

Table 20: Beach reflection, irregular waves with ARA, h = 0.5 m, H = 0.1 m

Test #	ARA		Spectrum	Period	Wave Ht	Calc L	Wave Probe Spacing (cm)		Reflection	Average
	local	overall		(sec)	(m)	(m)	X12	X13		
2a	1.00	0.20	JONSWAP	1.00	0.10	1.50	0.15	0.50	12.39%	16.93%
2b	1.00	0.20		1.00	0.10	1.50	0.15	0.50	19.41%	
2c	1.00	0.10		1.00	0.10	1.50	0.15	0.50	18.98%	
4a	1.00	0.10		1.50	0.10	2.20	0.28	0.50	8.45%	7.85%
4b	1.00	0.10		1.50	0.10	2.20	0.28	0.50	7.45%	
4c	1.00	0.10		1.50	0.10	2.20	0.28	0.50	7.65%	
14a	1.00	0.10		2.00	0.10	2.80	0.40	0.95	49.73%	82.53%
14b	1.00	0.10		2.00	0.10	2.80	0.40	0.95	86.77%	
14c	1.00	0.10		2.00	0.10	2.80	0.40	0.95	111.10%	
10a	1.00	0.10	PM	1.00	0.10	1.50	0.15	0.50	69.03%	69.05%
10b	1.00	0.10		1.00	0.10	1.50	0.15	0.50	69.40%	
10c	1.00	0.10		1.00	0.10	1.50	0.15	0.50	68.72%	
6a	1.00	0.10		1.50	0.10	2.20	0.28	0.50	6.20%	6.21%
6b	1.00	0.10		1.50	0.10	2.20	0.28	0.50	6.84%	
6c	1.00	0.10		1.50	0.10	2.20	0.28	0.50	5.59%	
16a	1.00	0.10		2.00	0.10	2.80	0.40	0.95	72.61%	71.13%
16b	1.00	0.10		2.00	0.10	2.80	0.40	0.95	69.92%	
16c	1.00	0.10		2.00	0.10	2.80	0.40	0.95	70.86%	

Table 20 cont.

Test #	ARA		Spectrum	Period	Wave Ht	Calc L	Wave Probe Spacing (cm)		Reflection	Average
	local	overall		(sec)	(m)	(m)	X12	X13		
12a	1.00	0.10		1.00	0.10	1.50	0.15	0.50	65.42%	
12b	1.00	0.10		1.00	0.10	1.50	0.15	0.50	65.30%	64.95%
12c	1.00	0.10		1.00	0.10	1.50	0.15	0.50	64.14%	
8a	1.00	0.10		1.50	0.10	2.20	0.28	0.50	5.38%	
8b	1.00	0.10	TMA	1.50	0.10	2.20	0.28	0.50	6.31%	5.67%
8c	1.00	0.10		1.50	0.10	2.20	0.28	0.50	5.33%	
18a	1.00	0.10		2.00	0.10	2.80	0.40	0.95	53.92%	
18b	1.00	0.10		2.00	0.10	2.80	0.40	0.95	54.05%	53.97%
18c	1.00	0.10		2.00	0.10	2.80	0.40	0.95	53.95%	

.

Reflection analysis was also completed for 1.0 meter water depth, 0.2 meter monochromatic waves. The results were slightly lower on average than 0.5 meter water depth, ranging from 4.1 – 10.3 percent, see Table 21. This data was also collected with wireless wave gauges but the data dropout problems were not significant enough to affect the analysis. ARA testing was done as well with slightly higher reflection than without, see Table 21. The three irregular wave spectra were run as well for this water depth and wave height. This data did not have the same problems that recurred in the 0.5 meter water depth data. Irregular wave reflection showed mostly below 10 percent reflection, see Table 23 and Table 24. Throughout all of the reflection analysis some trends were apparent. The most significant is that all waves with a two second periods had higher reflection values.

Table 21: Beach reflection, monochromatic wave, h = 1.0 m, H = 0.2 m

Test #	**Period** (sec)	**Wave Ht** (m)	**Calc L** (m)	**Wave Probe Spacing (cm)** X12	X13	**Reflection**	**Average**
R7a	1.25	0.20	2.41	0.24	0.60	2.823%	4.136%
R7b	1.25	0.20	2.41	0.24	0.60	5.015%	
R7c	1.25	0.20	2.41	0.24	0.60	4.570%	
R5a	1.50	0.20	3.35	0.34	0.60	5.878%	5.630%
R5b	1.50	0.20	3.35	0.34	0.60	4.775%	
R5c	1.50	0.20	3.35	0.34	0.60	6.237%	
R3a	2.00	0.20	5.21	0.52	1.65	10.130%	10.273%
R3b	2.00	0.20	5.21	0.52	1.65	10.500%	
R3c	2.00	0.20	5.21	0.52	1.65	10.190%	
R1a	2.50	0.20	6.99	0.70	1.65	5.314%	5.304%
R1b	2.50	0.20	6.99	0.70	1.65	5.090%	
R1c	2.50	0.20	6.99	0.70	1.65	5.507%	

Table 22: Beach reflection, monochromatic wave with ARA, h = 1.0 m, H = 0.2 m

Test #	ARA		Period	Wave Ht	Calc L	Wave Probe Spacing (m)		Reflection	Average
	local	overall	(sec)	(m)	(m)	X12	X13		
R8a	1.00	0.10	1.25	0.20	2.41	0.24	0.60	5.075%	
R8b	1.00	0.10	1.25	0.20	2.41	0.24	0.60	8.698%	7.393%
R8c	1.00	0.10	1.25	0.20	2.41	0.24	0.60	8.406%	
R6a	1.00	0.10	1.50	0.20	3.35	0.34	0.60	5.254%	
R6b	1.00	0.10	1.50	0.20	3.35	0.34	0.60	5.104%	5.077%
R6c	1.00	0.10	1.50	0.20	3.35	0.34	0.60	4.873%	
R4a	1.00	0.10	2.00	0.20	5.21	0.52	1.65	9.996%	
R4b	1.00	0.10	2.00	0.20	5.21	0.52	1.65	9.953%	9.969%
R4c	1.00	0.10	2.00	0.20	5.21	0.52	1.65	9.958%	
R2a	1.00	0.10	2.50	0.20	6.99	0.70	1.65	5.350%	
R2b	1.00	0.10	2.50	0.20	6.99	0.70	1.65	5.121%	5.236%
R2c	1.00	0.10	2.50	0.20	6.99	0.70	1.65	50.13%[6]	

[6] This value not included in average calculation due to data corruption from wireless wave gauge.

Table 23: Beach reflection, irregular waves, h = 1.0 m, H = 0.2 m

Test #	Spectrum	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm) X12	Wave Probe Spacing (cm) X13	Reflection	Average
T7a	JONSWAP	1.50	0.20	3.35	0.34	0.60	81.44%[7]	10.39%
T7b		1.50	0.20	3.35	0.34	0.60	10.71%	
T7c		1.50	0.20	3.35	0.34	0.60	10.07%	
T1a		2.00	0.20	5.21	0.52	1.65	9.76%	9.55%
T1b		2.00	0.20	5.21	0.52	1.65	9.60%	
T1c		2.00	0.20	5.21	0.52	1.65	9.28%	
T9a	PM	1.50	-	3.35	0.34	0.60	3.18%	3.35%
T9b		1.50	-	3.35	0.34	0.60	3.39%	
T9c		1.50	-	3.35	0.34	0.60	3.48%	
T3a		2.00	-	5.21	0.52	1.65	7.16%	7.75%
T3b		2.00	-	5.21	0.52	1.65	8.03%	
T3c		2.00	-	5.21	0.52	1.65	8.05%	
T11a	TMA	1.50	0.20	3.35	0.34	0.60	6.96%	6.63%
T11b		1.50	0.20	3.35	0.34	0.60	7.75%	
T11c		1.50	0.20	3.35	0.34	0.60	5.18%	
T5a		2.00	0.20	5.21	0.52	1.65	10.16%	

[7] This value not included in average calculation due to data correction from wireless wave gauge.

Table 23 cont.

Test #	Spectrum	Period (sec)	Wave Ht (m)	Calc L (m)	Wave Probe Spacing (cm) X12	Wave Probe Spacing (cm) X13	Reflection	Average
T5b	TMA	2.00	0.20	5.21	0.52	1.65	8.86%	9.93%
T5c		2.00	0.20	5.21	0.52	1.65	10.76%	

Table 24: Beach reflection, irregular waves with ARA, h = 1.0 m, H = 0.2 m

Test #	ARA		Spectrum	Period	Wave Ht	Calc L	Wave Probe Spacing (cm)		Reflection	Average
	local	overall		(sec)	(m)	(m)	X12	X13		
T8a	1.00	0.10	JONSWAP	1.50	0.20	3.35	0.34	0.60	10.27%	9.00%
T8b	1.00	0.10		1.50	0.20	3.35	0.34	0.60	8.00%	
T8c	1.00	0.10		1.50	0.20	3.35	0.34	0.60	8.72%	
T2a	1.00	0.10		2.00	0.20	5.21	0.52	1.65	11.13%	10.20%
T2bb	1.00	0.10		2.00	0.20	5.21	0.52	1.65	8.68%	
T2c	1.00	0.10		2.00	0.20	5.21	0.52	1.65	10.79%	
T10a	1.00	0.10	PM	1.50	-	3.35	0.34	0.60	3.57%	4.11%
T10b	1.00	0.10		1.50	-	3.35	0.34	0.60	4.79%	
T10c	1.00	0.10		1.50	-	3.35	0.34	0.60	3.97%	
T4a	1.00	0.10		2.00	-	5.21	0.52	1.65	7.59%	7.79%
T4b	1.00	0.10		2.00	-	5.21	0.52	1.65	7.22%	
T4c	1.00	0.10		2.00	-	5.21	0.52	1.65	8.58%	

Table 24 cont.

Test #	ARA		Spectrum	Period	Wave Ht	Calc L	Wave Probe Spacing (cm)		Reflection	Average
	Local	Overall					X12	X13		
T12a	1.00	0.10	TMA	1.50	0.20	3.35	0.34	0.60	8.95%	8.89%
T12b	1.00	0.10		1.50	0.20	3.35	0.34	0.60	10.32%	
T12c	1.00	0.10		1.50	0.20	3.35	0.34	0.60	7.42%	
T6a	1.00	0.10		2.00	0.20	5.21	0.52	1.65	10.31%	10.26%
T6b	1.00	0.10		2.00	0.20	5.21	0.52	1.65	9.70%	
T6c	1.00	0.10		2.00	0.20	5.21	0.52	1.65	10.76%	

3.4.3 ARA

A test of the ARA was conducted by measuring the reflection off a stack of three concrete blocks located 8.23 meters from the wave generator with and without ARA active. For the 1.5 second period monochromatic waves with ARA active had a slightly higher reflection than waves without ARA. The ARA was able to compensate for reflection in the 2.0 second period monochromatic waves, see Table 25.

Table 25: Comparison of reflection off blocks with and without ARA, h = 0.5 m

Test #	**ARA**		**Period**	**Wave Ht**	**Reflection**
	local	overall	(sec)	(m)	
A1a	0.10	1.00	1.50	0.10	97.90%
A1b	0.10	1.00			97.21%
A1c	0.10	1.00			95.28%
A2a	-	-	1.50	0.10	92.55%
A2b	-	-			94.07%
A2c	-	-			90.74%
A3a	0.10	1.00	2.00	0.10	103.90%
A3b	0.10	1.00			108.00%
A3c	0.10	1.00			117.80%
A4a	-	-	2.00	0.10	120.10%
A4b	-	-			136.10%
A4c	-	-			114.80%

The ARA was not designed for these conditions which may help explain the poor performance. The most significant contributor to the performance is the fact that the ARA has not been tuned for the wave basin yet. There could be other contributors, such as localized build up of wave height and water level over time. However, once the ARA has been fine-tuned the performance should be improved.

CHAPTER IV

CONCLUSION

The velocity data taken in the tow tank shows that flow is not steady across the tank or along its length. The power spectra for Test 5, Stations 1 and 3, at location 22.86 meters identified three small peaks, one corresponding to an oscillation with a period of 1.8 seconds at Station 1 and the others of 1.58 and 2.28 seconds at the Station 3 side of the tank. These peaks also appeared in other spectra, however they were less defined. It appears that there is some oscillation occurring in the tow tank, but of very low magnitude. It seems that velocity fluctuations are not related to any regular oscillation occurring in the tow tank.

Varying degrees of success were obtained in the seven different tests conducted in the tow tank. In general, flow was more even as the tests went on, with Test 7 being the best. Test 7 was not perfect, however, and flow could be improved. Test 4 had filters near the diffuser and also before the weirs. Having filters at both ends helped steady the flow across and along the tank. A combination of the concrete blocks used in Test 7 with a horsehair filter in front of the weirs should prove better than anything used thus far. In the future this should be tested to determine if the flow differences are reduced.

The current state in the tow tank should be satisfactory for many experiments. Steadier flow across and along portions of the tank may be demanded of the tank in the future. A combination of filters will likely be found that can greatly reduce flow problems in the tank. However, these problems will never disappear due to the construction of the tow tank. The placement of the weirs, while allowing flexibility, will always funnel the water towards one side of the tank or the other.

Wave height data was recorded with both wired and wireless wave gauges. The gauges have advantages and disadvantages. The lab currently has only three wired wave gauges, and the relative placement between them is somewhat limited due to the wires connecting to the signal amplifier. The amplifier wanders over time and must be re-zeroed periodically. The wireless wave gauges do not have these disadvantages, with up to eight able to be used at the same time as well as there not being wires running between the gauges. However, the wireless gauges have a severe limitation. They are subject either to an external source of interference or an internal fault causes data dropouts. Much of the data collected with the wireless gauges needed to be run through multiple cleaning stages before it was fit to be analyzed. The source of the data loss needs to be determined but, once it is, the wireless wave gauges should prove to be a great data collection tool.

Testing the wave generator and wave basin was successful overall. Some limitations were found during testing, however. The worst problem with the basin is the cross-oscillation that occurs when short period waves, 0.75 and 1.0 second, are run. So far nothing has been found that will prevent the oscillation from occurring at 0.75 seconds. One-second period waves will develop the cross-oscillation unless the water is very still before they are run. Longer period waves did not develop this oscillation, so it is easy to avoid the cross-oscillation.

Waves correlated well in general, but energy loss was visible as flattened crests in correlation plots, and also in the power spectra, for many waves. Running the waves with buoys in place took care of most of the power loss. The correlation and power spectrum plots were nearly all better when buoys were in place. When the basin has 0.5 meters of water in it, the 0.1 meter waves were well formed, but 0.2 meter waves had energy loss from breaking. With one meter of water in the tank, both the 0.1 and 0.2 meter waves were well formed. Monochromatic waves correlated better than irregular waves, with typical correlation values greater than 0.9 for monochromatic and 0.5 to 0.7 being typical of irregular waves. Of the irregular wave spectra, JONSWAP were the best formed, as far as correlation and power spectra can reveal.

The wave generator is currently set up to generate the target wave in the center of the tank. The wave gauge data confirmed this for the most part. Channel 4, the center wave gauge, had better correlation and energy than did any other, in nearly every test. Channels 3 and 5, the gauges flanking number 4, showed nearly as good data as channel 4 did. It can be concluded that the wave generator is operating well, and working as designed.

The rubble mound beach works well as a wave absorber. Most reflection values were near or below 10 percent, which is what is to be expected. Also, as waves are run, the shape of the beach changes some, and may need to be re-shaped periodically. The most significant problems were with the wireless wave gauges. Before these gauges are used for experiments they need to have their problems investigated and resolved.

The wave generator's ARA function has only been operational for a short while and has seen very little use. ARA has only been tested in a limited sense and needs further investigation in the future to fully establish the capabilities of the system. The two gain settings, individual and overall, need to be experimented with to determine what will provide the best performance varying wave spectra. It is anticipated that wave quality will improve drastically once ARA is tested and proper settings are determined.

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APPENDIX A

VELOCITY PLOTS FOR TOW TANK

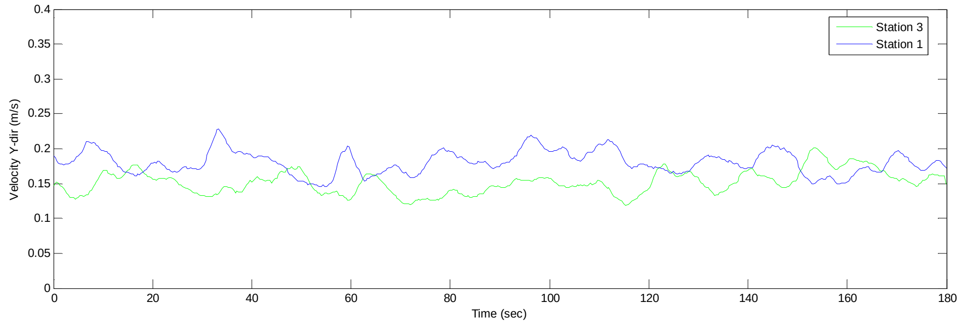

Figure A- 1 – TEST 1 Velocity Plot, Location 21.34 meters

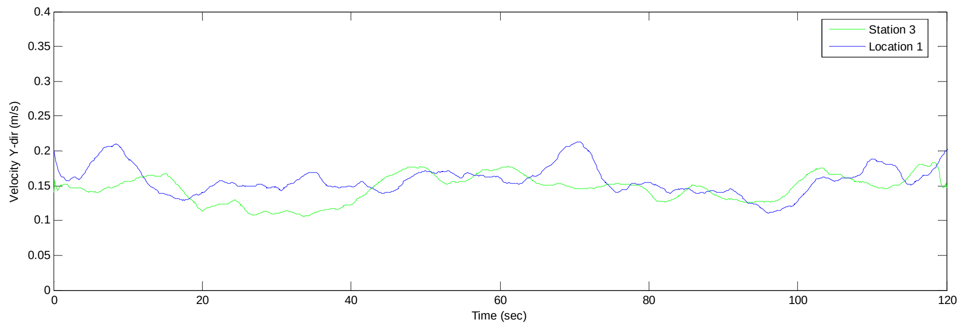

Figure A- 2– TEST 2 Velocity Plot, Location 16.76 meters

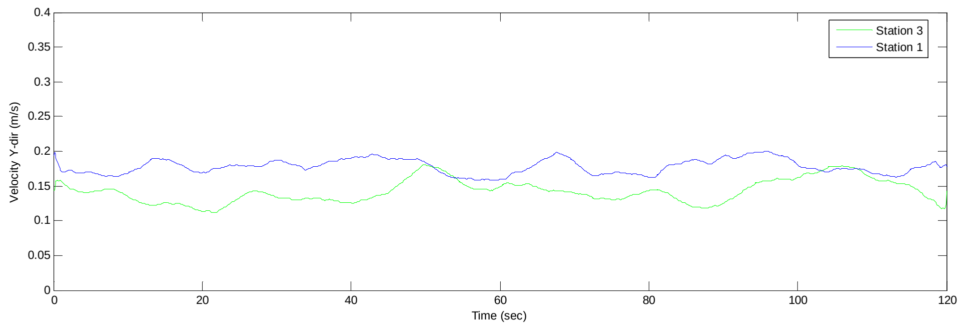

Figure A- 3 – TEST 2 Velocity Plot, Location 21.34 meters

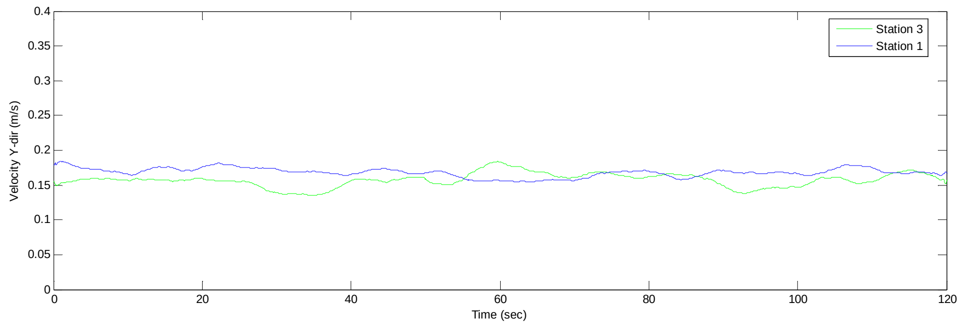

Figure A- 4 – TEST 2 Velocity Plot, Location 30.48 meters

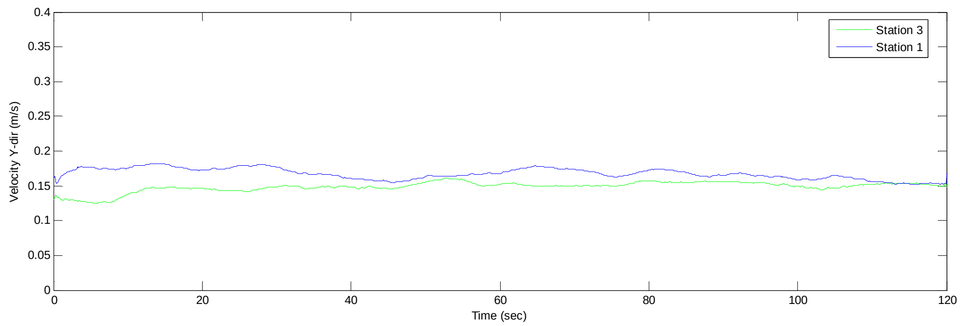

Figure A- 5 – TEST 2 Velocity Plot, Location 42.67 meters

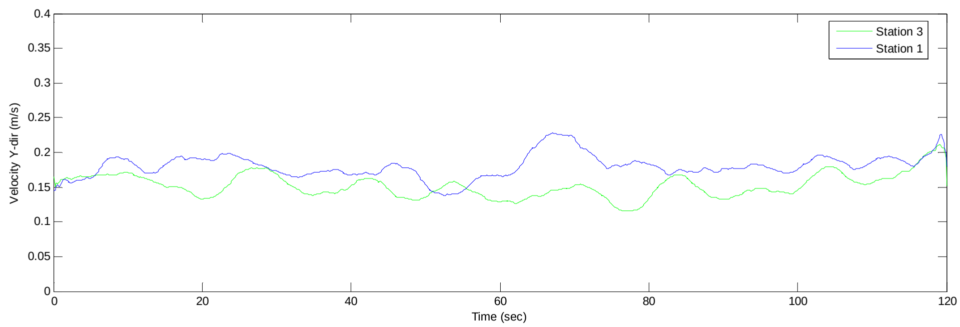

Figure A- 6 –TEST 3 Velocity Plot, Location 16.76 meters

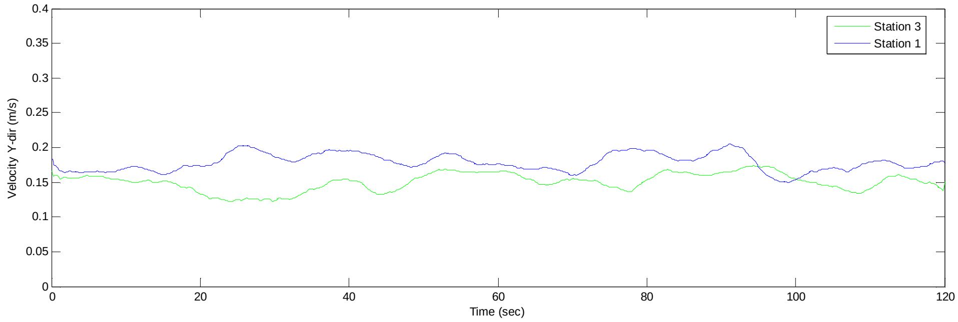

Figure A- 7 – TEST 3 Velocity Plot, Location 21.34 meters

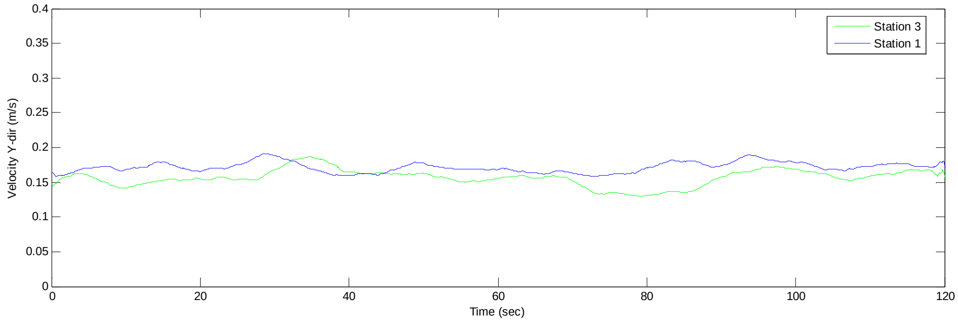

Figure A- 8 – TEST 3 Velocity Plot, Location 30.48 meters

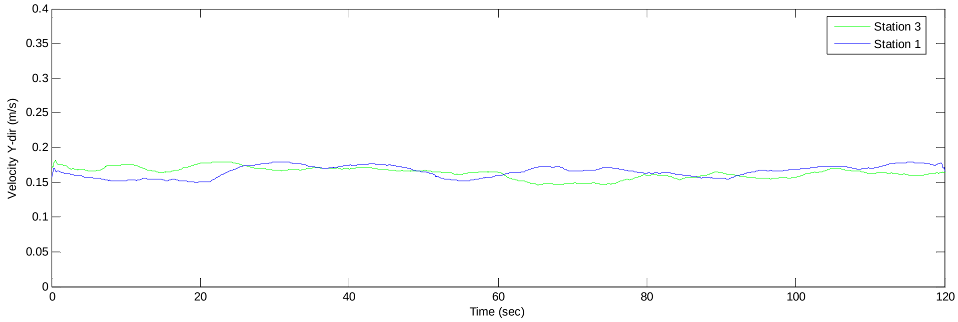

Figure A- 9 – TEST 3 Velocity Plot, Location 42.67 meters

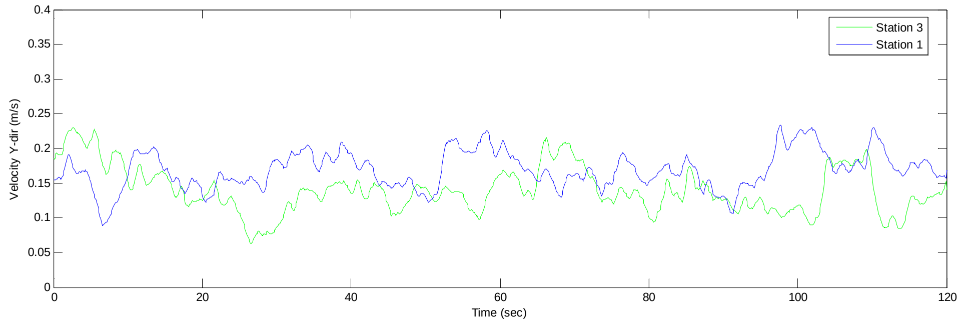

Figure A- 10 – TEST 4 Velocity Plot, Location 16.76 meters

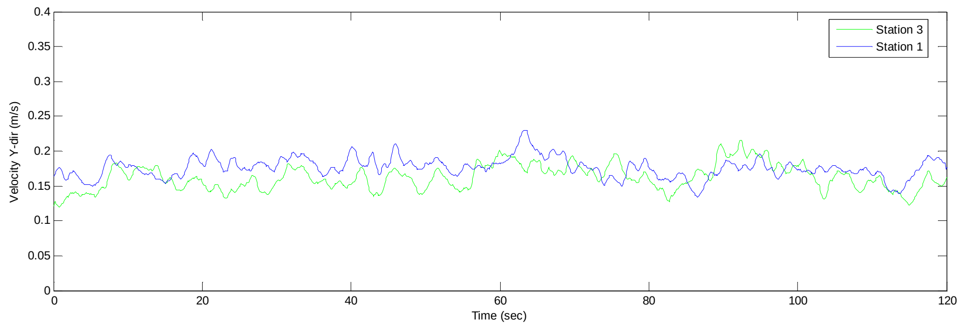

Figure A- 11 – TEST 4 Velocity Plot, Location 21.34 meters

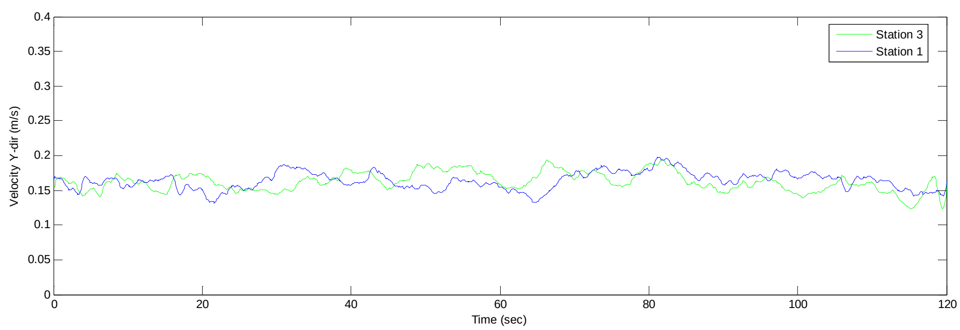

Figure A- 12 – TEST 4 Velocity Plot, Location 30.48 meters

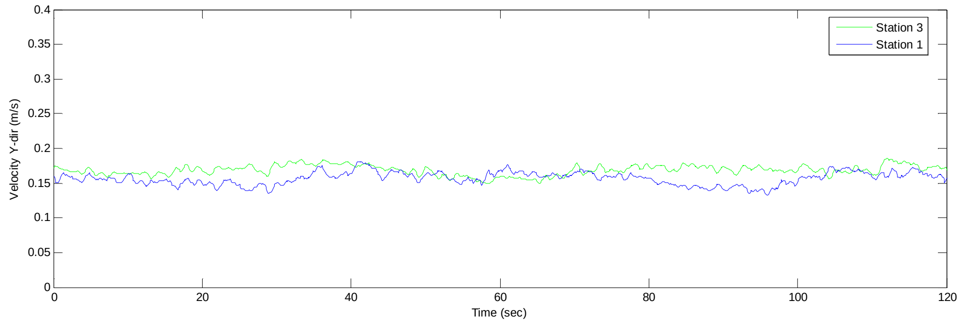

Figure A- 13 – TEST 4 Velocity Plot, Location 42.67 meters

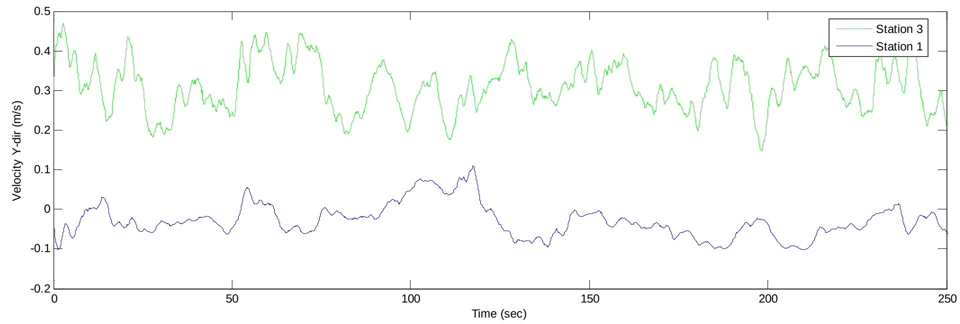

Figure A- 14 – TEST 5 Velocity Plot, Location 9.14 meters

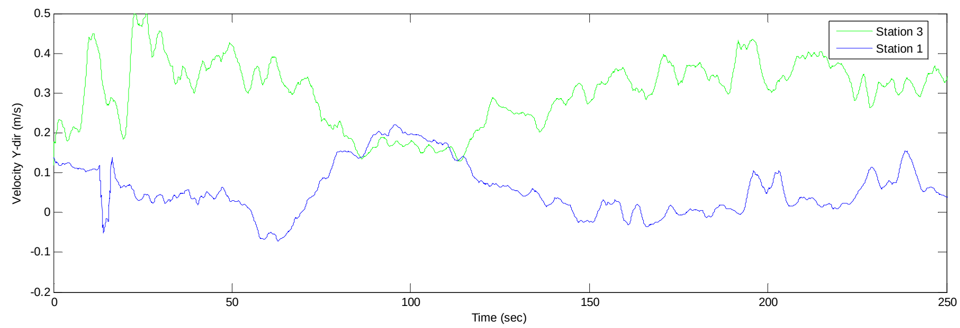

Figure A- 15 – TEST 5 Velocity Plot, Location 15.24 meters

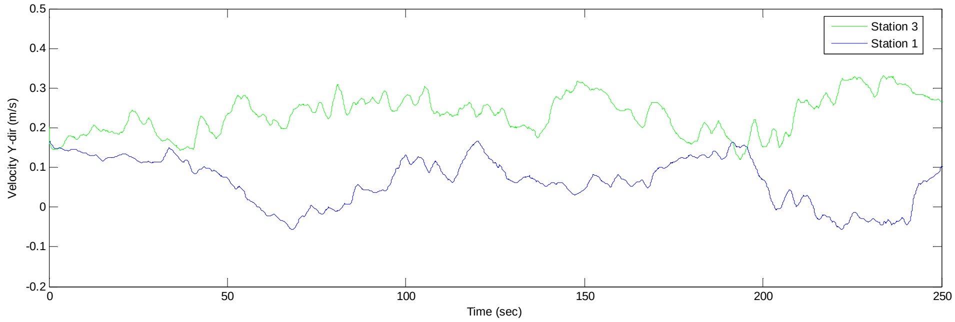

Figure A- 16 – TEST 5 Velocity Plot, Location 22.86 meters

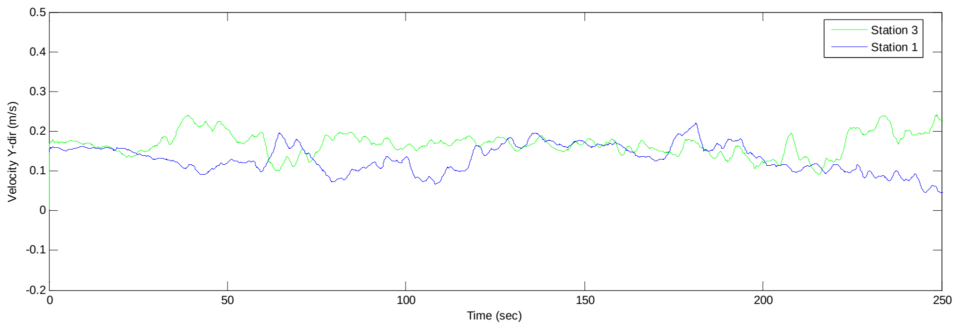

Figure A- 17 – TEST 5 Velocity Plot, Location 28.96 meters

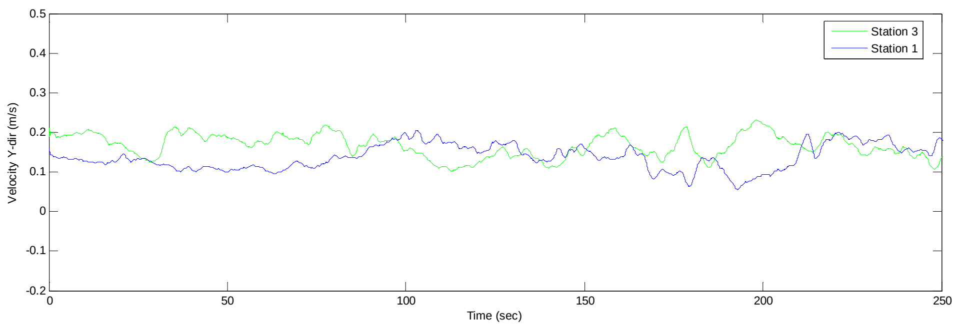

Figure A- 18 – TEST 5 Velocity Plot, Location 35.05 meters

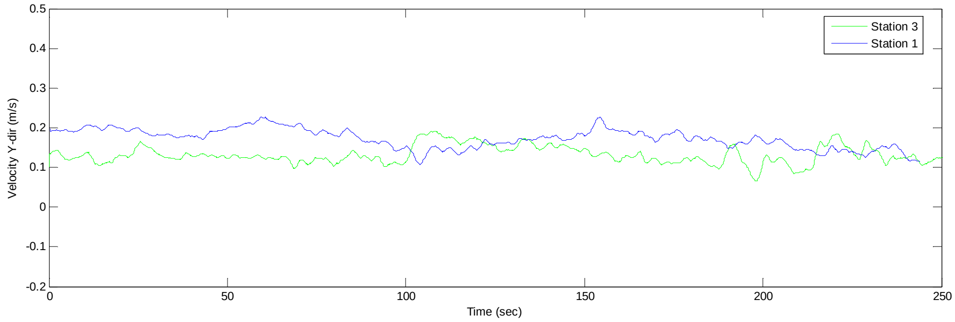

Figure A- 19 – TEST 5 Velocity Plot, Location 41.15 meters

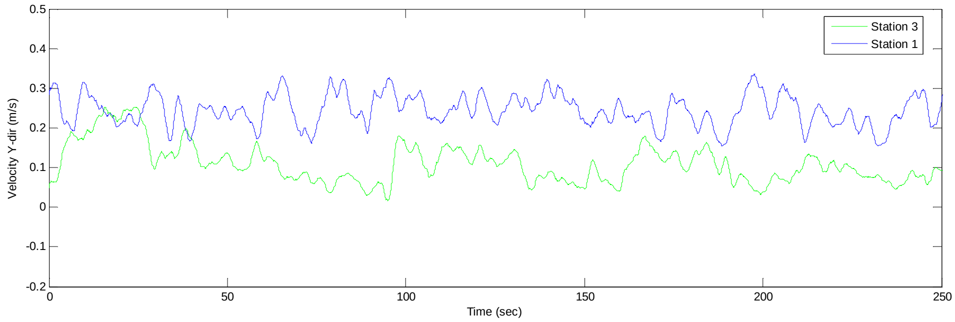

Figure A- 20 – TEST 6 Velocity Plot, Location 9.14 meters

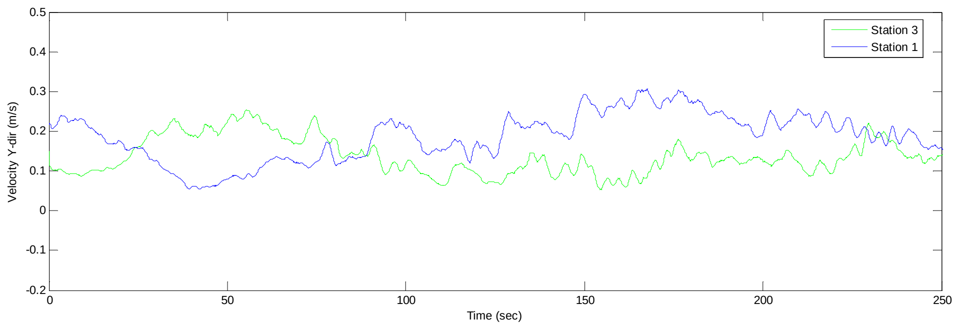

Figure A- 21 – TEST 6 Velocity Plot, Location 15.24 meters

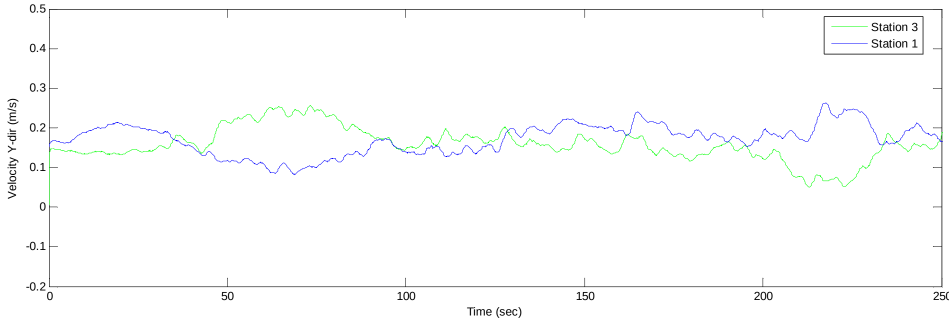

Figure A- 22- TEST 6 Velocity Plot, Location 22.86 meters

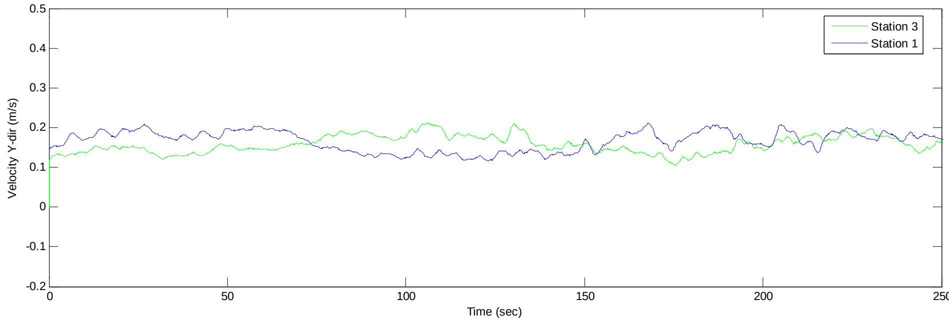

Figure A- 23 – TEST 6 Velocity Plot, Location 28.96 meters

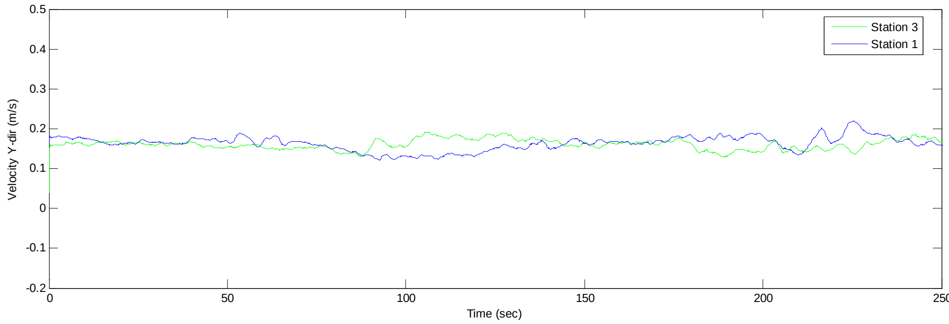

Figure A- 24 – TEST 6 Velocity Plot, Location 35.05 meters

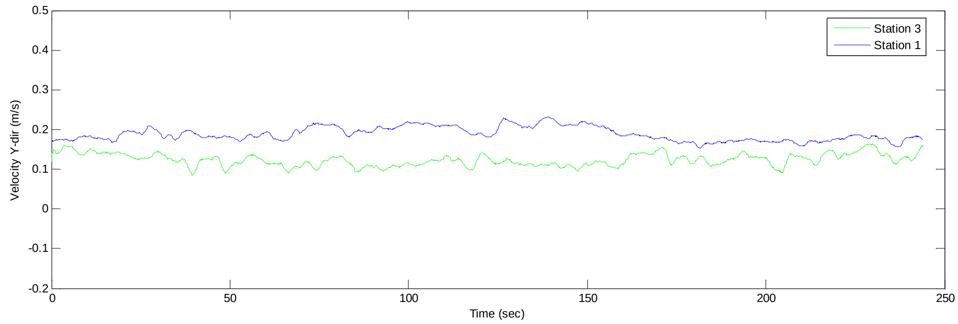

Figure A- 25 – TEST 6 Velocity Plot, Location 41.15 meters

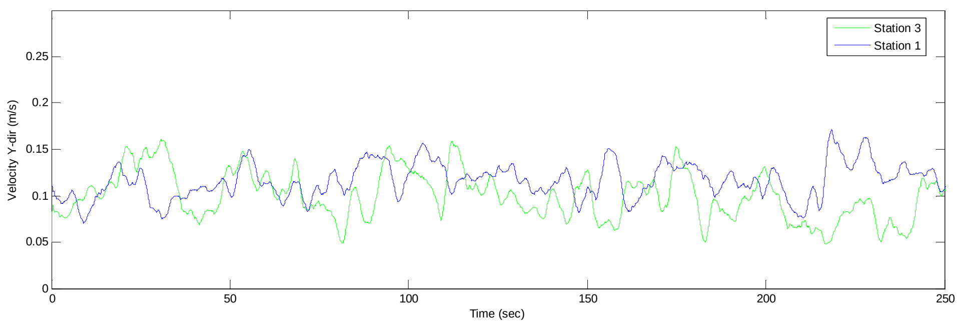

Figure A- 26 – TEST 7 Velocity Plot, Location 9.14 meters

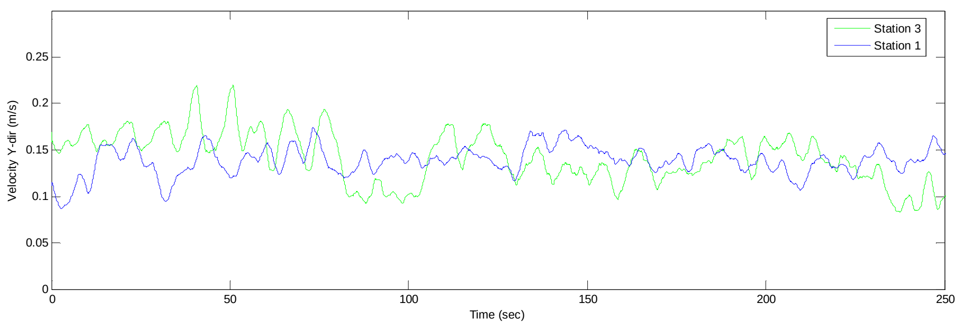

Figure A- 27 – TEST 7 Velocity Plot, Location 15.24 meters

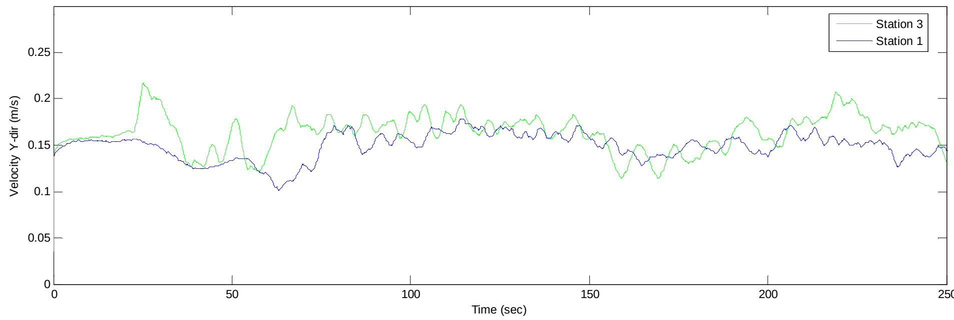

Figure A- 28 – TEST 7 Velocity Plot, Location 22.86 meters

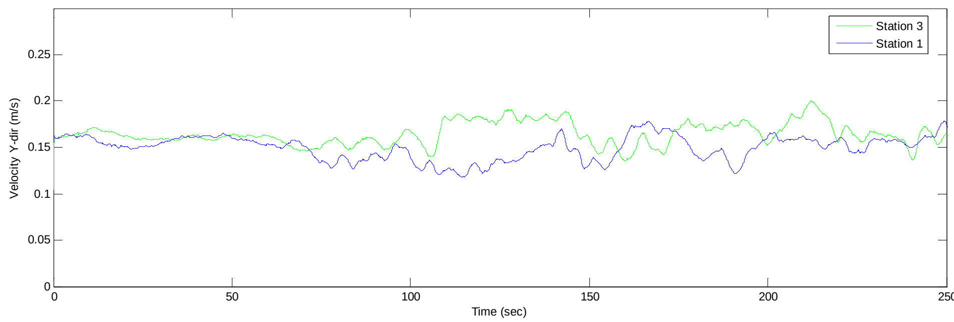

Figure A- 29 – TEST 7 Velocity Plot, Location 28.96 meters

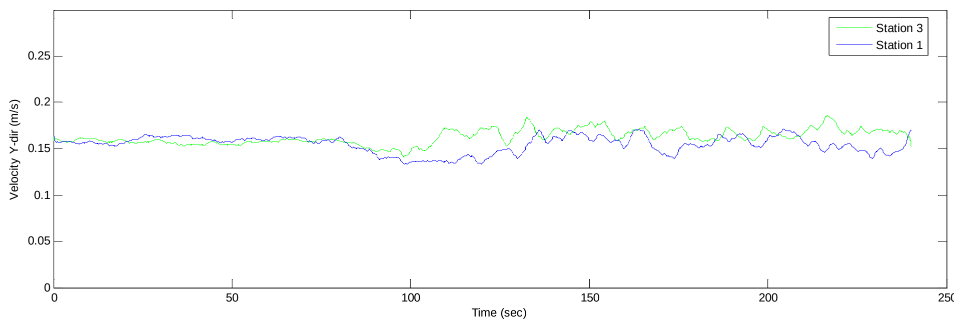

Figure A- 30 – TEST 7 Velocity Plot, Location 35.05 meters

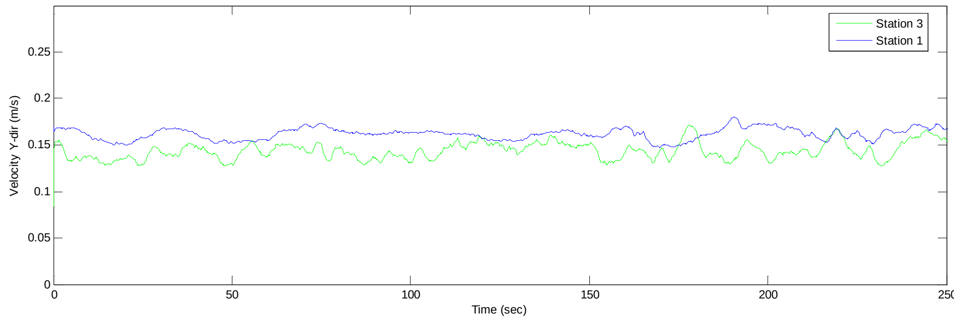

Figure A- 31 – TEST 7 Velocity Plot, Location 41.15 meters

APPENDIX B

POWER SPECTRUM PLOTS FOR TOW TANK

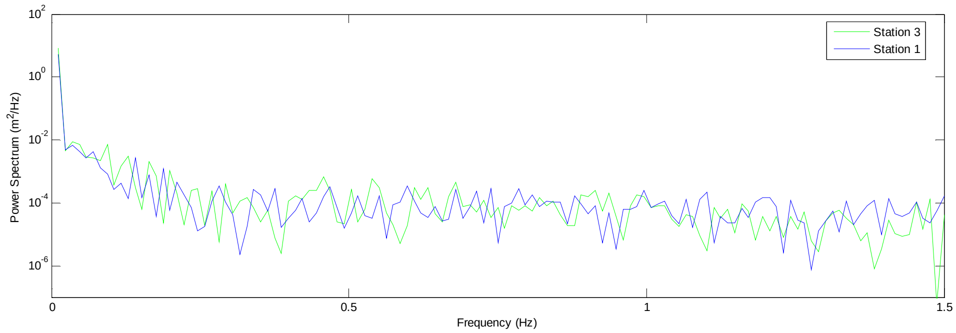

Figure B- 1 – TEST 1, Location 21.34 meters

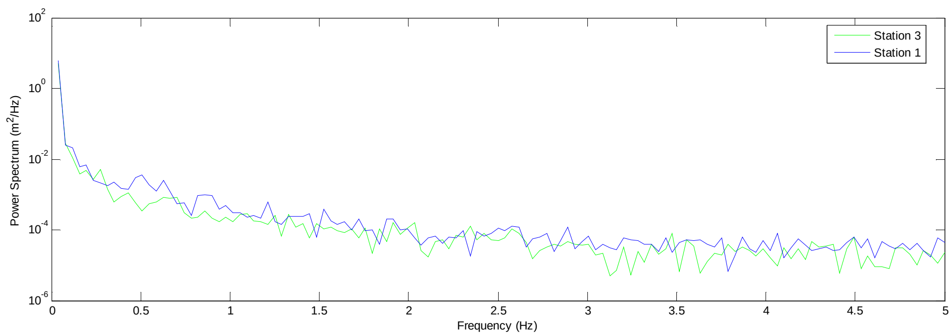

Figure B- 2 – TEST 2, Location 16.76 meters

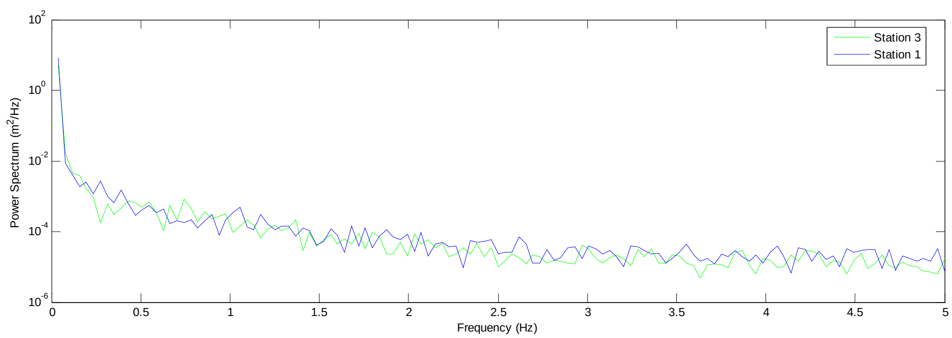

Figure B- 3 – TEST 2, Location 21.34 meters

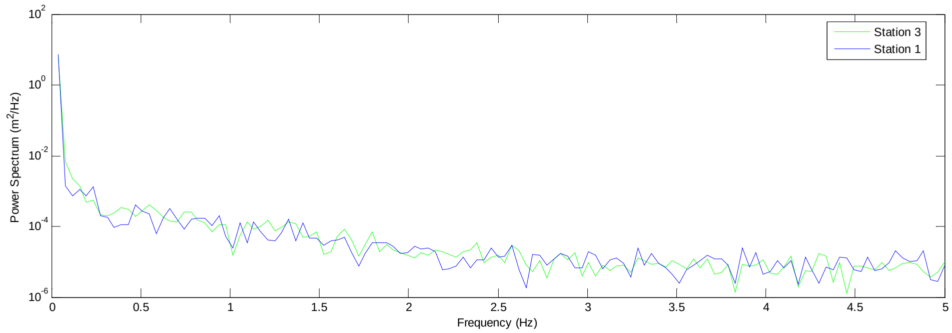

Figure B- 4 – TEST 2, Location 30.48 meters

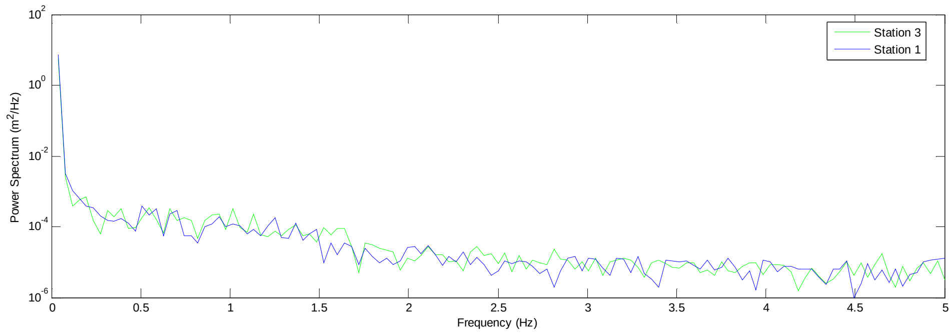

Figure B- 5 – TEST 2, Location 42.67 meters

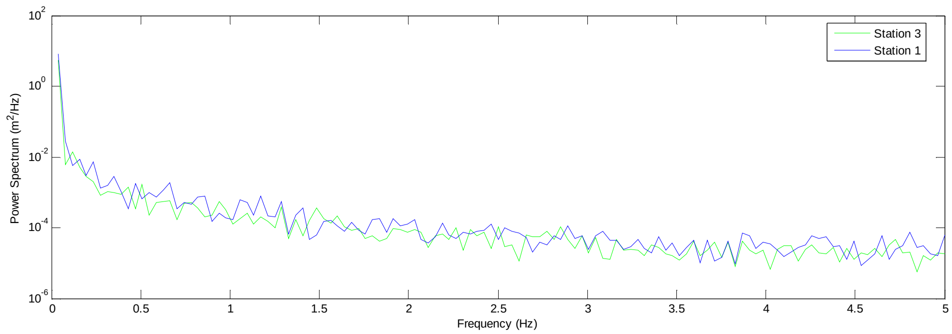

Figure B- 6 – TEST 3, Location 16.76 meters

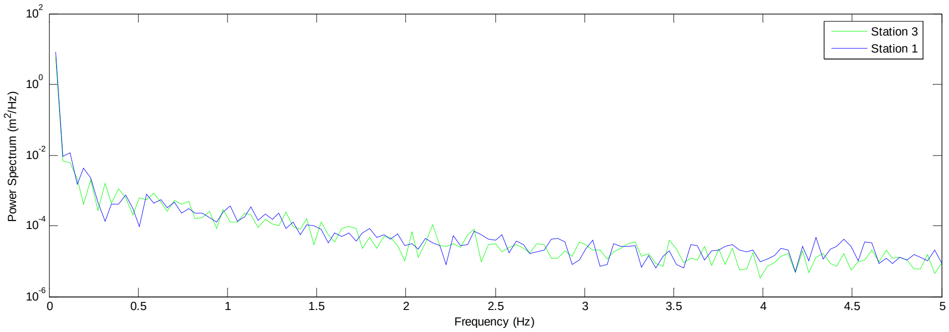

Figure B- 7 – TEST 3, Location 21.34 meters

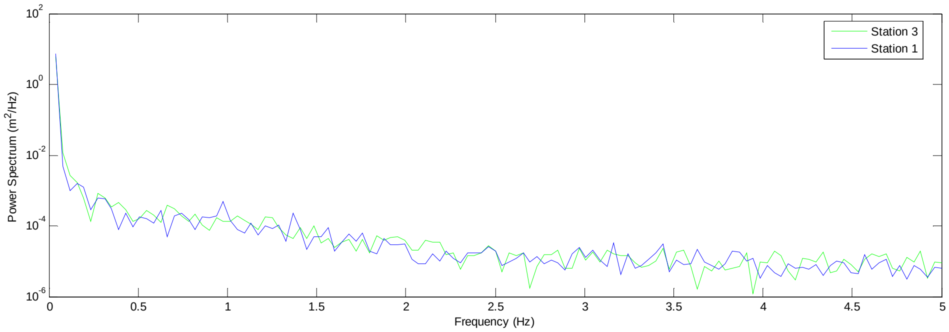

Figure B- 8 – TEST 3, Location 30.48 meters

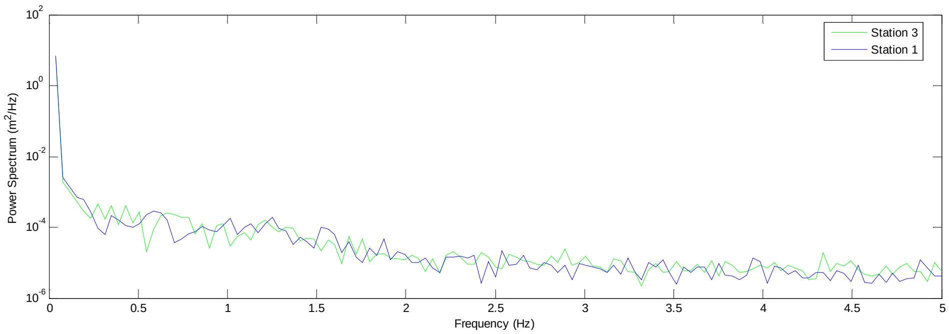

Figure B- 9 – TEST 3, Location 42.67 meters

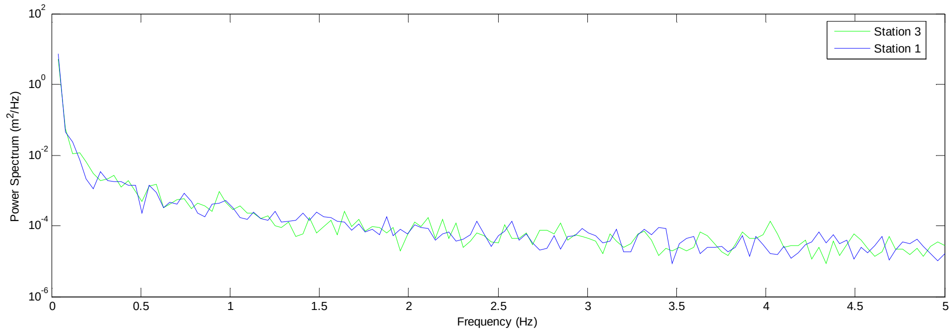

Figure B- 10 – TEST 4, Location 16.76 meters

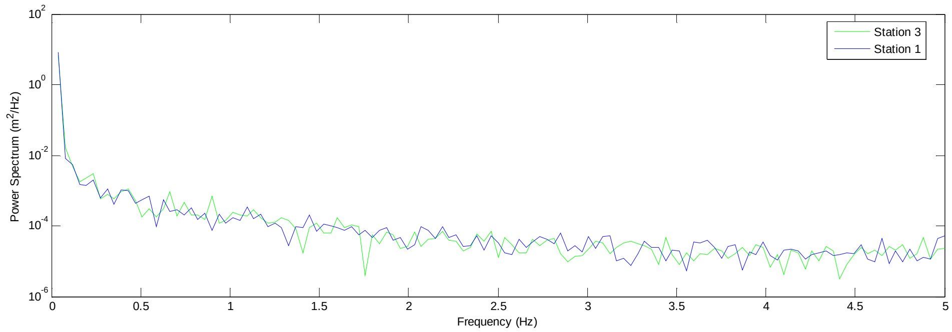

Figure B- 11 – TEST 4, Location 21.34 meters

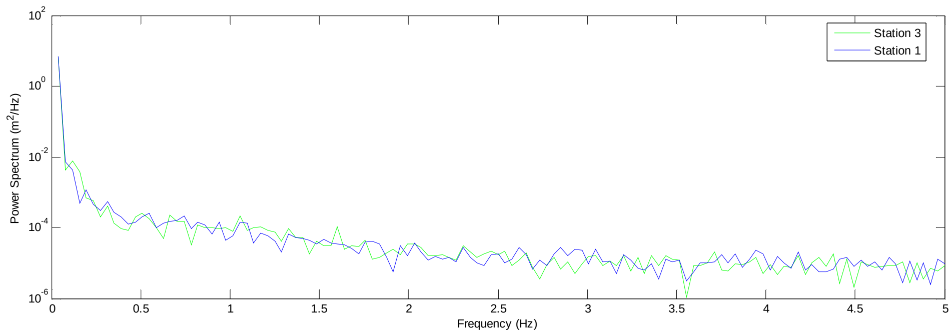

Figure B- 12 – TEST 4, Location 30.48 meters

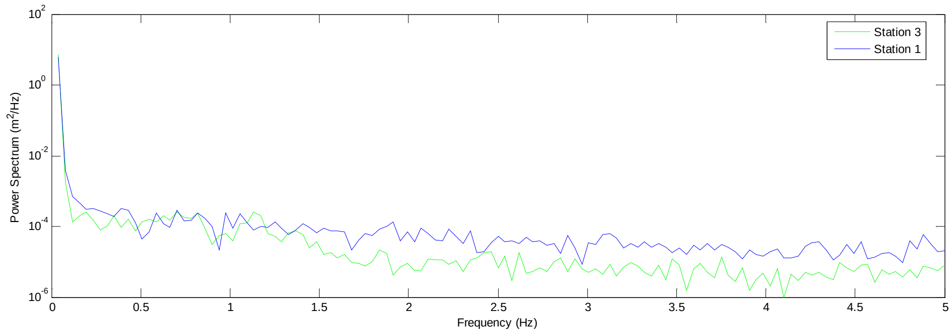

Figure B- 13 – TEST 4, Location 42.67 meters

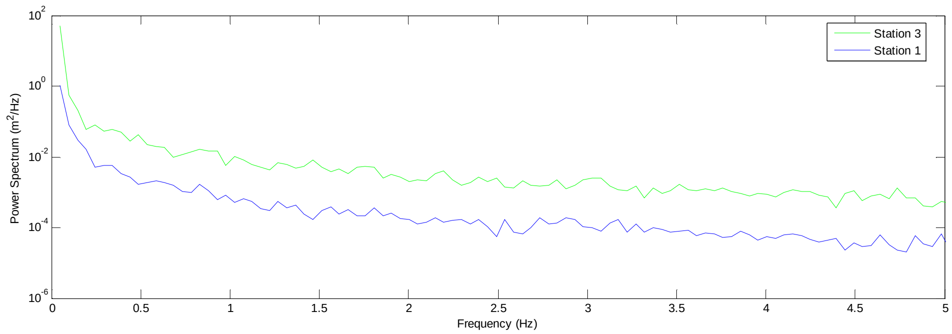

Figure B- 14 – TEST 5, Location 9.14 meters

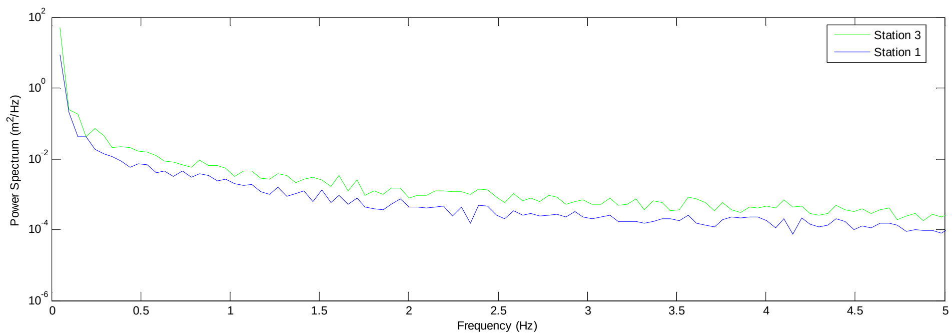

Figure B- 15 – TEST 5, Location 15.24 meters

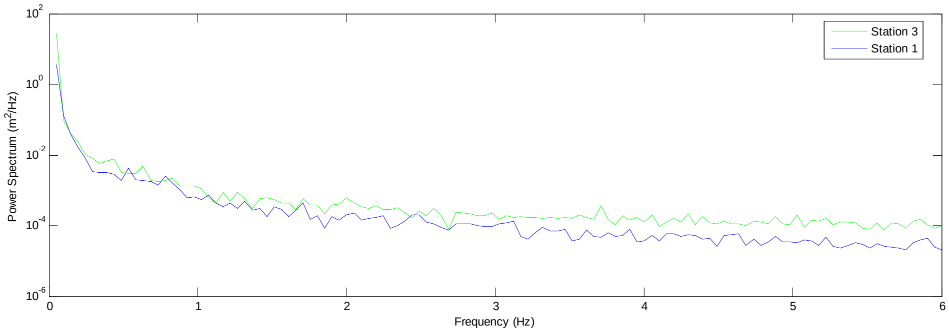

Figure B- 16 – TEST 5, Location 22.86 meters

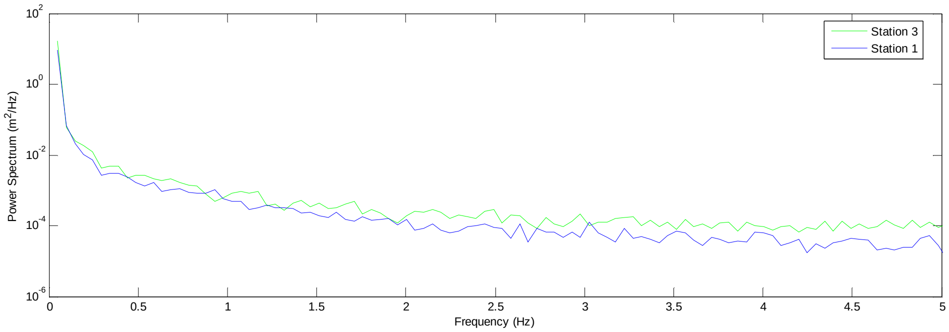

Figure B- 17 – TEST 5, Location 28.96 meters

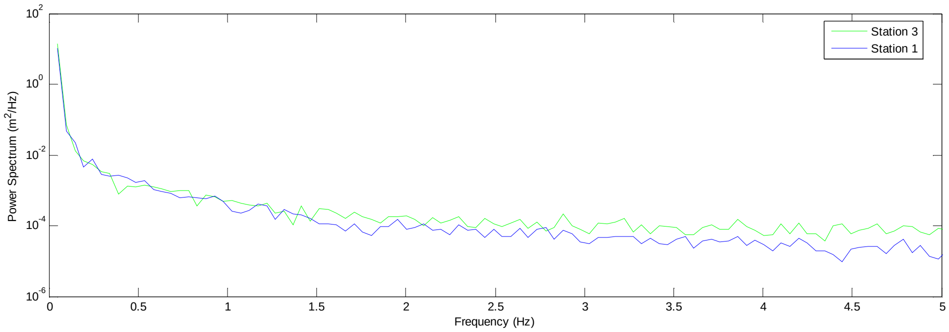

Figure B- 18 – TEST 5, Location 35.05 meters

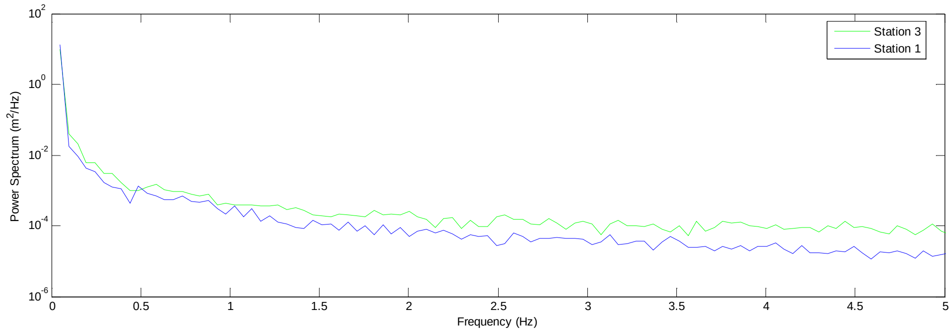

Figure B- 19 – TEST 5, Location 41.15 meters

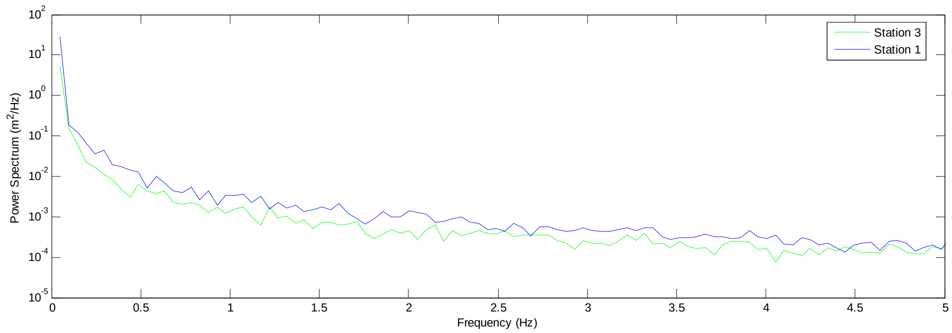

Figure B- 20 – TEST 6, Location 9.14 meters

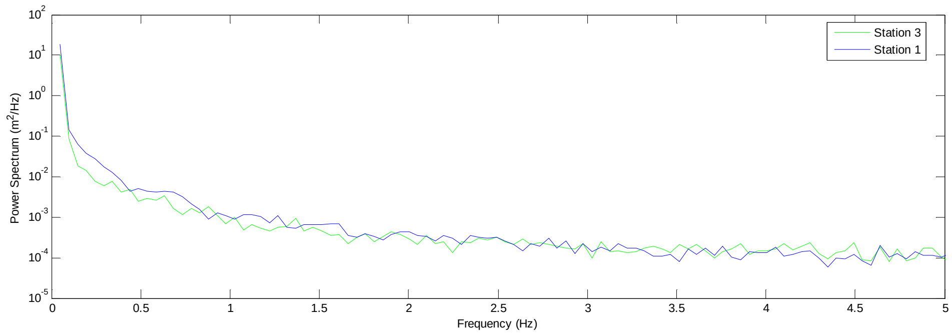

Figure B- 21 – TEST 6, Location 15.24 meters

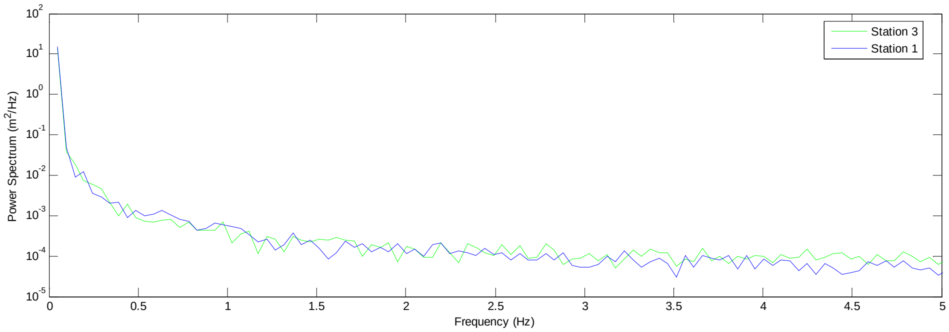

Figure B- 22 – TEST 6, Location 22.86 meters

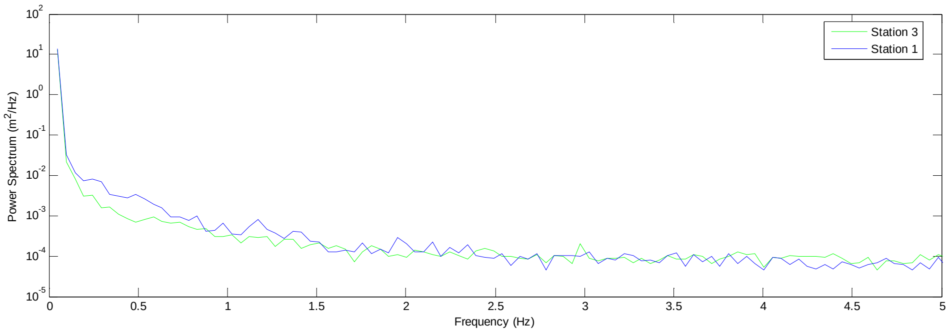

Figure B- 23 – TEST 6, Location 28.96 meters

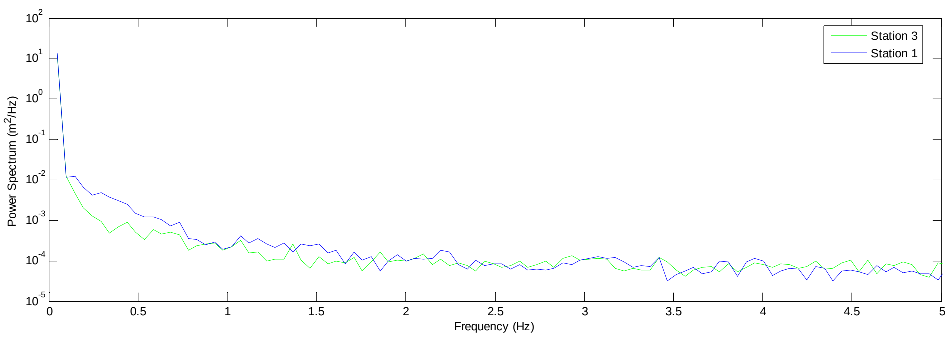

Figure B- 24 – TEST 6, Location 35.05 meters

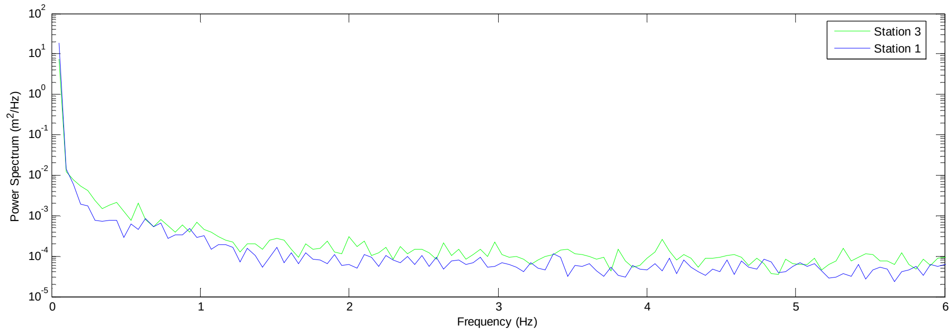

Figure B- 25 – TEST 6, Location 41.15 meters

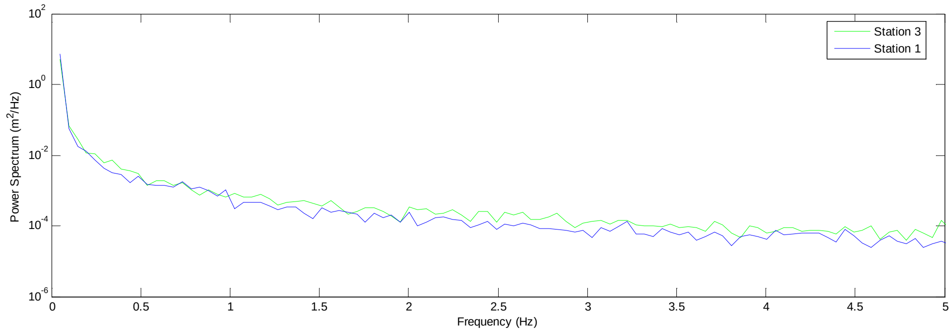

Figure B- 26 –TEST 7, Location 9.14 meters

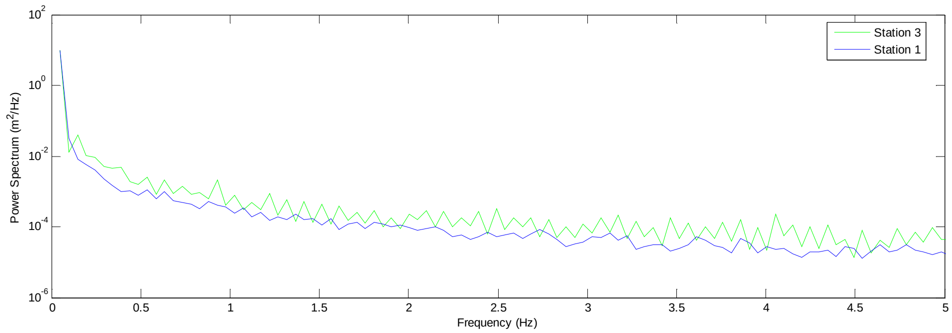

Figure B- 27 – TEST 7, Location 15.24 meters

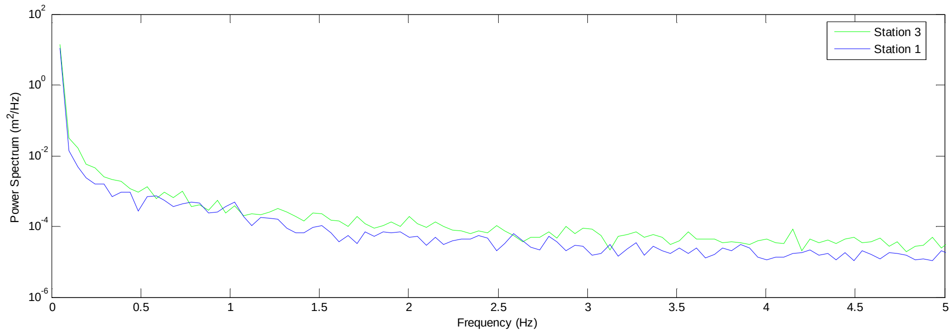

Figure B- 28 – TEST 7, Location 22.86 meters

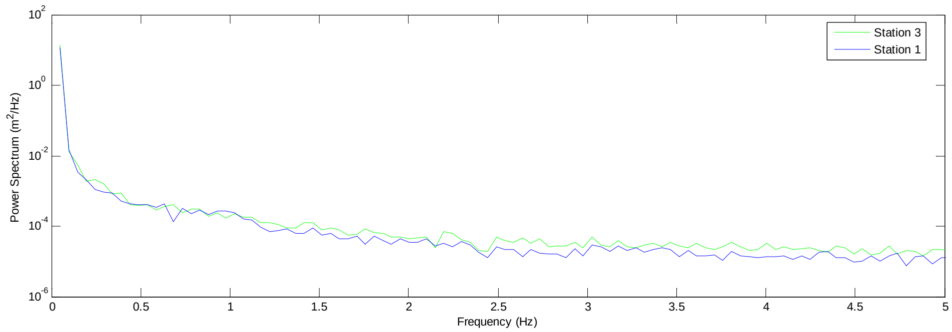

Figure B- 29 – TEST 7, Location 28.96 meters

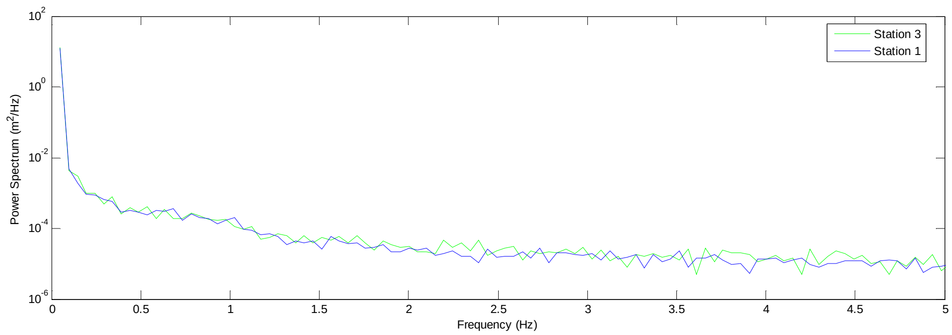

Figure B- 30 – TEST 7, Location 35.05 meters

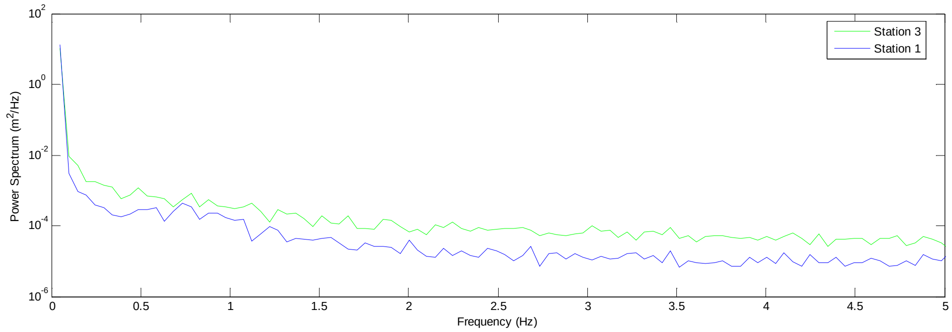

Figure B- 31 – TEST 7, Location 41.15 meters

APPENDIX C

CORRELATION

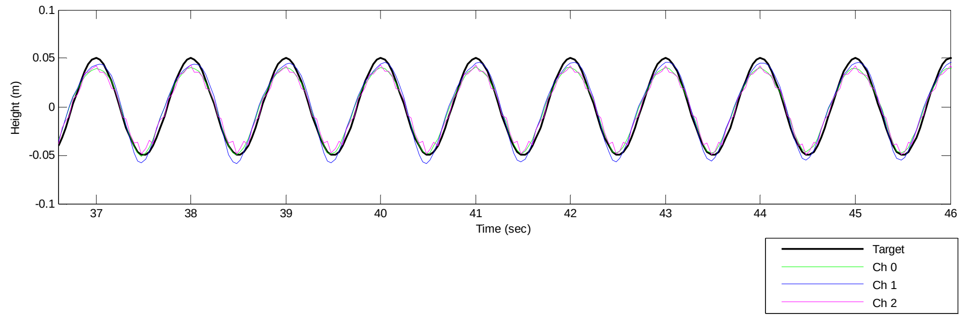

Figure C- 1: Test 1, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 0 – 2

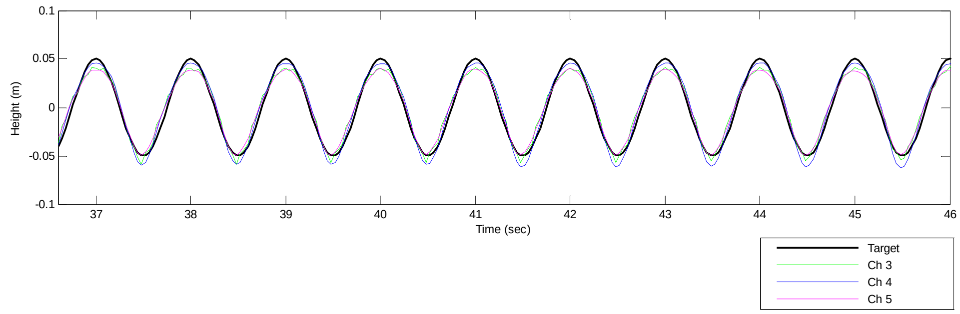

Figure C- 2: Test 1, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 3 – 5

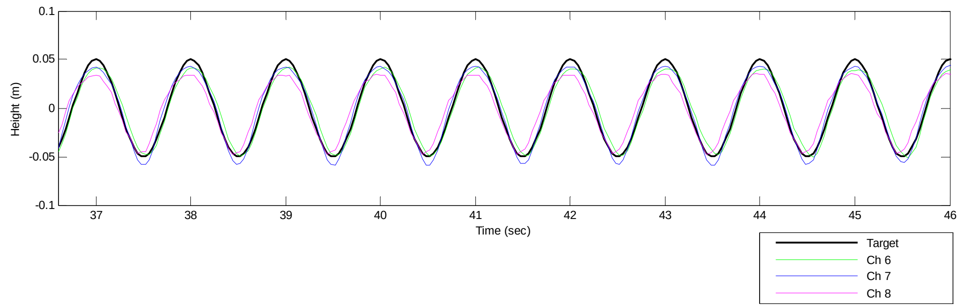

Figure C- 3: Test 1, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 6 – 8

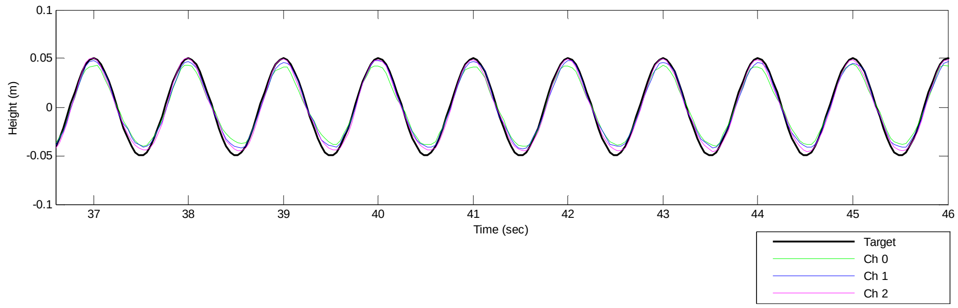

Figure C- 4: Test 1 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 0 – 2

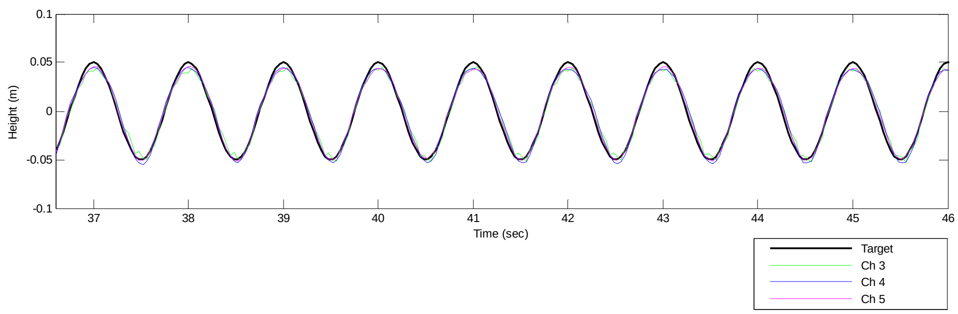

Figure C- 5: Test 1 with Buoys, Monochromatic h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 3 – 5

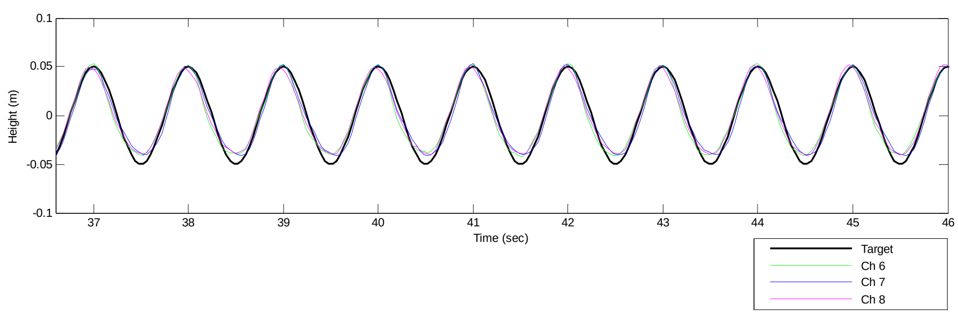

Figure C- 6: Test 1 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 6 – 8

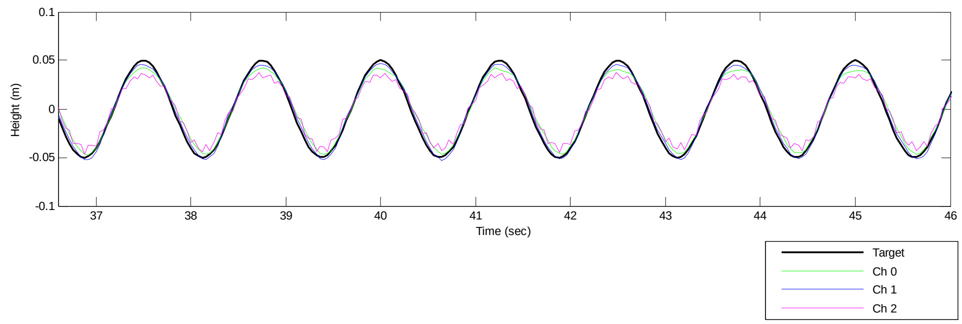

Figure C- 7: Test 2, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 0 –2

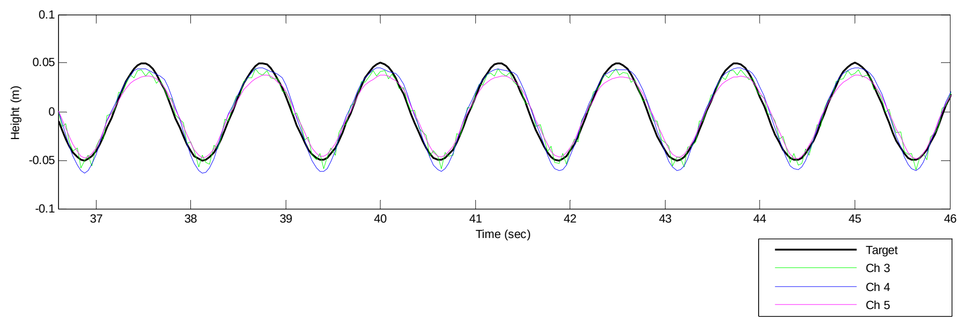

Figure C- 8: Test 2, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 3 - 5

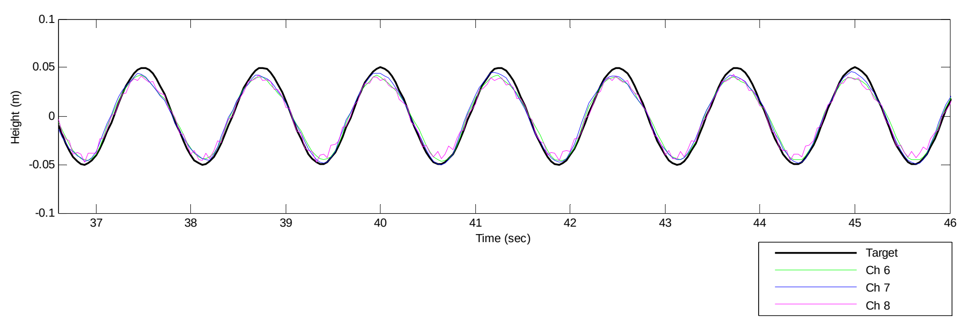

Figure C- 9: Test 2, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 6 – 8

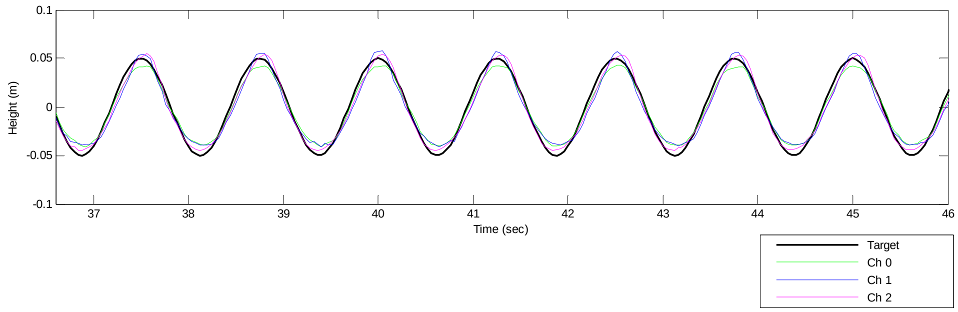

Figure C- 10: Test 2 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 0 - 2

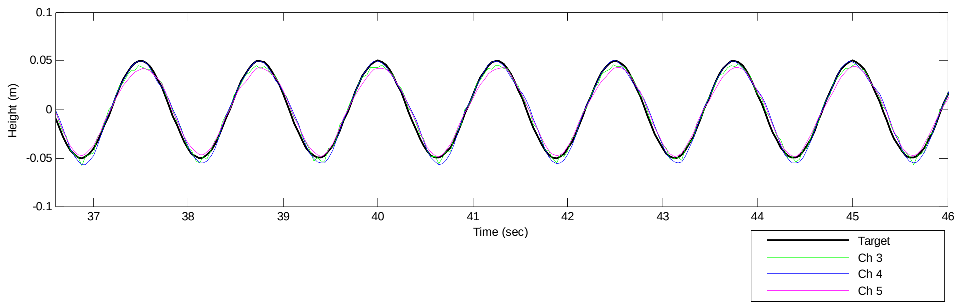

Figure C- 11: Test 2 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 3 - 5

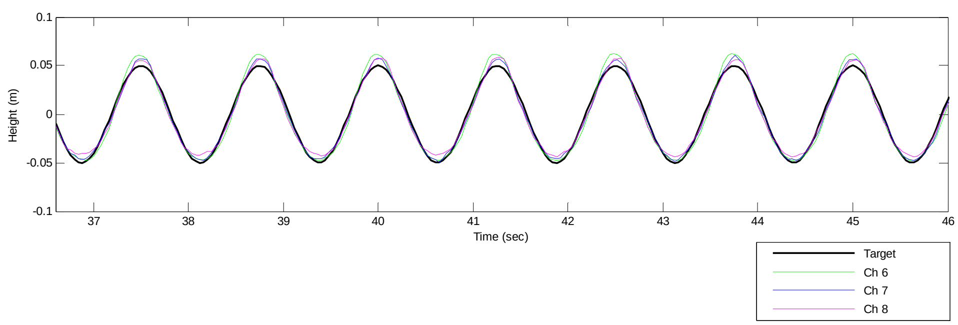

Figure C- 12: Test 2 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec, Ch 6 – 8

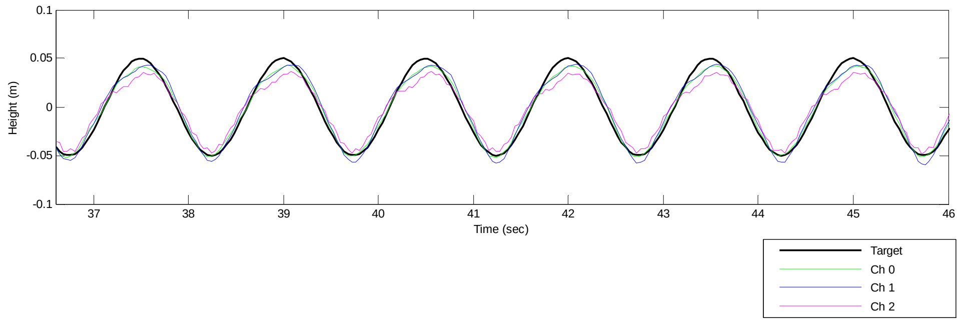

Figure C- 13: Test 3, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 0 – 2

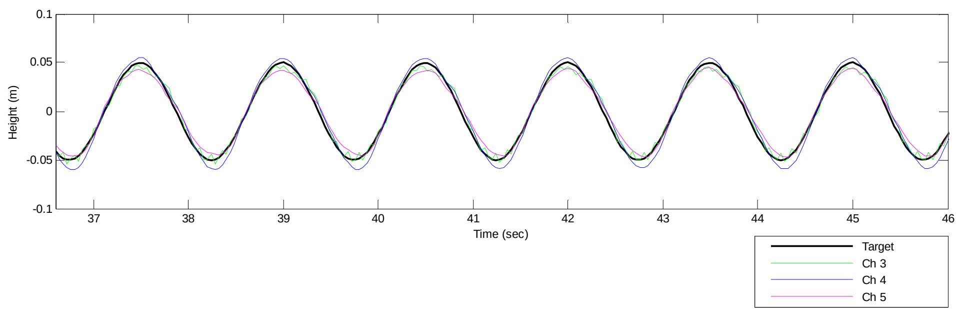

Figure C- 14: Test 3, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

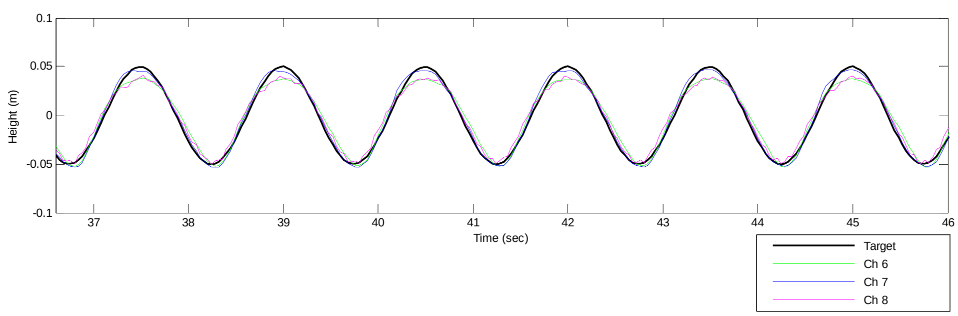

Figure C- 15: Test 3, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 6 – 8

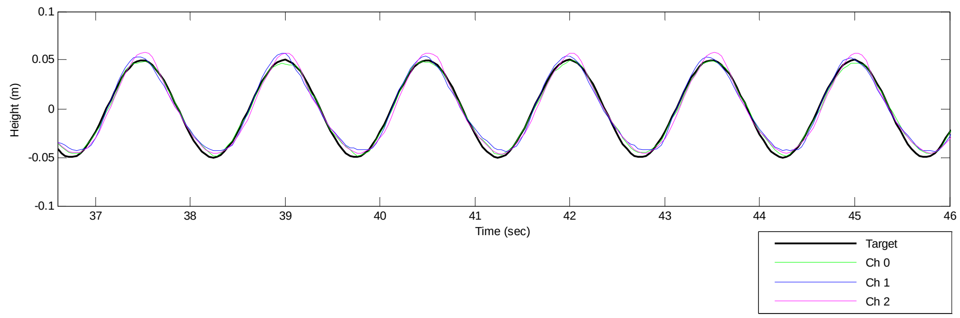

Figure C- 16: Test 3 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 0 – 2

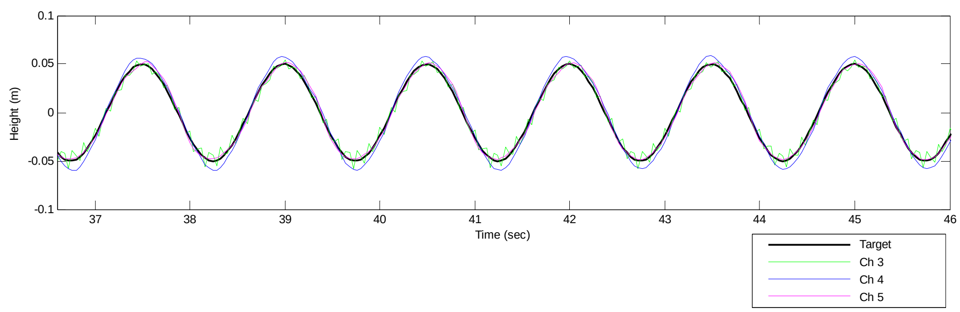

Figure C- 17: Test 3 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

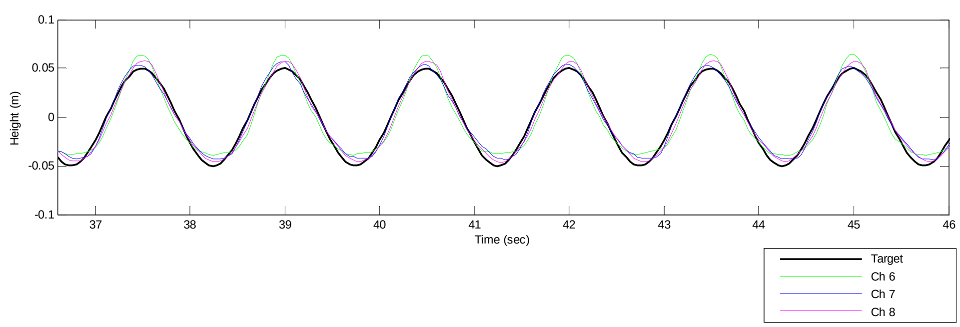

Figure C- 18: Test 3 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 6 – 8

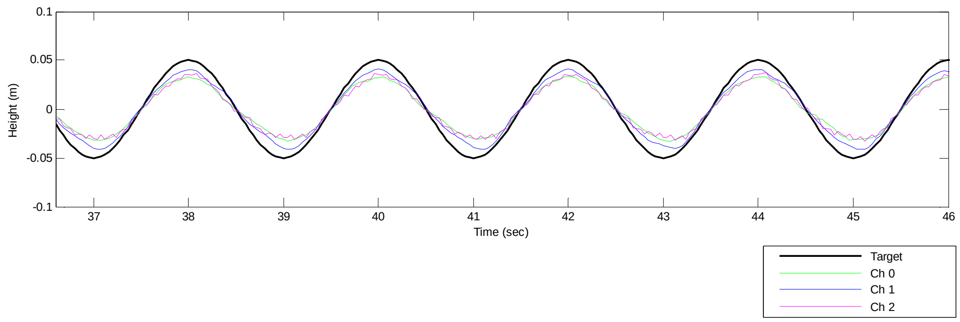

Figure C- 19: Test 4, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 0 – 2

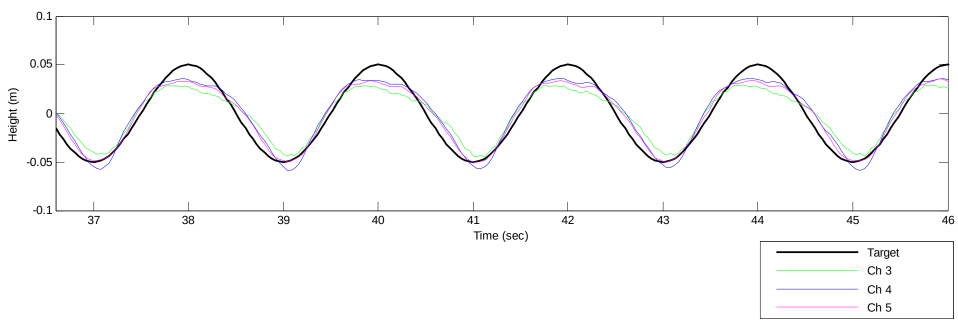

Figure C- 20: Test 4, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 3 – 5

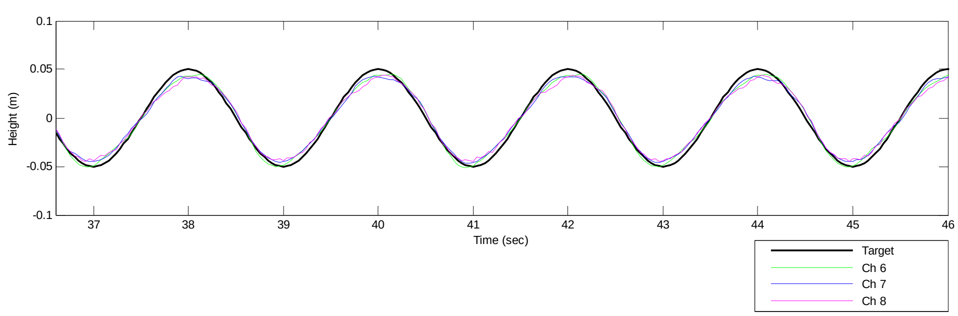

Figure C- 21: Test 4, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 6 – 8

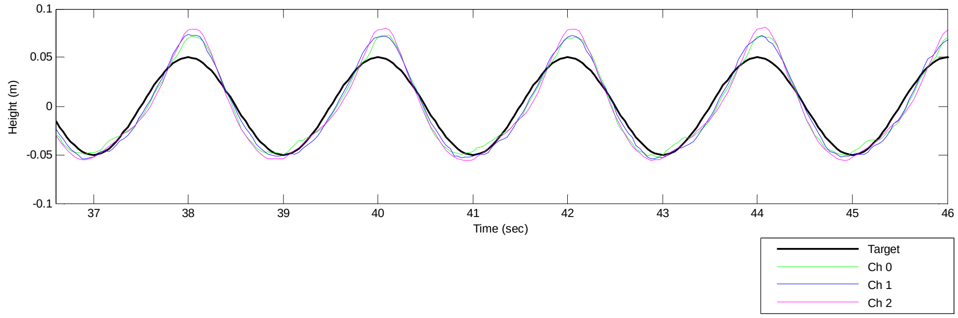

Figure C- 22: Test 4 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 0 – 2

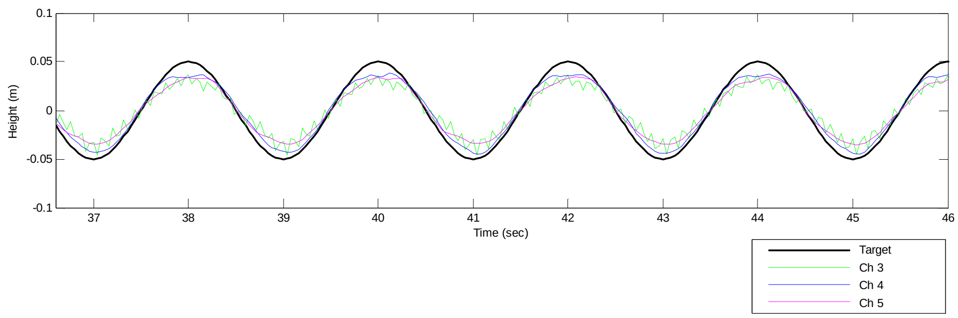

Figure C- 23: Test 4 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 3 – 5

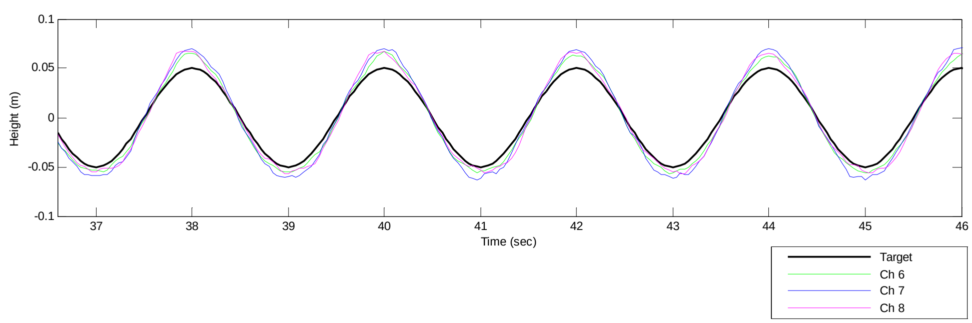

Figure C- 24: Test 4 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec, Ch 6 – 8

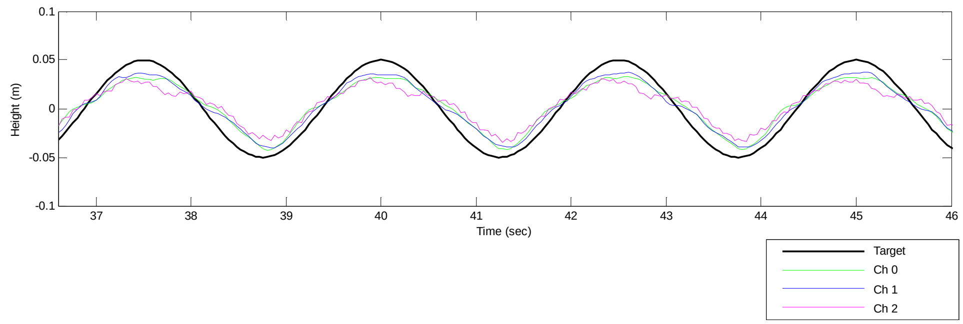

Figure C- 25: Test 5, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 0 – 2

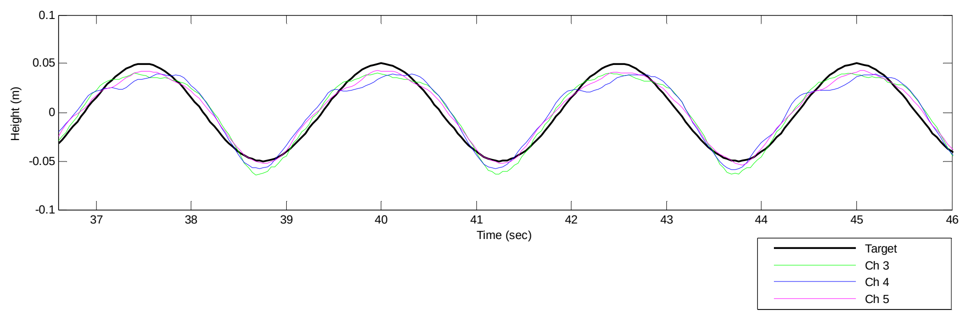

Figure C- 26: Test 5, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 3 – 5

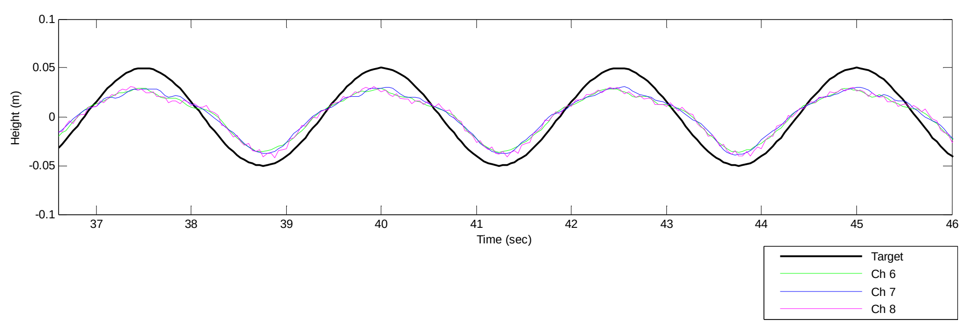

Figure C- 27: Test 5, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 6 – 8

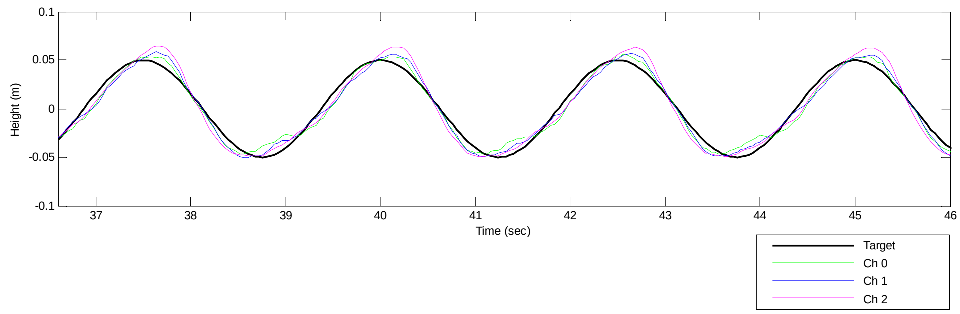

Figure C- 28: Test 5 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 0 – 2

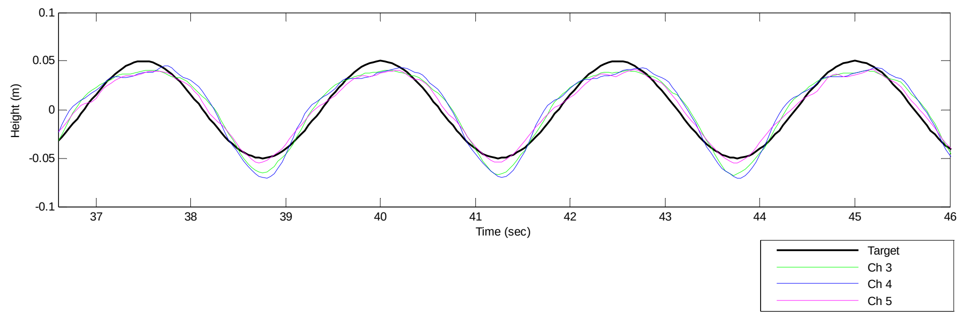

Figure C- 29: Test 5 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 3 - 5

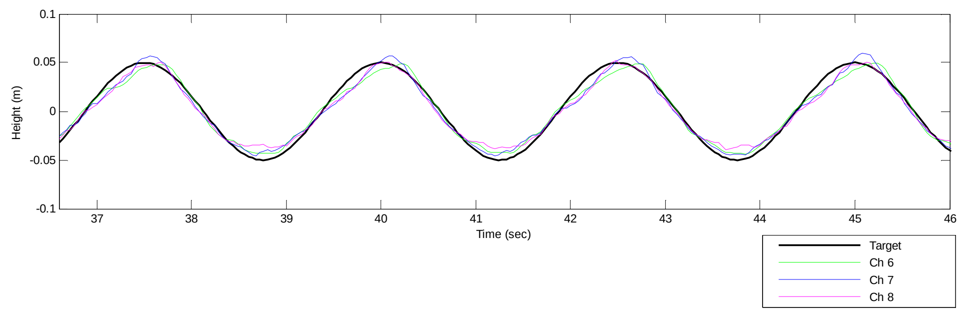

Figure C- 30: Test 5 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec, Ch 6 – 8

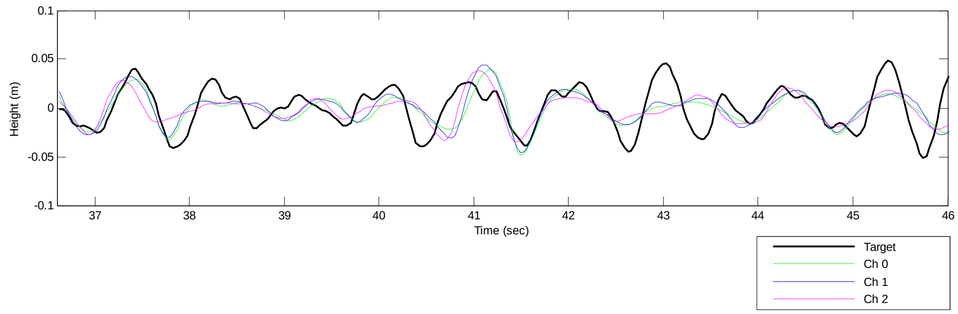

Figure C- 31: Test 6, JONSWAP h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 0 - 2

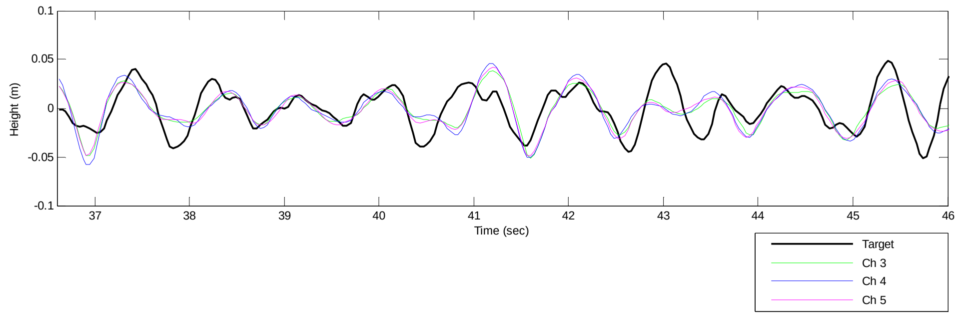

Figure C- 32: Test 6, JONSWAP h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 3 – 5

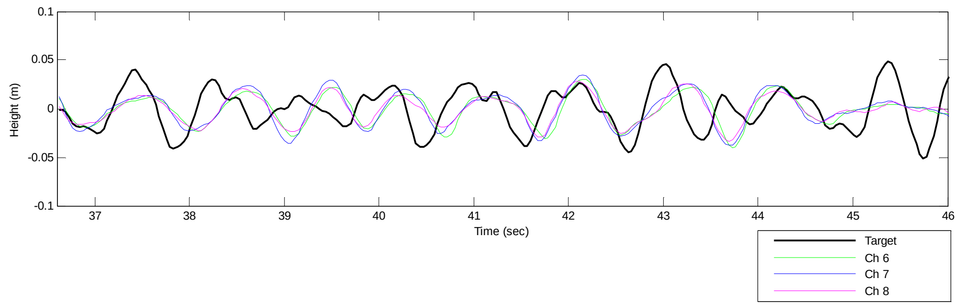

Figure C- 33: Test 6, JONSWAP h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 6 – 8

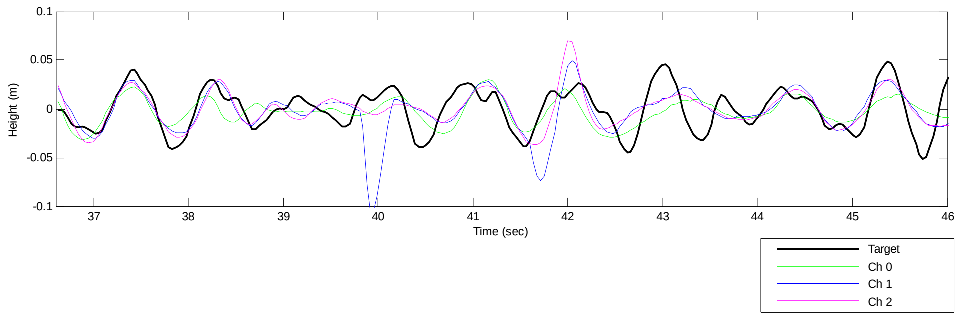

Figure C- 34: Test 6 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3 Ch 0 – 2

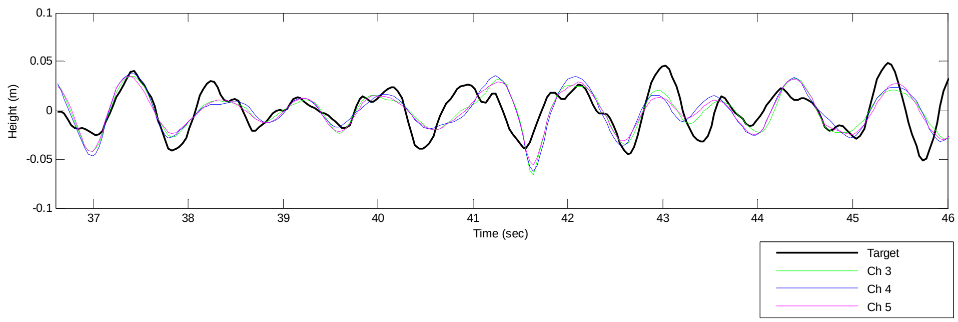

Figure C- 35: Test 6 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3 Ch 3 - 5

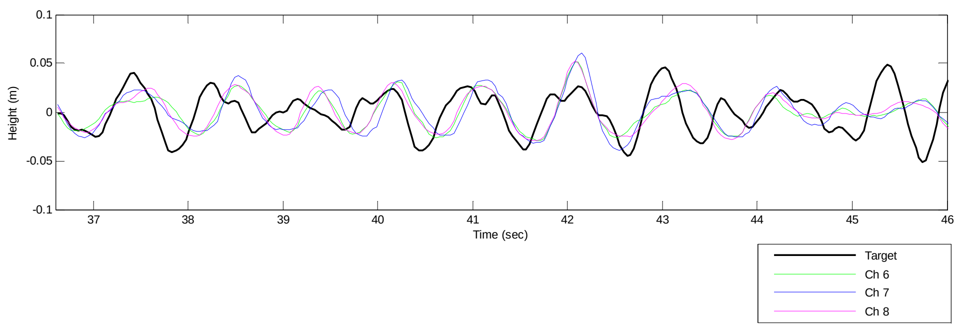

Figure C- 36: Test 6 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3 Ch 6 – 8

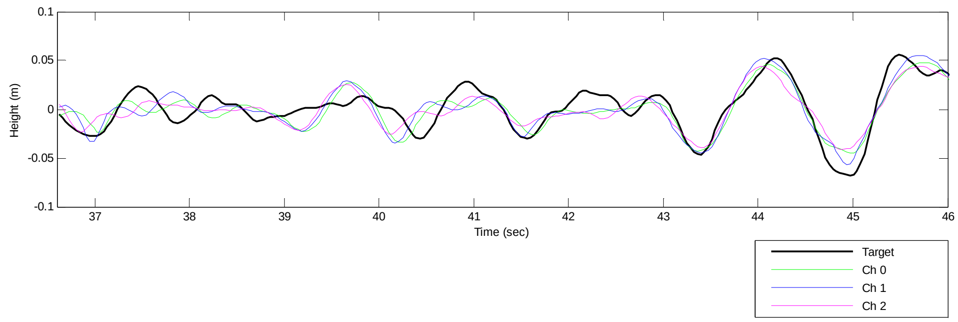

Figure C- 37: Test 7, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 0 - 2

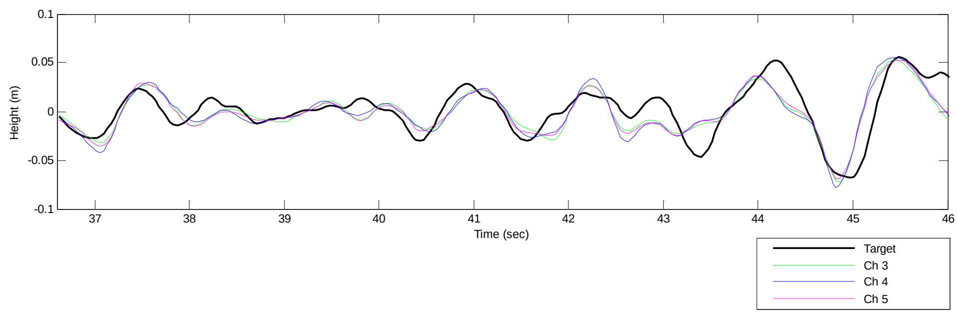

Figure C- 38: Test 7, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 3 – 5

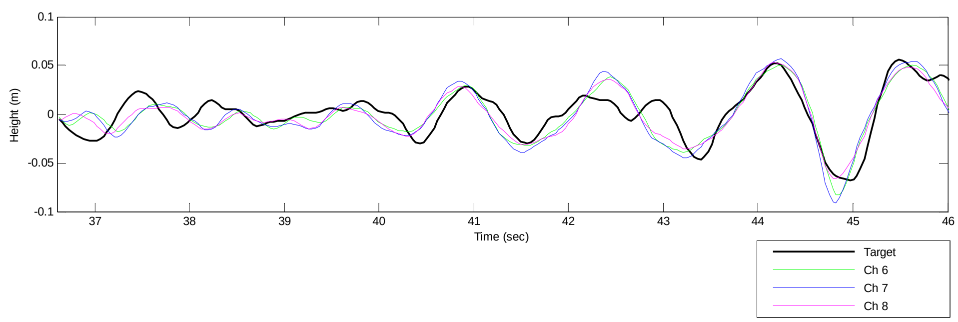

Figure C- 39: Test 7, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 6 – 8

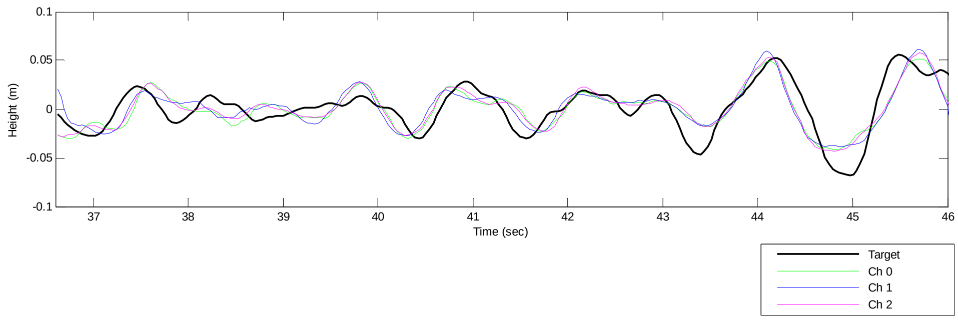

Figure C- 40: Test 7 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 0 - 2

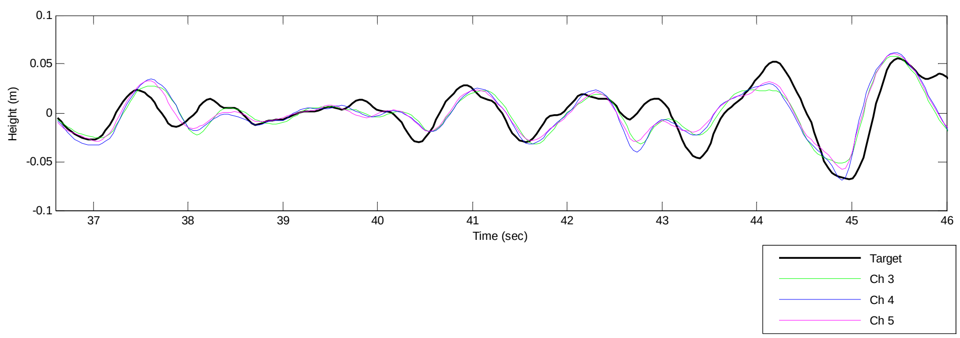

Figure C- 41: Test 7 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 3 - 5

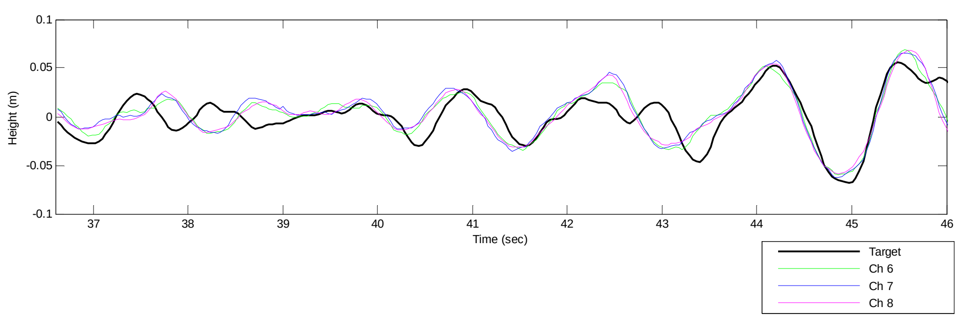

Figure C- 42: Test 7 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 6 – 8

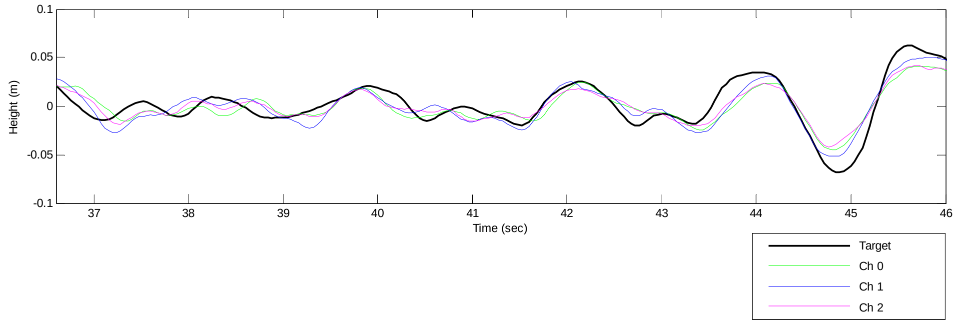

Figure C- 43: Test 8, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 0 - 2

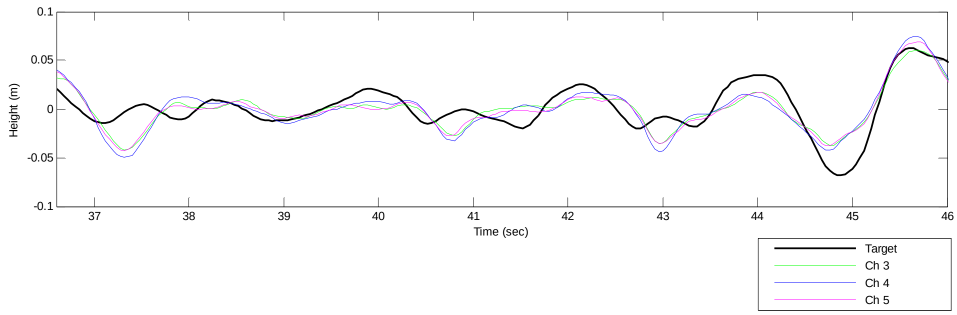

Figure C- 44: Test 8, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 3 - 5

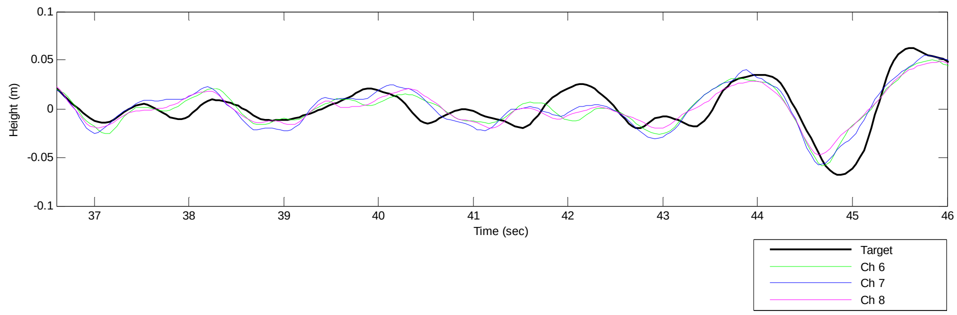

Figure C- 45: Test 8, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 6 - 8

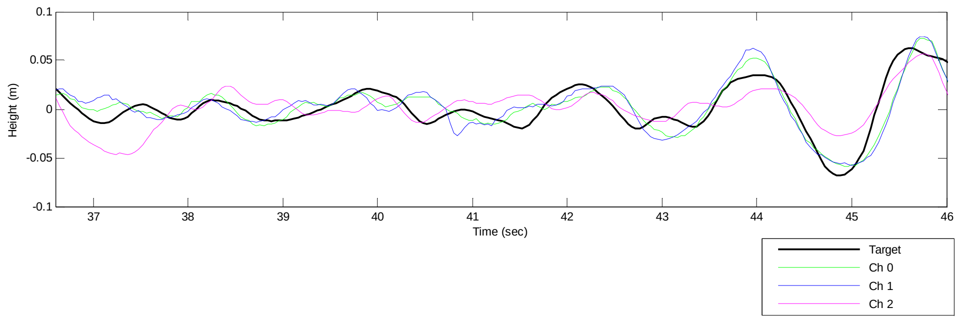

Figure C- 46: Test 8 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 0 – 2

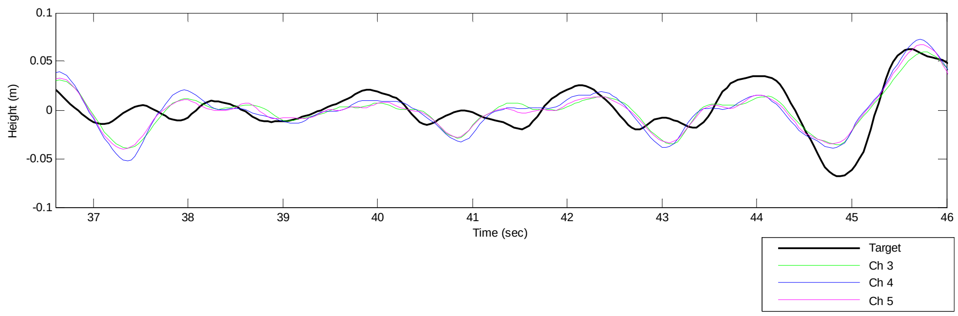

Figure C- 47: Test 8 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 3 – 5

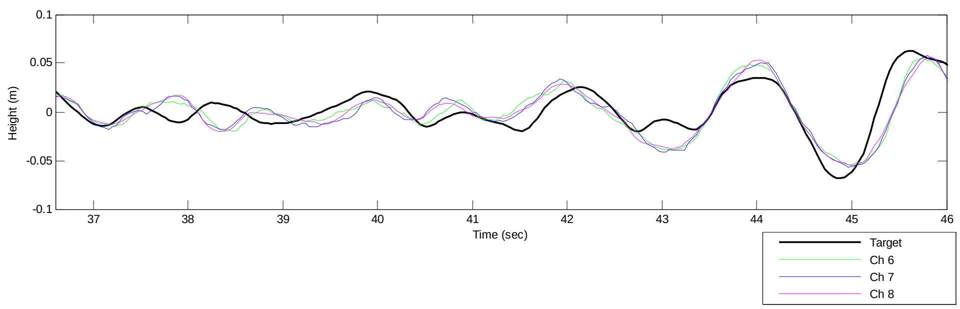

Figure C- 48: Test 8 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 6 – 8

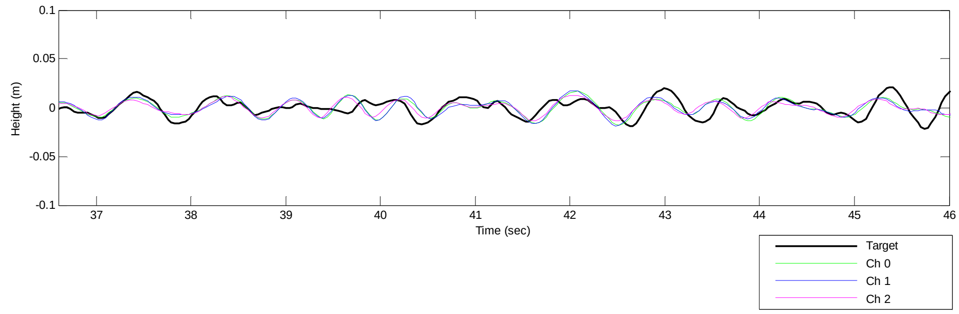

Figure C- 49: Test 9, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 0 – 2

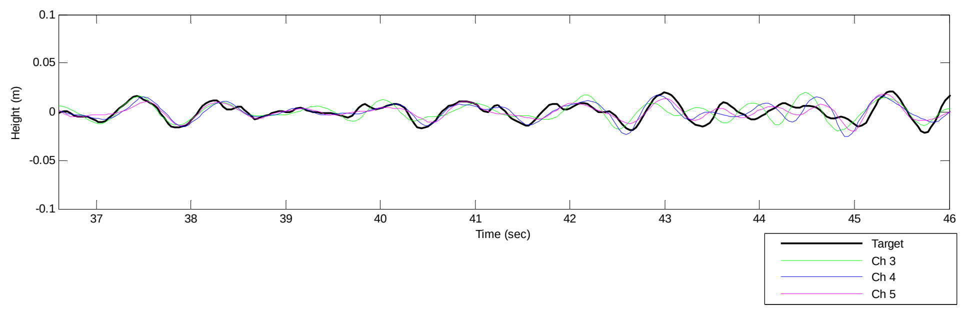

Figure C- 50: Test 9, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 3 - 5

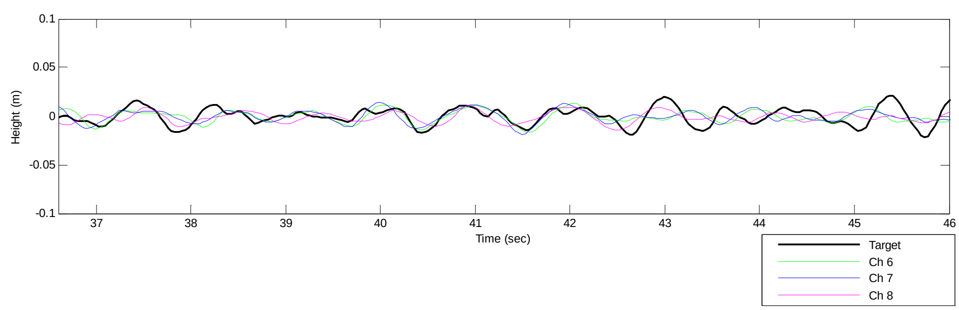

Figure C- 51: Test 9, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 6 – 8

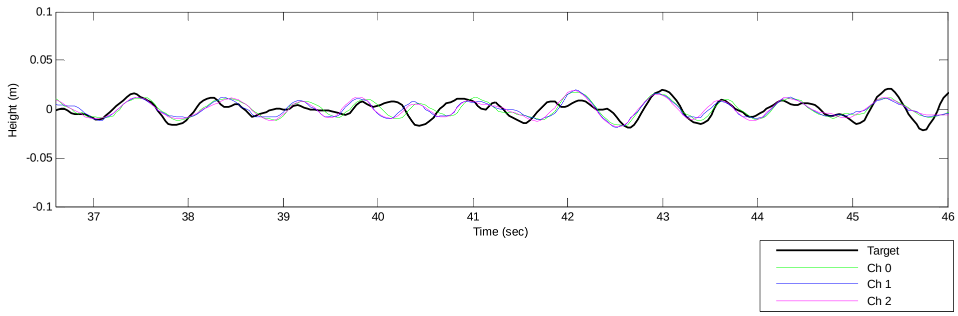

Figure C- 52: Test 9 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 0 – 2

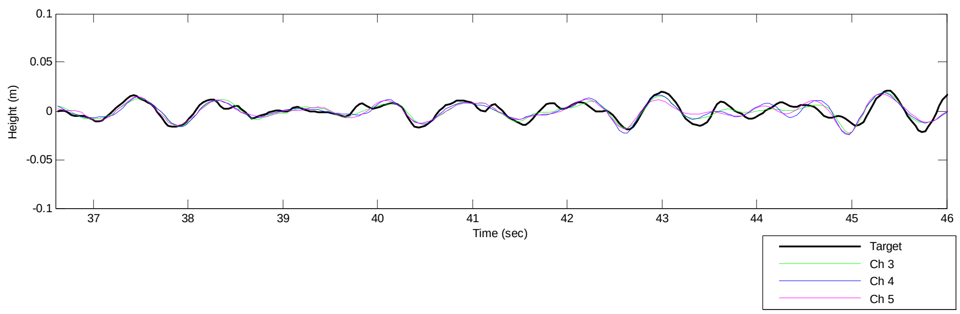

Figure C- 53: Test 9 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 3 - 5

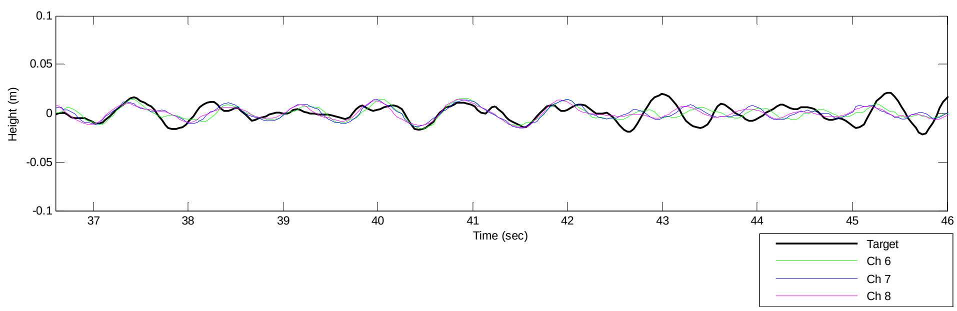

Figure C- 54: Test 9 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.0 sec, Ch 6 – 8

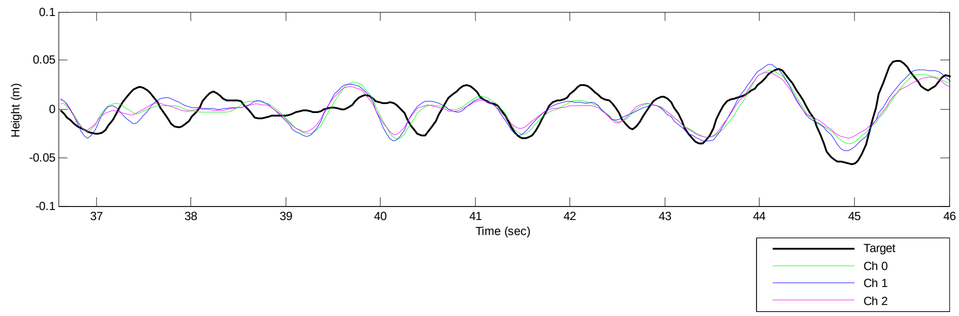

Figure C- 55: Test 10, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 0 – 2

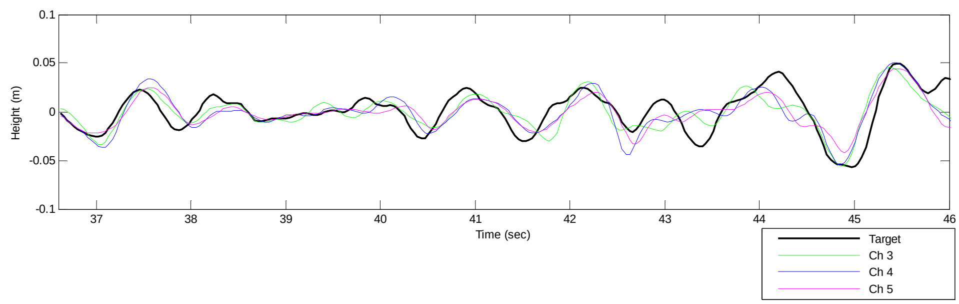

Figure C- 56: Test 10, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

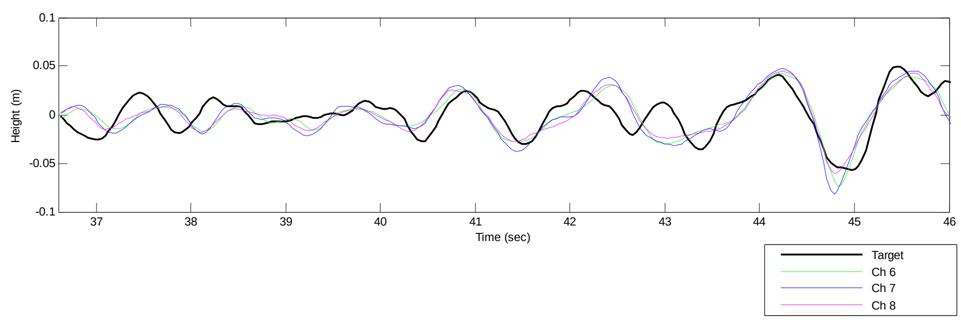

Figure C- 57: Test 10, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 6 – 8

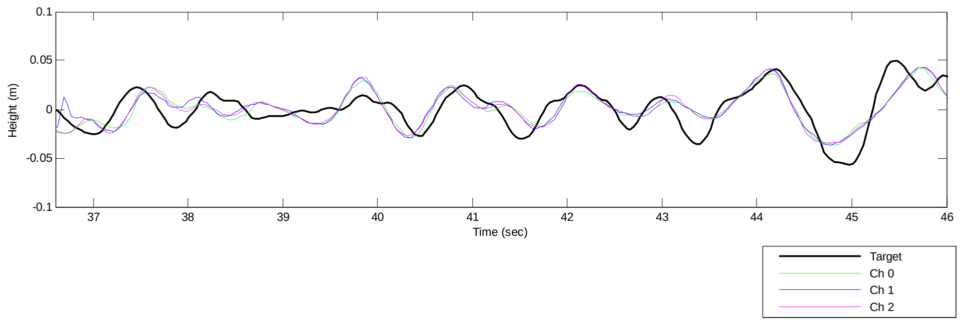

Figure C- 58: Test 10 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 0 – 2

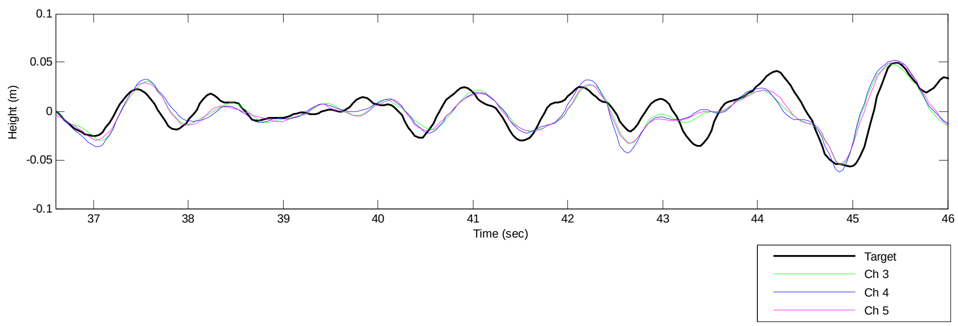

Figure C- 59: Test 10 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 3 – 5

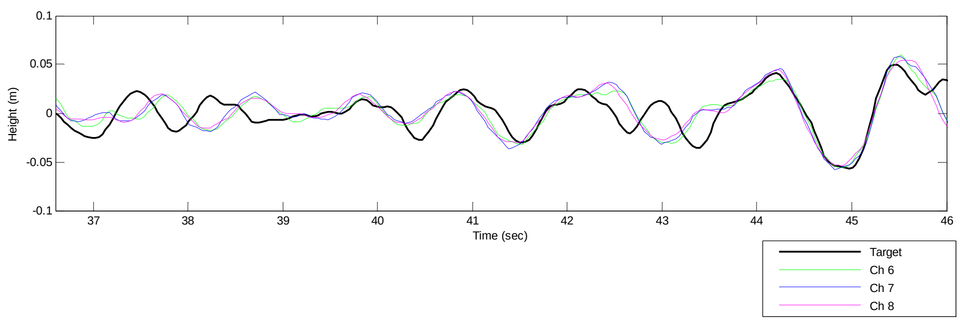

Figure C- 60: Test 10 with Buoys, PM, h = 0.5 m, H = 0.1 m, T = 1.5 sec, Ch 6 – 8

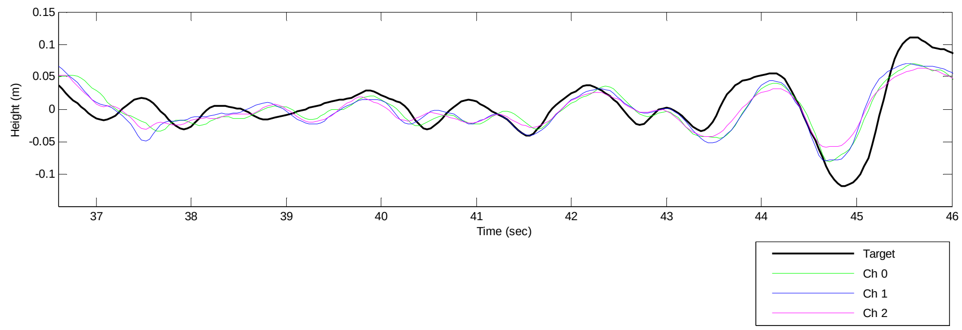

Figure C- 61: Test 11, PM, h = 0.5 m, T = 2.0 sec, Ch 0 – 2

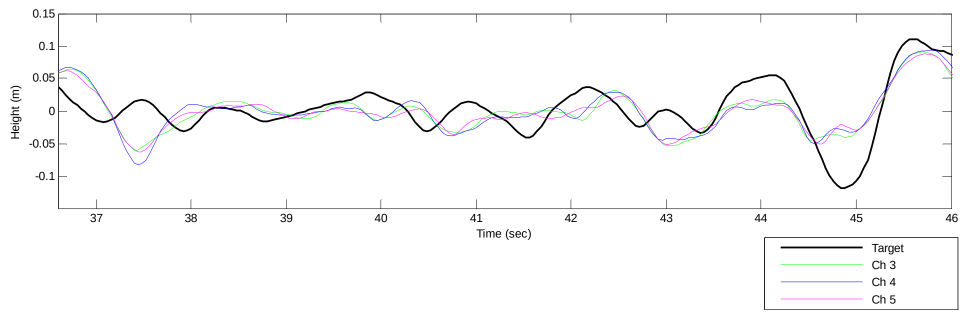

Figure C- 62: Test 11, PM, h = 0.5 m, T = 2.0 sec, Ch 3 – 5

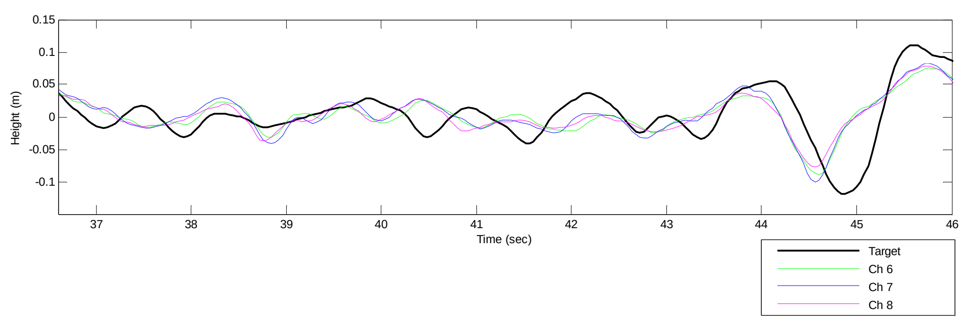

Figure C- 63: Test 11, PM, h = 0.5 m, T = 2.0 sec, Ch 6 -8

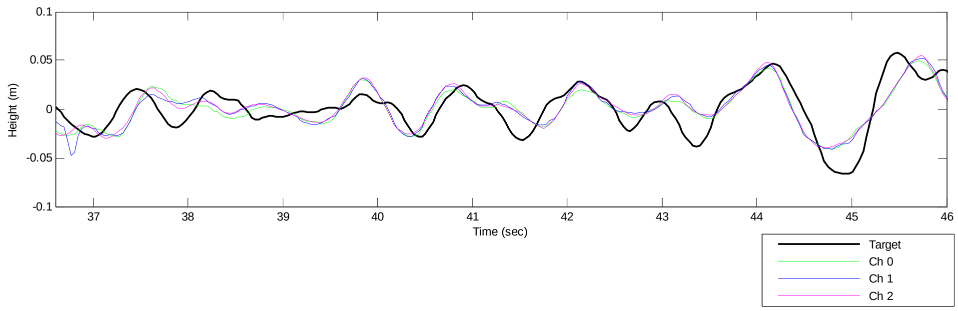

Figure C- 64: Test 11 with Buoys, PM, h = 0.5 m, T = 2.0 sec, Ch 0 - 2

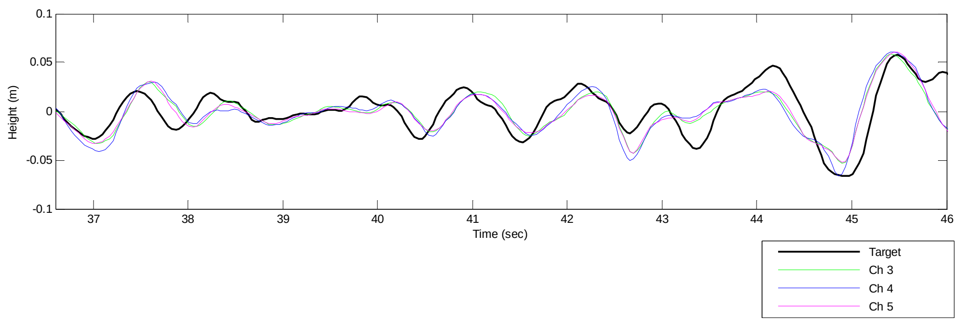

Figure C- 65: Test 11 with Buoys, PM, h = 0.5 m, T = 2.0 sec, Ch 3 - 5

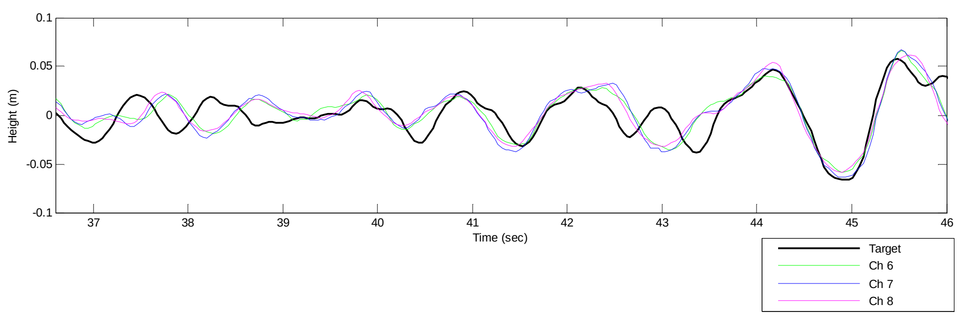

Figure C- 66: Test 11 with Buoys, PM, h = 0.5 m, T = 2.0 sec, Ch 6 – 8

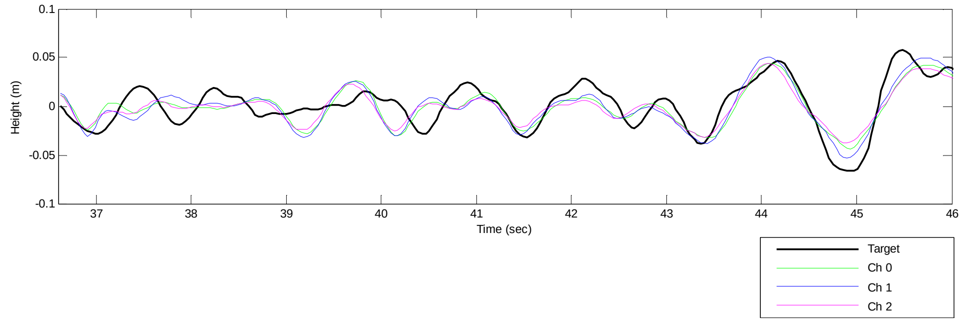

Figure C- 67: Test 12, PM-Hsig, h = 0.5 m, H = 0.1 m, Ch 0 – 2

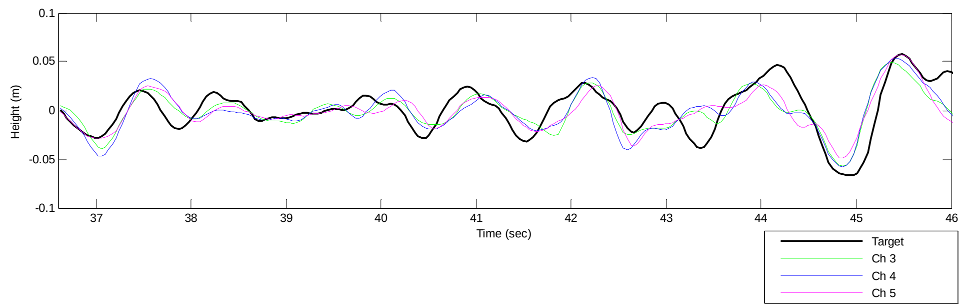

Figure C- 68: Test 12, PM-Hsig, h = 0.5 m, H = 0.1 m, Ch 3 – 5

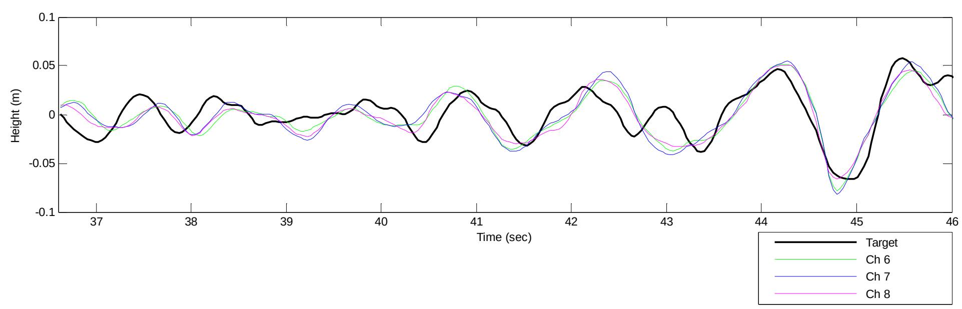

Figure C- 69: Test 12, PM-Hsig, h = 0.5 m, H = 0.1m, Ch 6 – 8

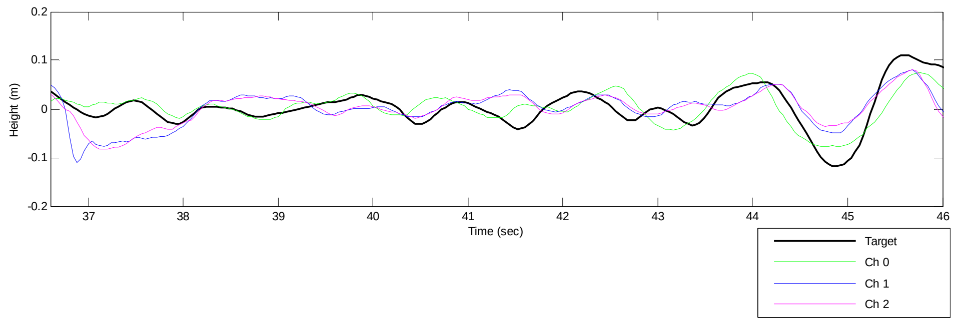

Figure C- 70: Test 12 with Buoys, PM-Hsig, h = 0.5 m, H = 0.1 m, Ch 0 – 2

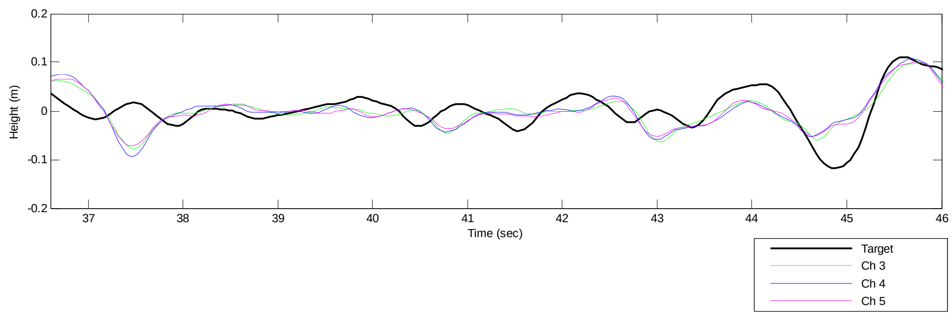

Figure C- 71: Test 12 with Buoys, PM-Hsig, h = 0.5 m, H = 0.1 m, Ch 3 – 5

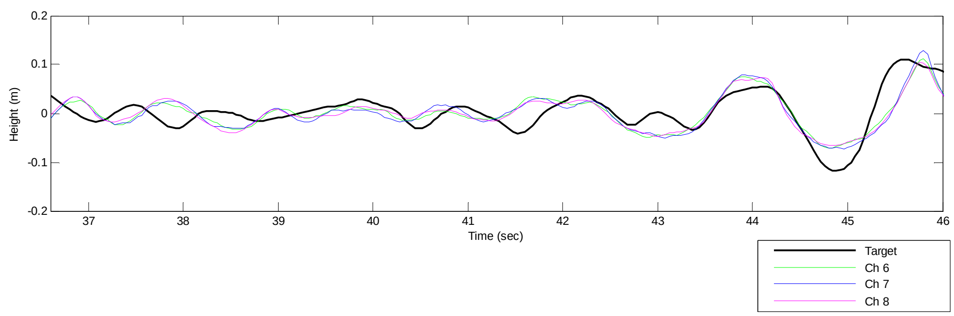

Figure C- 72: Test 12 with Buoys, PM-Hsig, h = 0.5 m, H = 0.1 m, Ch 6- 8

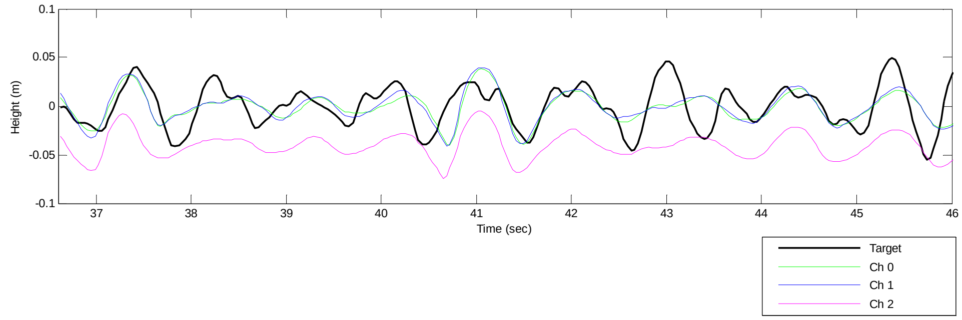

Figure C- 73: Test 13, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 0 -2

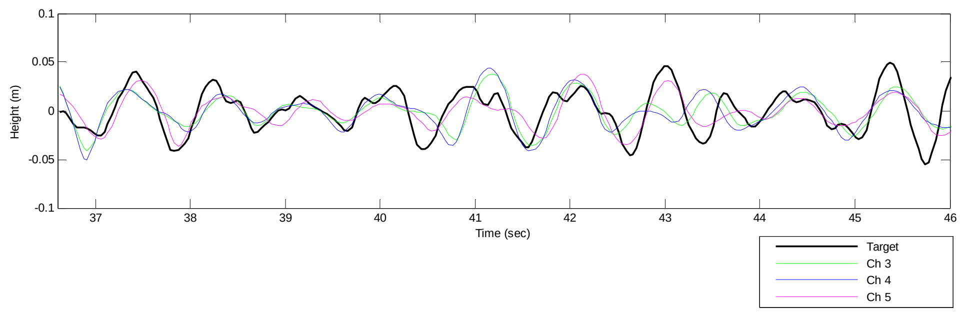

Figure C- 74: Test 13, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 3 - 5

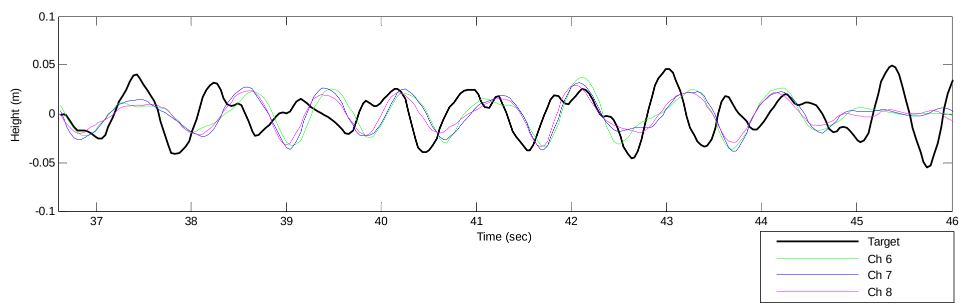

Figure C- 75: Test 13, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 6 – 8

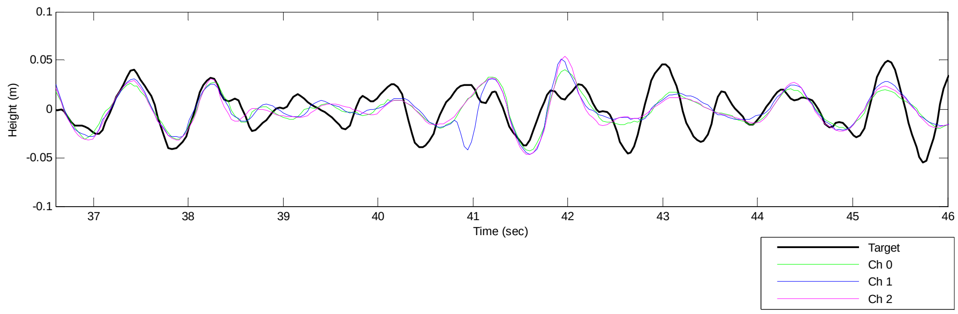

Figure C- 76: Test 13 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 0 -2

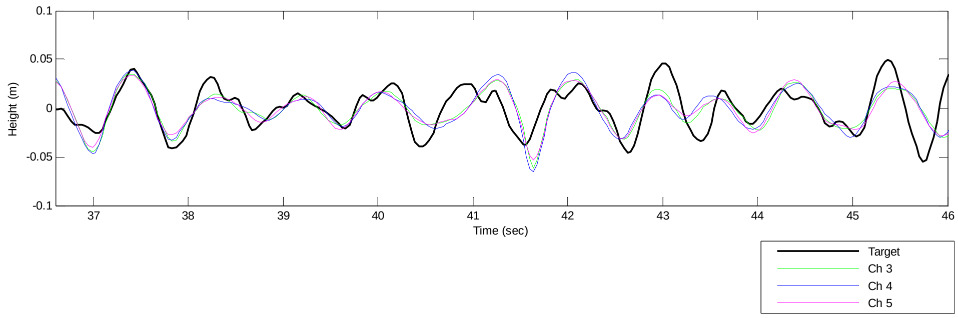

Figure C- 77: Test 13 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 3 - 5

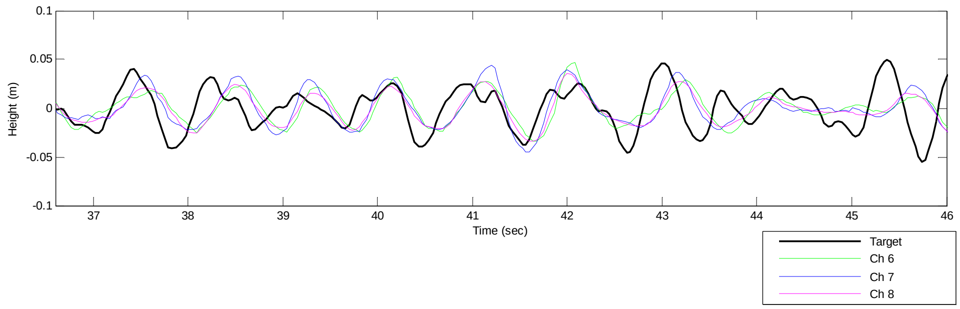

Figure C- 78: Test 13 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec, gamma = 3.3, Ch 6 – 8

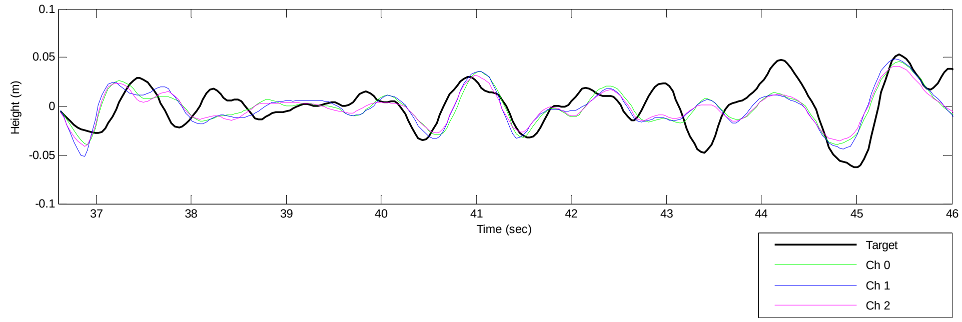

Figure C- 79: Test 14, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 0 – 2

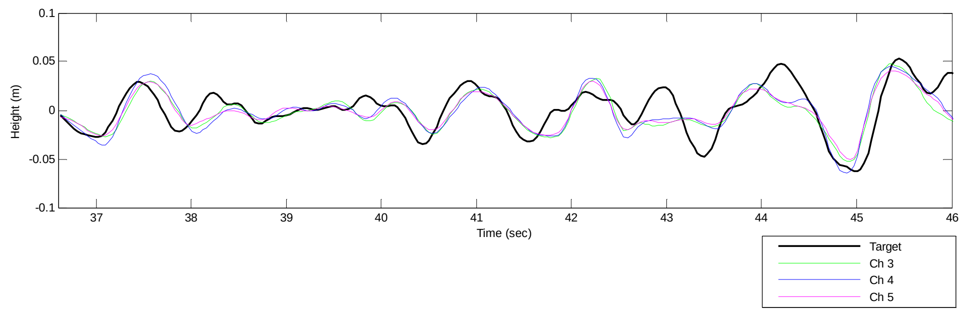

Figure C- 80: Test 14, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 3 - 5

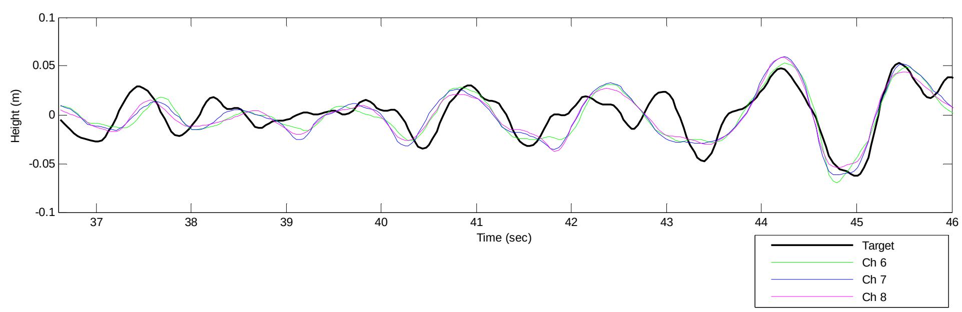

Figure C- 81: Test 14, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 6 – 8

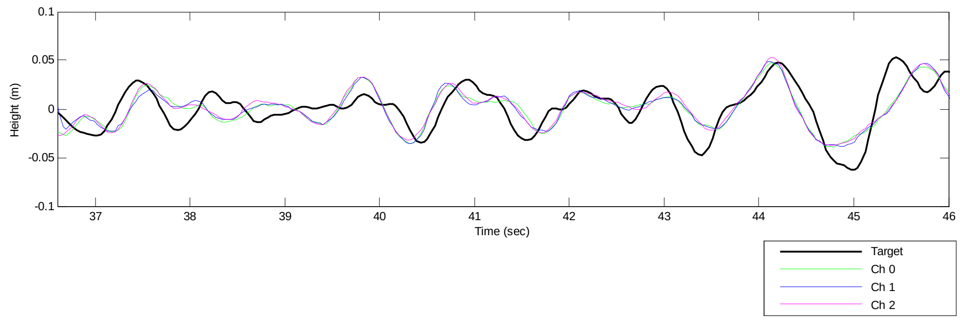

Figure C- 82: Test 14 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 0 – 2

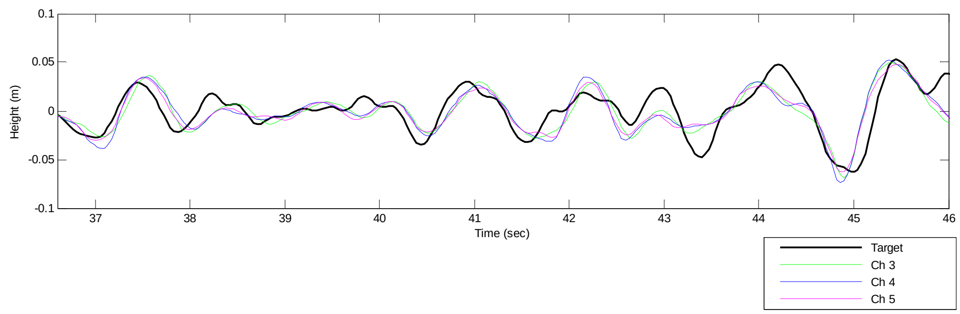

Figure C- 83: Test 14 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 3 – 5

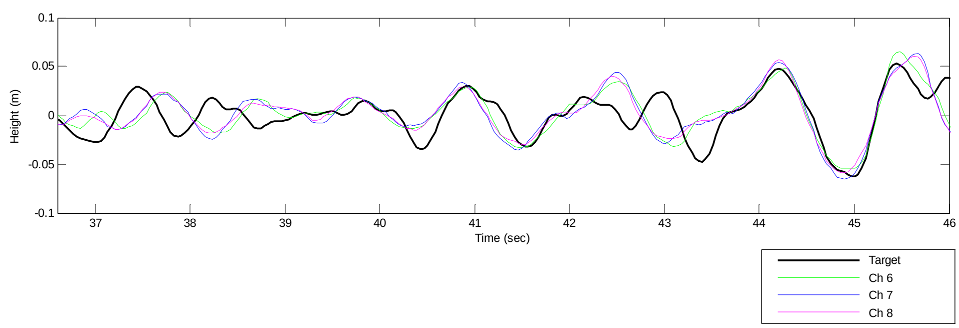

Figure C- 84: Test 14 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec, gamma = 3.3, Ch 6 – 8

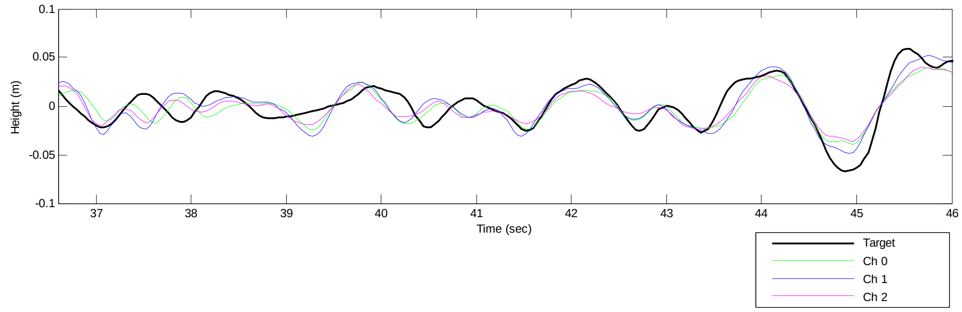

Figure C- 85: Test 15, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 0 – 2

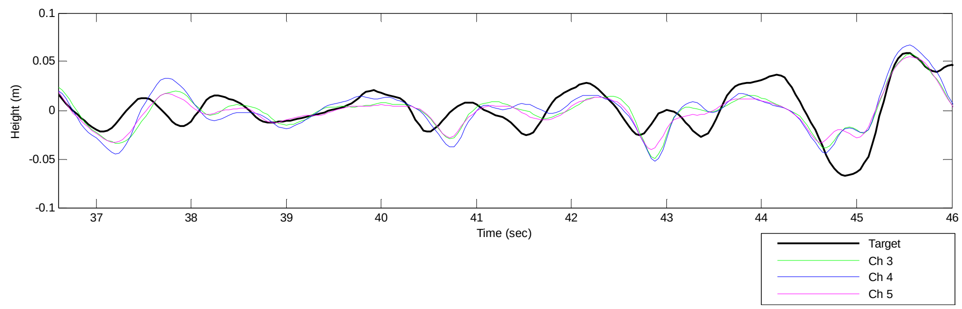

Figure C- 86: Test 15, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 3 – 5

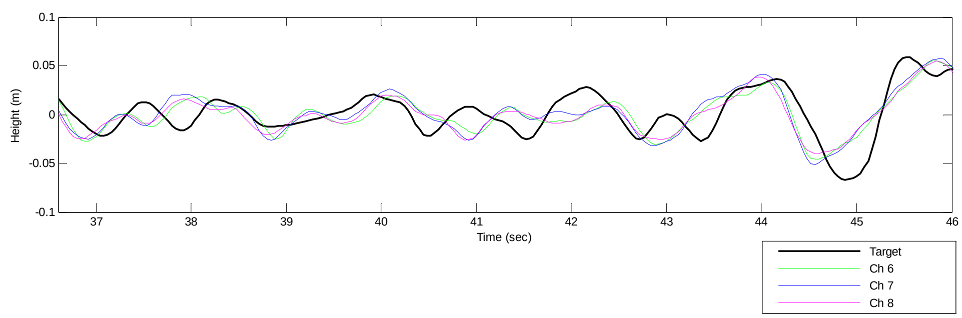

Figure C- 87: Test 15, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 6 – 8

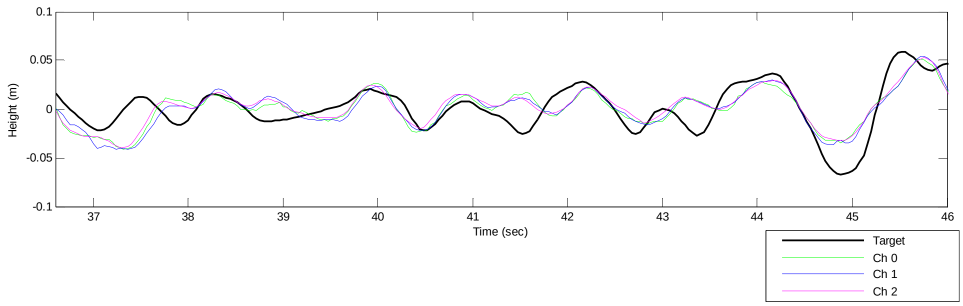

Figure C- 88: Test 15 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 0 - 2

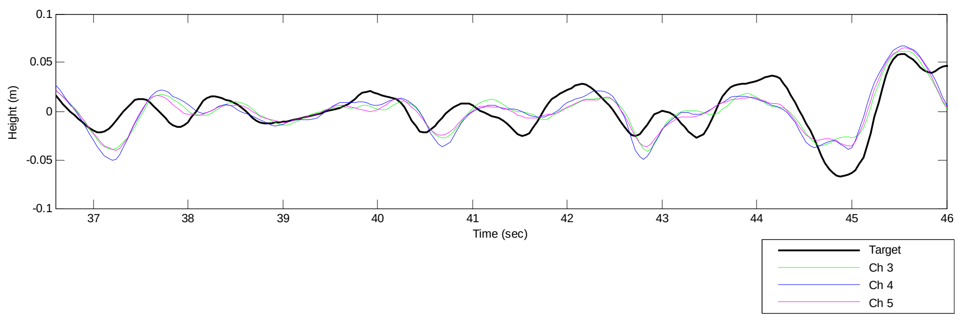

Figure C- 89: Test 15 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 3 - 5

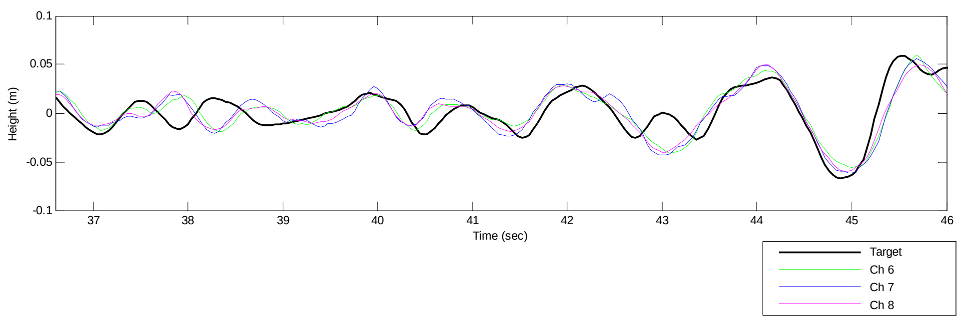

Figure C- 90: Test 15 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec, gamma = 3.3, Ch 6 – 8

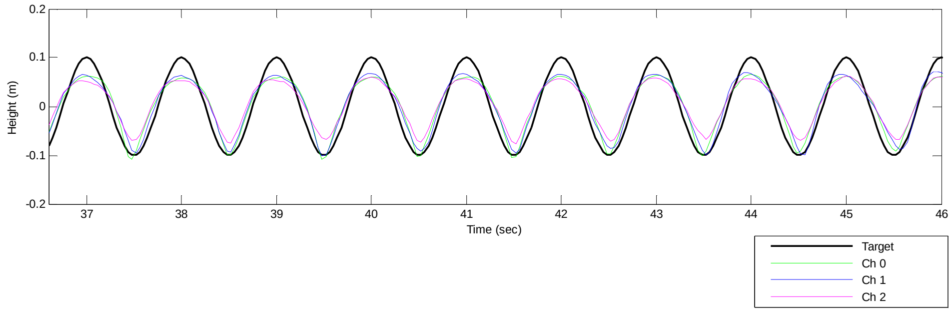

Figure C- 91: Test 16, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.0 sec, Ch 0 – 2

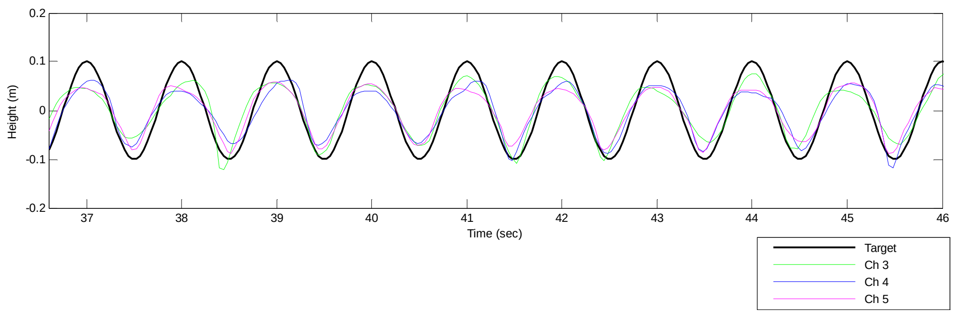

Figure C- 92: Test 16, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.0 sec, Ch 3 – 5

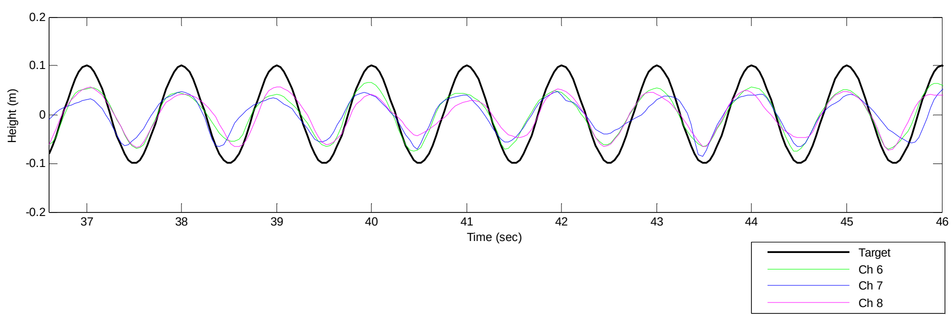

Figure C- 93: Test 16, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.0 sec, Ch 6 – 8

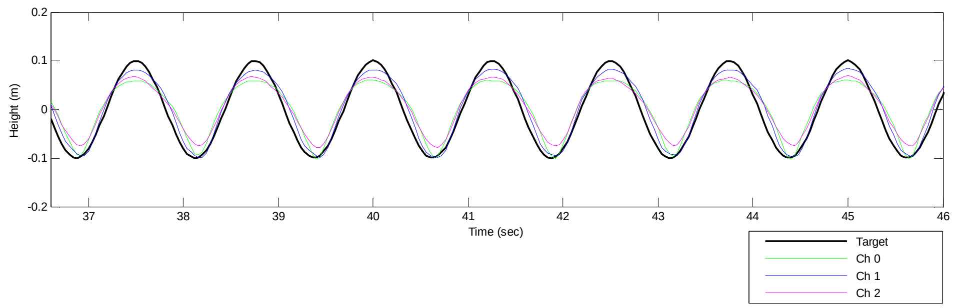

Figure C- 94: Test 17, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.25 sec, Ch 0 – 2

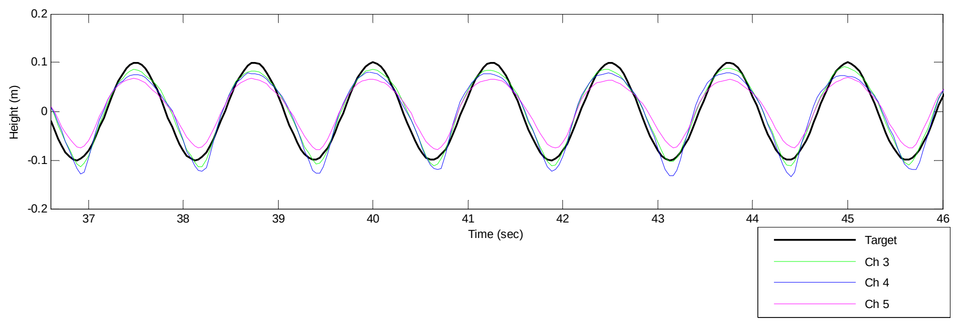

Figure C- 95: Test 17, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.25 sec, Ch 3 – 5

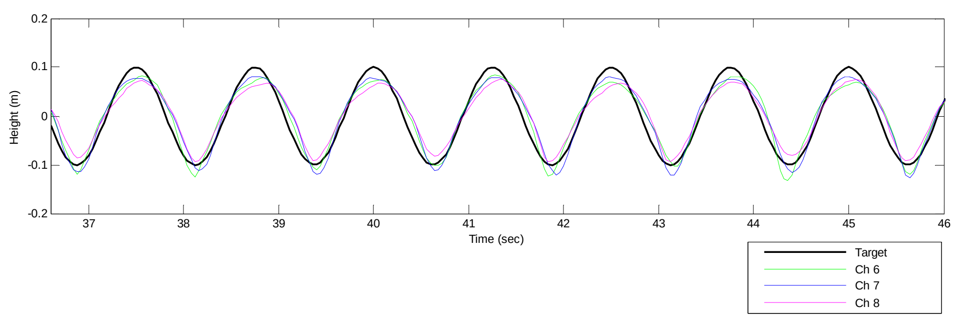

Figure C- 96: Test 17, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.25 sec, Ch 6 – 8

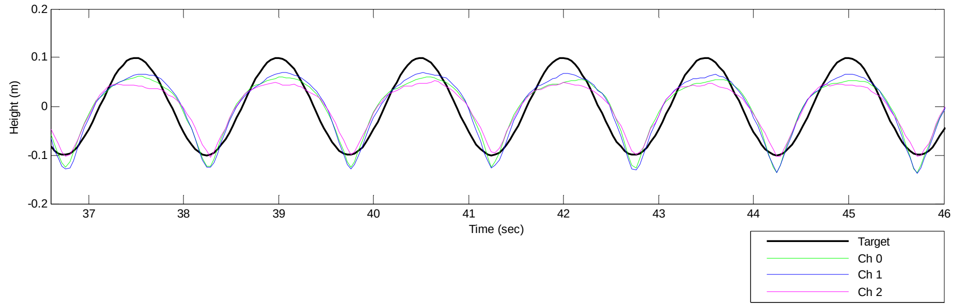

Figure C- 97: Test 18, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.5 sec, Ch 0 – 2

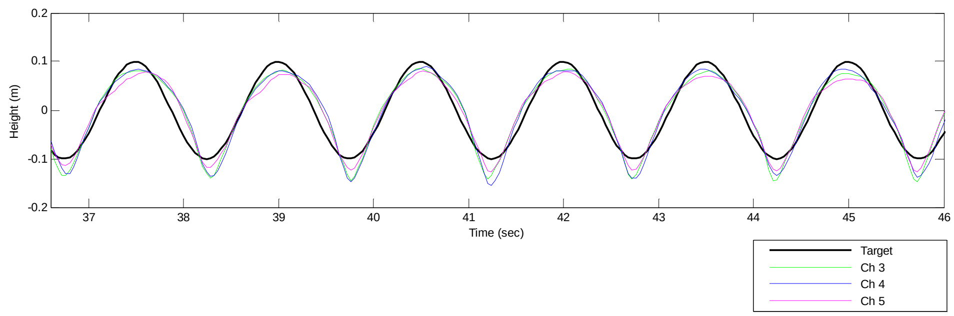

Figure C- 98: Test 18, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.5 sec, Ch 3 – 5

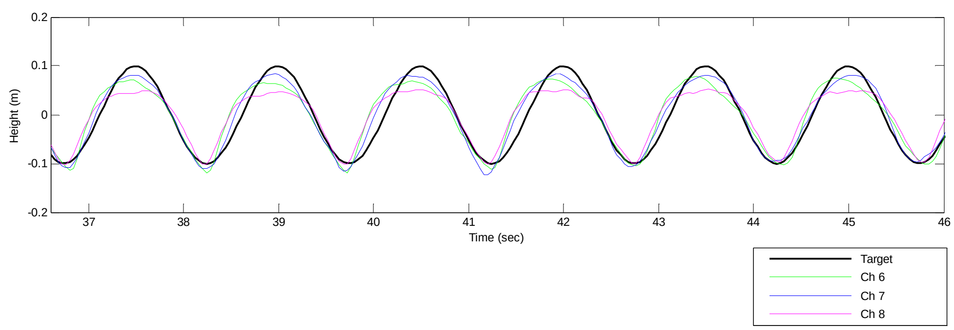

Figure C- 99: Test 18, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.5 sec, Ch 6 – 8

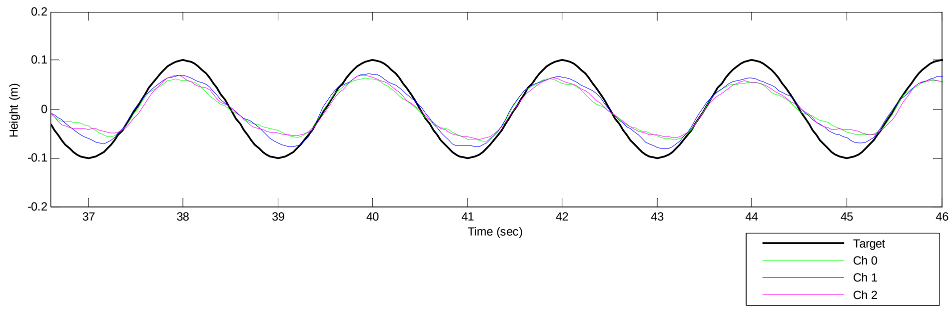

Figure C- 100: Test 19, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.0 sec, Ch 0 – 2

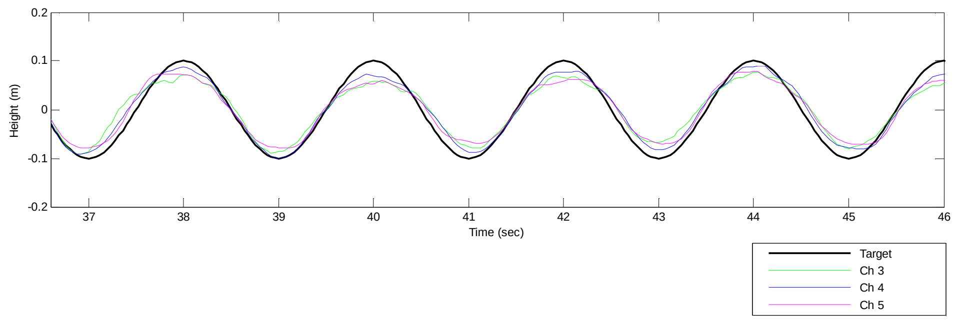

Figure C- 101: Test 19, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.0 sec, Ch 3 – 5

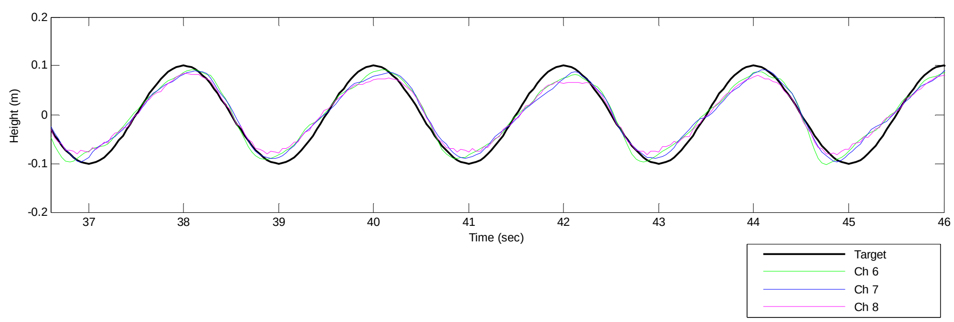

Figure C- 102: Test 19, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.0 sec, Ch 6 – 8

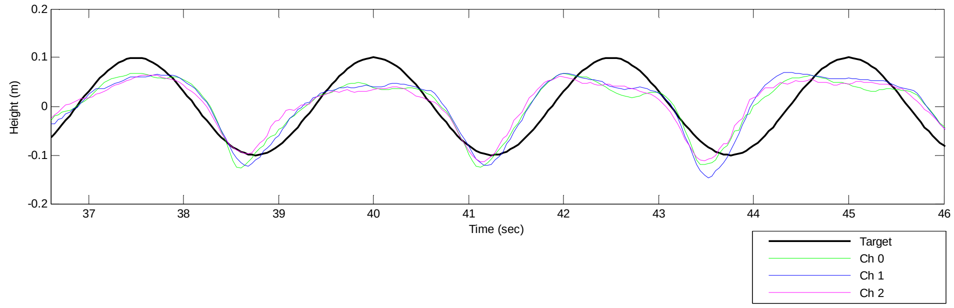

Figure C- 103: Test 20, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.5 sec, Ch 0 – 2

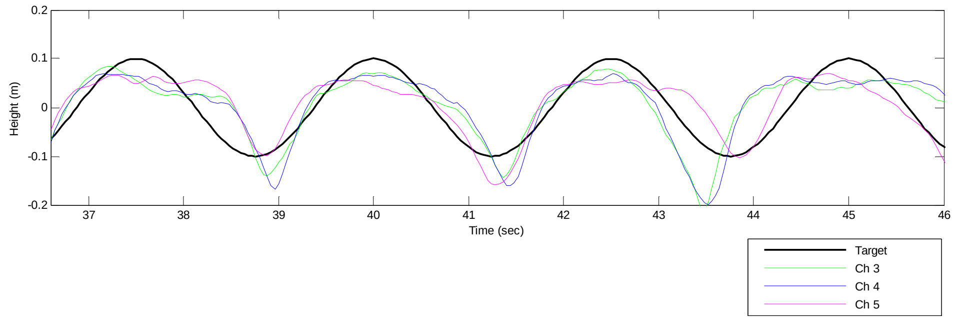

Figure C- 104: Test 20, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.5 sec, Ch 3 – 5

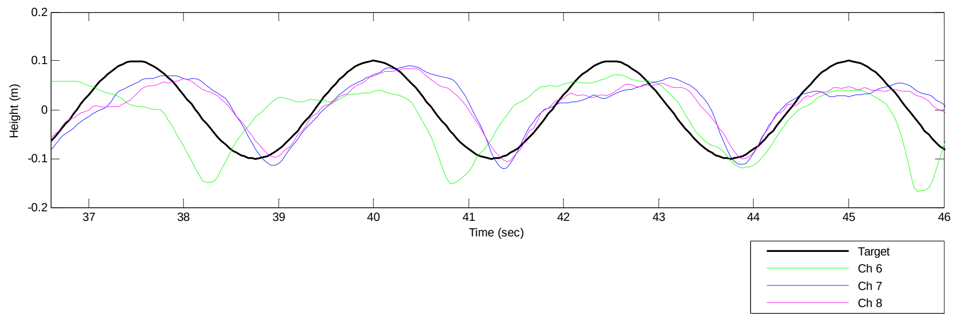

Figure C- 105: Test 20, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.5 sec, Ch 6 – 8

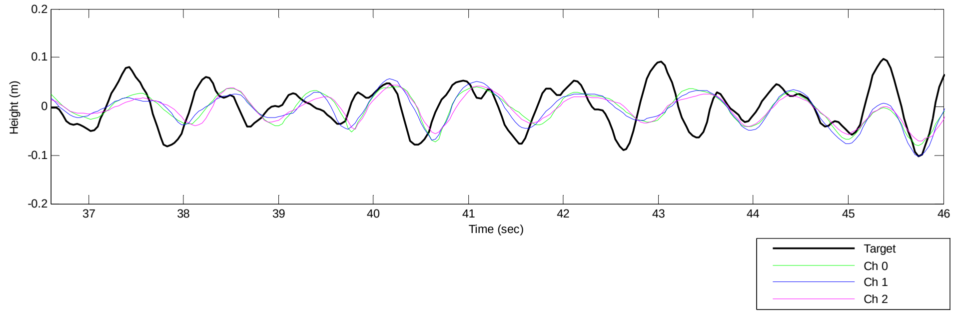

Figure C- 106: Test 21, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.0 sec, gamma = 3.3, Ch 0 – 2

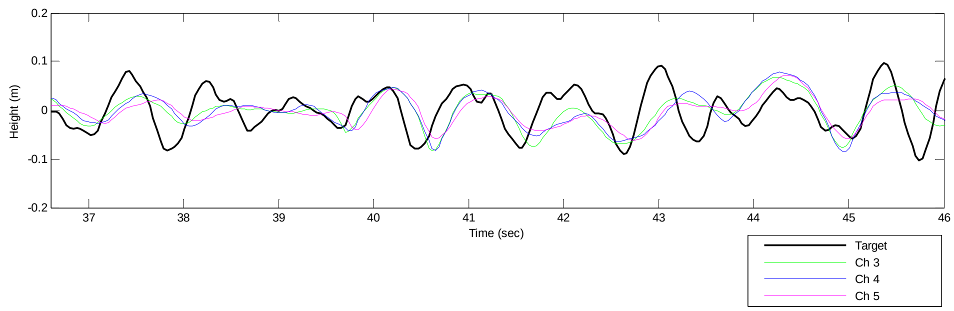

Figure C- 107: Test 21, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.0 sec, gamma = 3.3, Ch 3 – 5

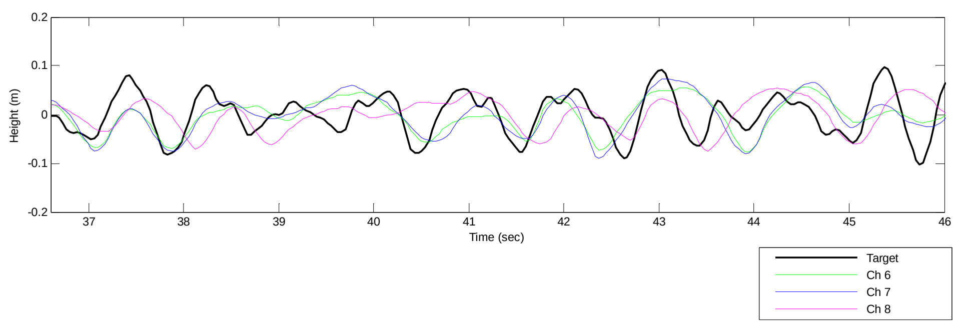

Figure C- 108: Test 21, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.0 sec, gamma = 3.3, Ch 6 – 8

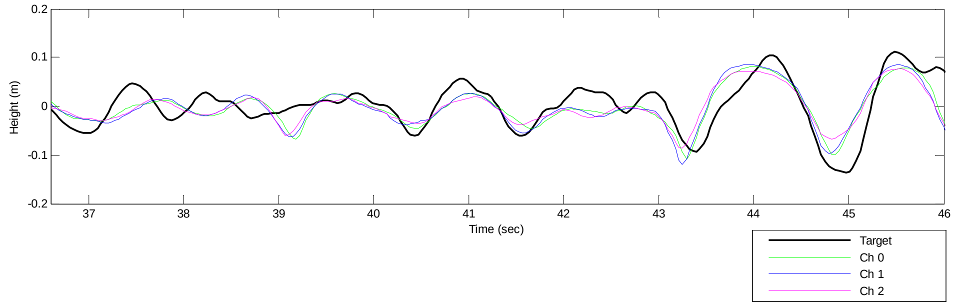

Figure C- 109: Test 22, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0 - 2

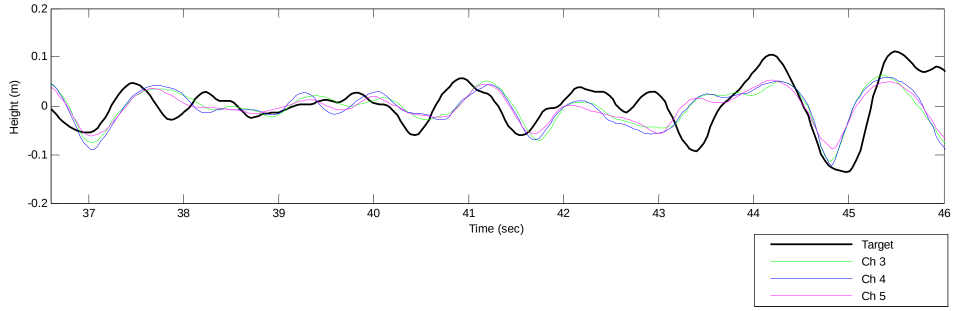

Figure C- 110: Test 22, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 3 - 5

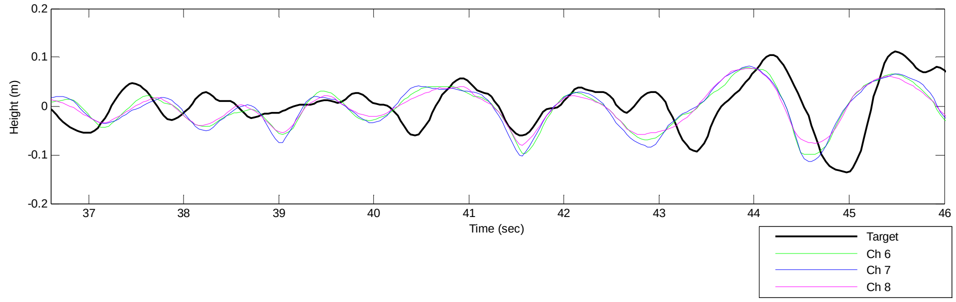

Figure C- 111: Test 22, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 6 - 8

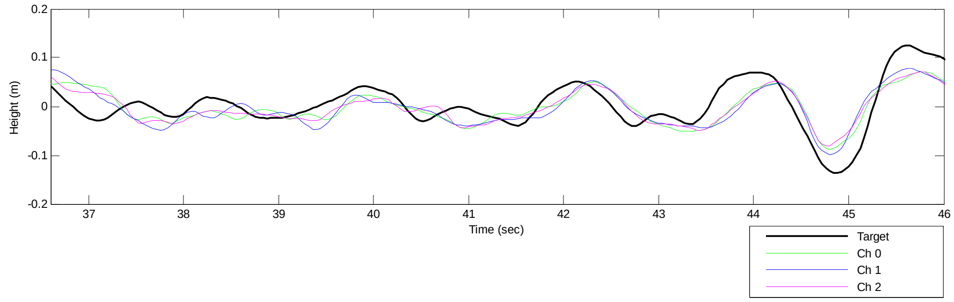

Figure C- 112: Test 23, JONSWAP, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0 – 2

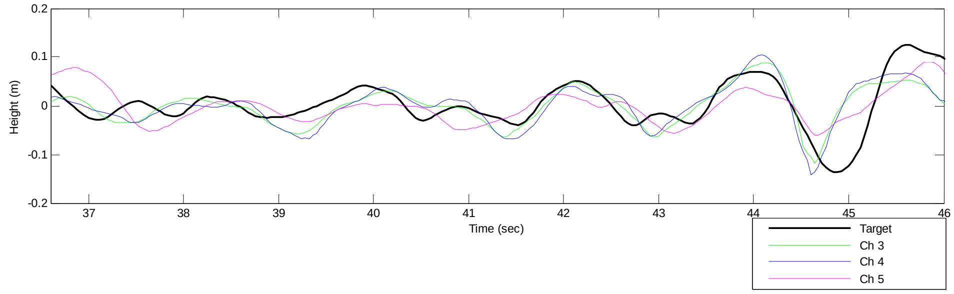

Figure C- 113: Test 23, JONSWAP, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 3 – 5

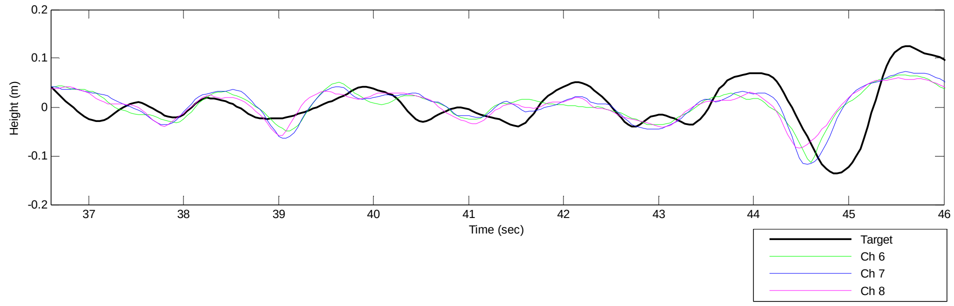

Figure C- 114: Test 23, JONSWAP, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 6 - 8

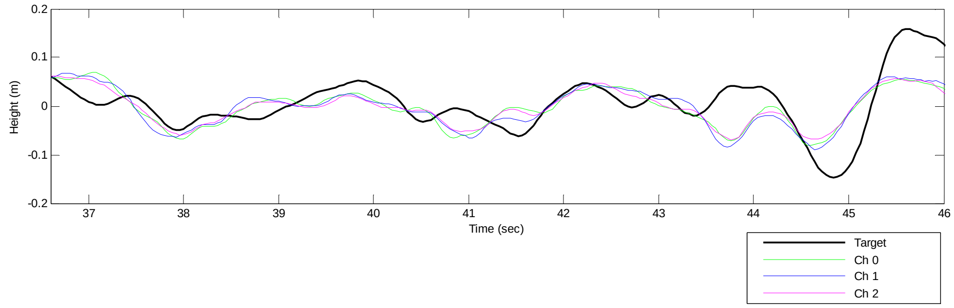

Figure C- 115: Test 24, PM-Hsig, h = 0.5 m, H = 0.2 m, Ch 0 – 2

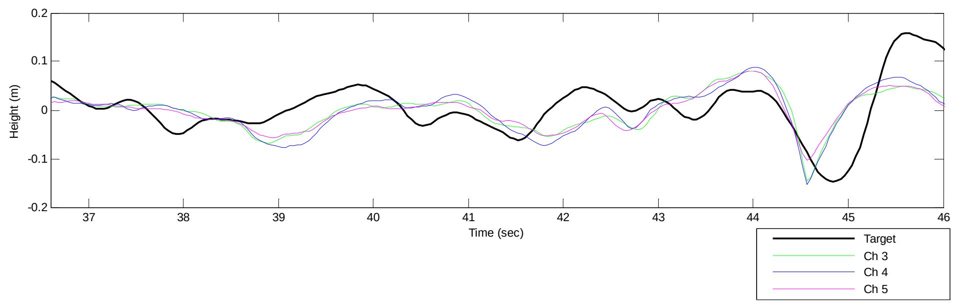

Figure C- 116: Test 24, PM-Hsig, h = 0.5 m, H = 0.2 m, Ch 3 - 5

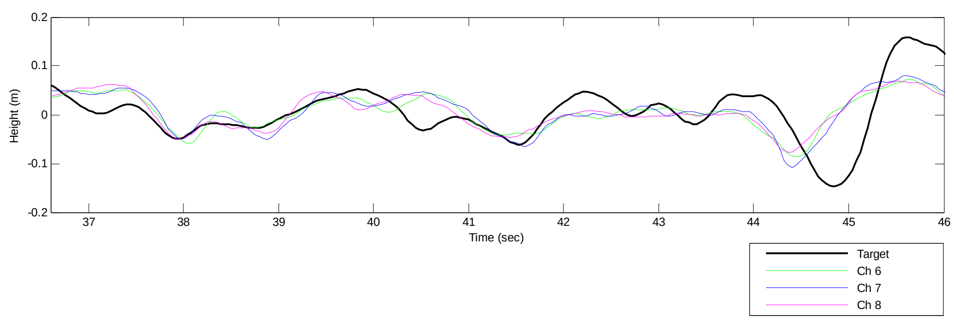

Figure C- 117: Test 24, PM-Hsig, h = 0.5 m, H = 0.2 m, Ch 6 - 8

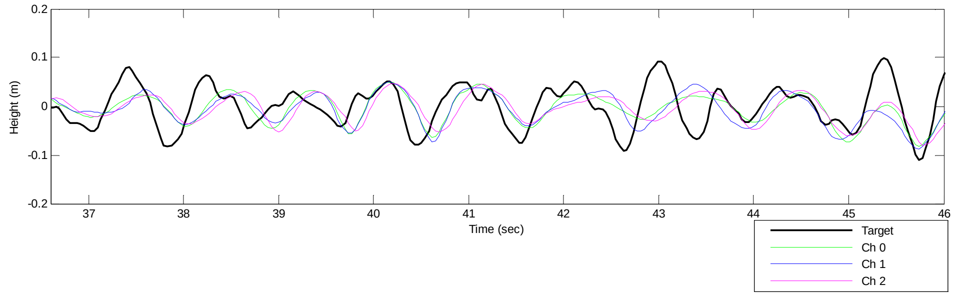

Figure C- 118: Test 25, TMA, h = 0.5 m, H =0.2 m, T = 1.0 sec, gamma= 3.3, Ch 0 - 2

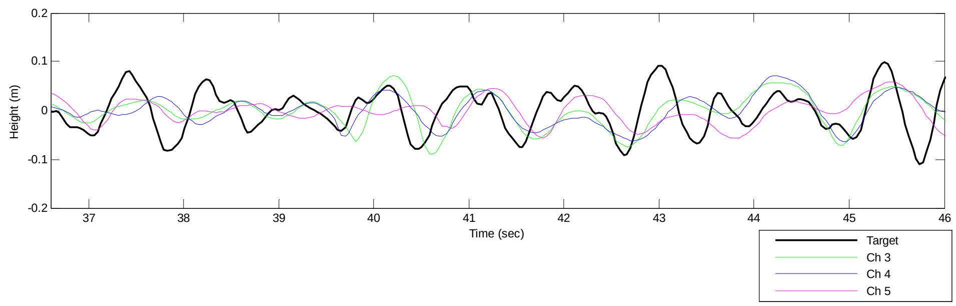

Figure C- 119: Test 25, TMA, h = 0.5 m, H =0.2 m, T = 1.0 sec, gamma= 3.3, Ch 3 - 5

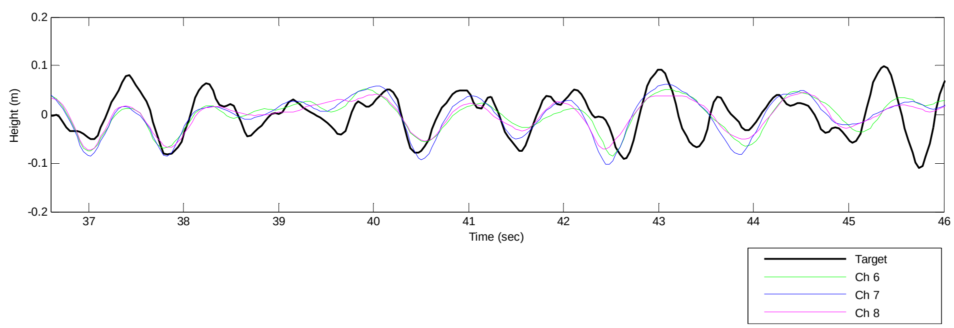

Figure C- 120: Test 25, TMA, h = 0.5 m, H =0.2 m, T = 1.0 sec, gamma= 3.3, Ch 6 - 8

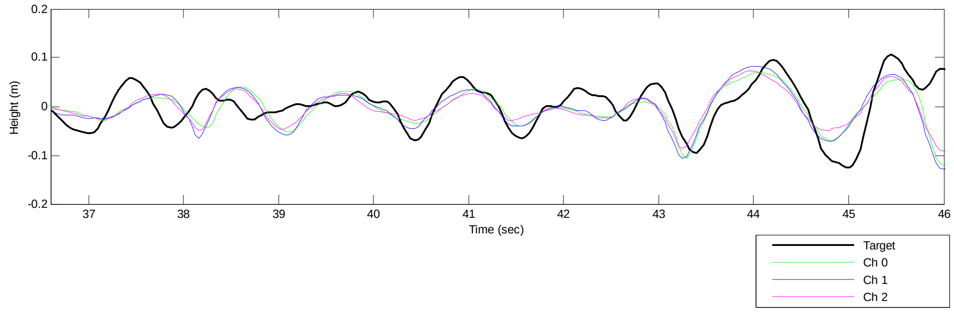

Figure C- 121: Test 26, TMA, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0 – 2

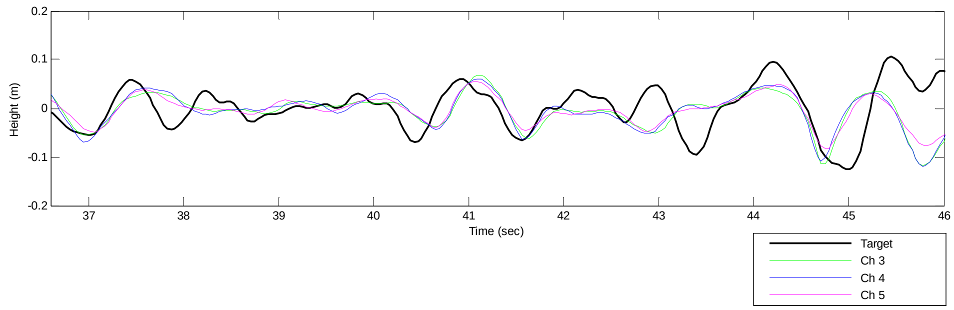

Figure C- 122: Test 26, TMA, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 3 - 5

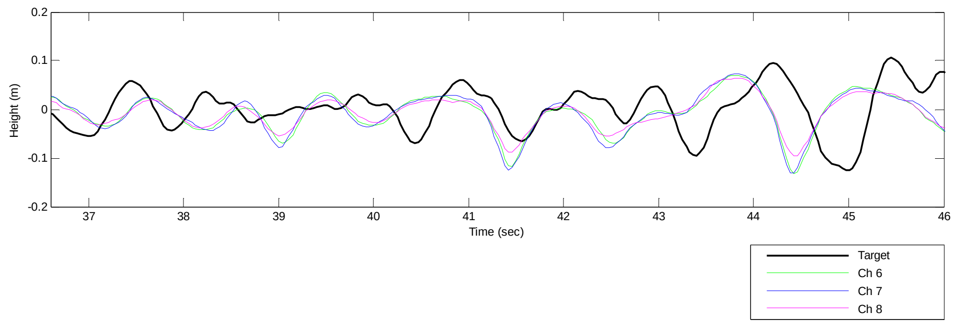

Figure C- 123: Test 26, TMA, h = 0.5 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 6 - 8

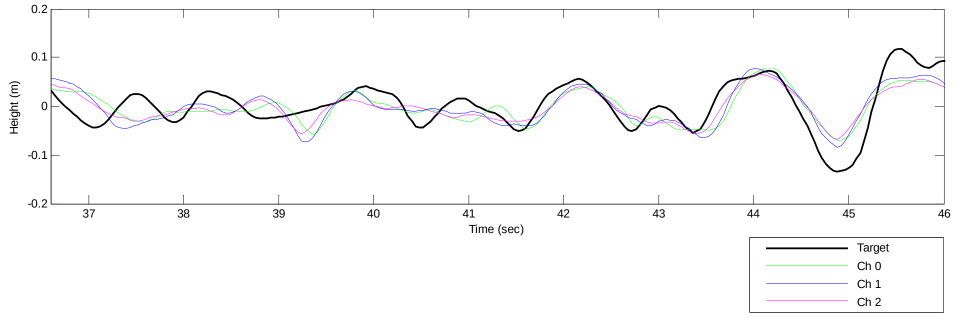

Figure C- 124: Test 27, TMA, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch0-2

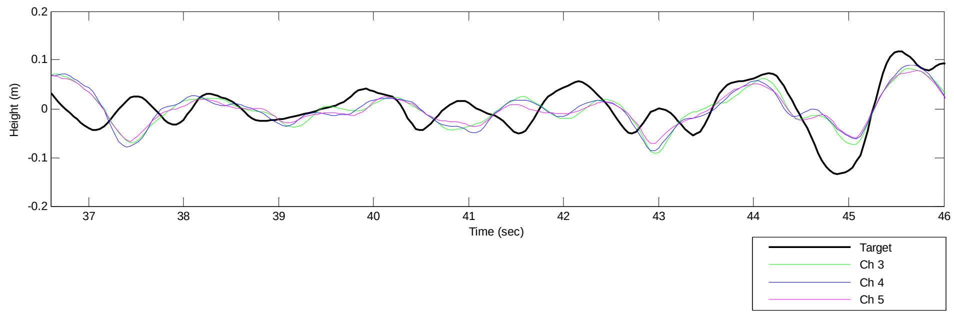

Figure C- 125: Test 27, TMA, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch3-5

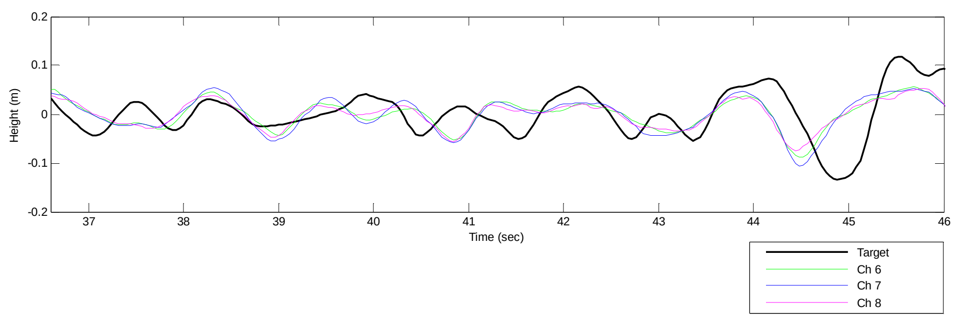

Figure C- 126: Test 27, TMA, h = 0.5 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch6-8

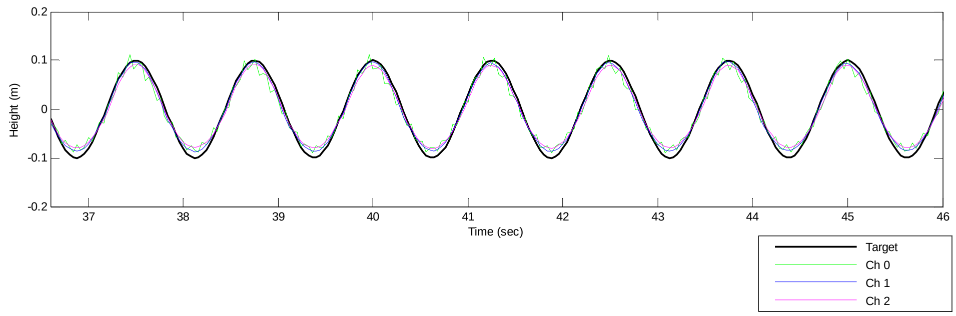

Figure C- 127: Test 31, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 0 – 2

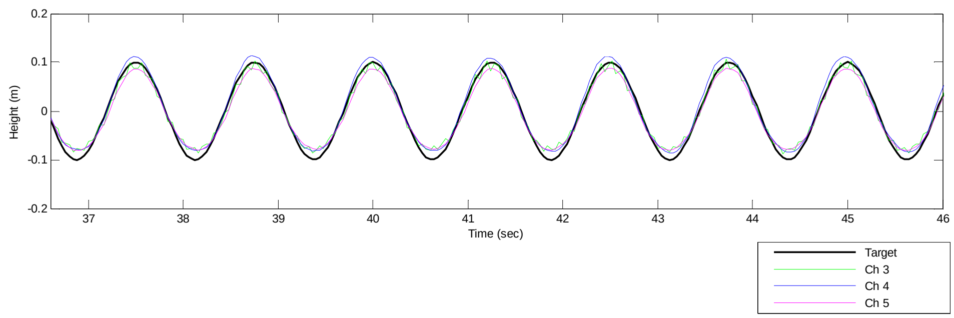

Figure C- 128: Test 31, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 03 – 5

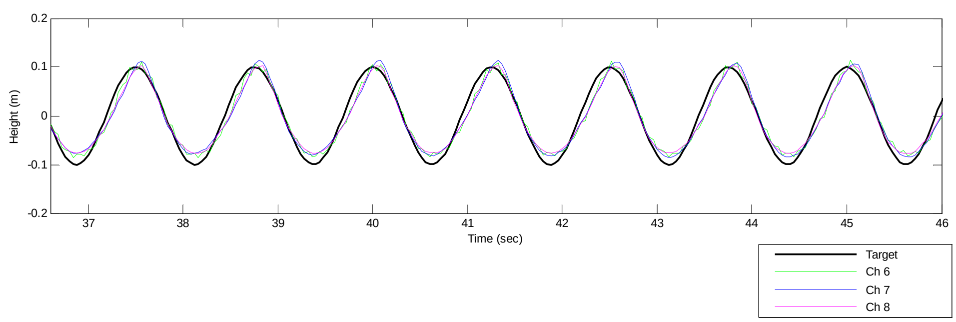

Figure C- 129: Test 31, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 06 – 8

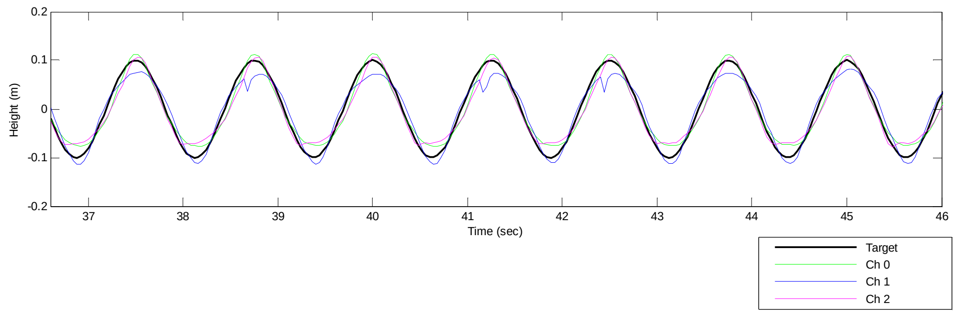

Figure C- 130: Test 31 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 0 – 2

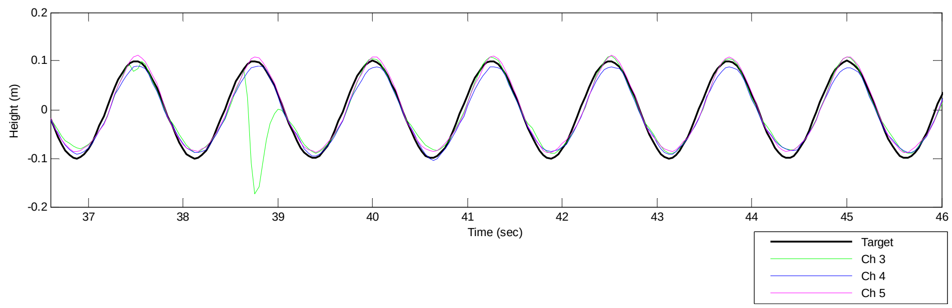

Figure C- 131: Test 31 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 3 – 5

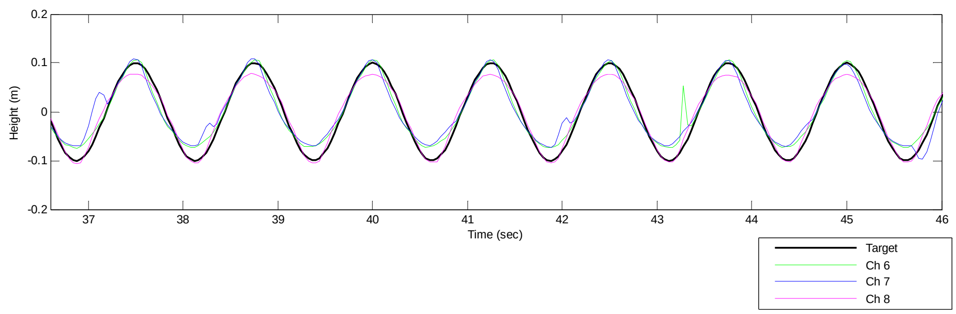

Figure C- 132: Test 31 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 6 – 8

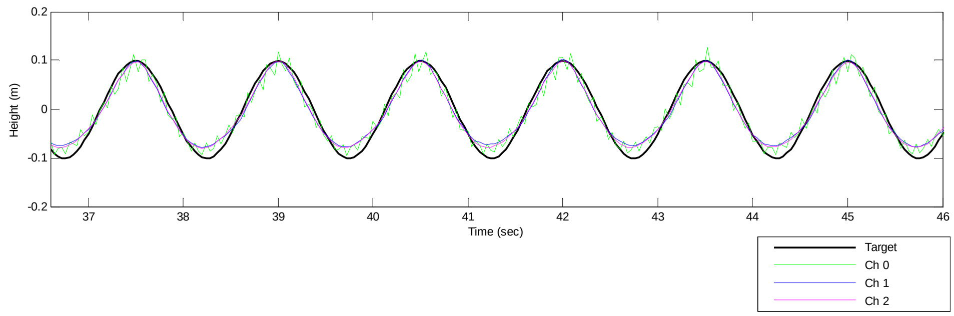

Figure C- 133: Test 32, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 0 – 2

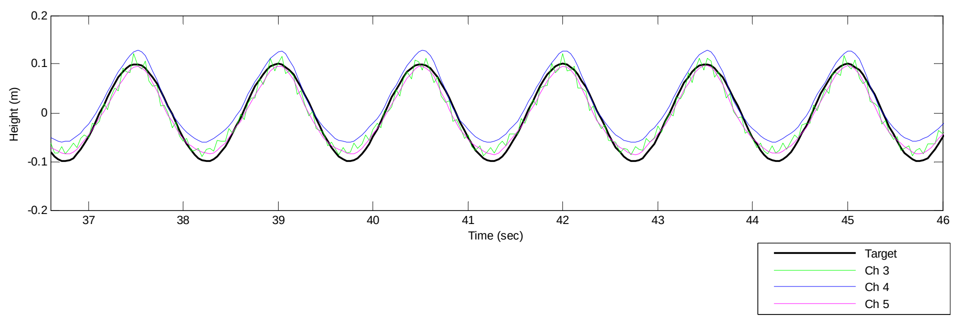

Figure C- 134: Test 32, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 3 – 5

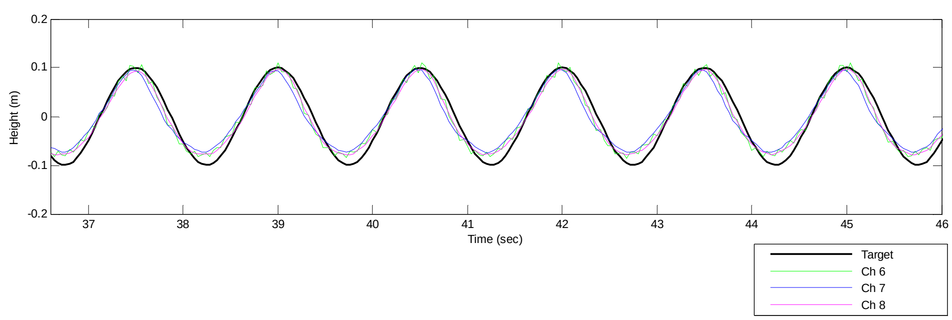

Figure C- 135: Test 32, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 6 – 8

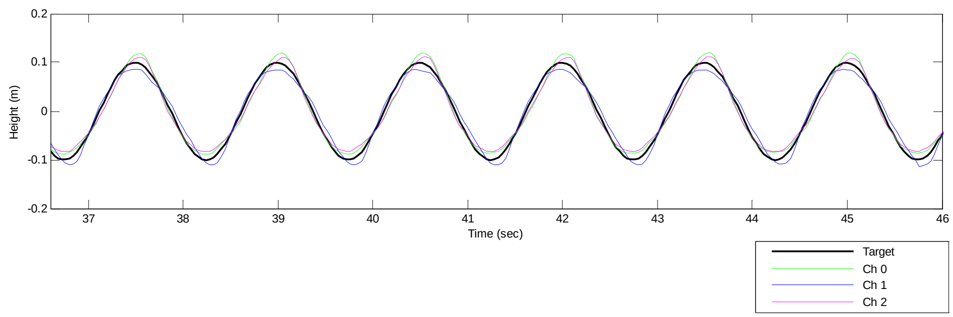

Figure C- 136: Test 32 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 0 – 2

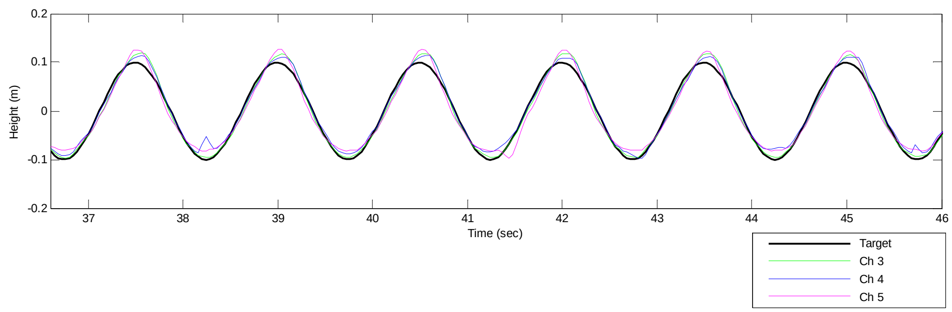

Figure C- 137: Test 32 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 3 – 5

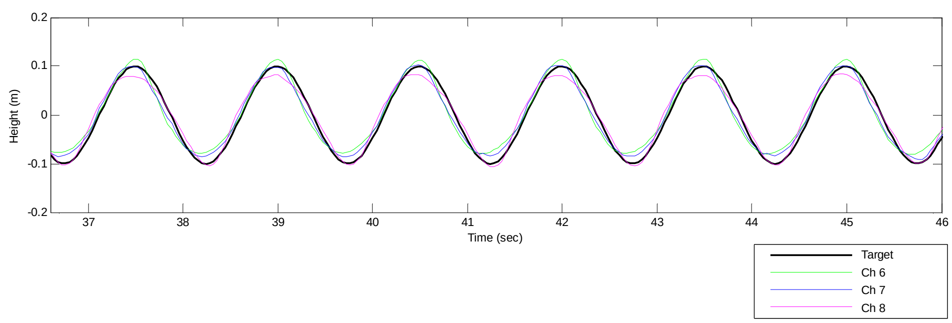

Figure C- 138: Test 32 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 6 – 8

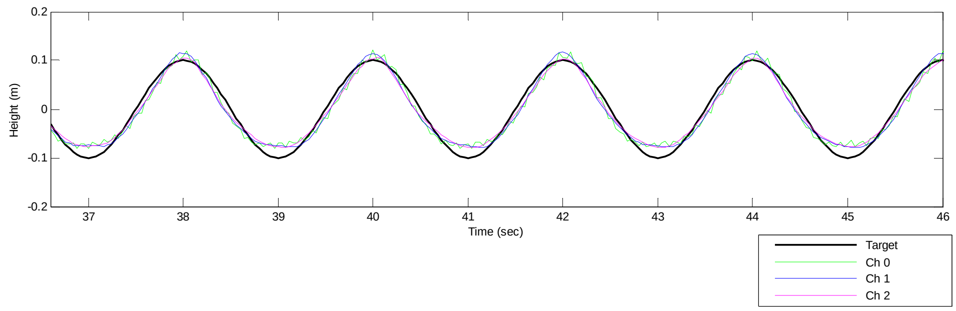

Figure C- 139: Test 33, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 0 – 2

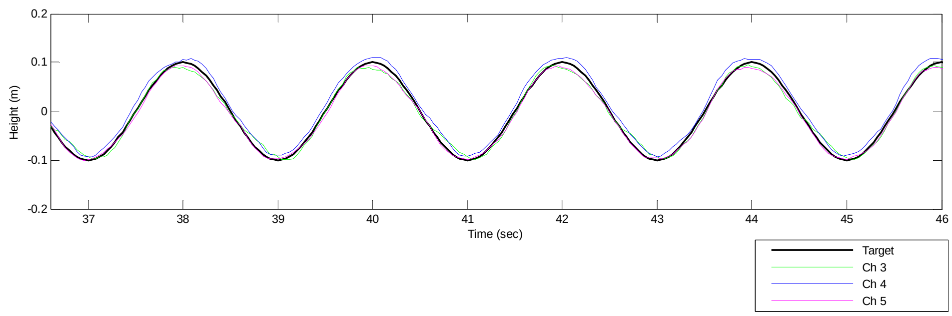

Figure C- 140: Test 33, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 3 – 5

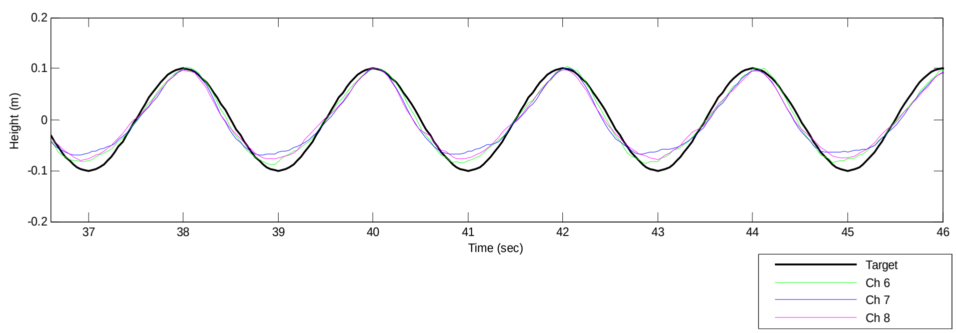

Figure C- 141: Test 33, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 6 – 8

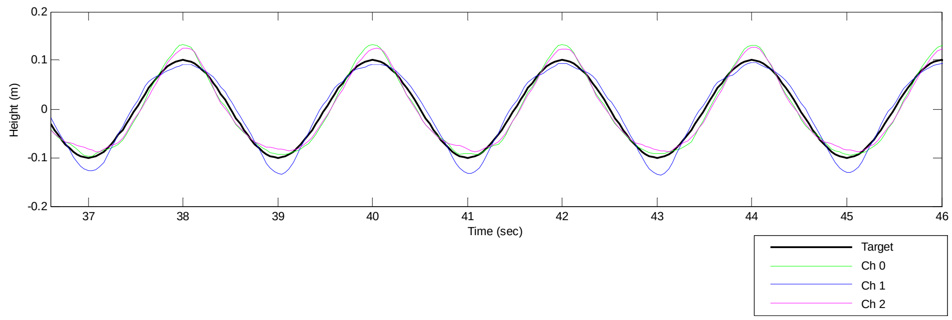

Figure C- 142: Test 33 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 0 – 2

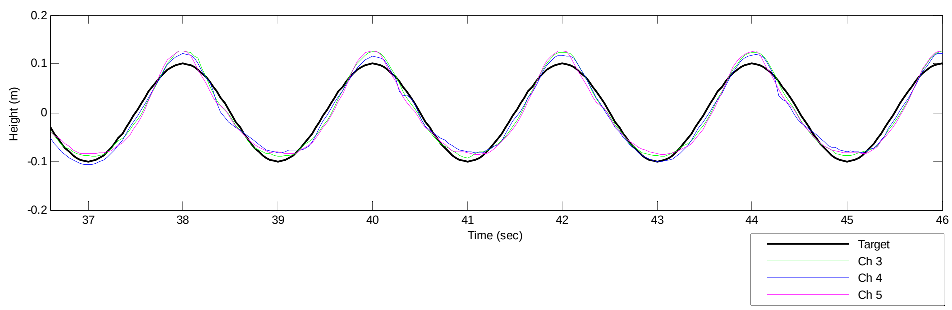

Figure C- 143: Test 33 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 3 – 5

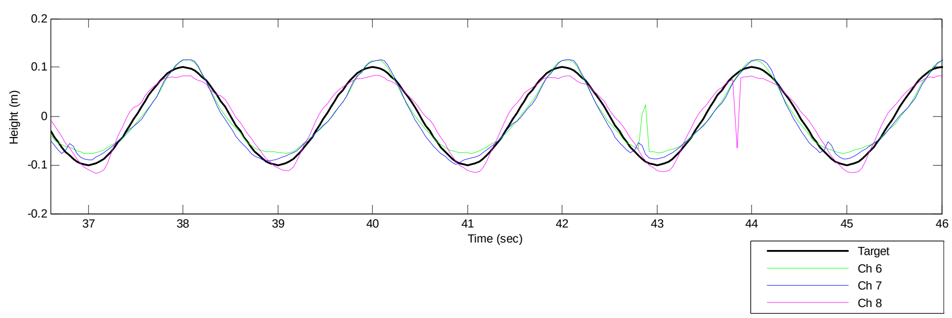

Figure C- 144: Test 33 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 6 – 8

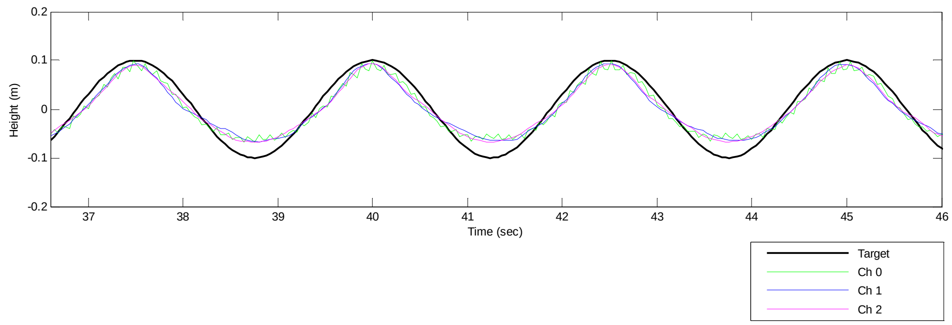

Figure C- 145: Test 34, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 0 – 2

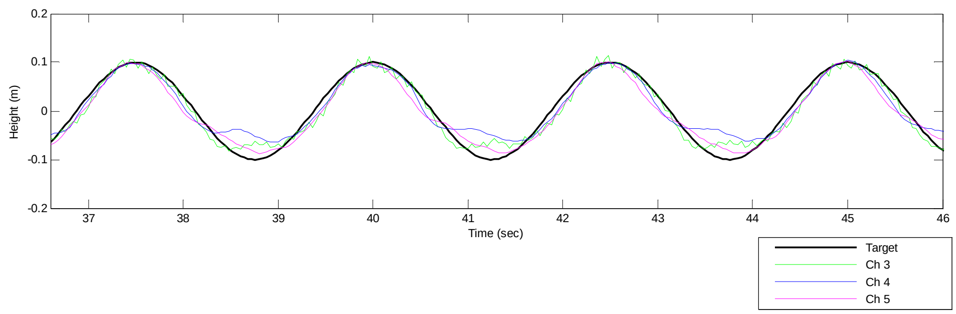

Figure C- 146: Test 34, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 3 – 5

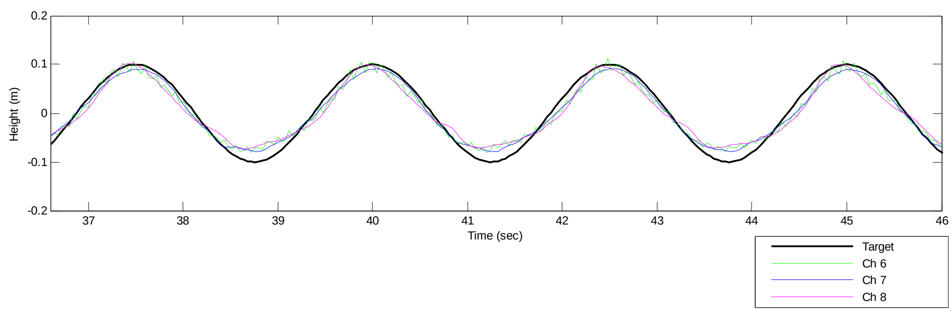

Figure C- 147: Test 34, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 6 – 8

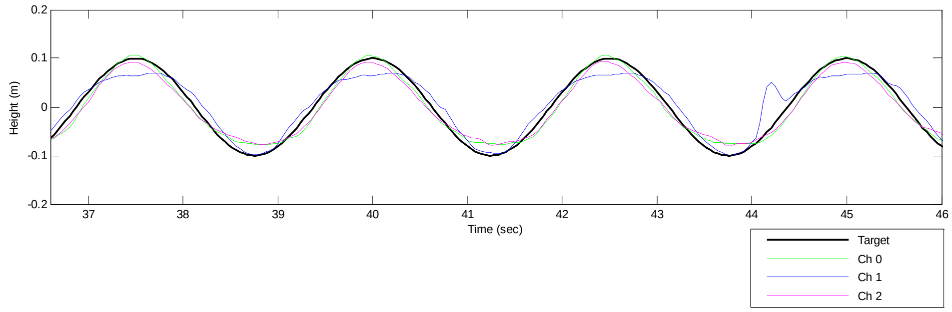

Figure C- 148: Test 34 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 0 – 2

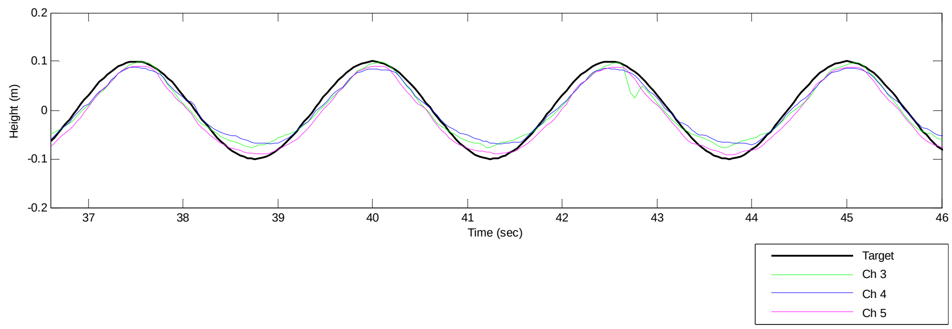

Figure C- 149: Test 34 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 3 – 5

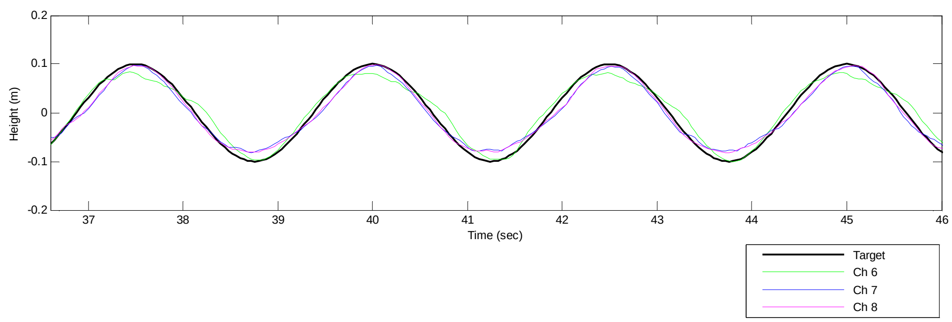

Figure C- 150: Test 34 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 6 – 8

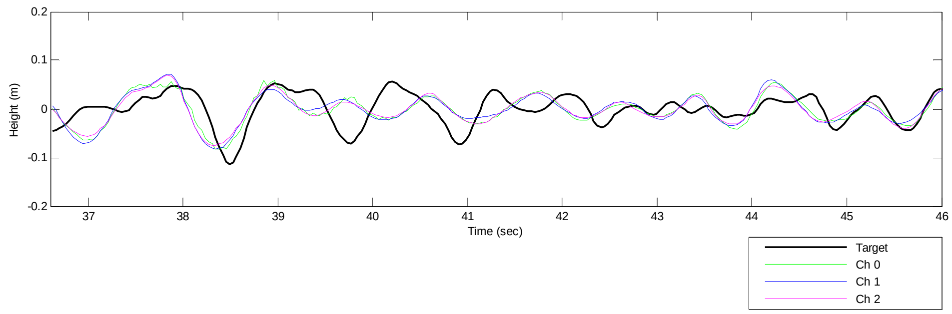

Figure C- 151: Test 35, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0 - 2

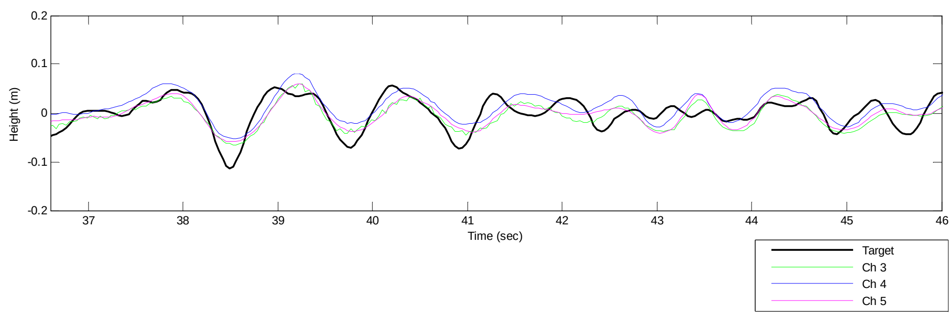

Figure C- 152: Test 35, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 3 - 5

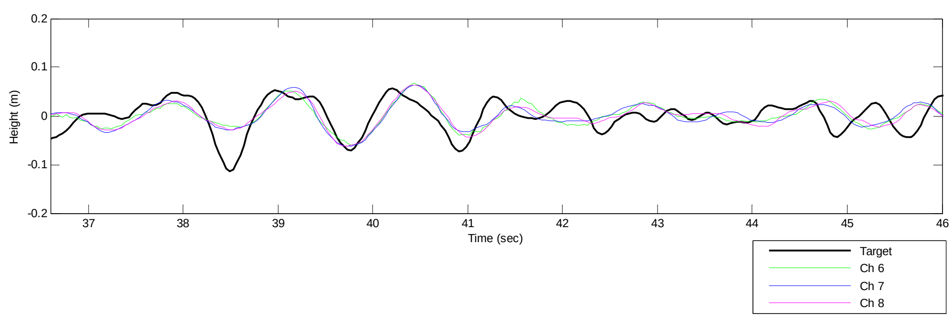

Figure C- 153: Test 35, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 6 - 8

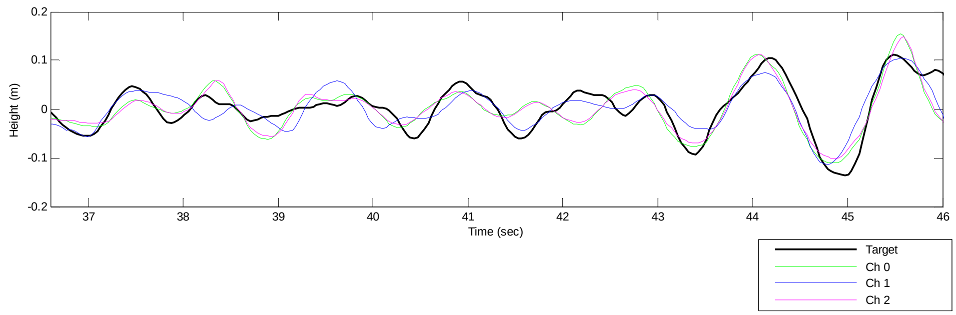

Figure C-154: Test 35 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0-2

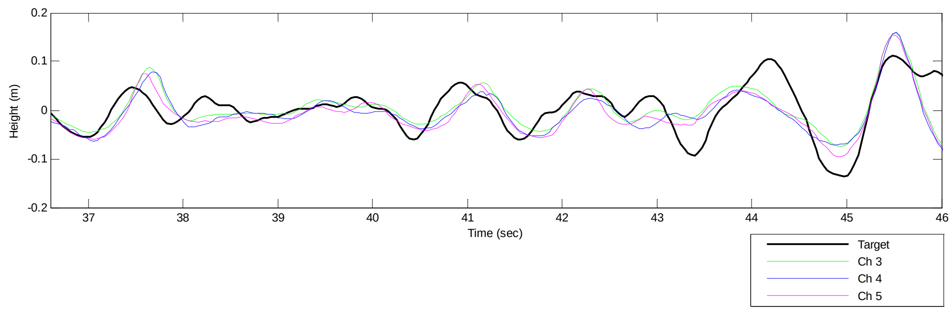

Figure C-155: Test 35 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 3-5

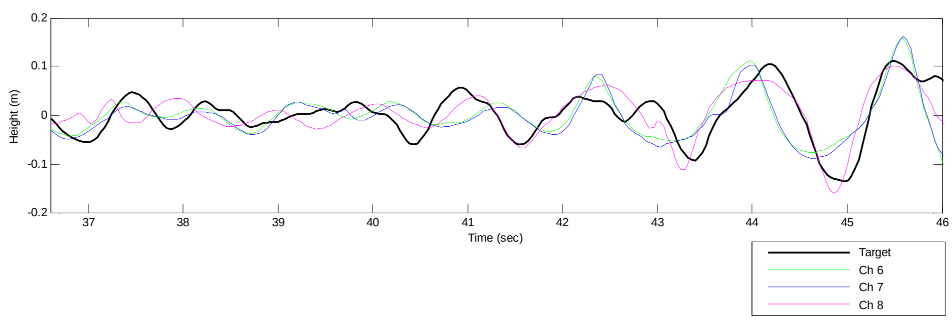

Figure C-156: Test 35 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 6-8

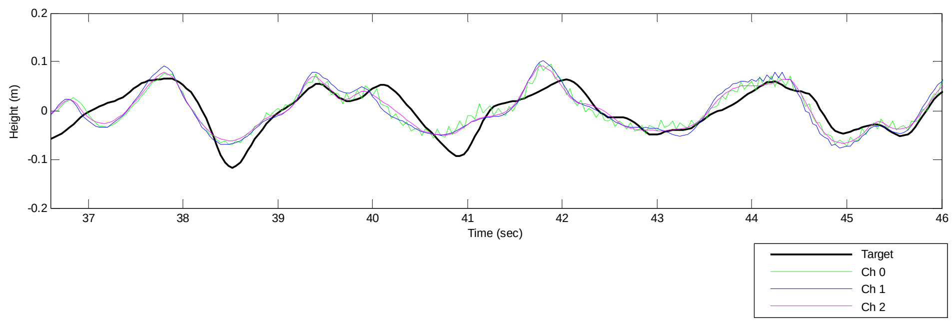

Figure C- 157: Test 36, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0 - 2

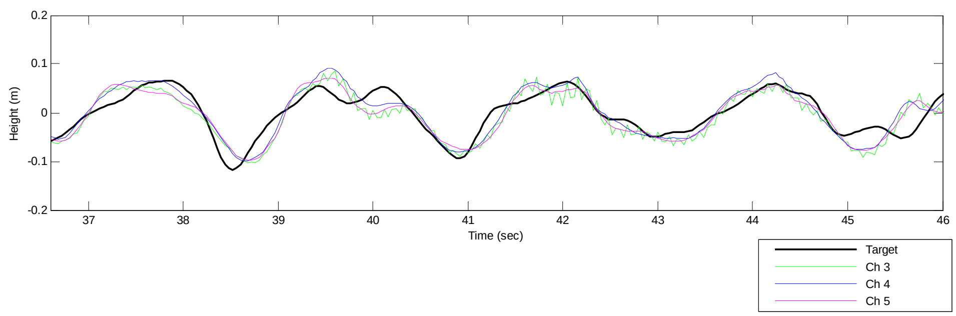

Figure C- 158: Test 36, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 3 – 5

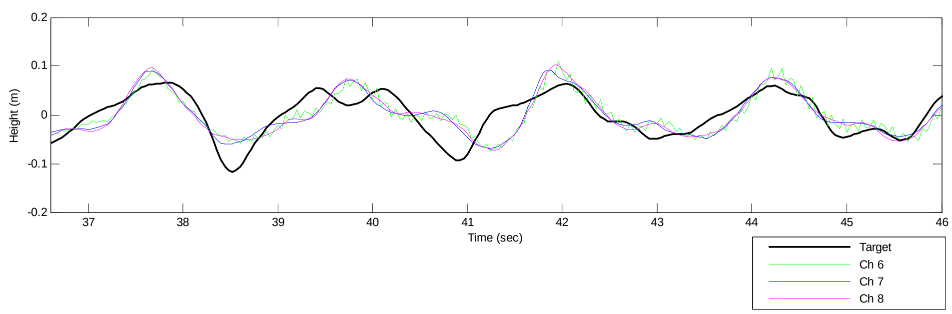

Figure C- 159: Test 36, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 6 – 8

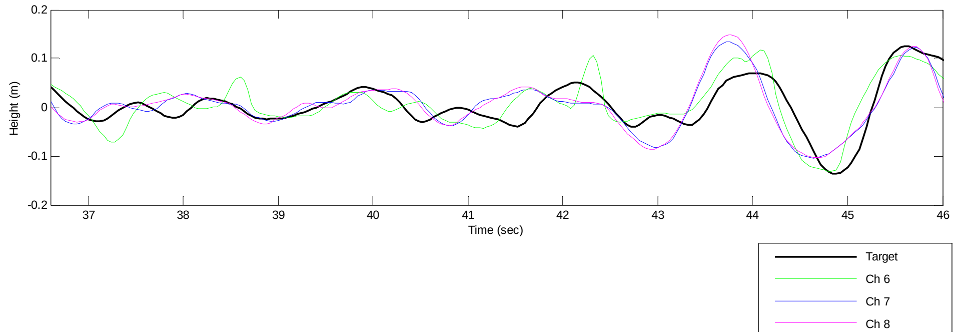

Figure C-160: Test 36 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0-2

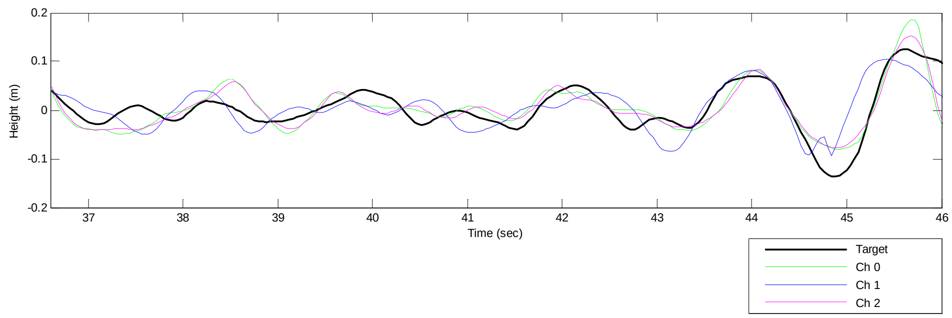

Figure C-161: Test 36 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 3-5

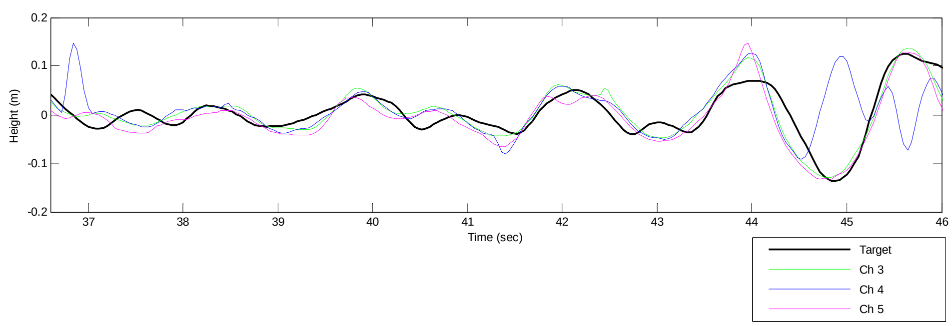

Figure C-162: Test 36 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 6-8

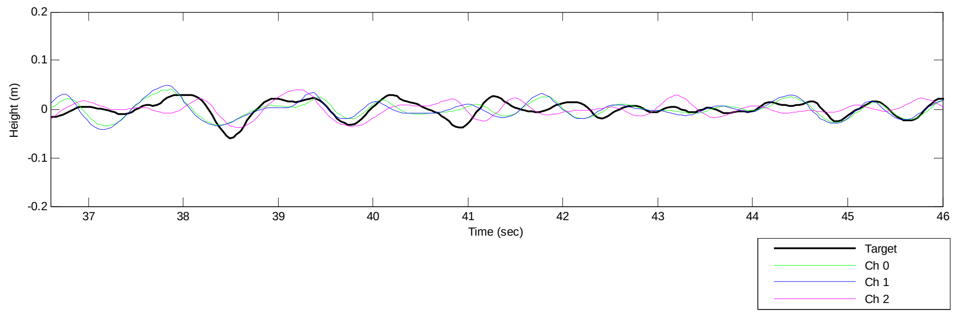

Figure C- 163: Test 37, PM, h = 1.0 m, T = 1.5 sec, Ch 0 – 2

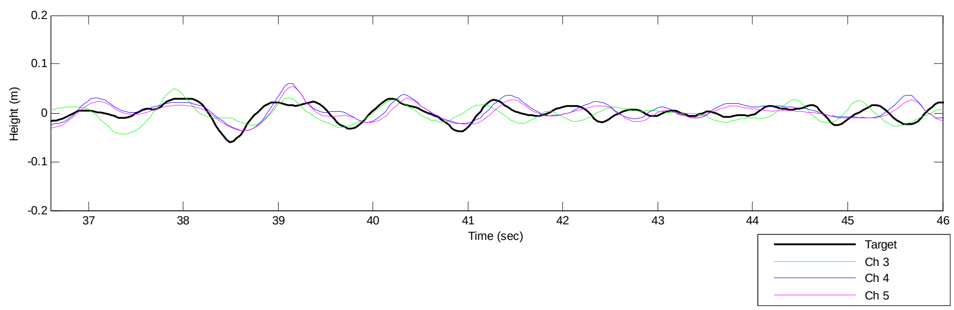

Figure C- 164: Test 37, PM, h = 1.0 m, T = 1.5 sec, Ch 3 – 5

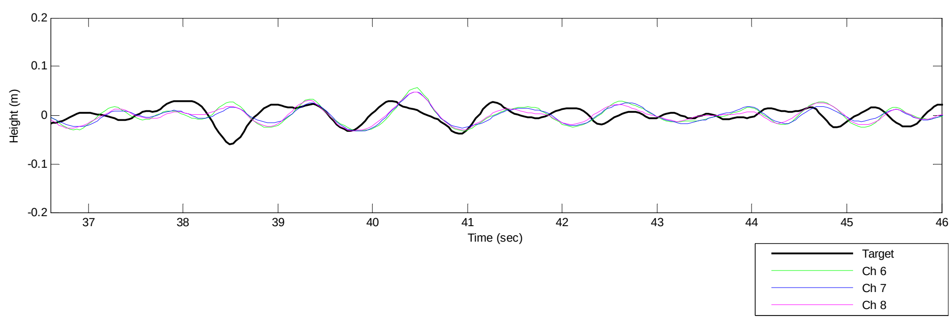

Figure C- 165: Test 37, PM, h = 1.0 m, T = 1.5 sec, Ch 6 – 8

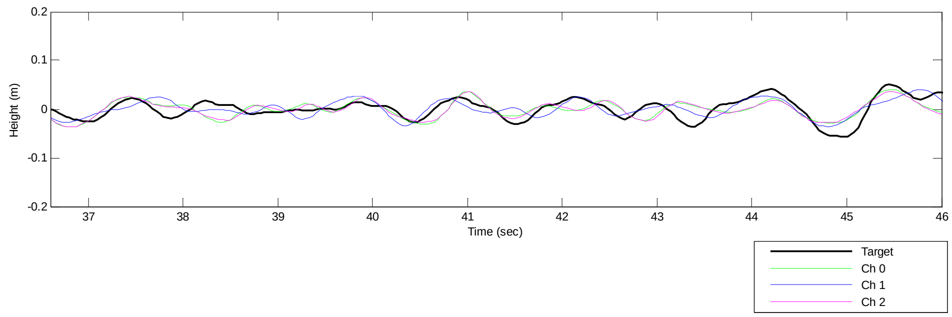

Figure C- 166: Test 37 with Buoys, PM, h = 1.0 m, T = 1.5 sec, Ch 0 – 2

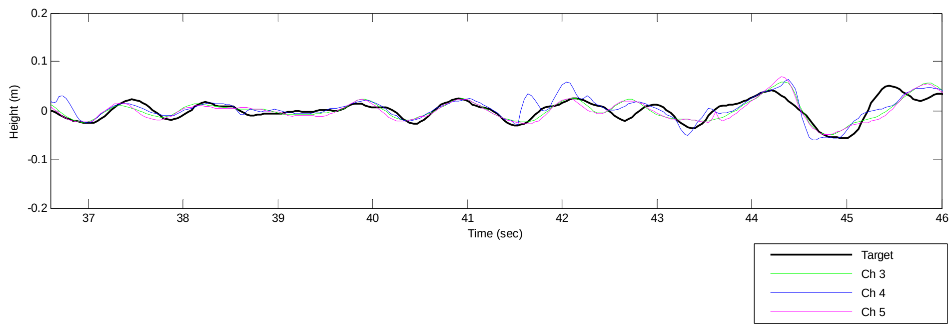

Figure C- 167: Test 37 with Buoys, PM, h = 1.0 m, T = 1.5 sec, Ch 3 – 5

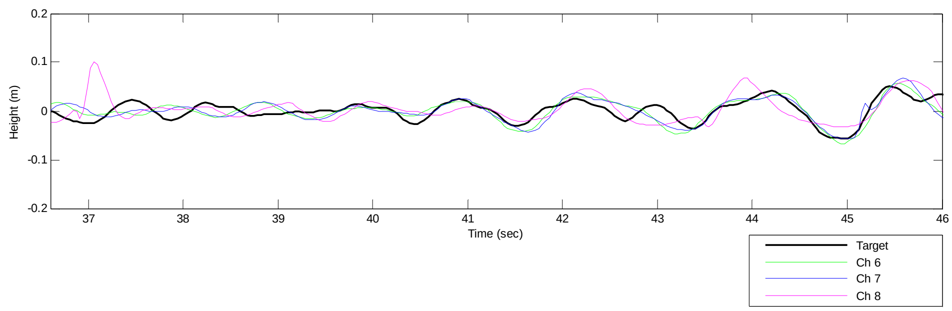

Figure C- 168: Test 37 with Buoys, PM, h = 1.0 m, T = 1.5 sec, Ch 6 – 8

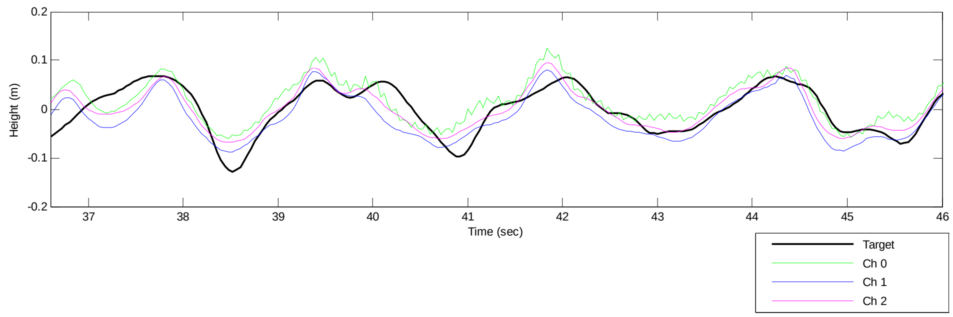

Figure C- 169: Test 38, PM, h = 1.0 m, T = 2.0 sec, Ch 0 – 2

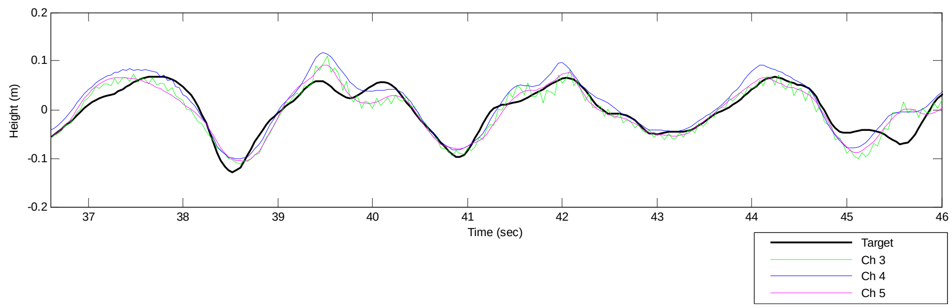

Figure C- 170: Test 38, PM, h = 1.0 m, T = 2.0 sec, Ch 3 – 5

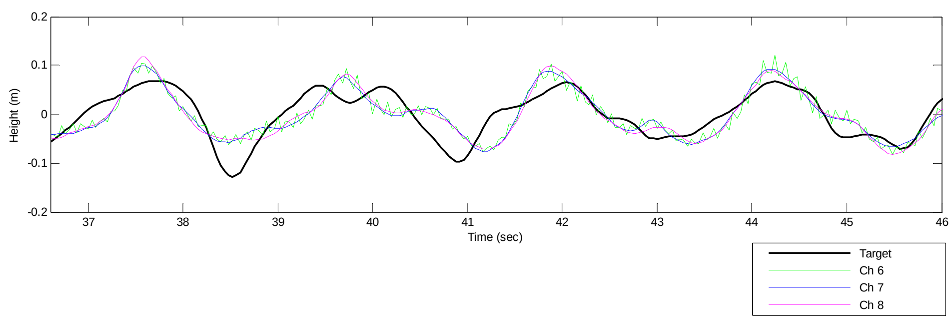

Figure C- 171: Test 38, PM, h = 1.0 m, T = 2.0 sec, Ch 6 – 8

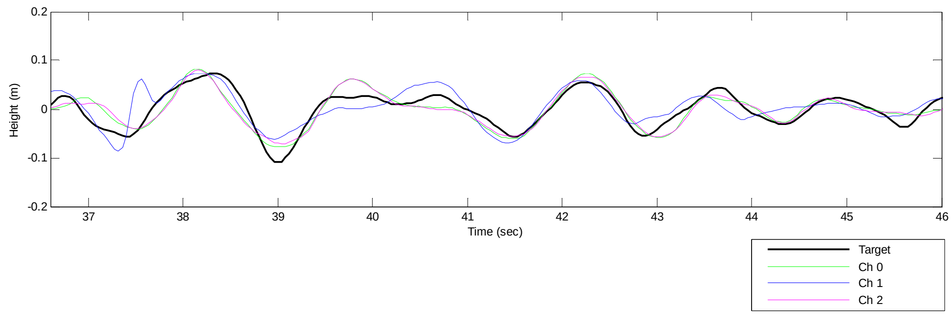

Figure C- 172: Test 38 with Buoys, PM, h = 1.0 m, T = 2.0 sec, Ch 0 – 2

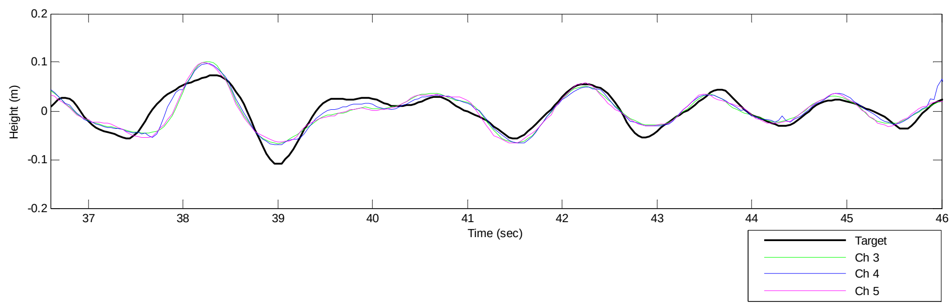

Figure C- 173: Test 38 with Buoys, PM, h = 1.0 m, T = 2.0 sec, Ch 3 – 5

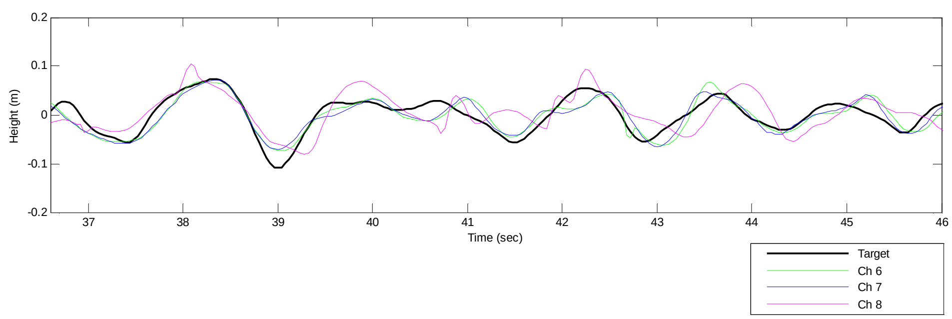

Figure C- 174: Test 38 with Buoys, PM, h = 1.0 m, T = 2.0 sec, Ch 6 – 8

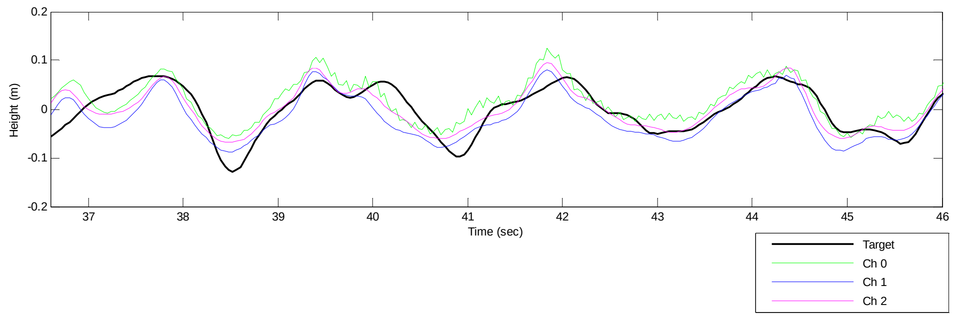

Figure C- 175: Test 39, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 0 – 2

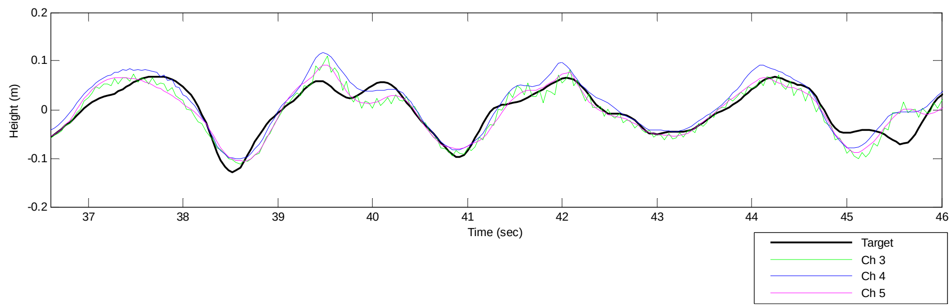

Figure C- 176: Test 39, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 3 – 5

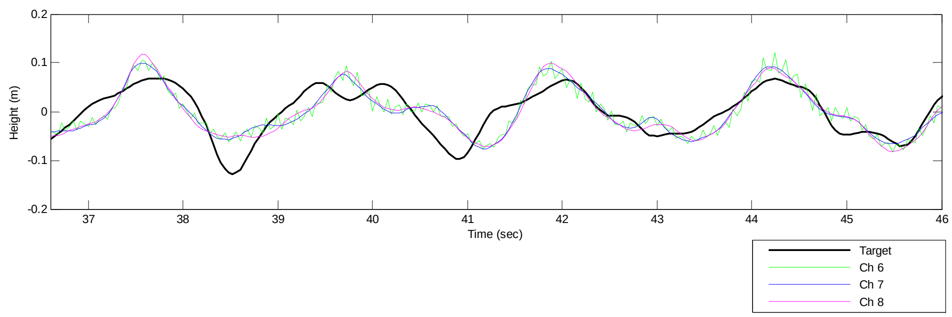

Figure C- 177: Test 39, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 6 – 8

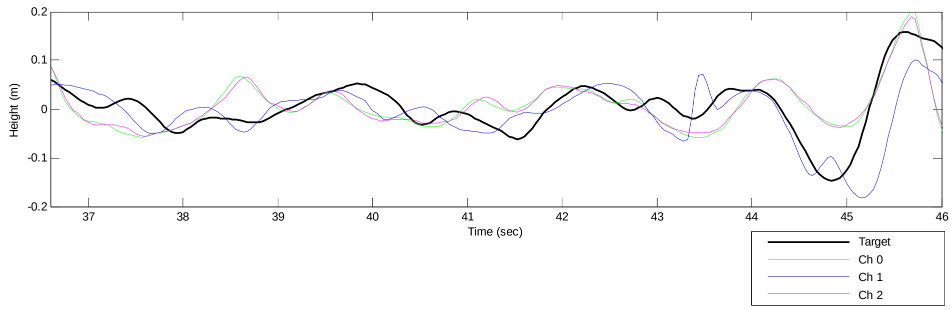

Figure C- 178: Test 39 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 0 – 2

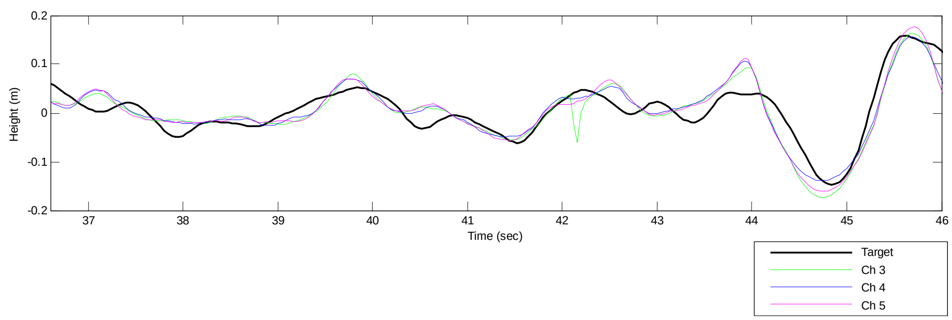

Figure C- 179: Test 39 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 3 – 5

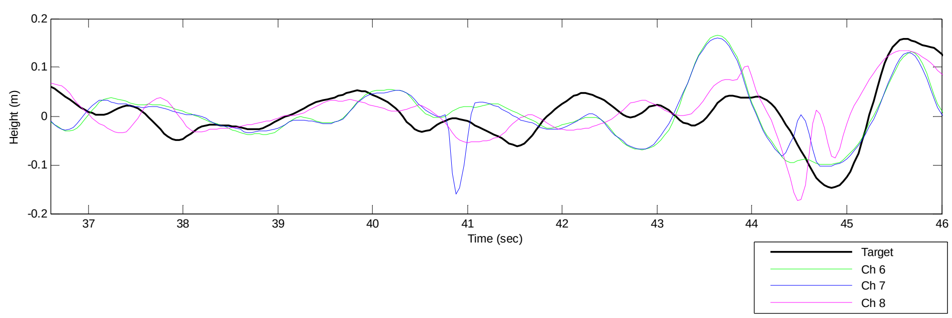

Figure C- 180: Test 39 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 6 – 8

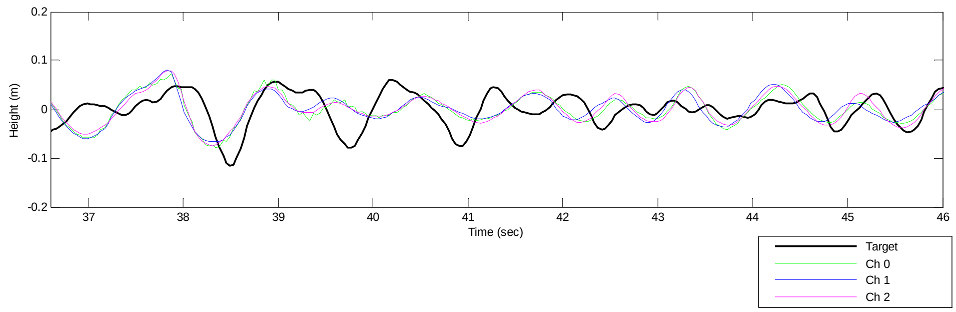

Figure C- 181: Test 40, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 0 – 2

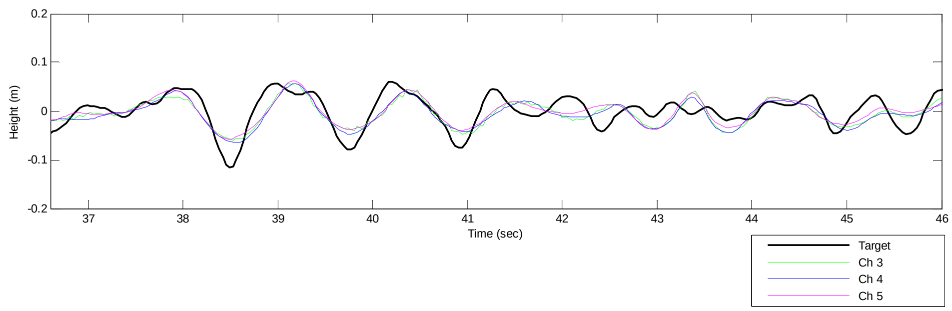

Figure C- 182: Test 40, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 3 – 5

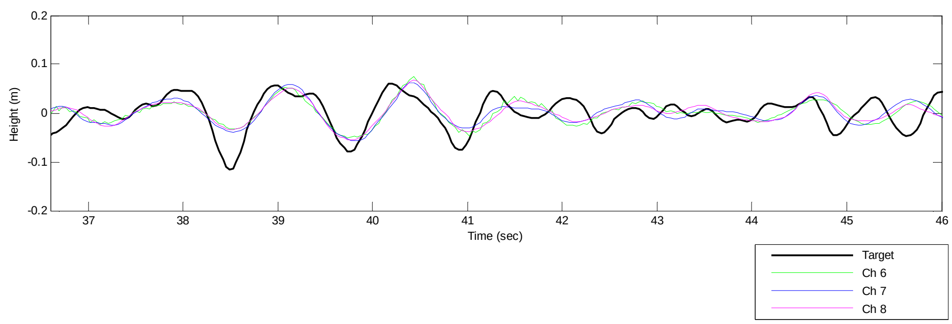

Figure C- 183: Test 40, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 6 – 8

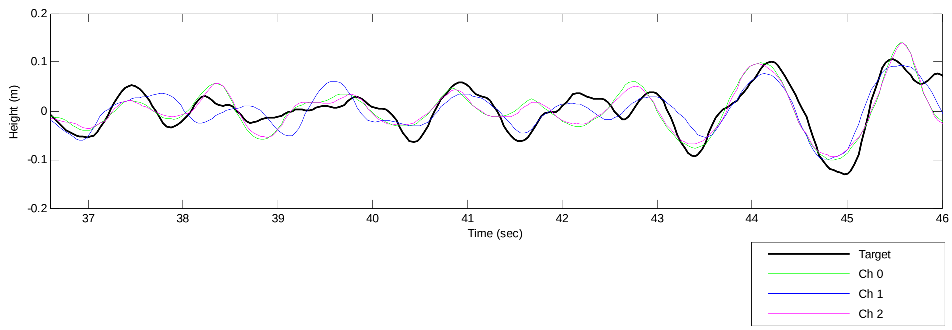

Figure C- 184: Test 40 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 0 – 2

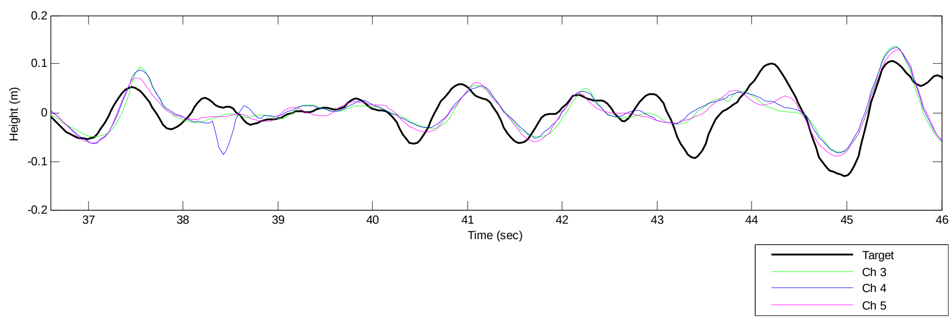

Figure C- 185: Test 40 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 3 – 5

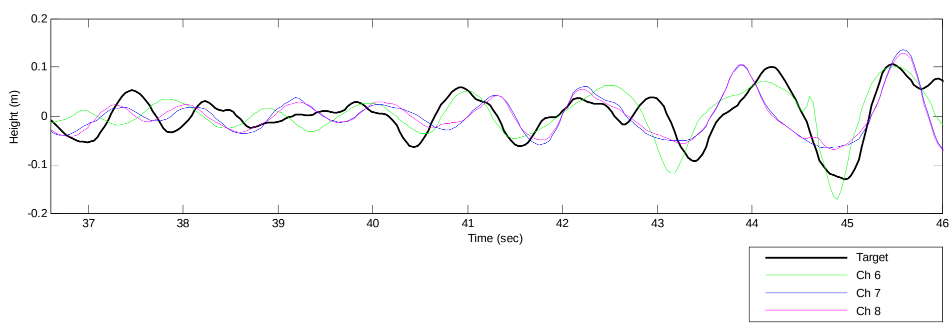

Figure C- 186: Test 40 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 6 – 8

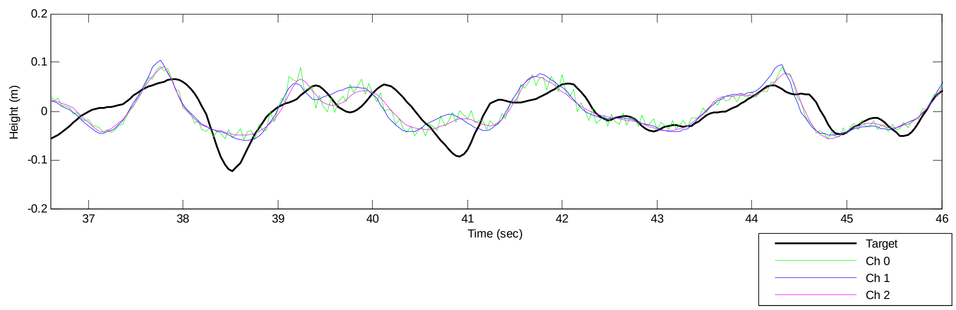

Figure C- 187: Test 41, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 0 – 2

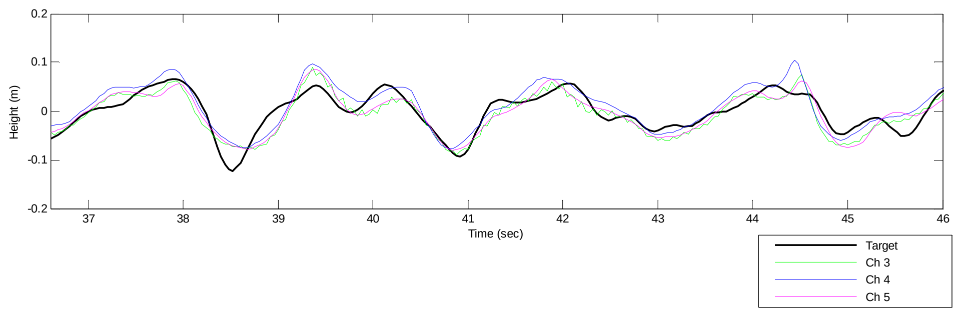

Figure C- 188: Test 41, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 3 – 5

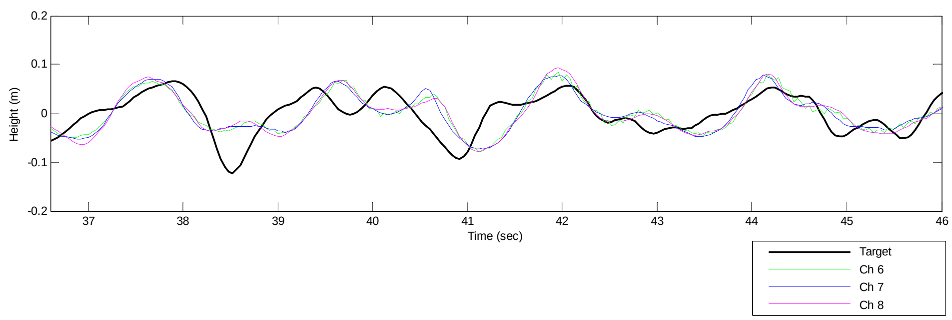

Figure C- 189: Test 41, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 6 – 8

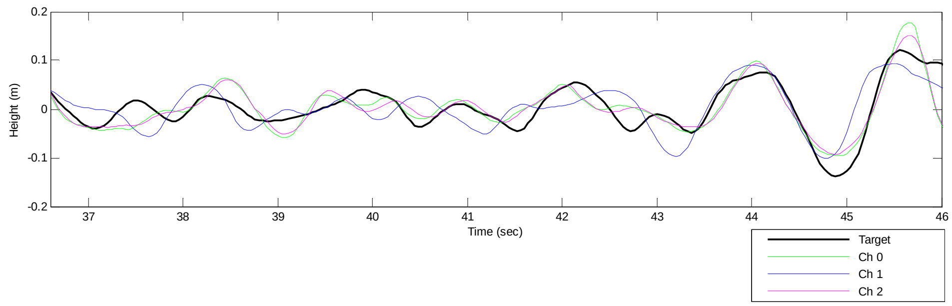

Figure C- 190: Test 41 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 0 – 2

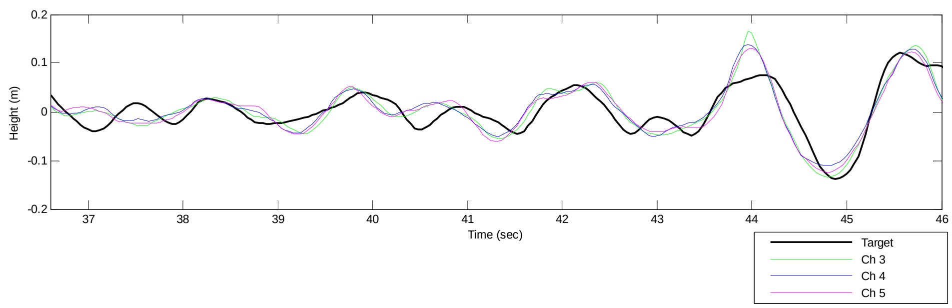

Figure C- 191: Test 41 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 3 – 5

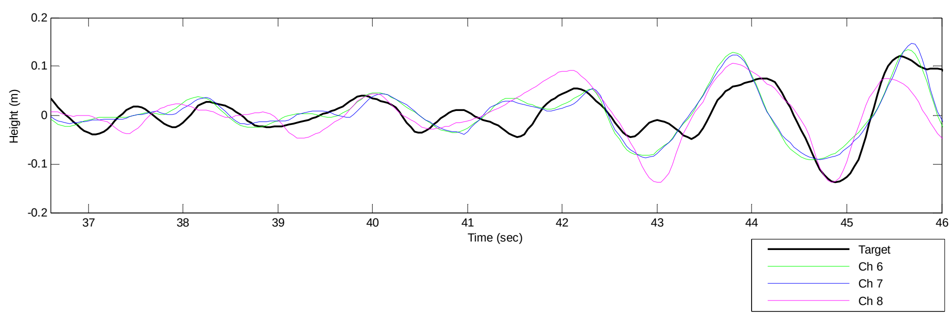

Figure C- 192: Test 41 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 6 – 8

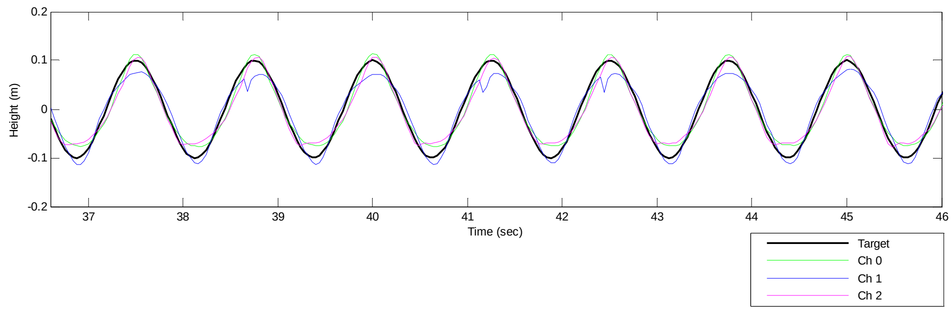

Figure C- 193: Test 42 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 0 – 2

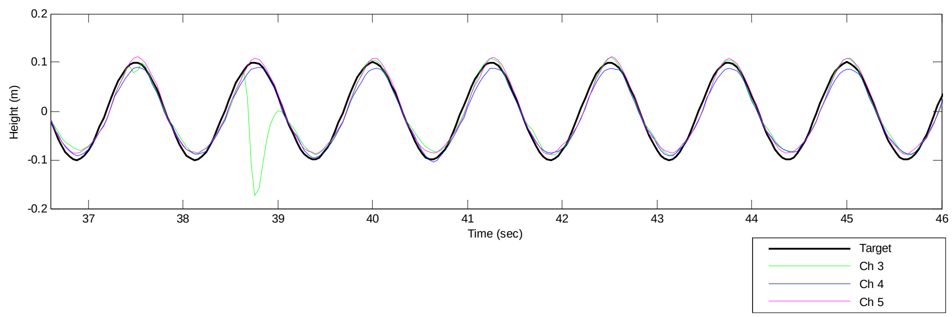

Figure C- 194: Test 42 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 3 – 5

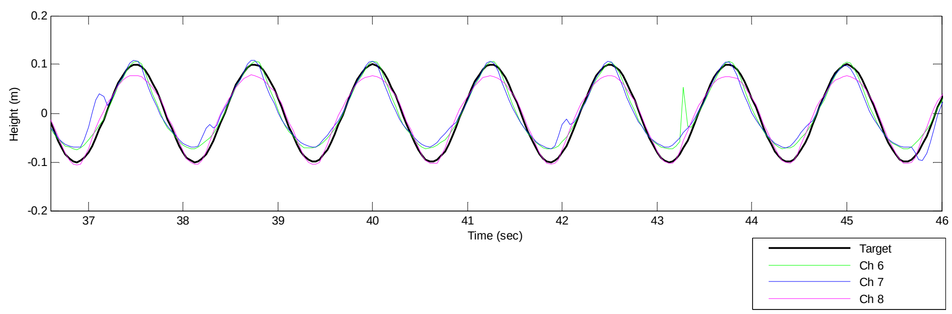

Figure C- 195: Test 42 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec, Ch 6 – 8

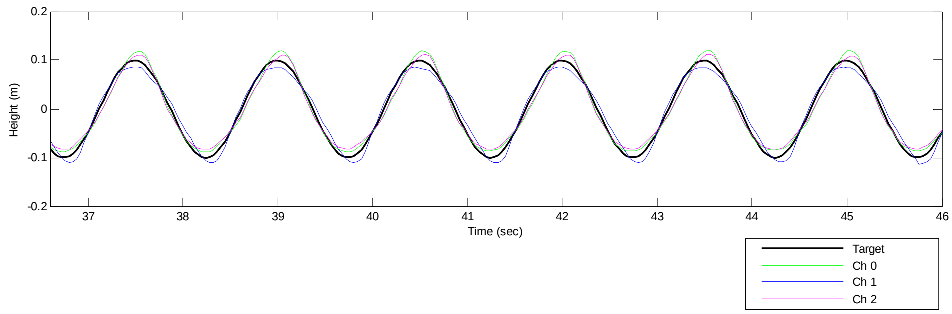

Figure C- 196: Test 43 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 0 – 2

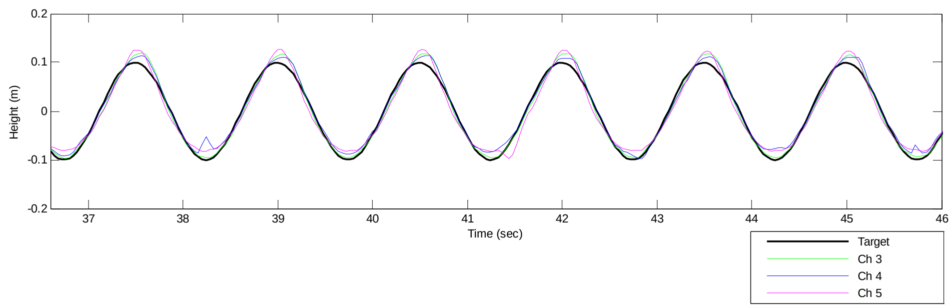

Figure C- 197: Test 43 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 3 – 5

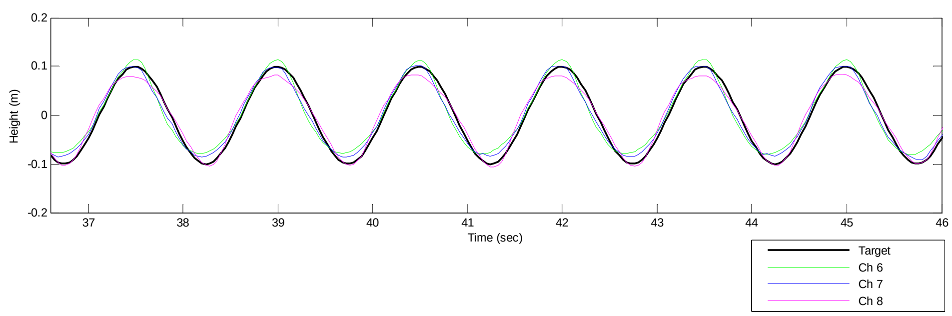

Figure C- 198: Test 43 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec, Ch 6 – 8

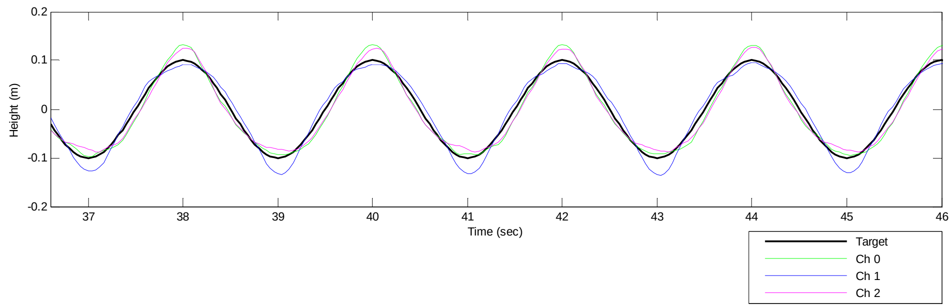

Figure C- 199: Test 44 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 0 – 2

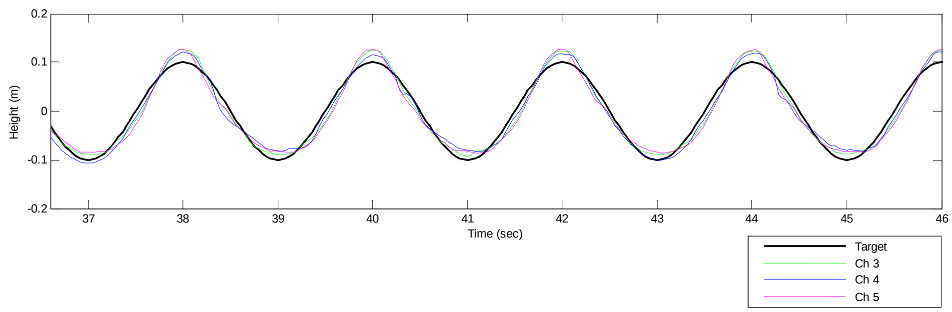

Figure C- 200: Test 44 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 3 – 5

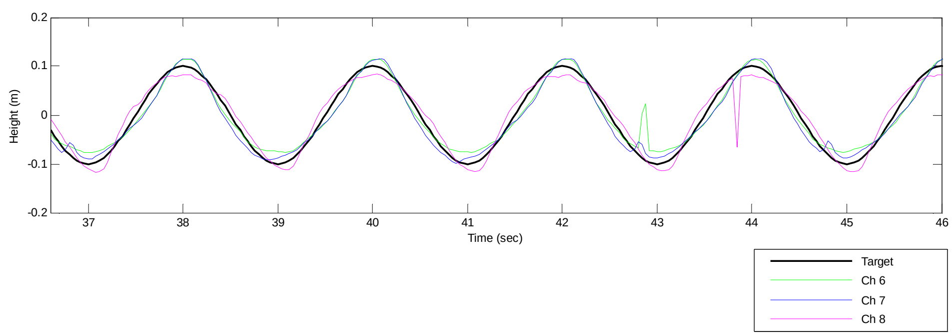

Figure C- 201: Test 44 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec, Ch 6 – 8

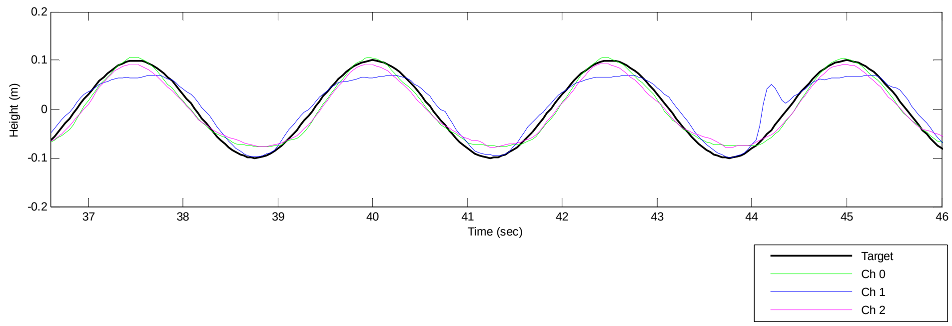

Figure C- 202: Test 45 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 0 – 2

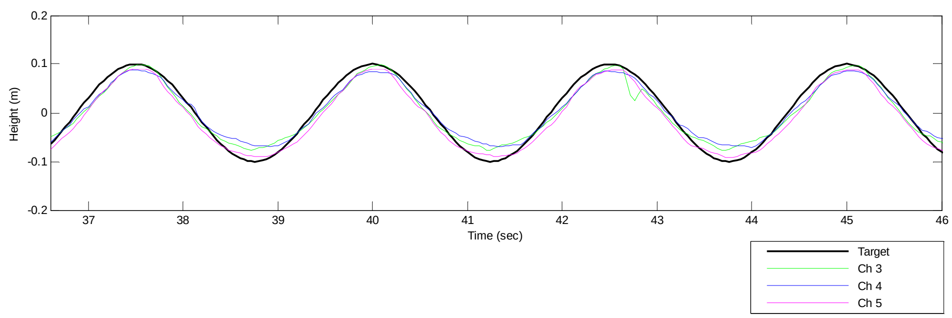

Figure C- 203: Test 45 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 3 – 5

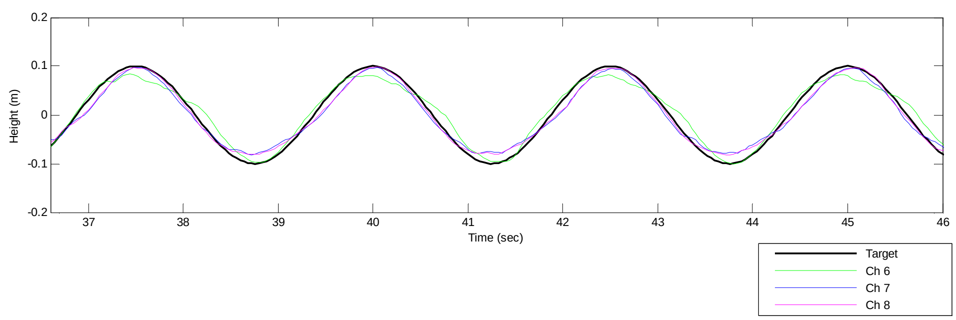

Figure C- 204: Test 45 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec, Ch 6 – 8

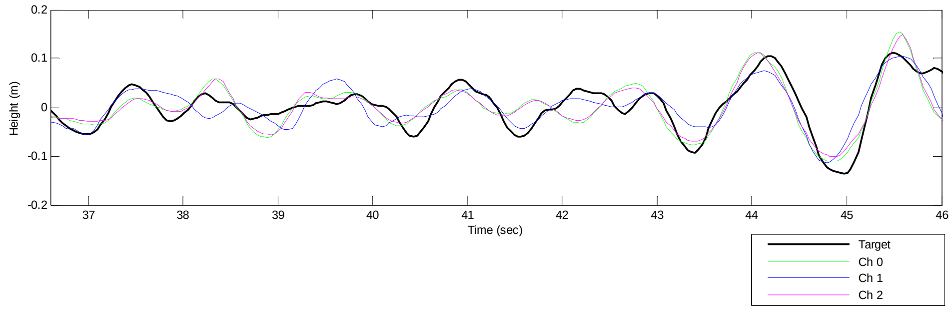

Figure C-205: Test 46 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0-2

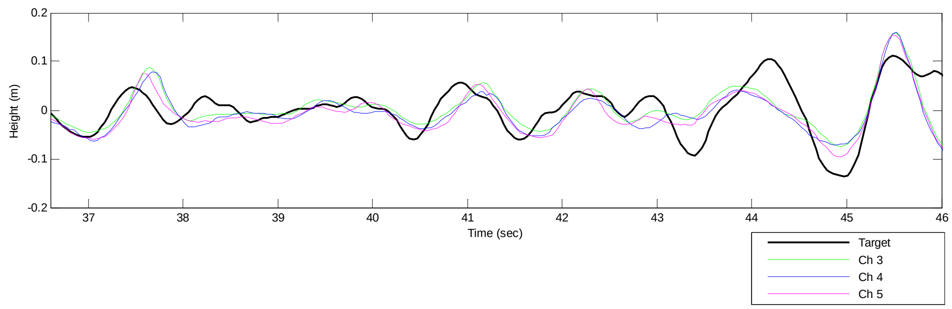

Figure C-206: Test 46 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0-2

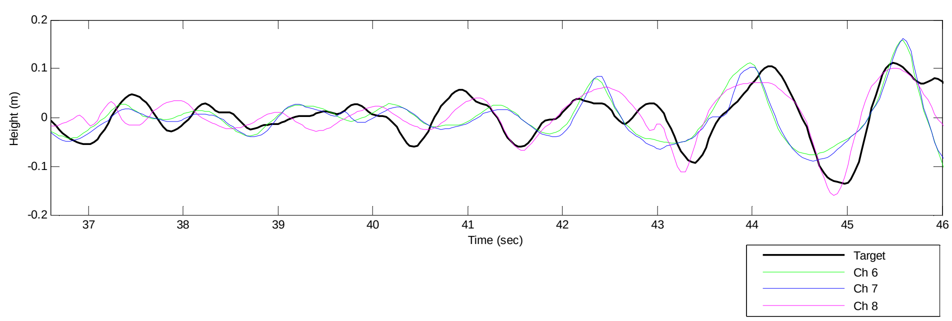

Figure C-207: Test 46 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma = 3.3, Ch 0-2

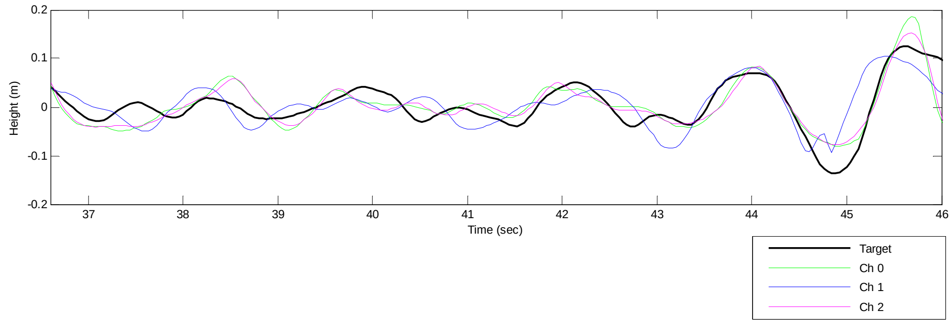

Figure C-208: Test 47 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0-2

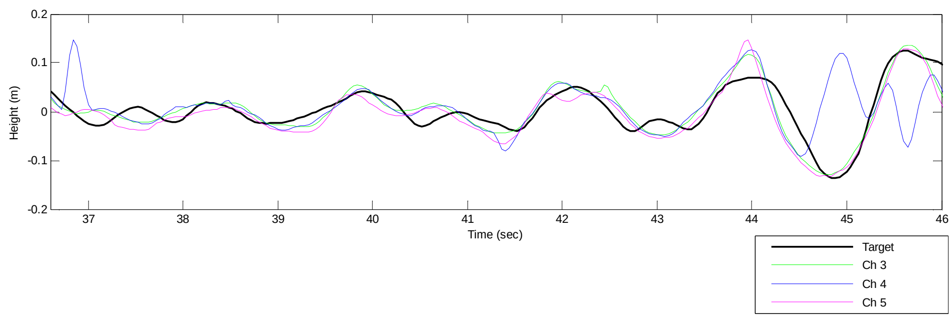

Figure C-209: Test 47 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0-2

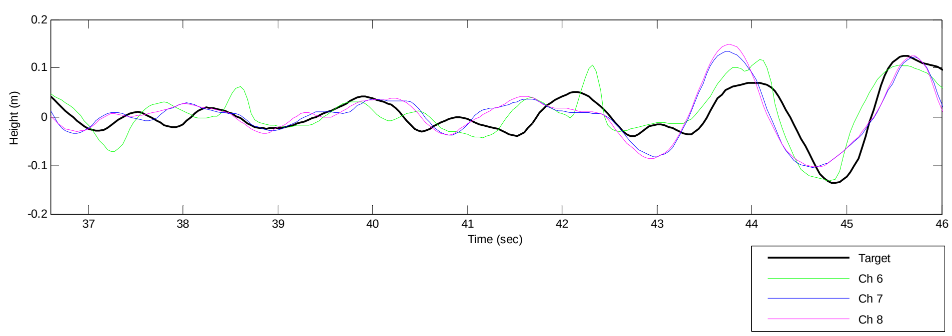

Figure C-210: Test 47 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma = 3.3, Ch 0-2

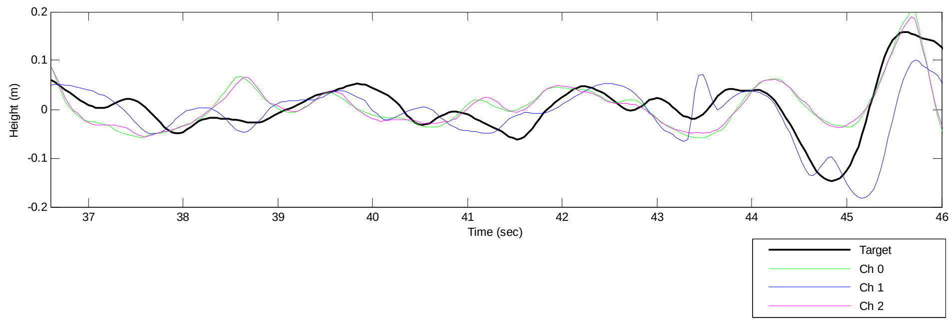

Figure C- 211: Test 48 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 0 – 2

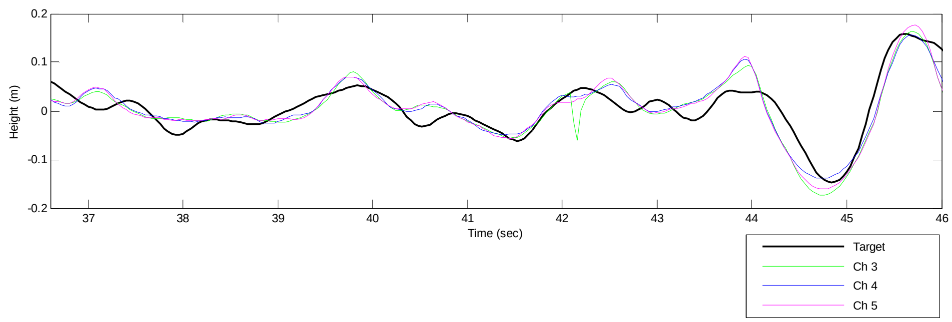

Figure C- 212: Test 48 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 3 – 5

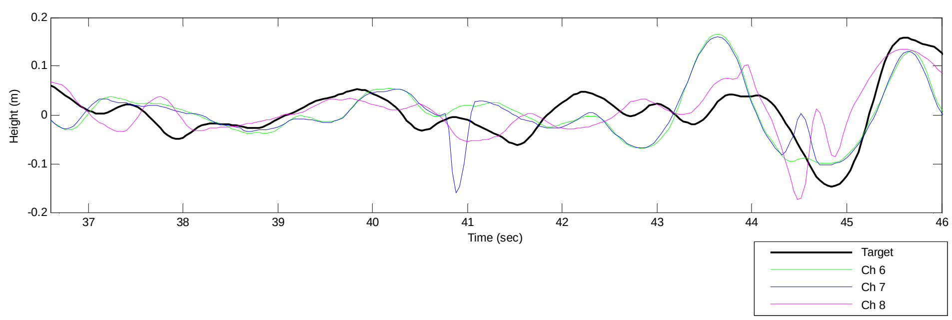

Figure C- 213: Test 48 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m, Ch 6 – 8

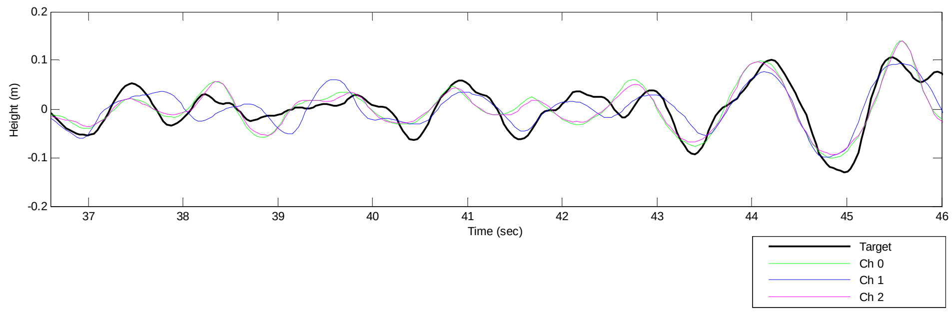

Figure C- 214: Test 49 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 0 – 2

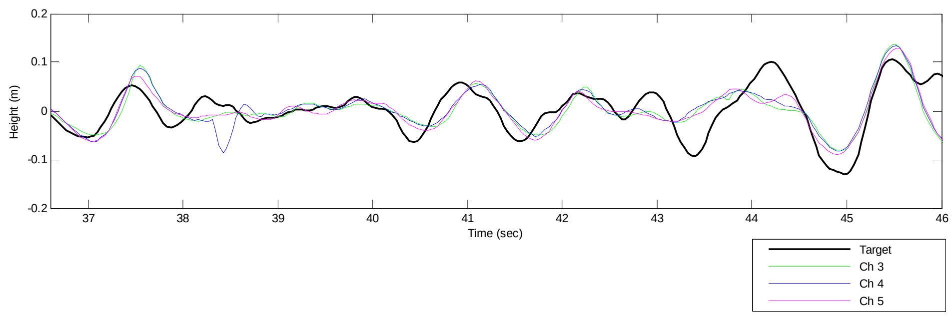

Figure C- 215: Test 49 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 3 – 5

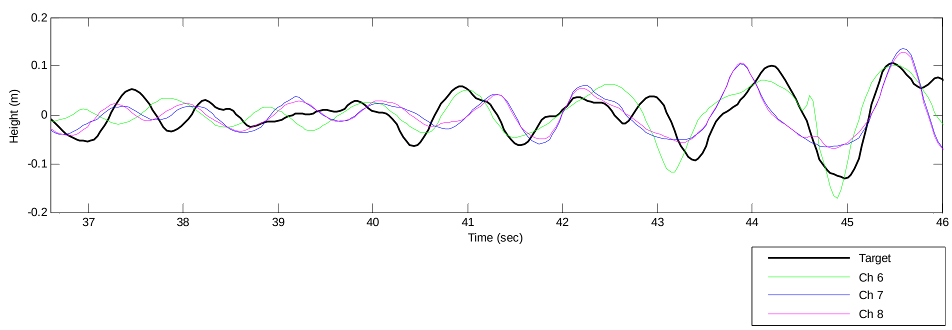

Figure C- 216: Test 49 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec, gamma=3.3, Ch 6 – 8

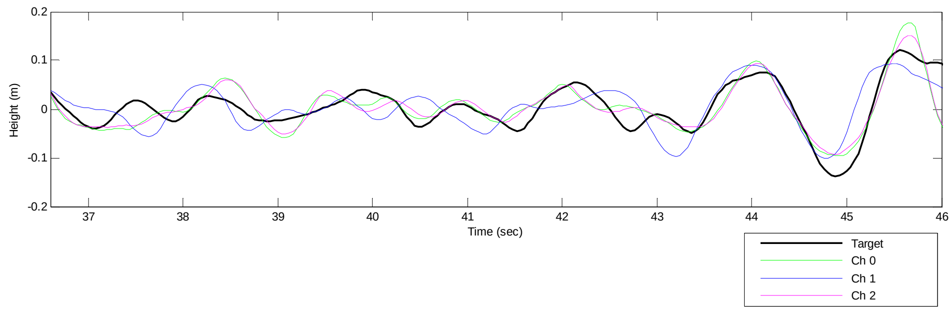

Figure C- 217: Test 50 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 0 – 2

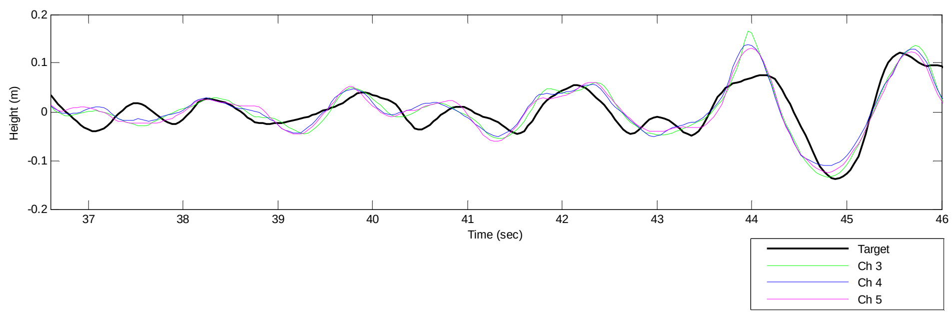

Figure C- 218: Test 50 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 3 – 5

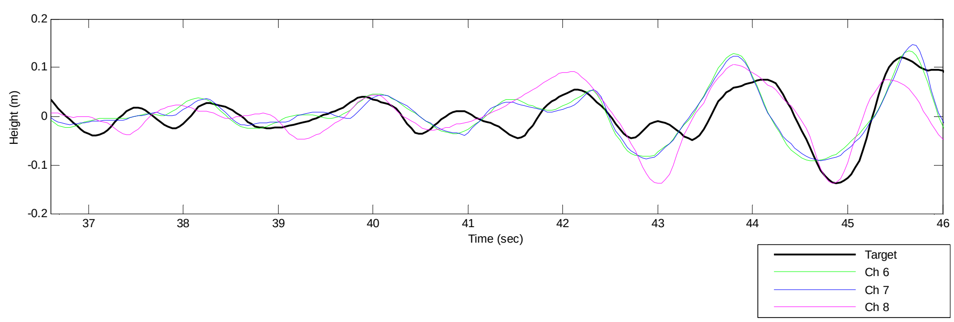

Figure C- 219: Test 50 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec, gamma=3.3, Ch 6 – 8

APPENDIX D

WAVE CHARACTERISTICS

Table D- 1: Wave characteristics for 0.5 meter water depth

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
1	Reg	Target	0.1415	0.1000	1.00	1.0000	-
		0	0.1221	0.0894	1.00	1.0000	0.9915
		1	0.1417	0.1053	1.00	1.0000	0.9882
		2	0.1204	0.9329	1.00	1.0000	0.9907
		3	0.1346	0.1070	1.00	1.0000	0.9790
		4	0.1484	0.1090	1.00	1.0000	0.9881
		5	0.1237	0.0905	1.00	1.0000	0.9878
		6	0.1298	0.0974	1.00	1.0000	0.9428
		7	0.1371	0.1015	1.00	1.0000	0.9839
		8	0.1231	0.0978	1.00	1.0000	0.9524
2	Reg	Target	0.1414	0.1000	1.25	0.8000	-
		0	0.1262	0.0907	1.24	0.8056	0.9925
		1	0.1404	0.1027	1.24	0.8056	0.9915
		2	0.1089	0.0864	1.24	0.8056	0.9837
		3	0.1327	0.1085	1.24	0.8056	0.9712
		4	0.1502	0.1106	1.24	0.8056	0.9814
		5	0.1201	0.0881	1.24	0.8056	0.9835
		6	0.1215	0.0898	1.24	0.8056	0.9947
		7	0.1260	0.0941	1.24	0.8056	0.9900
		8	0.1176	0.0928	1.24	0.8056	0.9879
3	Reg	Target	0.1414	0.1000	1.50	0.6667	-
		0	0.1304	0.0960	1.50	0.6667	0.9880

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
3	Reg		0.1368	0.1026	1.50	0.6667	0.9796
		2	0.1092	0.0870	1.50	0.6667	0.9761
		3	0.1366	0.1094	1.50	0.6667	0.9809
		4	0.1571	0.1147	1.50	0.6667	0.9919
		5	0.1249	0.0909	1.50	0.6667	0.9915
		6	0.1265	0.0916	1.50	0.6667	0.9847
		7	0.1453	0.1045	1.50	0.6667	0.9936
		8	0.1258	0.0980	1.50	0.6667	0.9854
4	Reg	Target	0.1414	0.1000	2.00	0.5000	-
		0	0.0894	0.0666	2.00	0.5000	0.9918
		1	0.1111	0.0828	2.00	0.5000	0.9944
		2	0.0922	0.0732	2.00	0.5000	0.9822
		3	0.9748	0.0764	2.00	0.5000	0.9577
		4	0.1284	0.0976	2.00	0.5000	0.9567
		5	0.1195	0.0867	2.00	0.5000	0.9711
		6	0.1333	0.0975	2.00	0.5000	0.9910
		7	0.1267	0.0912	2.00	0.5000	0.9944
		8	0.1254	0.0932	2.00	0.5000	0.9916
5	Reg	Target	0.1414	0.1000	2.50	0.4000	-
		0	0.0969	0.0764	2.40	0.4167	0.9788
		1	0.1027	0.0811	2.57	0.3889	0.9883
		2	0.0797	0.0671	2.40	0.4167	0.9507
		3	0.1434	0.1008	2.57	0.3889	0.9685

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
5	Reg	4	0.1323	0.0991	2.57	0.3889	0.9532
		5	0.1292	0.0965	2.40	0.4167	0.9859
		6	0.0855	0.0662	2.40	0.4167	0.9730
		7	0.0889	0.0705	2.40	0.4167	0.9730
		8	0.0898	0.0755	2.40	0.4167	0.9577
6	JONSWAP	Target	0.1000	0.1000	1.00	1.0000	-
		0	0.0737	0.0793	1.00	1.0000	0.5940
		1	0.0795	0.0827	1.00	1.0000	0.5889
		2	0.0651	0.0662	1.00	1.0000	0.5798
		3	0.0784	0.0803	0.97	1.0290	0.6111
		4	0.0856	0.0882	0.97	1.0290	0.6068
		5	0.0782	0.0801	0.97	1.0290	0.6061
		6	0.0693	0.0714	0.97	1.0290	0.4082
		7	0.0768	0.0781	0.97	1.0290	0.4073
		8	0.0641	0.0650	0.97	1.0290	0.4206
7	JONSWAP	Target	0.1000	0.1000	1.50	0.6667	-
		0	0.0831	0.0817	1.57	0.6389	0.7179
		1	0.0901	0.0883	1.57	0.6389	0.7222
		2	0.0749	0.0725	1.57	0.6389	0.7131
		3	0.0883	0.0890	1.57	0.6389	0.8228
		4	0.0971	0.0970	1.57	0.6389	0.8286
		5	0.0884	0.0884	1.57	0.6389	0.8294
		6	0.0802	0.0778	1.57	0.6389	0.7140

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
7	JONSWAP	7	0.0899	0.0870	1.57	0.6389	0.7089
		8	0.0770	0.0752	1.57	0.6389	0.7229
8	JONSWAP	Target	0.1000	0.1000	2.00	0.5000	-
		0	0.0833	0.0844	1.90	0.5278	0.8236
		1	0.0901	0.0890	1.90	0.5278	0.8314
		2	0.0741	0.0723	1.90	0.5278	0.8310
		3	0.0895	0.0874	1.90	0.5278	0.7142
		4	0.0985	0.0970	1.90	0.5278	0.7262
		5	0.0883	0.0866	1.90	0.5278	0.7378
		6	0.0823	0.0792	2.00	0.5000	0.7413
		7	0.0898	0.0880	2.00	0.5000	0.7433
		8	0.0776	0.0759	2.00	0.5000	0.7520
9	PM	Target	0.0400	0.0400	1.00	1.0000	-
		0	0.0335	0.0330	1.09	0.9167	0.4850
		1	0.0358	0.0358	1.09	0.9167	0.4834
		2	0.0296	0.0291	1.09	0.9167	0.4857
		3	0.0360	0.0351	0.92	1.0830	0.4047
		4	0.0382	0.0376	0.97	1.0280	0.4474
		5	0.0305	0.0295	0.92	1.0830	0.4685
		6	0.0345	0.0338	0.92	1.0830	0.3956
		7	0.0376	0.0370	0.92	1.0830	0.3969
		8	0.0295	0.0287	1.09	0.9167	0.4253

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
10	PM	Target	0.0896	0.0896	1.50	0.6667	-
		0	0.0743	0.0733	1.57	0.6389	0.6125
		1	0.0810	0.0798	1.57	0.6389	0.6174
		2	0.0670	0.0644	1.57	0.6389	0.6080
		3	0.0775	0.0777	1.57	0.6389	0.7963
		4	0.0831	0.0838	1.57	0.6389	0.7972
		5	0.0661	0.0653	1.57	0.6389	0.7860
		6	0.0730	0.0716	1.57	0.6389	0.6175
		7	0.0832	0.0825	1.57	0.6389	0.6172
		8	0.0707	0.0697	1.57	0.6389	0.6299
11	PM	Target	0.1599	0.1599	2.00	0.5000	-
		0	0.1251	0.2065	1.90	0.5278	0.7190
		1	0.1372	0.2161	1.90	0.5278	0.7172
		2	0.1108	0.1591	1.90	0.5278	0.7194
		3	0.1247	0.1780	1.90	0.5278	0.6296
		4	0.1387	0.1960	1.90	0.5278	0.6208
		5	0.1182	0.1609	1.90	0.5278	0.6052
		6	0.1240	0.1675	1.90	0.5278	0.6292
		7	0.1337	0.1845	1.90	0.5278	0.6245
		8	0.1181	0.1577	1.90	0.5278	0.6365
12	PM	Target	0.1000	0.1000	1.58	0.6324	-
		0	0.8285	0.0809	1.57	0.6389	0.6582
		1	0.0898	0.0884	1.57	0.6389	0.6644

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
12	PM	2	0.0738	0.0711	1.57	0.6389	0.6606
		3	0.0811	0.0796	1.57	0.6389	0.7951
		4	0.0914	0.0908	1.57	0.6389	0.7920
		5	0.0776	0.0770	1.57	0.6389	0.7820
		6	0.0826	0.0816	1.57	0.6389	0.6166
		7	0.0925	0.0904	1.57	0.6389	0.6185
		8	0.0797	0.0780	1.57	0.6389	0.6349
13	TMA	Target	0.1000	0.1000	1.00	1.0000	-
		0	0.0724	0.0753	1.00	1.0000	0.5552
		1	0.0774	0.0803	0.92	1.0830	0.5498
		2	0.0652	0.0650	1.00	1.0000	0.5586
		3	0.0708	0.0722	1.03	0.9722	0.5729
		4	0.0773	0.0793	1.00	1.0000	0.5631
		5	0.0649	0.0660	1.03	0.9722	0.5617
		6	0.0709	0.0733	1.03	0.9722	0.3847
		7	0.0758	0.0780	1.03	0.9722	0.3939
		8	0.0651	0.0663	1.03	0.9722	0.4004
14	TMA	Target	0.1000	0.1000	1.50	0.6667	-
		0	0.0809	0.7856	1.57	0.6389	0.6530
		1	0.0886	0.0867	1.57	0.6389	0.6502
		2	0.0738	0.0718	1.57	0.6389	0.6509
		3	0.0796	0.0804	1.57	0.6389	0.7839

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
14	TMA	5	0.0741	0.0750	1.57	0.6389	0.7899
		6	0.0811	0.0812	1.57	0.6389	0.6328
		7	0.0890	0.0875	1.57	0.6389	0.6327
		8	0.0782	0.0769	1.57	0.6389	0.6491
15	TMA	Target	0.1000	0.1000	2.00	0.5000	-
		0	0.0826	0.0812	1.90	0.5278	0.7307
		1	0.0904	0.0898	1.90	0.5278	0.7390
		2	0.0739	0.0729	1.90	0.5278	0.7353
		3	0.0830	0.0806	1.90	0.5278	0.6739
		4	0.0926	0.0923	1.90	0.5278	0.6775
		5	0.0758	0.0738	1.90	0.5278	0.7064
		6	0.0837	0.0810	1.90	0.5278	0.5998
		7	0.0919	0.8914	1.90	0.5278	0.5937
		8	0.0805	0.0778	2.00	0.5000	0.6057
16	Reg	Target	0.2829	0.2000	1.00	1.0000	-
		0	0.2132	0.1692	1.00	1.0000	0.9625
		1	0.2191	0.1724	1.00	1.0000	0.9633
		2	0.1856	0.1435	1.00	1.0000	0.9698
		3	0.2018	0.1727	1.00	1.0000	0.9414
		4	0.2234	0.1875	1.00	1.0000	0.9335
		5	0.1905	0.1578	1.00	1.0000	0.9495
		6	0.1777	0.1497	1.00	1.0000	0.9434
		7	0.1718	0.1497	1.00	1.0000	0.9152

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
17	Reg	Target	0.2829	0.2000	1.25	0.8000	-
		0	0.2135	0.1697	1.24	0.8056	0.9497
		1	0.2583	0.1885	1.29	0.7778	0.9801
		2	0.1957	0.1450	1.24	0.8056	0.9724
		3	0.2676	0.2025	1.24	0.8056	0.9732
		4	0.2845	0.2138	1.24	0.8056	0.9713
		5	0.2146	0.1588	1.24	0.8056	0.9729
		6	0.2636	0.2205	1.29	0.7778	0.9472
		7	0.2668	0.2183	1.29	0.7778	0.9536
		8	0.2156	0.1704	1.29	0.7778	0.9609
18	Reg	Target	0.2829	0.2000	1.50	0.6667	-
		0	0.2346	0.1897	1.50	0.6667	0.9296
		1	0.2528	0.2032	1.50	0.6667	0.9304
		2	0.1930	0.1518	1.50	0.6667	0.9311
		3	0.2876	0.2320	1.50	0.6667	0.9365
		4	0.2980	0.2396	1.50	0.6667	0.9396
		5	0.2657	0.2042	1.50	0.6667	0.9510
		6	0.2531	0.1969	1.50	0.6667	0.9561
		7	0.2572	0.1927	1.50	0.6667	0.9659
		8	0.2199	0.1655	1.50	0.6667	0.9591
19	Reg	Target	0.2829	0.2000	2.00	0.5000	-
		0	0.1663	0.1267	2.00	0.5000	0.9711
		1	0.2015	0.1539	2.00	0.5000	0.9853

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
19	Reg	2	0.1704	0.1257	2.00	0.5000	0.9774
		3	0.2165	0.1760	2.00	0.5000	0.9411
		4	0.2451	0.1917	2.00	0.5000	0.9548
		5	0.2136	0.1653	2.00	0.5000	0.9482
		6	0.2529	0.2066	2.00	0.5000	0.9492
		7	0.2440	0.1892	2.00	0.5000	0.9640
		8	0.2266	0.1714	2.00	0.5000	0.9704
20	Reg	Target	0.2829	0.2000	2.50	0.4000	-
		0	0.2279	0.2057	2.40	0.4167	0.8418
		1	0.2425	.21.76	2.40	0.4167	0.8283
		2	0.2064	0.1781	2.40	0.4167	0.8117
		3	0.2585	0.2718	2.40	0.4167	0.8249
		4	0.2731	0.2780	2.40	0.4167	0.6941
		5	0.2224	0.2116	2.40	0.4167	0.7034
		6	0.2284	0.2161	2.40	0.4167	0.5583
		7	0.2350	0.2200	2.57	0.3889	0.5413
		8	0.2065	0.1888	2.40	0.4167	0.6031
21	JONSWAP	Target	0.2000	0.2000	1.00	1.0000	-
		0	0.1091	0.1105	1.00	1.0000	0.3679
		1	0.1188	0.1212	0.92	1.0910	0.3620
		2	0.0983	0.0986	1.00	1.0000	0.3630
		3	0.1059	0.1085	0.89	1.1250	0.3783
		4	0.1145	0.1172	0.86	1.1610	0.3648

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
21	JONSWAP	5	0.0932	0.0943	0.86	1.1610	0.3337
		6	0.1007	0.1044	0.86	1.1610	0.3061
		7	0.1203	0.1242	0.86	1.1610	0.3128
		8	0.0954	0.0974	0.83	1.2000	0.3027
22	JONSWAP	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1384	0.1368	1.57	0.6389	0.6964
		1	0.1525	0.1522	1.57	0.6389	0.6794
		2	0.1236	0.1203	1.57	0.6389	0.6908
		3	0.1368	0.1353	1.57	0.6389	0.6643
		4	0.1499	0.1470	1.57	0.6389	0.6611
		5	0.1245	0.1219	1.57	0.6389	0.6643
		6	0.1356	0.1323	1.57	0.6389	0.5761
		7	0.1450	0.1413	1.57	0.6389	0.5854
		8	0.1270	0.1211	1.57	0.6389	0.5922
23	JONSWAP	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1503	0.1499	1.90	0.5278	0.7177
		1	0.1647	0.1620	1.90	0.5278	0.7121
		2	0.1373	0.1349	1.90	0.5278	0.7122
		3	0.1531	0.1538	1.90	0.5278	0.6022
		4	0.1676	0.1666	1.90	0.5278	0.5964
		5	0.1399	0.1373	1.90	0.5278	0.5959
		6	0.1525	0.1542	2.00	0.5000	0.5432
		7	0.1583	0.1576	2.00	0.5000	0.5391

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
23	JONSWAP	8	0.1350	0.1329	2.00	0.5000	0.5449
24	PM	Target	0.2000	0.2000	2.24	0.4472	-
		0	0.1486	0.1464	2.77	0.3611	0.6682
		1	0.1687	0.1626	2.57	0.3889	0.6721
		2	0.1391	0.1324	2.77	0.3611	0.6671
		3	0.1510	0.1562	2.57	0.3889	0.5062
		4	0.1627	0.1640	1.90	0.5278	0.5117
		5	0.1361	0.1342	2.57	0.3889	0.4970
		6	0.1508	0.1518	2.77	0.3611	0.5400
		7	0.1559	0.1523	2.77	0.3611	0.5487
		8	0.1338	0.1335	2.57	0.3889	0.5654
25	TMA	Target	0.2000	0.2000	1.00	1.0000	-
		0	0.1099	0.1099	1.00	1.0000	0.3286
		1	0.1252	0.1286	1.03	0.9722	0.3146
		2	0.1002	0.1010	1.00	1.0000	0.3380
		3	0.1044	0.1087	1.00	1.0000	0.3043
		4	0.1111	0.1124	1.06	0.9444	0.3348
		5	0.0947	0.0934	1.00	1.0000	0.3235
		6	0.1020	0.1037	1.16	0.8611	0.3005
		7	0.1190	0.1209	1.16	0.8611	0.3000
		8	0.0887	0.0913	1.16	0.8611	0.2838
26	TMA	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1373	0.1352	1.57	0.6389	0.5902

Table D- 1 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H 1/3 (m)	Tp (sec)	Fp (Hz)	
26	TMA	1	0.1457	0.1413	1.57	0.6389	0.5822
		2	0.1176	0.1152	1.57	0.6389	0.5765
		3	0.1292	0.1294	1.57	0.6389	0.5955
		4	0.1420	0.1403	1.57	0.6389	0.5989
		5	0.1097	0.1073	1.57	0.6389	0.5951
		6	0.1293	0.1288	1.57	0.6389	0.5396
		7	0.1337	0.1326	1.39	0.7222	0.5477
		8	0.1171	0.1133	1.57	0.6389	0.5476
27	TMA	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1443	0.1430	1.90	0.5278	0.6943
		1	0.1598	0.1547	1.90	0.5278	0.6887
		2	0.1301	0.1274	1.90	0.5278	0.6964
		3	0.1457	0.1443	1.90	0.5278	0.6262
		4	0.1526	0.1483	1.90	0.5278	0.6232
		5	0.1286	0.1240	1.90	0.5278	0.6405
		6	0.1434	0.1451	2.00	0.5000	0.5447
		7	0.1531	0.1524	2.00	0.5000	0.5378
		8	0.1315	0.1305	2.00	0.5000	0.5453

Table D- 2: Wave characteristics in 0.5 meter water depth with Buoys

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
1B	Reg	Target	0.1415	0.1000	1.00	1.0000	-
		0	0.1177	0.0851	1.00	1.0000	0.9911
		1	0.1306	0.0971	1.00	1.0000	0.9892
		2	0.1342	0.1053	1.00	1.0000	0.9928
		3	0.1338	0.1040	1.00	1.0000	0.9784
		4	0.1417	0.0958	1.00	1.0000	0.9889
		5	0.1338	0.0947	1.00	1.0000	0.9897
		6	0.1235	0.0950	1.00	1.0000	0.9689
		7	0.1287	0.0950	1.00	1.0000	0.9838
		8	0.1274	0.0970	1.00	1.0000	0.9809
2B	Reg	Target	0.1414	0.1000	1.25	0.8000	-
		0	0.1195	0.0858	1.24	0.8056	0.9925
		1	0.1317	0.0975	1.24	0.8056	0.9815
		2	0.1373	0.0982	1.24	0.8056	0.9905
		3	0.1403	0.1113	1.24	0.8056	0.9830
		4	0.1446	0.1059	1.24	0.8056	0.9917
		5	0.1258	0.0915	1.24	0.8056	0.9916
		6	0.1394	0.1028	1.24	0.8056	0.9900
		7	0.1447	0.1072	1.24	0.8056	0.9907
		8	0.1523	0.1112	1.24	0.8056	0.9886
3B	Reg	Target	0.1414	0.1000	1.50	0.6667	-
		0	0.1360	0.0984	1.50	0.6667	0.9948

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
3B	Reg	1	0.1391	0.1029	1.50	0.6667	0.9728
		2	0.1431	0.1038	1.50	0.6667	0.9875
		3	0.1402	0.1135	1.50	0.6667	0.9816
		4	0.1625	0.1179	1.50	0.6667	0.9956
		5	0.1449	0.1048	1.50	0.6667	0.9944
		6	0.1471	0.1059	1.50	0.6667	0.9693
		7	0.1358	0.1020	1.50	0.6667	0.9769
		8	0.1493	0.1120	1.50	0.6667	0.9808
4B	Reg	Target	0.1414	0.1000	2.00	0.5000	-
		0	0.1680	0.1255	2.00	0.5000	0.9705
		1	0.1731	0.1275	2.00	0.5000	0.9875
		2	0.1807	0.1359	2.00	0.5000	0.9681
		3	0.0951	0.0704	2.00	0.5000	0.9685
		4	0.1173	0.0840	2.00	0.5000	0.9916
		5	0.0991	0.0718	2.00	0.5000	0.9922
		6	0.1173	0.1230	2.00	0.5000	0.9922
		7	0.1850	0.1345	2.00	0.5000	0.9952
		8	0.1676	0.1209	2.00	0.5000	0.9952
5B	Reg	Target	0.1414	0.1000	2.50	0.4000	-
		0	0.1392	0.1028	2.57	0.3889	0.9782
		1	0.1436	0.1079	2.40	0.4167	0.9822
		2	0.1564	0.1141	2.40	0.4167	0.9749
		3	0.1466	0.1083	2.57	0.3889	0.9633

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
5B	Reg	4	0.1545	0.1170	2.57	0.3889	0.9488
		5	0.1280	0.0970	2.57	0.3889	0.9823
		6	0.1234	0.0940	2.40	0.4167	0.9859
		7	0.1325	0.1065	2.40	0.4167	0.9843
		8	0.1276	0.0958	2.40	0.4167	0.9884
6B	JONSWAP	Target	0.1000	0.1000	1.00	1.0000	-
		0	0.0586	0.0579	1.03	0.9735	0.5708
		1	0.0815	0.0858	1.03	0.9727	0.5305
		2	0.0816	0.0860	1.03	0.9722	0.5911
		3	0.0794	0.0814	1.03	0.9722	0.6296
		4	0.0854	0.0868	1.03	0.9722	0.6251
		5	0.0769	0.0774	1.03	0.9722	0.6256
		6	0.0753	0.0768	1.06	0.9444	0.4495
		7	0.0868	0.0889	1.03	0.9722	0.4447
		8	0.7893	0.0813	1.06	0.9449	0.4445
7B	JONSWAP	Target	0.1000	0.1000	1.50	0.6667	-
		0	0.0874	0.0840	1.57	0.6389	0.7621
		1	0.0961	0.0888	1.57	0.6389	0.7346
		2	0.0898	0.0871	1.57	0.6389	0.7609
		3	0.0885	0.0870	1.57	0.6389	0.8049
		4	0.0991	0.9919	1.57	0.6389	0.8235
		5	0.0879	0.0866	1.57	0.6389	0.8299
		6	0.0882	0.0870	1.57	0.6389	0.7058

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
7B	JONSWAP	7	0.0910	0.0906	1.57	0.6389	0.7088
		8	0.0885	0.0869	1.57	0.6389	0.7226
8B	JONSWAP	Target	0.1000	0.1000	2.00	0.5000	-
		0	0.0871	0.0832	1.90	0.5278	0.6956
		1	0.0913	0.0889	1.90	0.5278	0.6427
		2	0.0878	0.0846	1.90	0.5278	0.6875
		3	0.0898	0.0877	1.90	0.5278	0.6814
		4	0.0994	0.0973	1.90	0.5278	0.7026
		5	0.0883	0.0856	1.90	0.5278	0.7066
		6	0.0891	0.0878	2.00	0.5000	0.7336
		7	0.0915	0.0894	1.90	0.5278	0.7255
		8	0.0875	0.0846	2.00	0.5000	0.7241
9B	PM	Target	0.0400	0.0400	1.00	1.0000	-
		0	0.0365	0.0354	1.09	0.9167	0.5093
		1	0.0363	0.0366	0.92	1.0840	0.4897
		2	0.0359	0.0355	1.09	0.9167	0.4905
		3	0.0356	0.0354	1.09	0.9167	0.8194
		4	0.0379	0.0375	0.92	1.0830	0.8094
		5	0.0342	0.0337	1.09	0.9167	0.7931
		6	0.0372	0.0373	1.11	0.9000	0.4367
		7	0.0371	0.0365	0.92	1.0830	0.4154
		8	0.0357	0.0352	1.09	0.9167	0.4404
10B	PM	Target	0.0896	0.0896	1.50	0.6667	-

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
10B	PM	0	0.0788	0.0757	1.57	0.6389	0.6808
		1	0.0772	0.0753	1.57	0.6389	0.6031
		2	0.0807	0.0786	1.57	0.6389	0.6805
		3	0.0798	0.0799	1.57	0.6389	0.8028
		4	0.0896	0.0912	1.57	0.6389	0.8065
		5	0.0796	0.0796	1.57	0.6389	0.8138
		6	0.0810	0.0811	1.57	0.6389	0.6377
		7	0.0847	0.0845	1.57	0.6389	0.6451
		8	0.0805	0.0797	1.57	0.6389	0.6572
11B	PM	Target	0.1599	0.1599	2.00	0.5000	-
		0	0.1324	0.1273	1.90	0.5278	0.5940
		1	0.1388	0.1419	1.90	0.5278	0.5695
		2	0.1330	0.1287	1.90	0.5278	0.5811
		3	0.1358	0.1343	1.90	0.5278	0.5957
		4	0.1494	0.1485	1.90	0.5278	0.6068
		5	0.1306	0.1265	1.90	0.5278	0.6062
		6	0.1303	0.1295	2.40	0.4167	0.5353
		7	0.1408	0.1399	1.90	0.5278	0.5377
		8	0.1297	0.1293	2.40	0.4167	0.5315
12B	PM	Target	0.1000	0.1000	1.58	0.6324	-
		0	0.0866	0.0829	1.57	0.6389	0.7008
		1	0.0887	0.0862	1.57	0.6389	0.6852
		2	0.0879	0.0850	1.57	0.6389	0.6989

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
12B	PM	3	0.0888	0.0872	1.57	0.6389	0.7796
		4	0.9870	0.0983	1.57	0.6389	0.7885
		5	0.0870	0.0854	1.57	0.6389	0.7956
		6	0.0893	0.0880	1.57	0.6389	0.6733
		7	0.0956	0.0954	1.57	0.6389	0.6757
		8	0.0884	0.0872	1.57	0.6389	0.6903
13B	TMA	Target	0.1000	0.1000	1.00	1.0000	-
		0	0.0737	0.0755	1.03	0.9722	0.5638
		1	0.0771	0.0800	1.03	0.9722	0.5479
		2	0.0786	0.0820	1.03	0.9722	0.5587
		3	0.0774	0.0784	1.03	0.9722	0.6095
		4	0.0833	0.0848	1.03	0.9722	0.6030
		5	0.0739	0.0750	1.03	0.9722	0.6068
		6	0.0745	0.0759	1.03	0.9722	0.4311
		7	0.0798	0.0820	1.03	0.9722	0.4325
		8	0.0715	0.0724	1.03	0.9722	0.4496
14B	TMA	Target	0.1000	0.1000	1.50	0.6667	-
		0	0.0859	0.0828	1.44	0.6944	0.6440
		1	0.0890	0.0871	1.57	0.6389	0.6272
		2	0.0877	0.0855	1.44	0.6944	0.6458
		3	0.0872	0.0880	1.57	0.6389	0.7975
		4	0.0959	0.0978	1.57	0.6389	0.8061

Table D- 2 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
14B	TMA	5	0.0847	0.0852	1.57	0.6389	0.8101
		6	0.0870	0.0874	1.57	0.6389	0.6273
		7	0.0930	0.0920	1.57	0.6389	0.6230
		8	0.0867	0.0862	1.57	0.6389	0.6432
15B	TMA	Target	0.1000	0.1000	2.00	0.5000	-
		0	0.0876	0.0830	1.90	0.5278	0.6792
		1	0.0886	0.0847	1.90	0.5278	0.6660
		2	0.0872	0.0831	1.90	0.5278	0.6859
		3	0.0897	0.0870	1.90	0.5278	0.7072
		4	0.0978	0.0959	1.90	0.5278	0.7333
		5	0.0860	0.0834	1.90	0.5278	0.7452
		6	0.0888	0.0850	1.90	0.5278	0.6837
		7	0.0950	0.0912	1.90	0.5278	0.6841
		8	0.0885	0.0847	1.90	0.5278	0.6813

Table D- 3: Wave characteristics in 1.0 meter water depth

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
31	Reg	Target	0.2829	0.2000	1.25	0.8000	-
		0	0.2533	0.2106	1.26	0.7917	0.9717

Table D- 3 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
31	Reg	1	0.2594	0.1853	1.23	0.8125	0.9953
		2	0.2481	0.1784	1.23	0.9125	0.9961
		3	0.2559	0.2104	1.24	0.8056	0.9708
		4	0.2750	0.1954	1.24	0.8056	0.9923
		5	0.2472	0.1782	1.24	0.8056	0.9957
		6	0.2548	0.2109	1.26	0.7917	0.9496
		7	0.2567	0.1952	1.26	0.7917	0.9661
		8	0.2536	0.1897	1.26	0.7917	0.9721
32	Reg	Target	0.2829	0.2000	1.50	0.6667	-
		0	0.2535	0.2117	1.50	0.6667	0.9685
		1	0.2407	0.1778	1.50	0.6667	0.9868
		2	0.2451	0.1800	1.50	0.6667	0.9884
		3	0.2509	0.2119	1.50	0.6667	0.9687
		4	0.2561	0.1894	1.50	0.6667	0.9847
		5	0.2506	0.1843	1.50	0.6667	0.9907
		6	0.2631	0.2191	1.50	0.6667	0.9612
		7	0.2393	0.1826	1.50	0.6667	0.9712
		8	0.2421	0.1787	1.50	0.6667	0.9899
33	Reg	Target	0.2829	0.2000	2.00	0.5000	-
		0	0.2688	0.2043	2.00	0.5000	0.9647
		1	0.2668	0.1955	2.00	0.5000	0.9885
		2	0.2492	0.1857	2.00	0.5000	0.9906
		3	0.2642	0.1939	2.00	0.5000	0.9947

Table D- 3 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
33	Reg	4	0.2804	0.2025	2.00	0.5000	0.9969
		5	0.2710	0.1994	2.00	0.5000	0.9968
		6	0.2600	0.2010	2.00	0.5000	0.9817
		7	0.2330	0.1712	2.00	0.5000	0.9853
		8	0.2366	0.1817	2.00	0.5000	0.9886
34	Reg	Target	0.2829	0.2000	2.50	0.4000	-
		0	0.2115	0.1702	2.40	0.4167	0.9623
		1	0.2119	0.1599	2.57	0.3889	0.9749
		2	0.2117	0.1624	2.40	0.4167	0.9833
		3	0.2634	0.2028	2.57	0.3889	0.9612
		4	0.2282	0.1715	2.57	0.3889	0.9542
		5	0.2512	0.1976	2.40	0.4167	0.9753
		6	0.2402	0.1975	2.40	0.4167	0.9790
		7	0.2415	0.1812	2.40	0.4167	0.9900
		8	0.2885	0.1738	2.40	0.4167	0.9763
35	JONSWAP	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1708	0.1536	1.50	0.6667	0.7235
		1	0.1729	0.1718	1.50	0.6667	0.7271
		2	0.1673	0.1660	1.50	0.6667	0.7277
		3	0.1711	0.1532	1.50	0.6667	0.7943
		4	0.1832	0.1800	1.50	0.6667	0.8104
		5	0.1650	0.1634	1.50	0.6667	0.8038
		6	0.1699	0.1494	1.55	0.6458	0.6458
		7	0.1718	0.1720	1.55	0.6458	0.6570

Table D- 3 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
35	JONSWAP	8	0.1660	0.1677	1.55	0.6458	0.6490
36	JONSWAP	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1838	0.1485	1.90	0.5278	0.7887
		1	0.1960	0.1945	2.00	0.5000	0.7969
		2	0.1795	0.1790	1.90	0.5278	0.8007
		3	0.1857	0.1518	2.00	0.5000	0.8689
		4	0.1918	0.1921	2.00	0.5000	0.8844
		5	0.1816	0.1818	2.00	0.5000	0.8850
		6	0.1857	0.1614	1.92	0.5208	0.7620
		7	0.1754	0.1764	1.92	0.5208	0.7719
		8	0.1807	0.1827	1.92	0.5208	0.7763
37	PM	Target	0.0899	0.0899	1.50	0.6667	-
		0	0.0927	0.0802	1.60	0.6250	0.5845
		1	0.0864	0.0823	1.66	0.6042	0.5822
		2	0.0826	0.0782	1.55	0.6458	0.5869
		3	0.0875	0.0869	1.60	0.6250	0.6585
		4	0.0868	0.0861	1.66	0.6042	0.6790
		5	0.0830	0.0815	1.60	0.6250	0.6690
		6	0.0918	0.0885	1.50	0.6667	0.5731
		7	0.0819	0.0789	1.60	0.6250	0.5815
		8	0.0822	0.0794	1.55	0.6458	0.5933
38	PM	Target	0.1599	0.1599	2.00	0.5000	-
		0	0.1398	0.1229	1.90	0.5278	0.7229

Table D- 3 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
38	PM	1	0.1371	0.1365	2.00	0.5000	0.7302
		2	0.1368	0.1352	1.90	0.5278	0.7369
		3	0.1425	0.1239	2.00	0.5000	0.8234
		4	0.1446	0.1446	2.00	0.5000	0.8431
		5	0.1399	0.1398	2.00	0.5000	0.8344
		6	0.1418	0.1215	1.92	0.5208	0.6728
		7	0.1320	0.1272	1.92	0.5208	0.6790
		8	0.1389	0.1326	1.92	0.5208	0.6811
39	PM	Target	0.2000	0.2000	2.24	0.4472	-
		0	0.1850	0.1502	2.00	0.5000	0.6790
		1	0.1822	0.1811	2.00	0.5000	0.6884
		2	0.1797	0.1786	2.00	0.5000	0.6929
		3	0.1838	0.1412	2.53	0.3958	0.7888
		4	0.1919	0.1893	2.29	0.4375	0.8052
		5	0.1802	0.1767	2.53	0.3958	0.8016
		6	0.1833	0.1496	1.57	0.6389	0.6799
		7	0.1748	0.1746	1.57	0.6389	0.6867
		8	0.1828	0.1866	1.57	0.6389	0.6869
40	TMA	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1676	0.1528	1.50	0.6667	0.6685
		1	0.1666	0.1657	1.50	0.6667	0.6786
		2	0.1622	0.1617	1.50	0.6667	0.6821
		3	0.1685	0.1506	1.50	0.6667	0.7743

Table D- 3 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
40	TMA	4	0.1689	0.1643	1.50	0.6667	0.7889
		5	0.1613	0.1596	1.50	0.6667	0.7839
		6	1.6470	0.1472	1.57	0.6389	0.6427
		7	0.1663	0.1657	1.57	0.6389	0.6541
		8	0.1634	0.1643	1.57	0.6389	0.6450
41	TMA	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1800	0.1499	1.90	0.5278	0.7541
		1	0.1831	0.1810	1.90	0.5278	0.7652
		2	0.1767	0.1748	1.90	0.5278	0.7669
		3	0.1816	0.1575	2.00	0.5000	0.8507
		4	0.1919	0.1909	2.00	0.5000	0.8678
		5	0.1777	0.1778	2.00	0.5000	0.8666
		6	0.1810	0.1534	1.92	0.5208	0.7272
		7	0.1743	0.1740	1.92	0.5208	0.7406
		8	0.1779	0.1794	1.92	0.5208	0.7388

Table D- 4: Wave characteristics in 1.0 meter water depth with Buoys

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
31B	Reg	Target	0.2829	0.2000	1.25	0.8000	-

Table D- 4 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
31B	Reg	0	0.2610	0.1925	1.24	0.8056	0.9766
		1	0.2568	0.1889	1.24	0.8056	0.9734
		2	0.2443	0.1832	1.24	0.8056	0.9728
		3	0.2669	0.2032	1.24	0.8056	0.9793
		4	0.2506	0.1864	1.24	0.8056	0.9845
		5	0.2729	0.1973	1.24	0.8056	0.9907
		6	0.2492	0.1864	1.26	0.8002	0.9817
		7	0.2440	0.1902	1.24	0.8056	0.9401
		8	0.2608	0.1912	1.24	0.8056	0.9850
32B	Reg	Target	0.2829	0.2000	1.50	0.6667	-
		0	0.2865	0.2098	1.50	0.6667	0.9845
		1	0.2707	0.1955	1.50	0.6667	0.9862
		2	0.2660	0.1957	1.50	0.6667	0.9866
		3	0.2946	0.2129	1.50	0.6667	0.9898
		4	0.2814	0.2038	1.50	0.6667	0.9921
		5	0.2850	0.2143	1.50	0.6667	0.9802
		6	0.2711	0.2067	1.50	0.6667	0.9789
		7	0.2654	0.1962	1.50	0.6667	0.9838
		8	0.2551	0.1898	1.50	0.6667	0.9839
33B	Reg	Target	0.2829	0.2000	2.00	0.5000	-
		0	0.3089	0.2284	1.96	0.5112	0.9850
		1	0.3095	0.2283	2.00	0.5000	0.9810
		2	0.2946	0.2130	2.05	0.4890	0.9795

Table D- 4 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
33B	Reg	3	0.2992	0.2205	2.00	0.5000	0.9795
		4	0.2868	0.2142	2.00	0.5000	0.9781
		5	0.2943	0.2172	2.00	0.5000	0.9730
		6	0.2602	0.1941	2.00	0.5000	0.9746
		7	0.2797	0.2112	2.00	0.5000	0.9801
		8	0.2773	0.2047	2.00	0.5000	0.9828
34B	Reg	Target	0.2829	0.2000	2.50	0.4000	-
		0	0.2598	0.1862	2.50	0.4000	0.9836
		1	0.2522	0.1905	2.40	0.4169	0.9304
		2	0.2378	0.1750	2.50	0.4000	0.9846
		3	0.2335	0.1744	2.57	0.3889	0.9810
		4	0.2580	0.1892	2.57	0.3889	0.8432
		5	0.2567	0.1900	2.40	0.4167	0.9872
		6	0.2498	0.1858	2.50	0.3891	0.9711
		7	0.2415	0.1835	2.50	0.4000	0.9888
		8	0.2505	0.1830	2.40	0.4167	0.9902
35B	JONSWAP	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1703	0.1691	1.57	0.6389	0.7002
		1	0.1691	0.1688	1.57	0.6389	0.6921
		2	0.1615	0.1597	1.57	0.6389	0.6979
		3	0.1652	0.1680	1.57	0.6389	0.7025
		4	0.1674	0.1743	1.57	0.6389	0.6690
		5	0.1718	0.1684	1.57	0.6389	0.7387

Table D- 4 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
35B	JONSWAP	6	0.1632	0.1673	1.57	0.6389	0.6433
		7	0.1611	0.1613	1.57	0.6389	0.6526
		8	0.1755	0.1810	1.57	0.6389	0.6512
36B	JONSWAP	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1809	0.1826	1.90	0.5278	0.7645
		1	0.1636	0.1645	1.90	0.5278	0.6277
		2	0.1709	0.1656	1.90	0.5278	0.7736
		3	0.1698	0.1696	1.90	0.5278	0.7883
		4	0.1715	0.1647	1.90	0.5278	0.7648
		5	0.1787	0.1855	1.90	0.5278	0.7953
		6	0.1847	0.1793	1.92	0.5335	0.6861
		7	0.1745	0.1727	1.90	0.5378	0.7589
		8	0.1738	0.1722	1.90	0.5278	0.7530
37B	PM	Target	0.0899	0.0899	1.50	0.6667	-
		0	0.0837	0.0797	1.57	0.6389	0.6134
		1	0.0826	0.0775	1.57	0.6389	0.6215
		2	0.0816	0.0788	1.57	0.6389	0.6070
		3	0.0809	0.0792	1.57	0.6389	0.7020
		4	0.0884	0.0892	1.57	0.6389	0.6730
		5	0.0874	0.0906	1.20	0.8333	0.6813
		6	0.0855	0.0845	1.24	0.8059	0.6017
		7	0.0806	0.0803	1.57	0.6392	0.6019

Table D- 4 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
37B	PM	8	0.0896	0.0919	1.44	0.6948	0.4852
38B	PM	Target	0.1599	0.1599	2.00	0.5000	-
		0	0.1387	0.1371	2.00	0.5000	
		1	0.1340	0.1334	2.00	0.5000	
		2	0.1318	0.1315	2.00	0.5000	
		3	0.1348	0.1325	2.05	0.4890	
		4	0.1339	0.1318	2.00	0.5000	
		5	0.1344	0.1320	2.00	0.5000	
		6	0.1369	0.1318	2.00	0.5000	
		7	0.1330	0.1277	2.00	0.5000	
		8	0.1473	0.1473	1.44	0.6948	
39B	PM	Target	0.2000	0.2000	2.24	0.4472	-
		0	0.1812	0.1769	2.57	0.3889	0.6460
		1	0.1660	0.1665	2.57	0.3891	0.6365
		2	0.1711	0.1699	2.65	0.3779	0.6535
		3	0.1742	0.1693	1.89	0.5280	0.8110
		4	0.1702	0.1651	1.89	0.5280	0.7960
		5	0.1821	0.1877	1.88	0.5335	0.7824
		6	0.1709	0.1661	2.40	0.4169	0.6683
		7	0.1665	0.1642	1.89	0.5280	0.6627
		8	0.1759	0.1725	1.89	0.5280	0.7719
40B	TMA	Target	0.2000	0.2000	1.50	0.6667	-
		0	0.1671	0.1664	1.57	0.6389	0.6421

Table D- 4 cont.

Test #	Spectrum	Channel	Measured				Correlation
			Hmo (m)	H1/3 (m)	Tp (sec)	Fp (Hz)	
40B	TMA	1	0.1634	0.1612	1.57	0.6392	0.6585
		2	0.1590	0.1571	0.16	0.6446	0.6512
		3	0.1610	0.1600	1.57	0.6392	0.7163
		4	0.1556	0.1518	1.57	0.6392	0.7131
		5	0.1644	0.1619	1.57	0.6392	0.7346
		6	0.1583	0.1622	1.55	0.6446	0.6535
		7	0.1531	0.1532	1.57	0.6392	0.6447
		8	0.1529	0.1541	1.57	0.6392	0.6318
41B	TMA	Target	0.2000	0.2000	2.00	0.5000	-
		0	0.1763	0.1747	1.90	0.5280	0.7364
		1	0.1665	0.1636	1.90	0.5280	0.6519
		2	0.1662	0.1625	1.90	0.5280	0.7398
		3	0.1733	0.1716	1.88	0.5335	0.7461
		4	0.1671	0.1604	1.90	0.5280	0.7277
		5	0.1745	0.1693	1.88	0.5335	0.7279
		6	0.1683	0.1642	1.89	0.5280	0.7560
		7	0.1651	0.1618	1.89	0.5280	0.7461
		8	0.1748	0.1688	1.89	0.5280	0.6747

APPENDIX E

POWER SPECTRUM PLOTS FOR WAVE TESTS

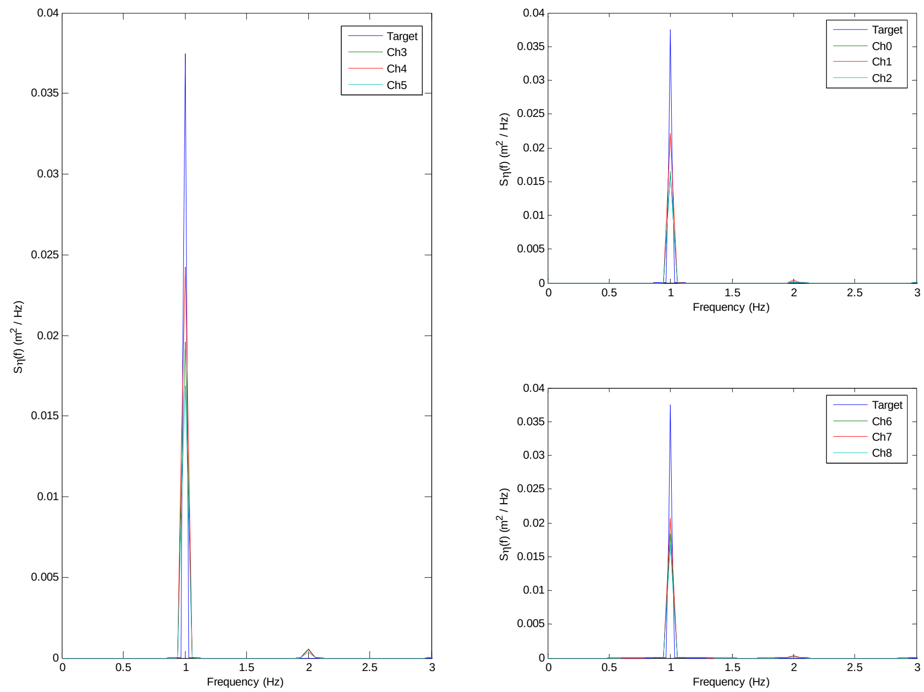

Figure E- 1: Test1, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec

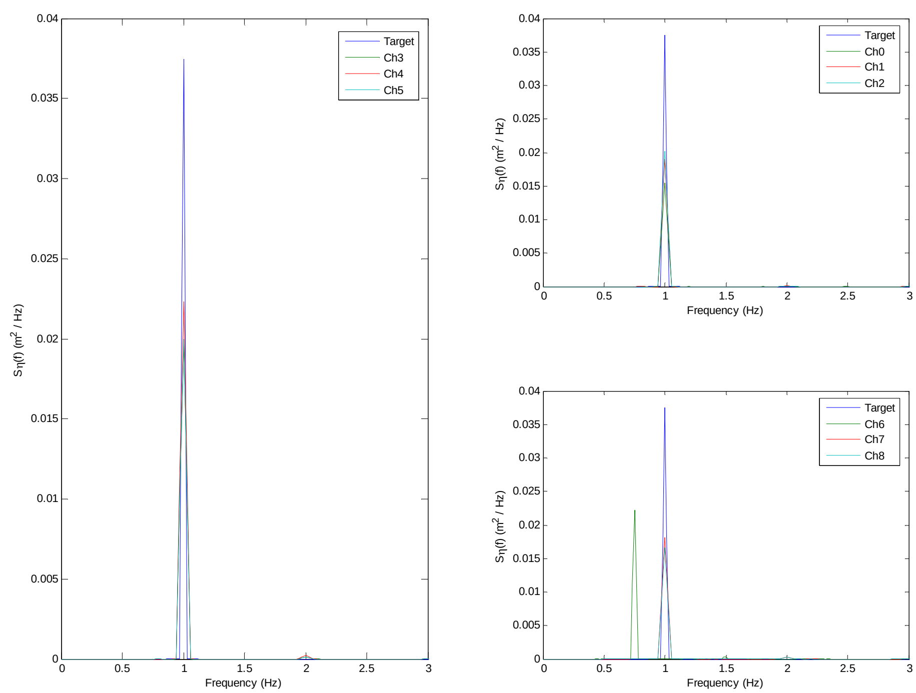

Figure E- 2: Test1 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.0 sec

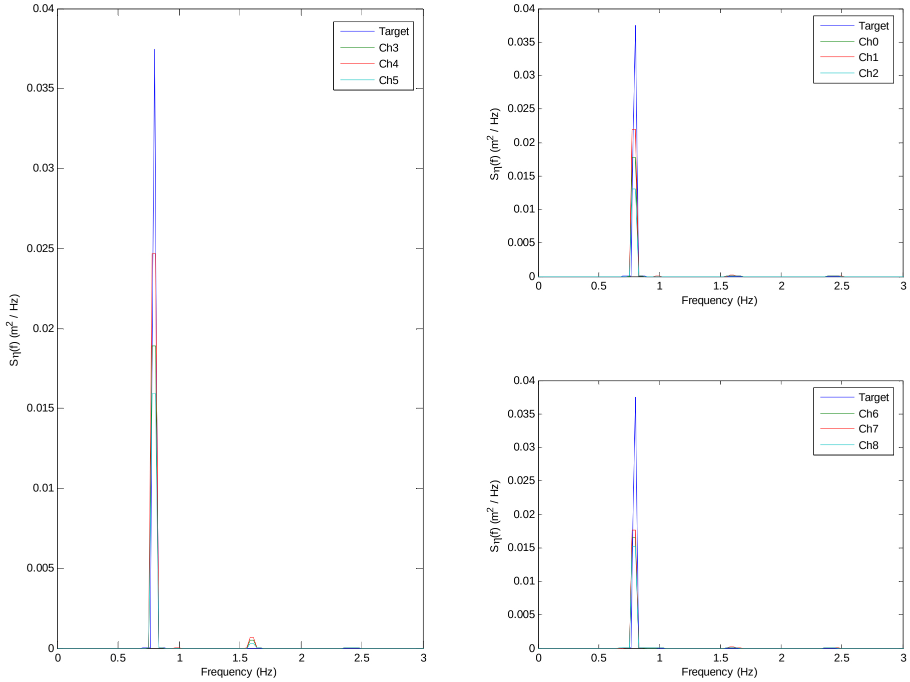

Figure E- 3: Test 2, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec

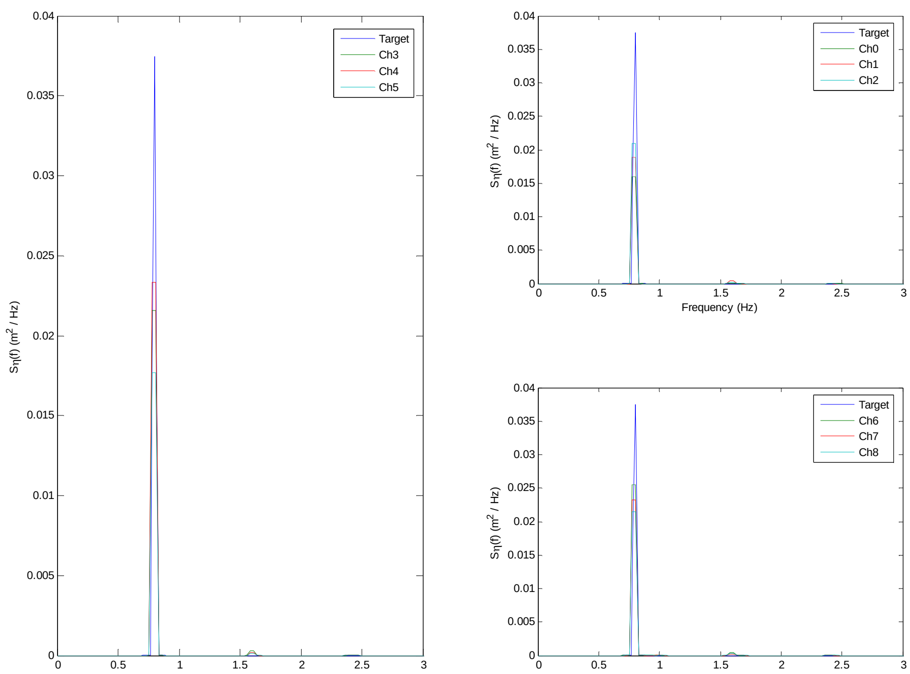

Figure E- 4: Test 2 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.25 sec

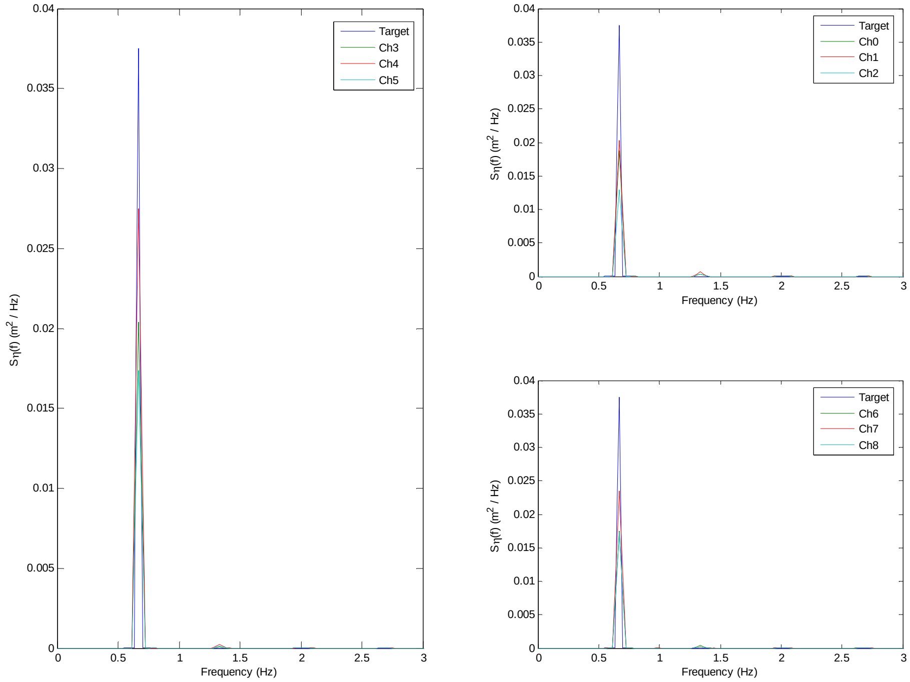

Figure E- 5: Test 3, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec

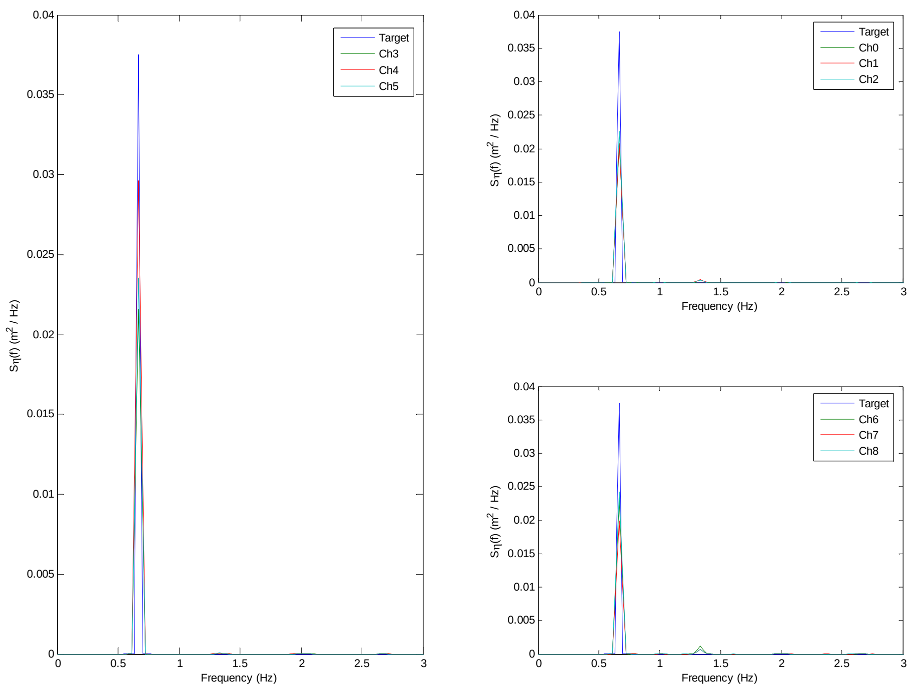

Figure E- 6: Test 3 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 1.5 sec

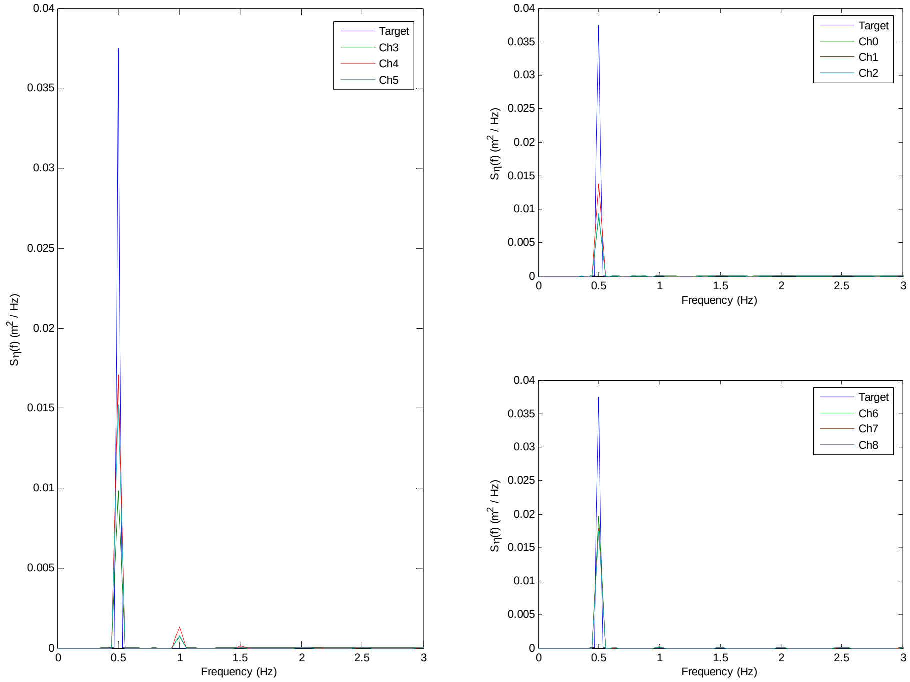

Figure E- 7: Test 4, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec

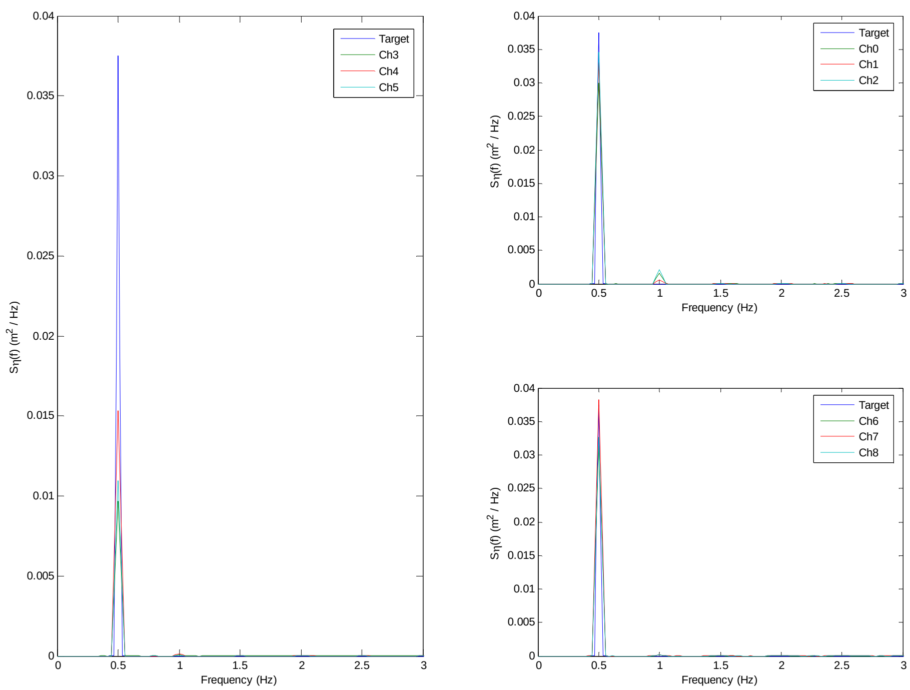

Figure E- 8: Test 4 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.0 sec

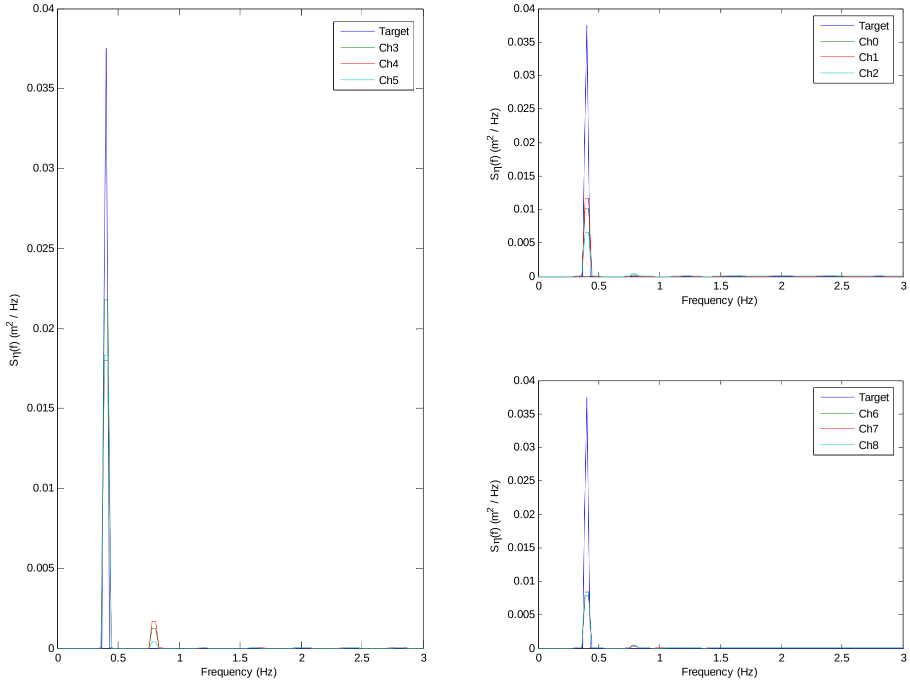

Figure E- 9: Test 5, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec

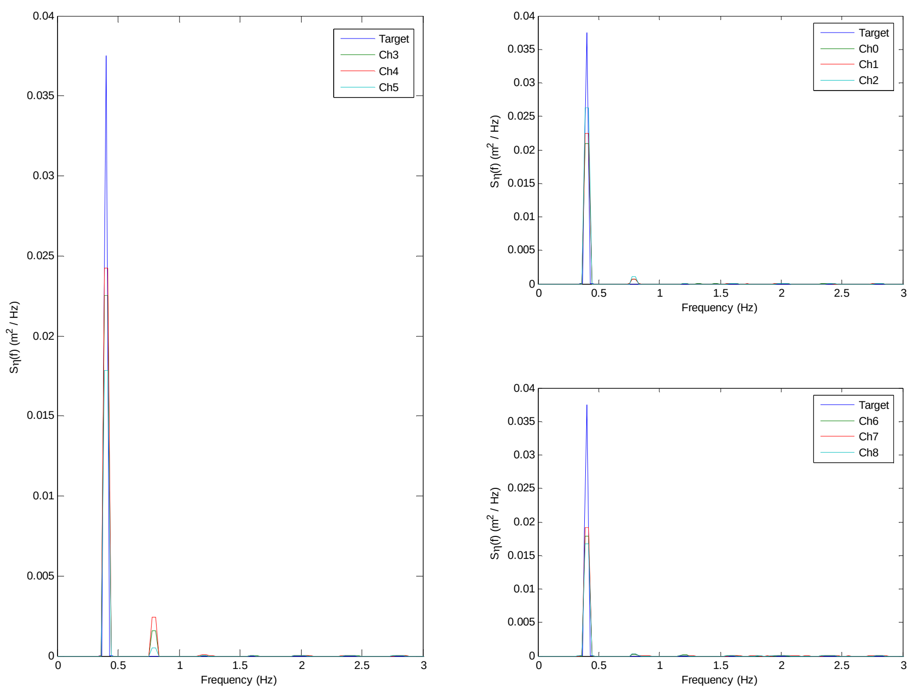

Figure E- 10: Test 5 with Buoys, Monochromatic, h = 0.5 m, H = 0.1 m, T = 2.5 sec

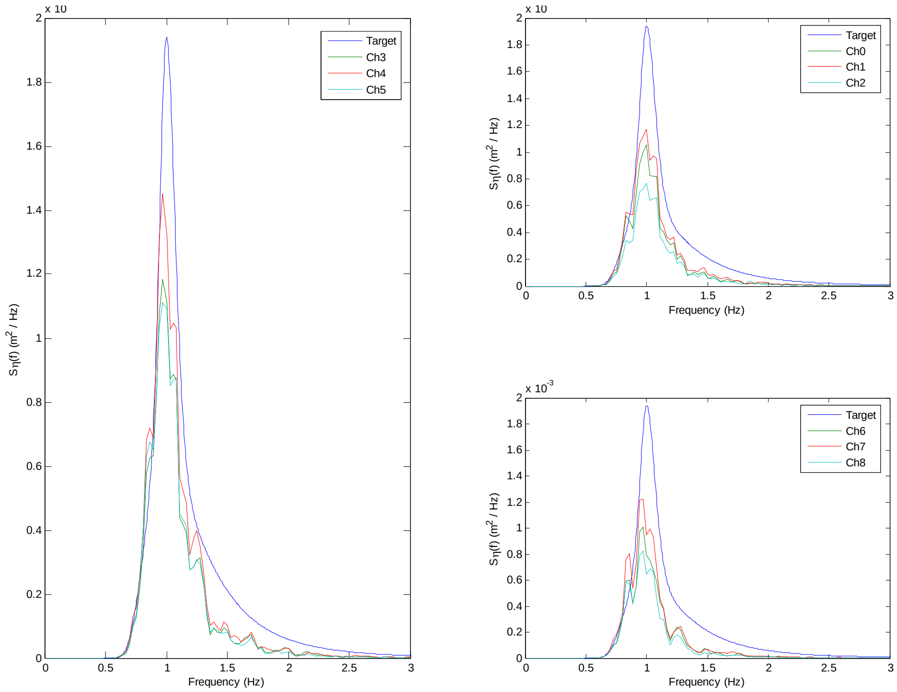

Figure E- 11: Test 6, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.0 sec

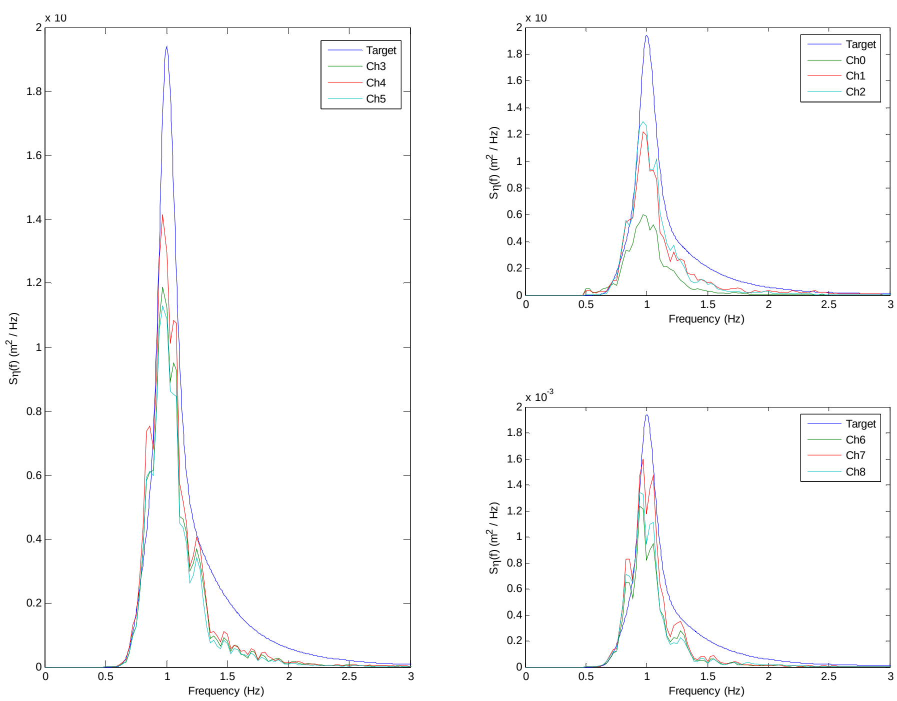

Figure E- 12: Test 6 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.0 sec

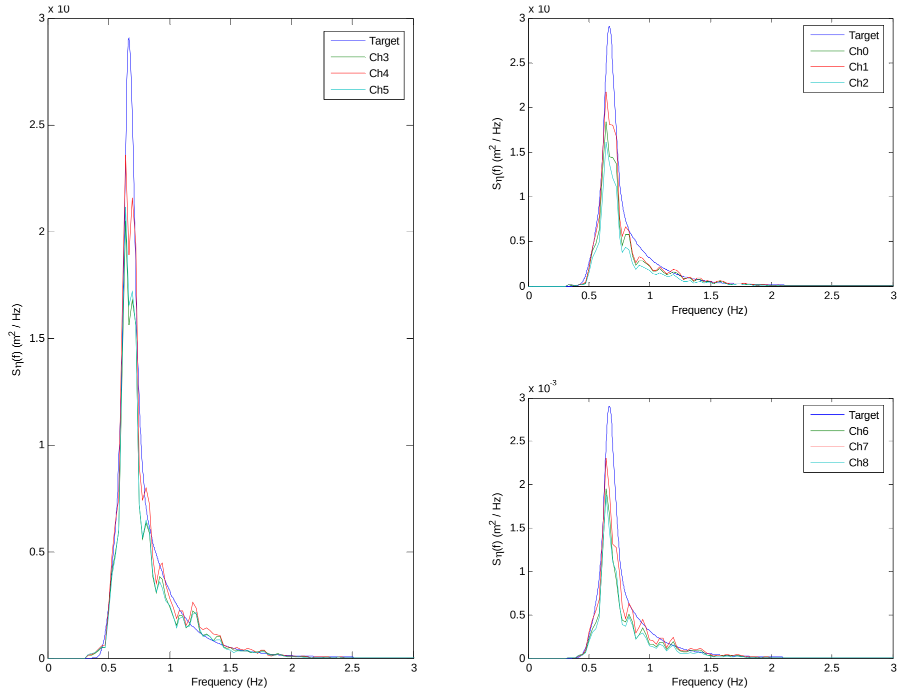

Figure E- 13: Test 7, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec

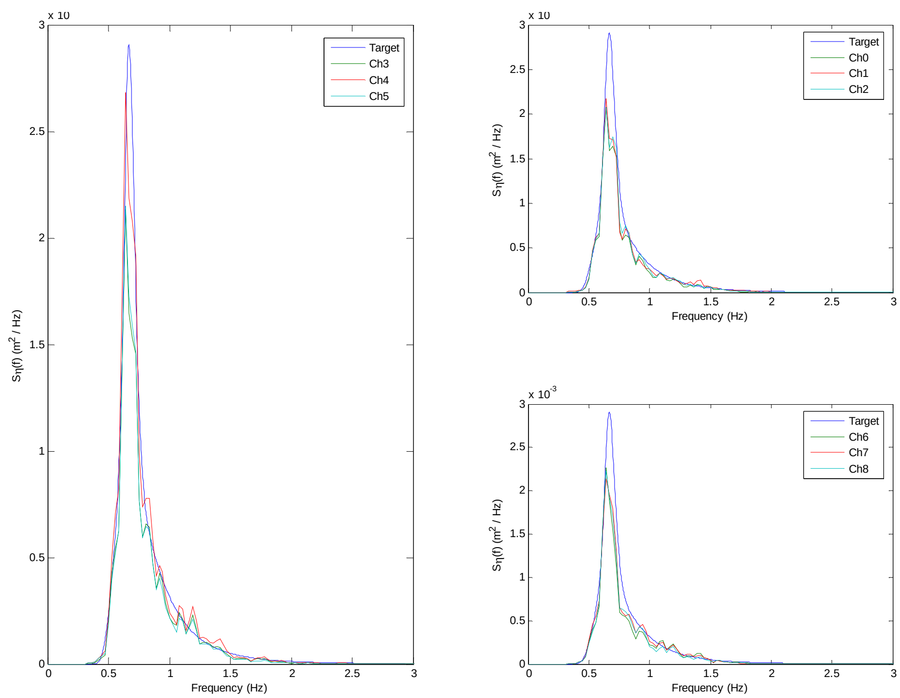

Figure E- 14: Test 7 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 1.5 sec

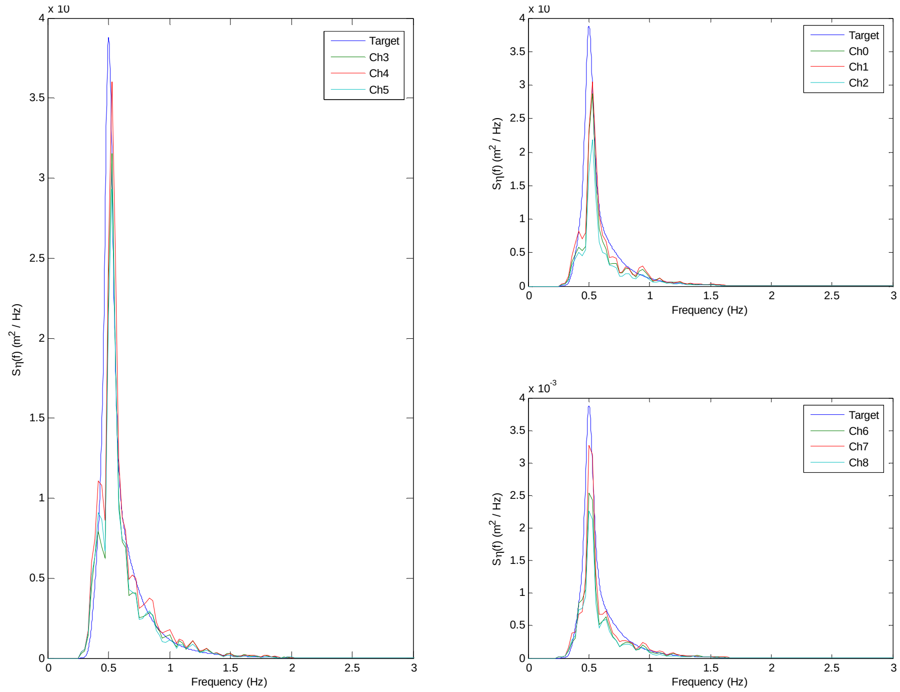

Figure E- 15: Test 8, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec

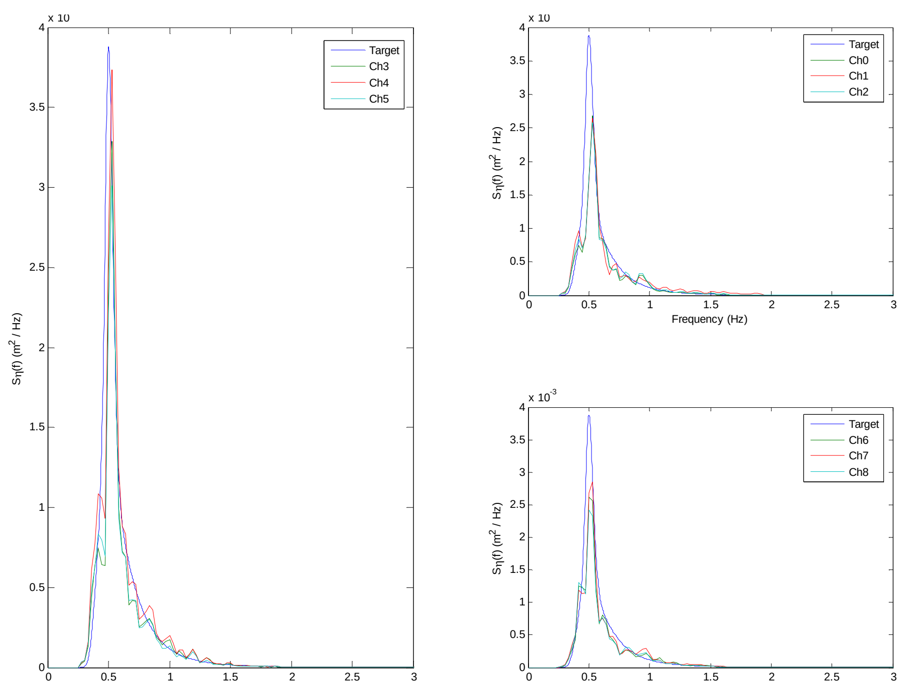

Figure E- 16: Test 8 with Buoys, JONSWAP, h = 0.5 m, H = 0.1 m, T = 2.0 sec

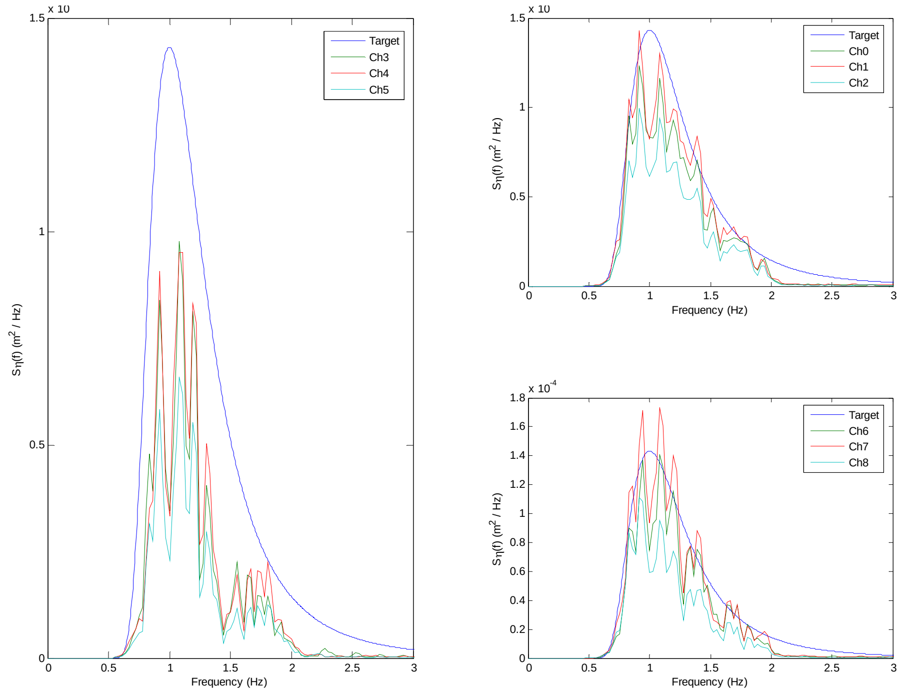

Figure E- 17: Test 9, PM, h = 0.5 m, T = 1.0 sec

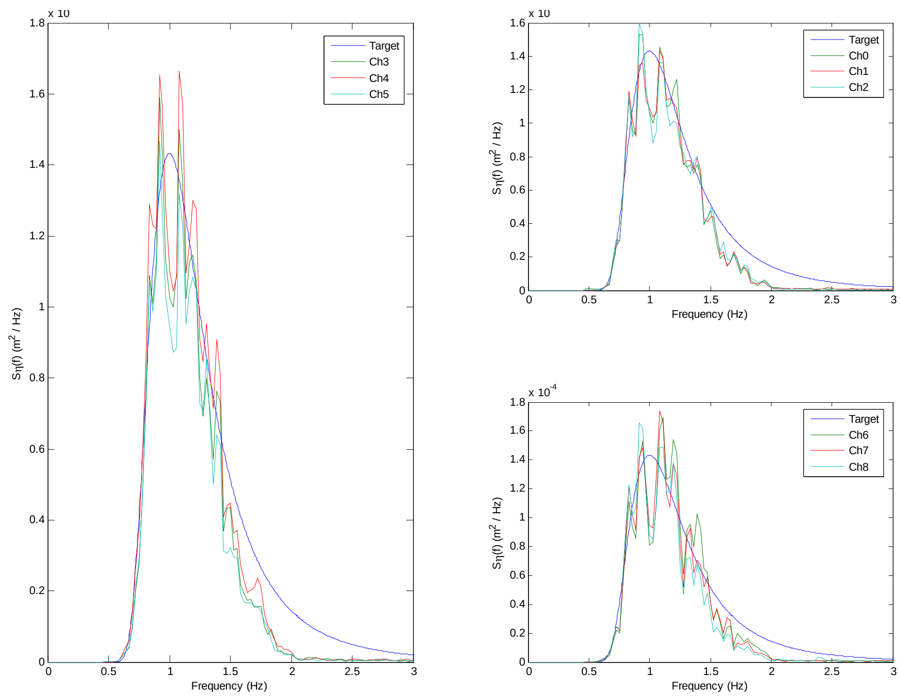

Figure E- 18: Test 9 with Buoys, PM, h = 0.5 m, T = 1.0 sec

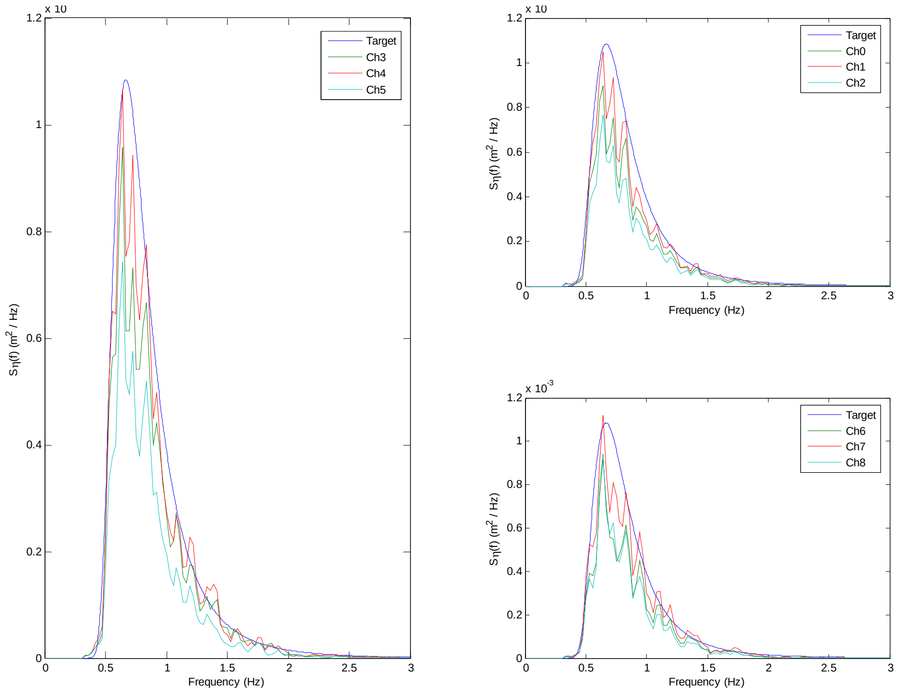

Figure E- 19: Test 10, PM, h = 0.5 m, T = 1.5 sec

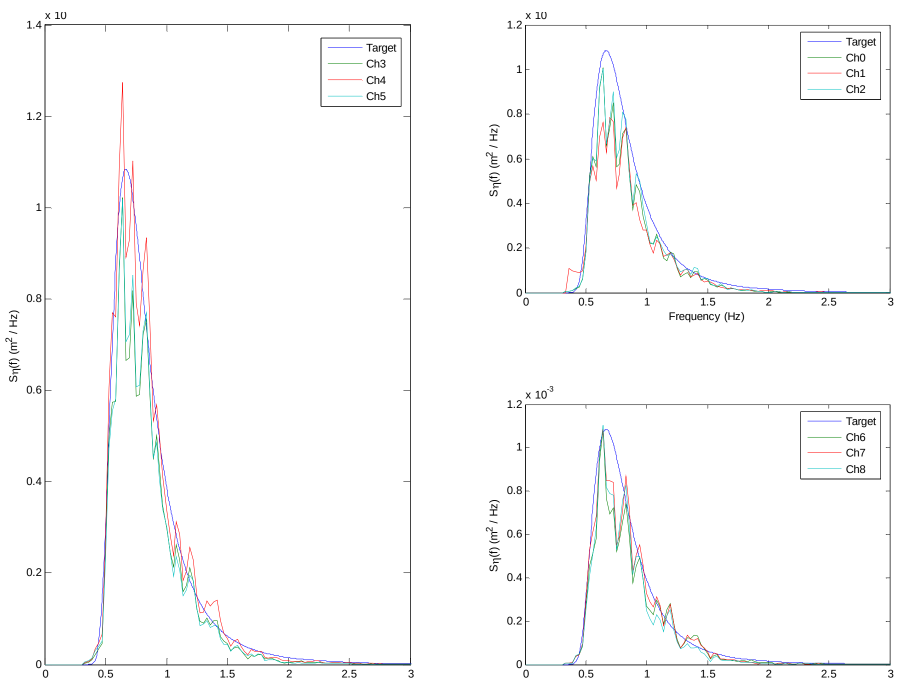

Figure E- 20: Test 10 with Buoys, PM, h = 0.5 m, T = 1.5 sec

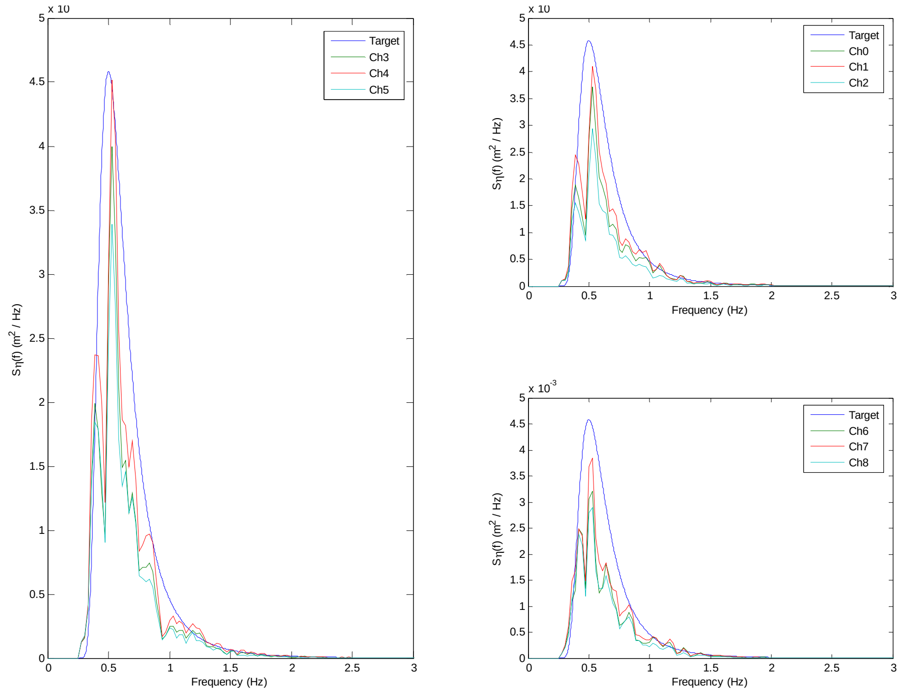

Figure E- 21: Test 11, PM, h = 0.5 m, T = 2.0 sec

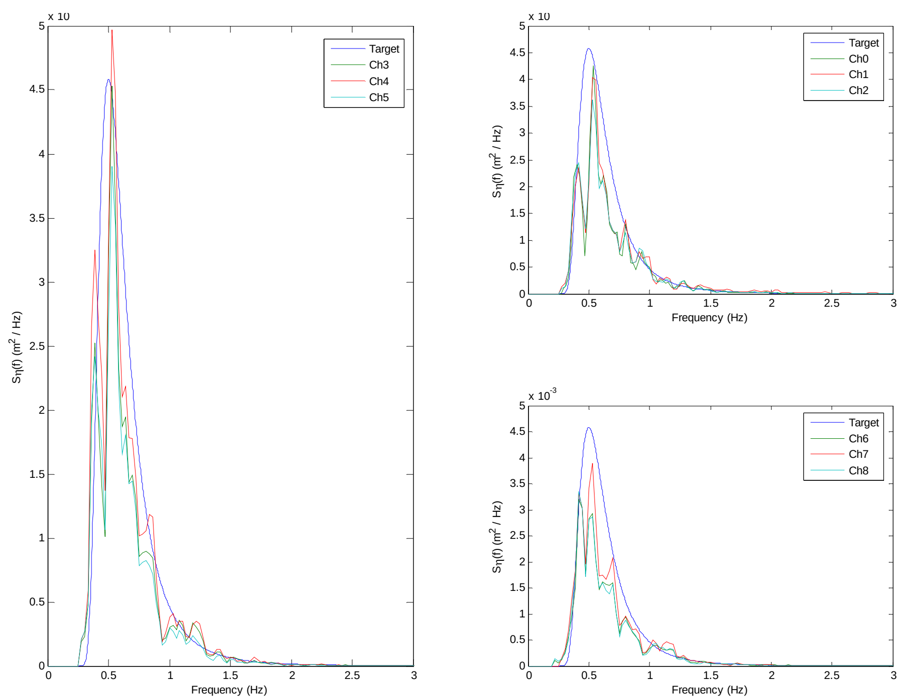

Figure E- 22: Test 11 with Buoys, PM, h = 0.5 m, T = 2.0 sec

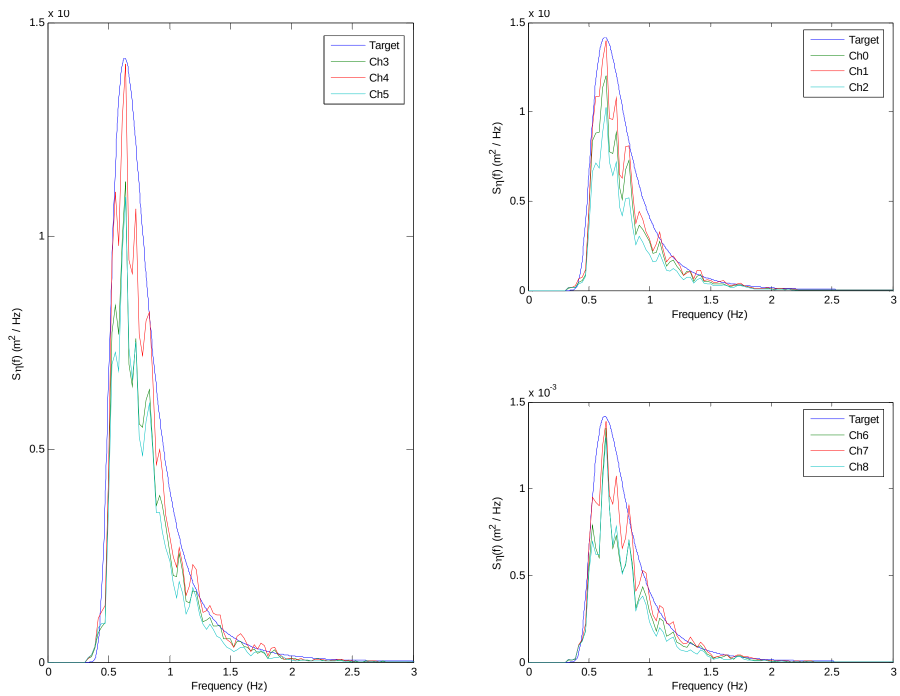

Figure E- 23: Test 12, PM-Hsig, h = 0.5 m, H = 0.1 m

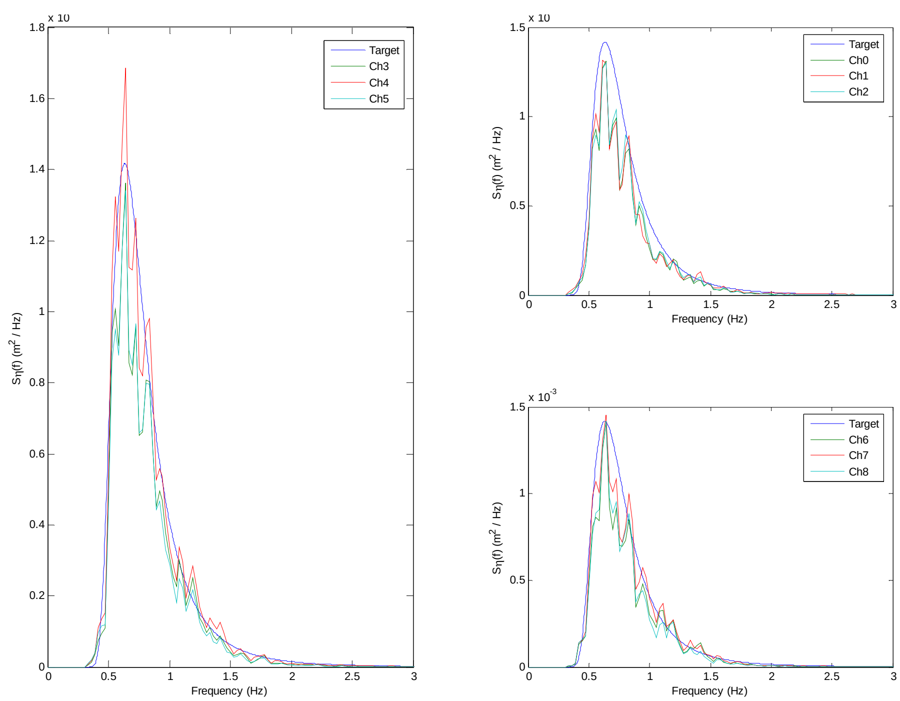

Figure E- 24: Test 12 with Buoys, PM-Hsig, h = 0.5 m, H = 0.1 m

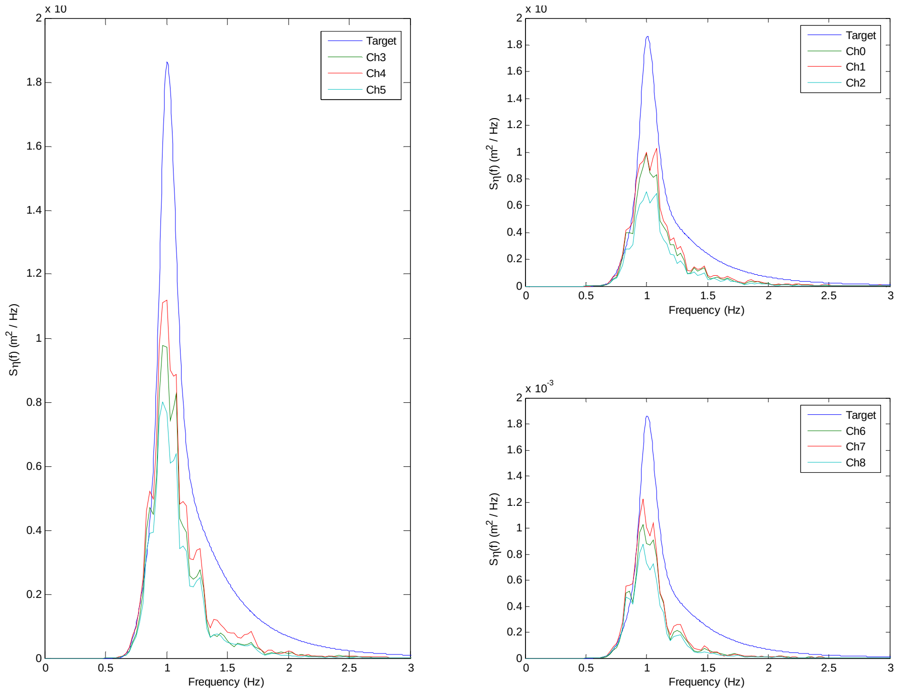

Figure E- 25: Test 13, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec

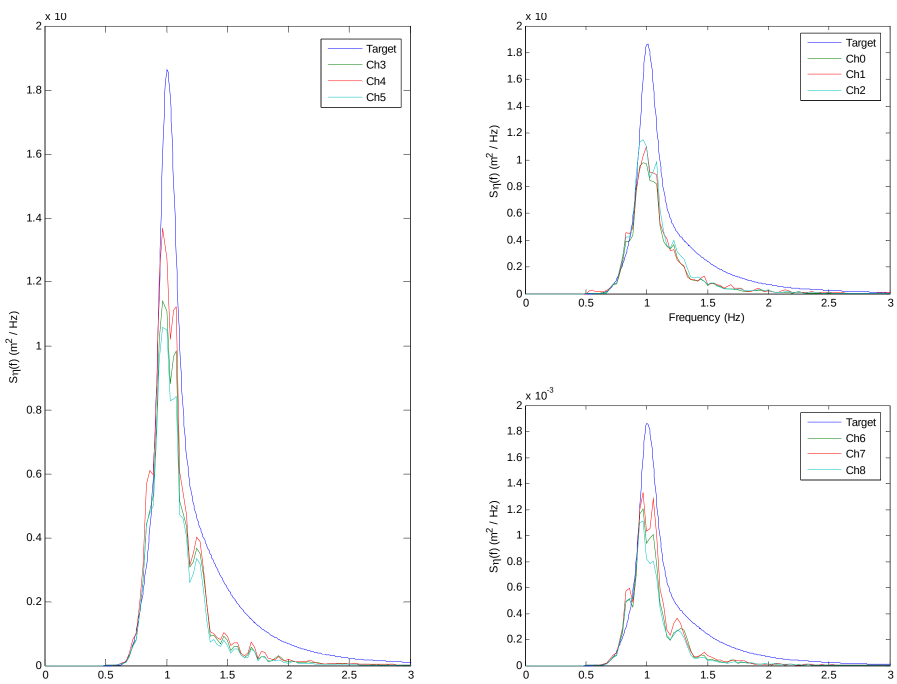

Figure E- 26: Test 13 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.0 sec

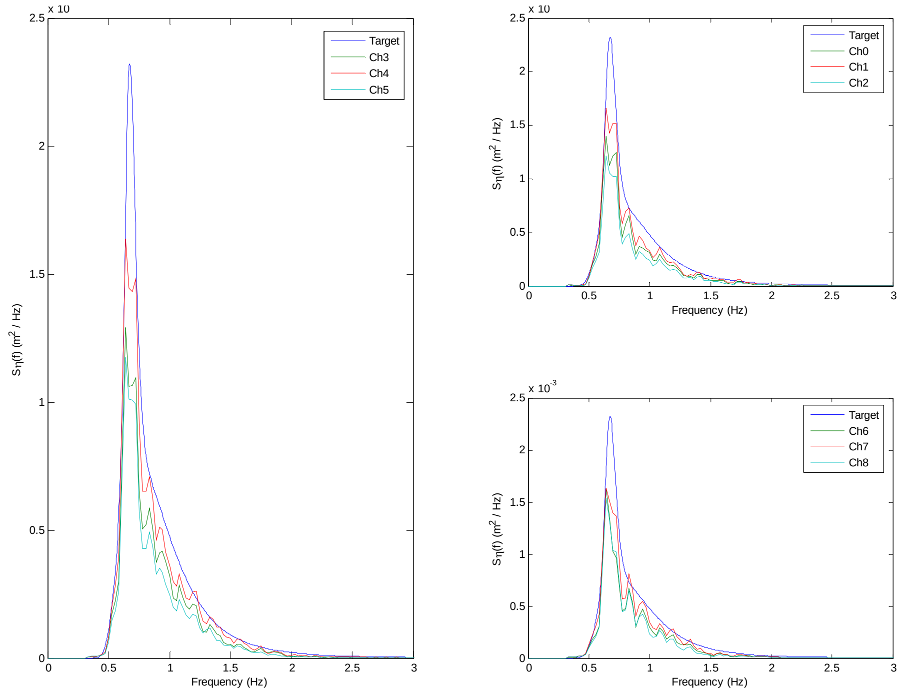

Figure E- 27: Test 14, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec

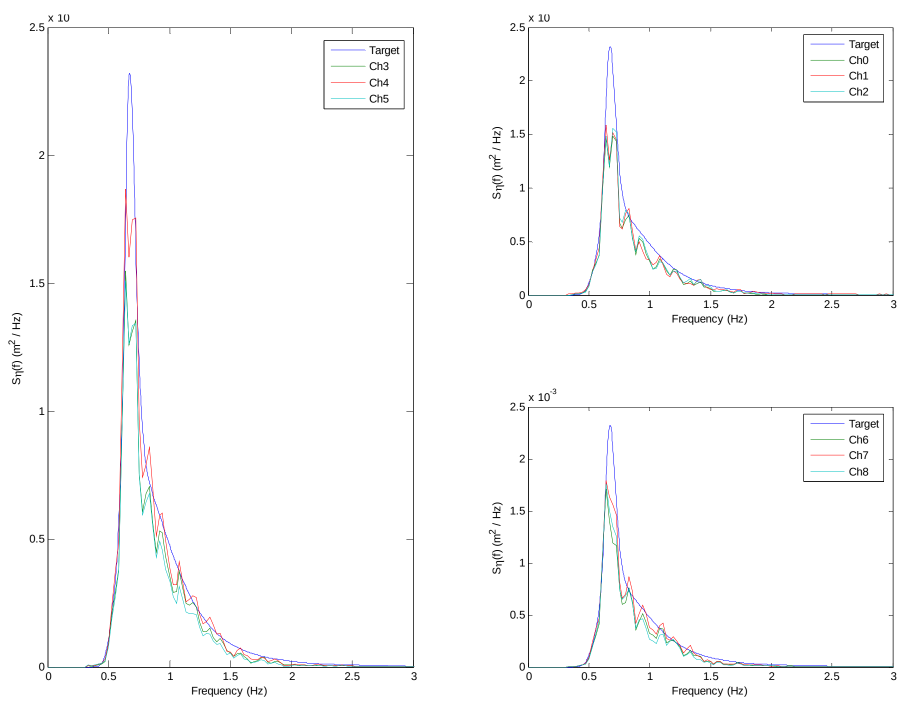

Figure E- 28: Test 14 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 1.5 sec

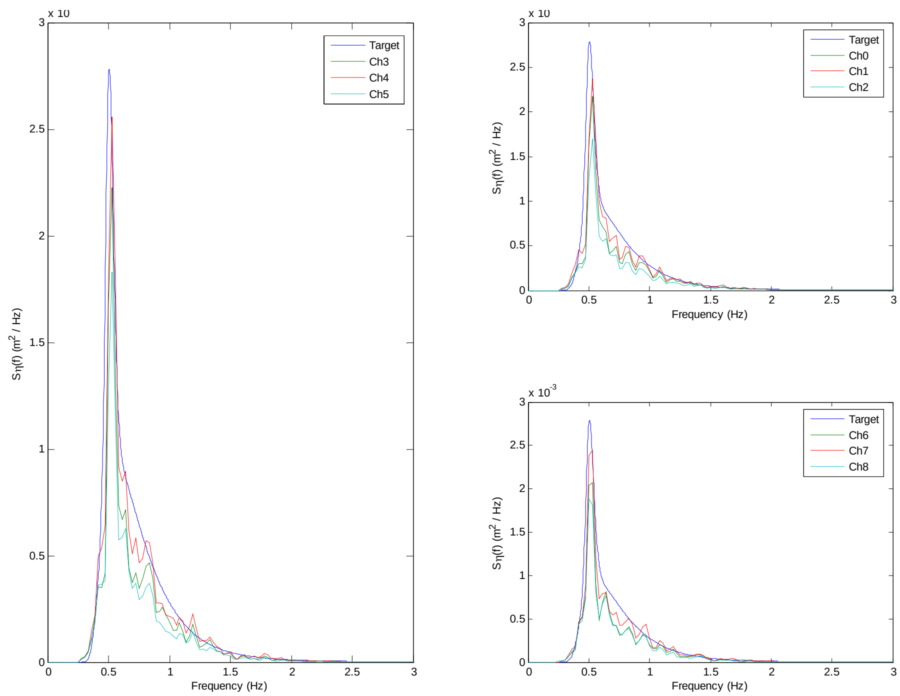

Figure E- 29: Test 15, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec

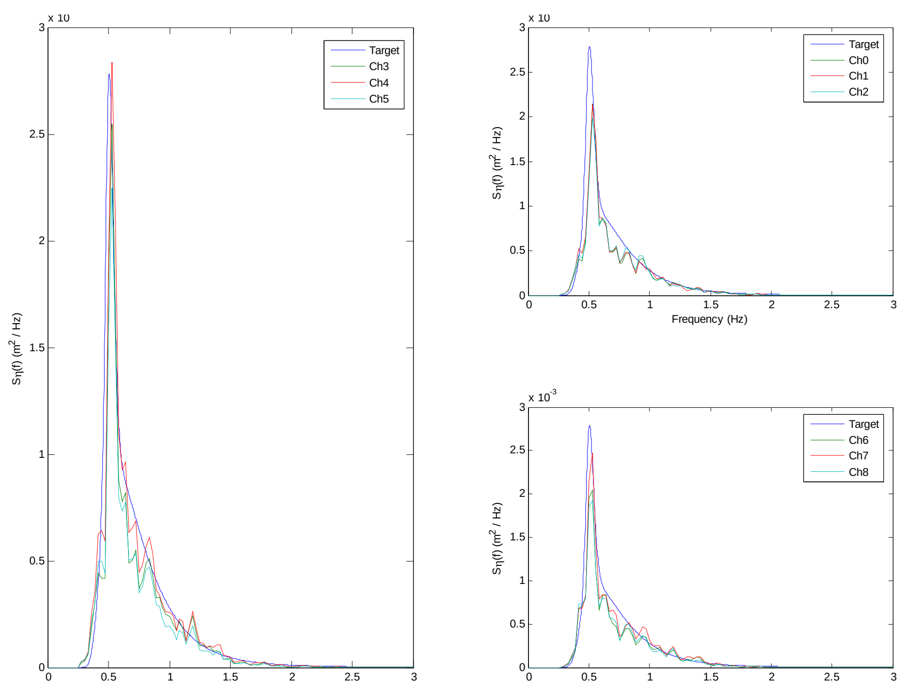

Figure E- 30: Test 15 with Buoys, TMA, h = 0.5 m, H = 0.1 m, T = 2.0 sec

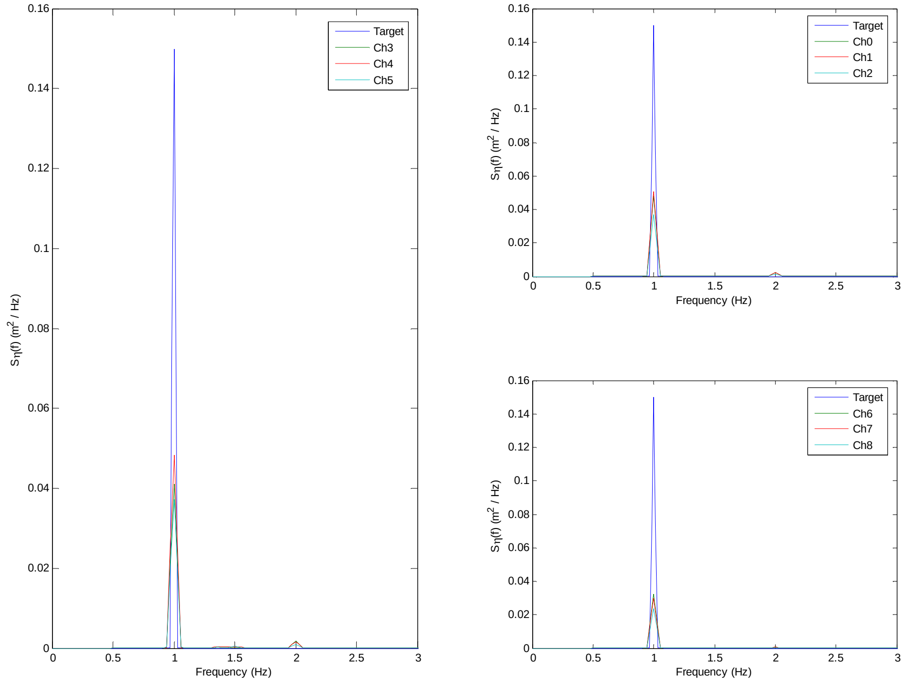

Figure E- 31: Test 16, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.0 sec

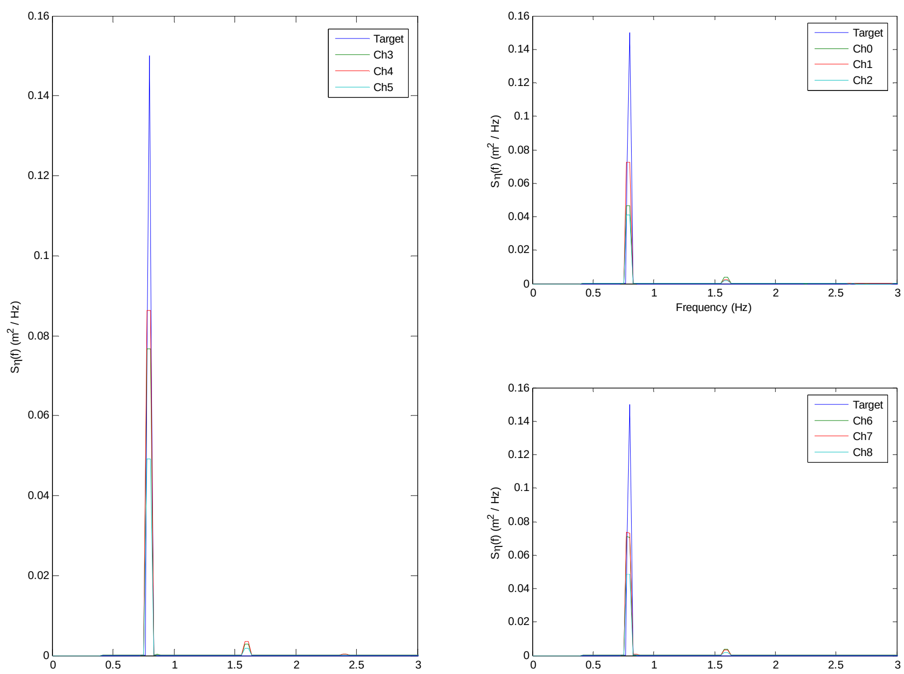

Figure E- 32: Test 17, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.25 sec

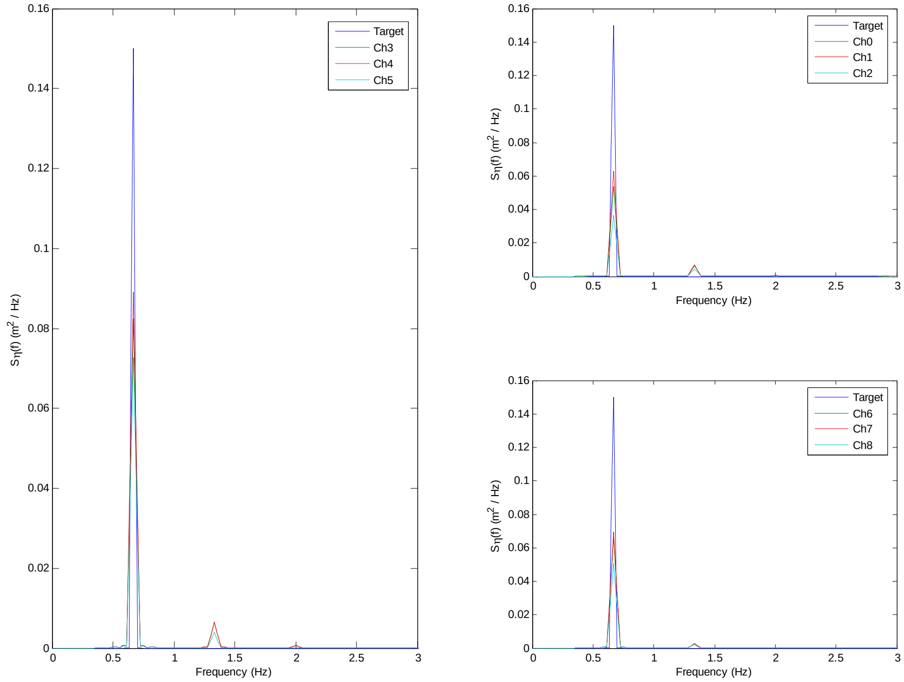

Figure E- 33: Test 18, Monochromatic, h = 0.5 m, H = 0.2 m, T = 1.5 sec

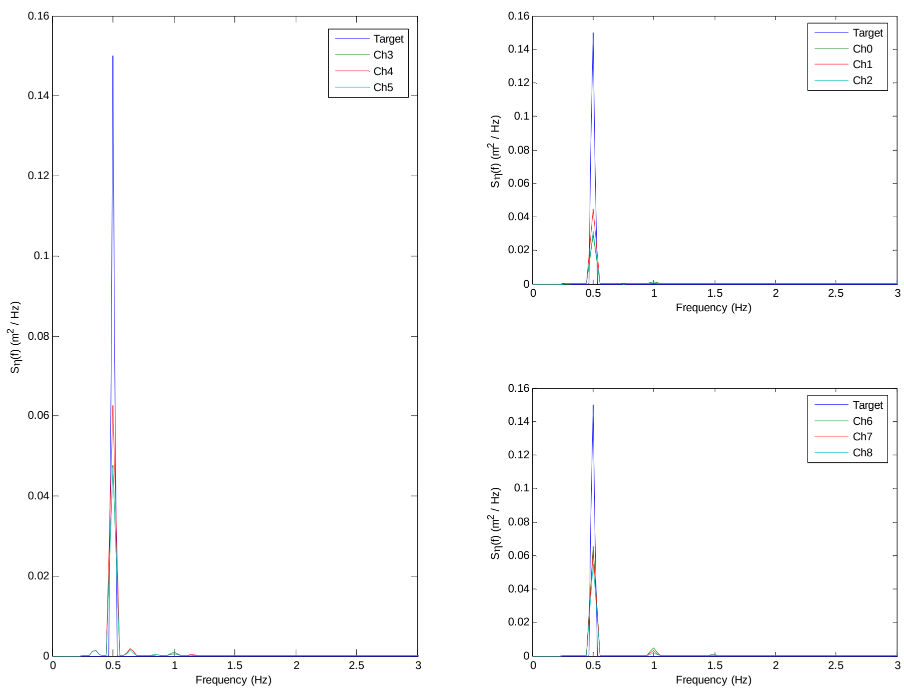

Figure E- 34: Test 19, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.0 sec

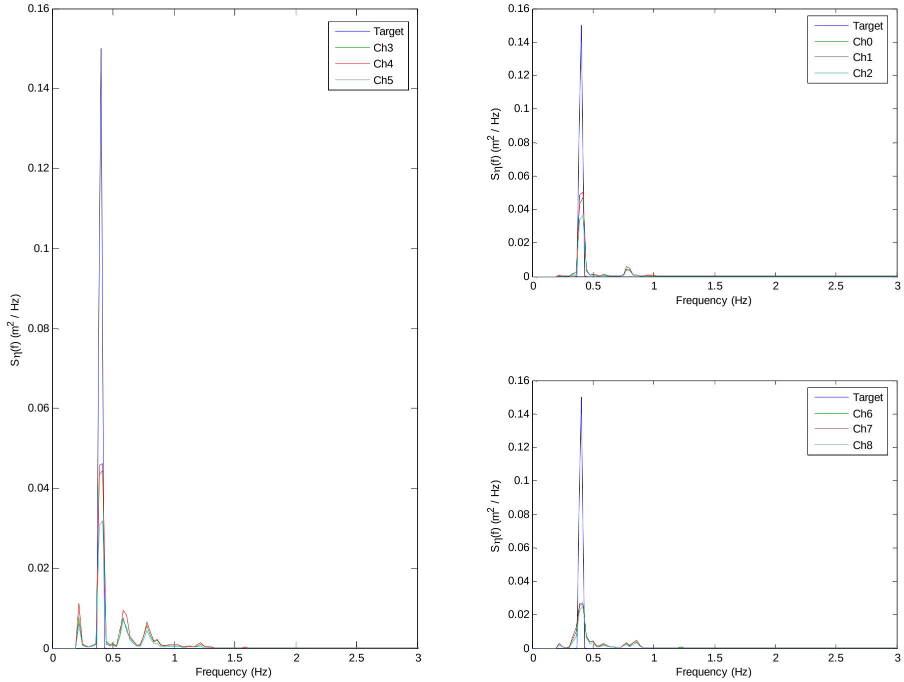

Figure E- 35: Test 20, Monochromatic, h = 0.5 m, H = 0.2 m, T = 2.5 sec

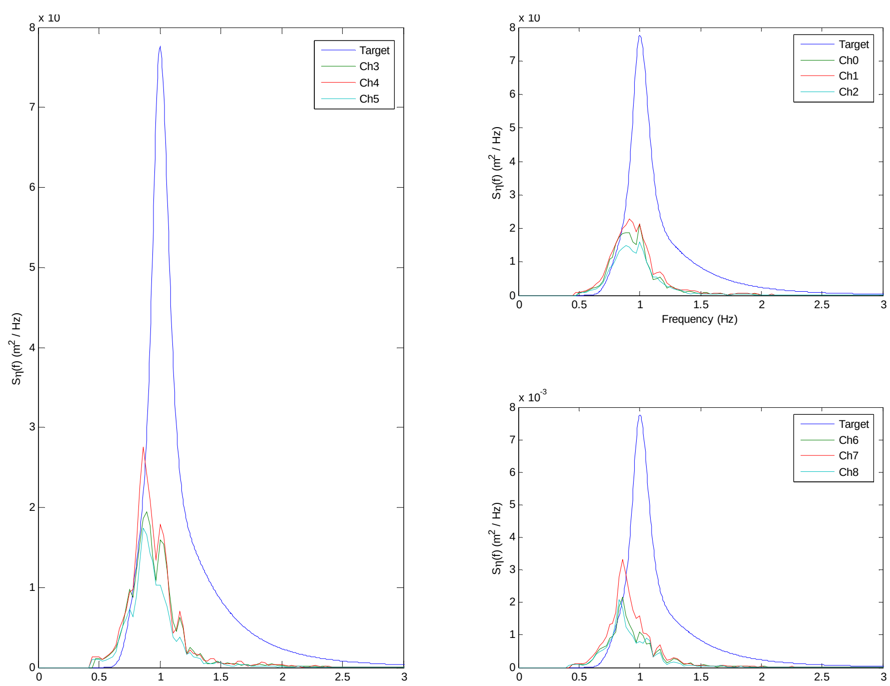

Figure E- 36: Test 21, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.0 sec

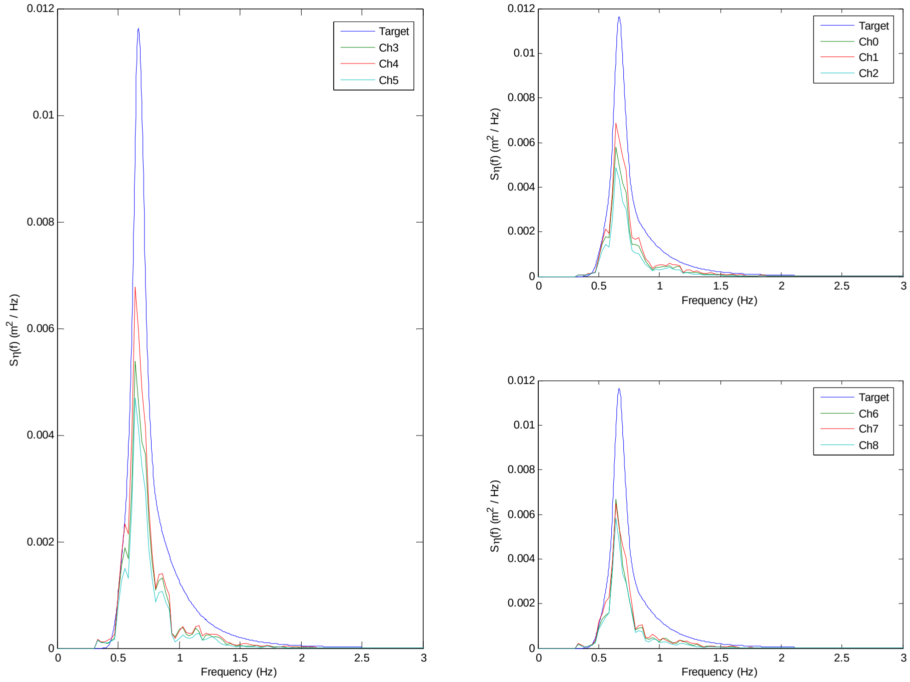

Figure E- 37: Test 22, JONSWAP, h = 0.5 m, H = 0.2 m, T = 1.5 sec

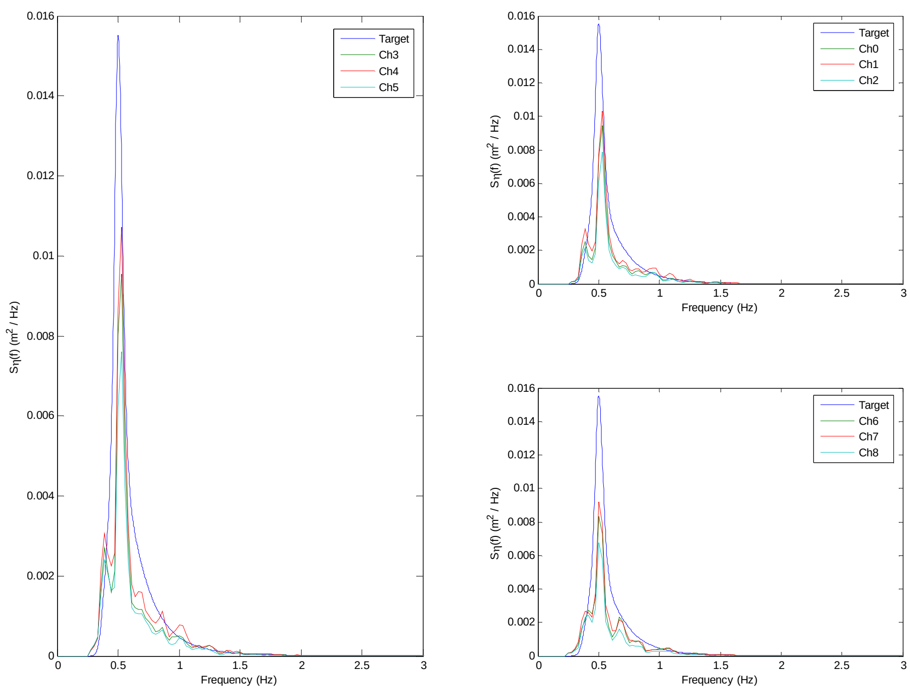

Figure E- 38: Test 23, JONSWAP, h = 0.5 m, H = 0.2 m, T = 2.0 sec

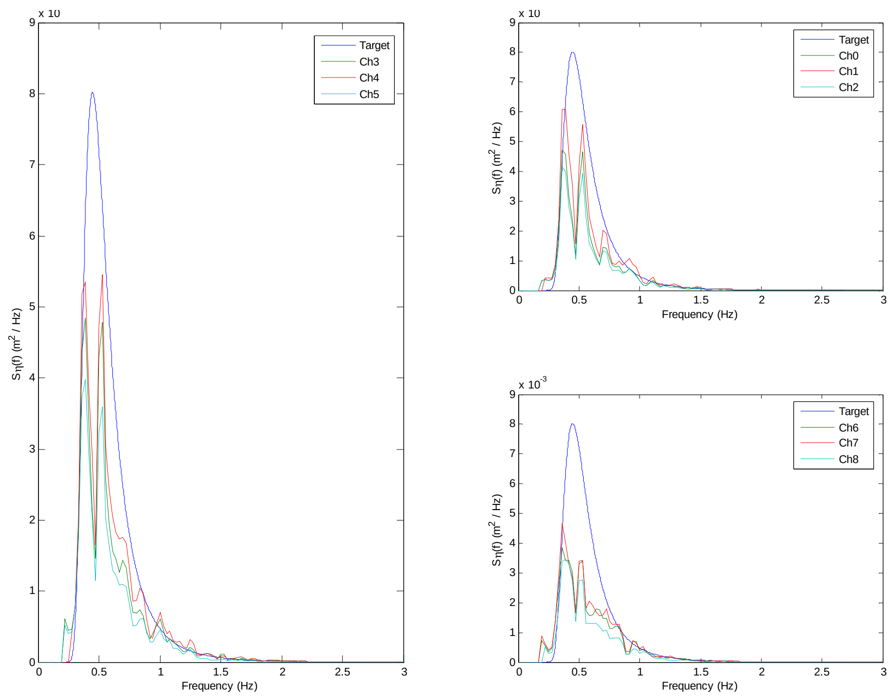

Figure E- 39: Test 24, PM-Hsig, h = 0.5 m, H = 0.2 m

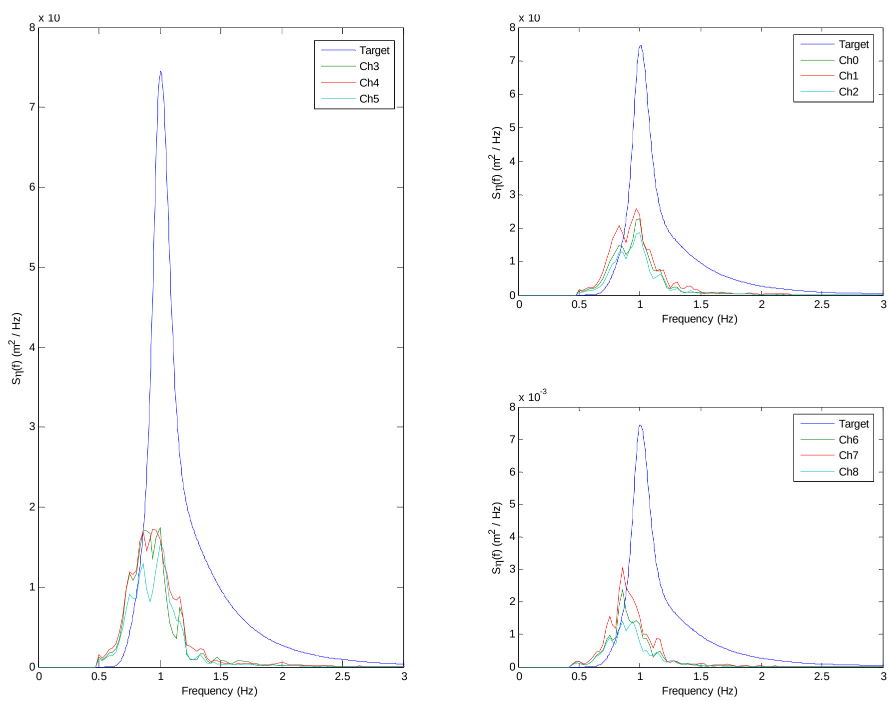

Figure E- 40: Test 25, TMA, h = 0.5 m, H = 0.2 m, T = 1.0 sec

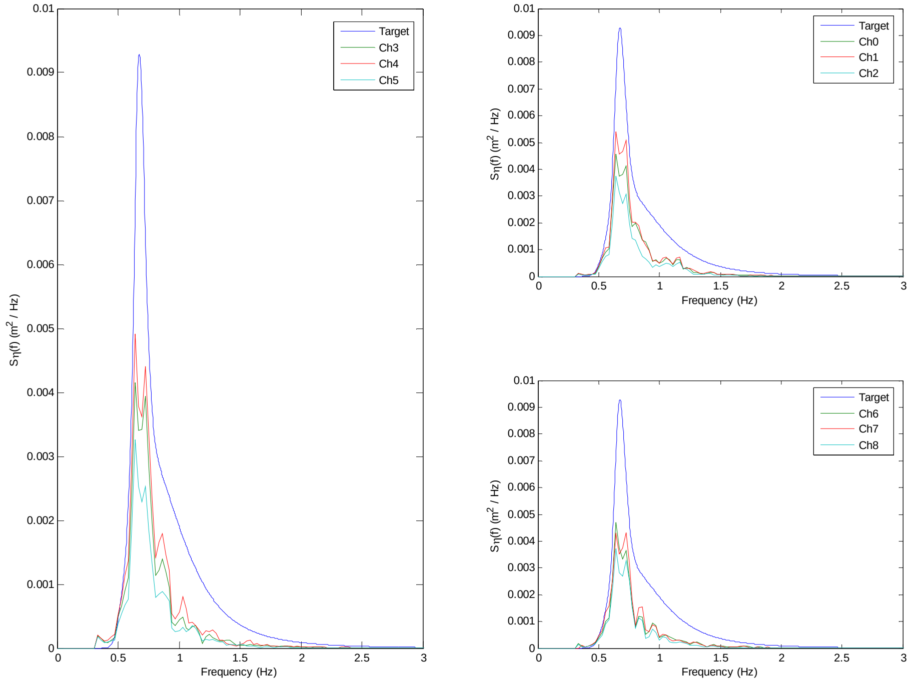

Figure E- 41: Test 26, TMA, h = 0.5 m, H = 0.2 m, T = 1.5 sec

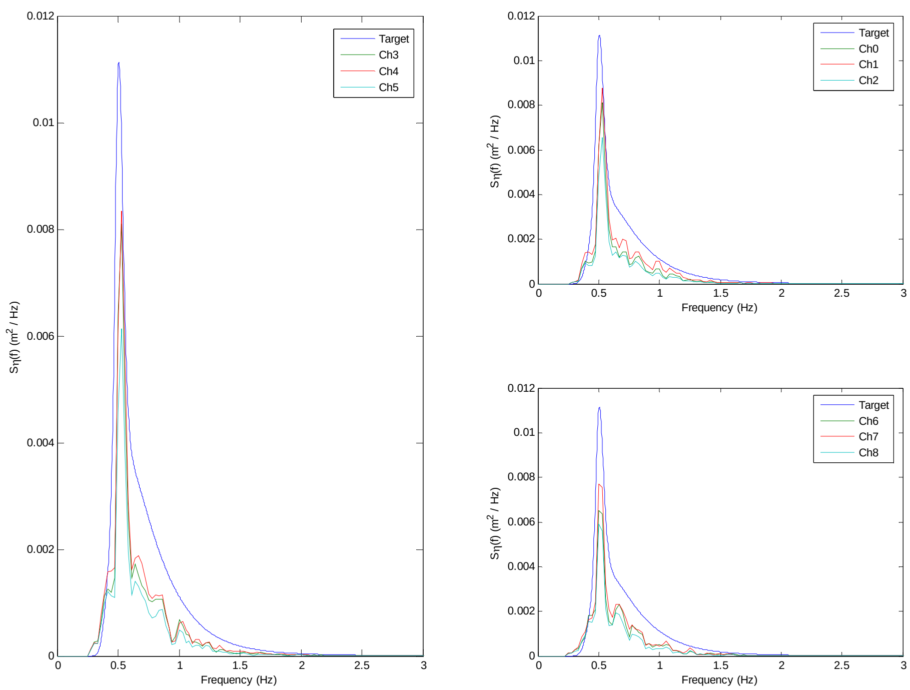

Figure E- 42: Test 27, TMA, h = 0.5 m, H = 0.2 m, T = 2.0 sec

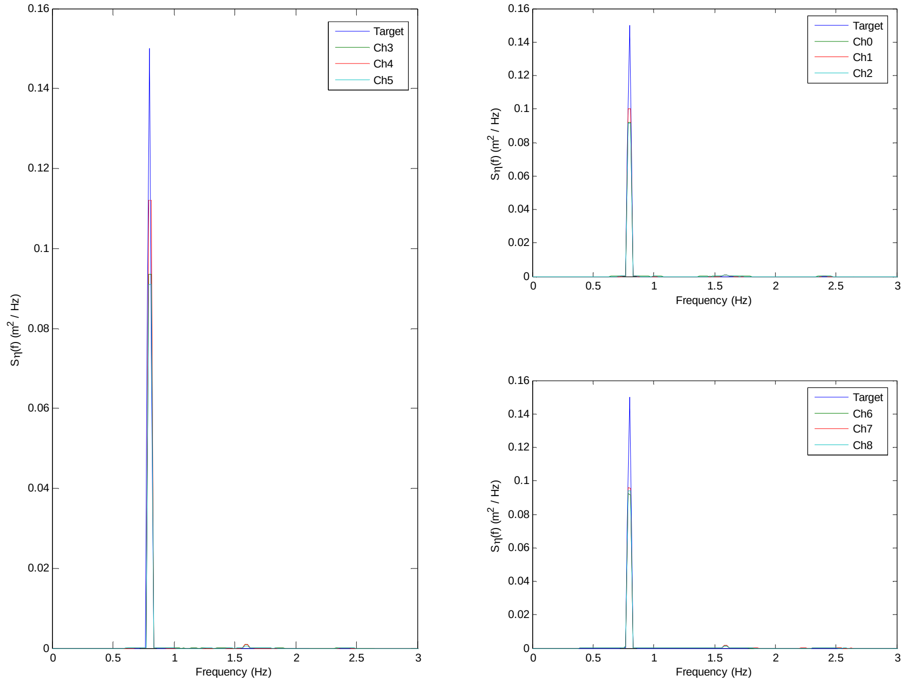

Figure E- 43: Test 31, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec

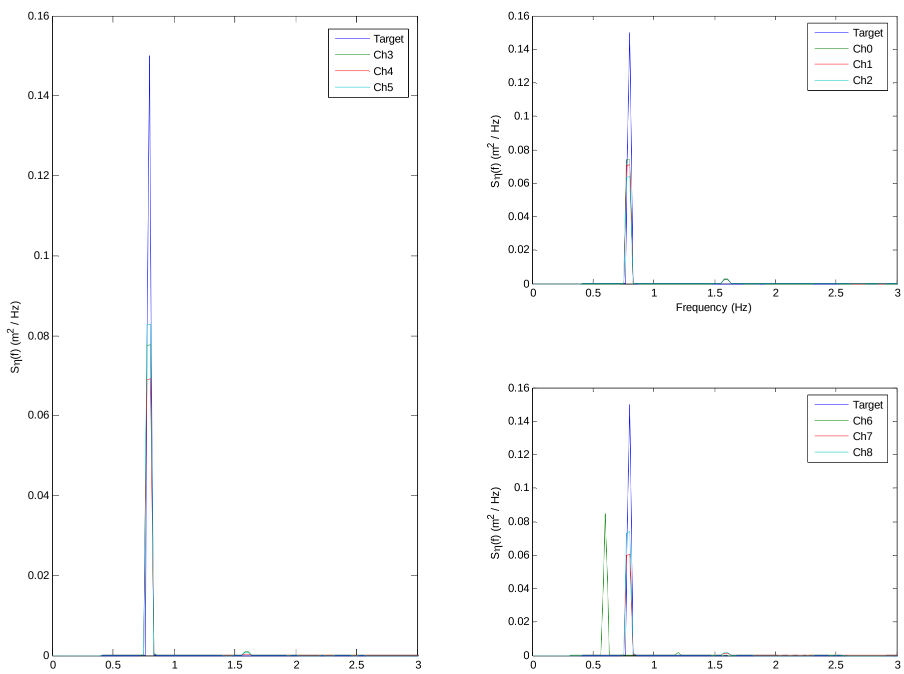

Figure E- 44: Test 31 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.25 sec

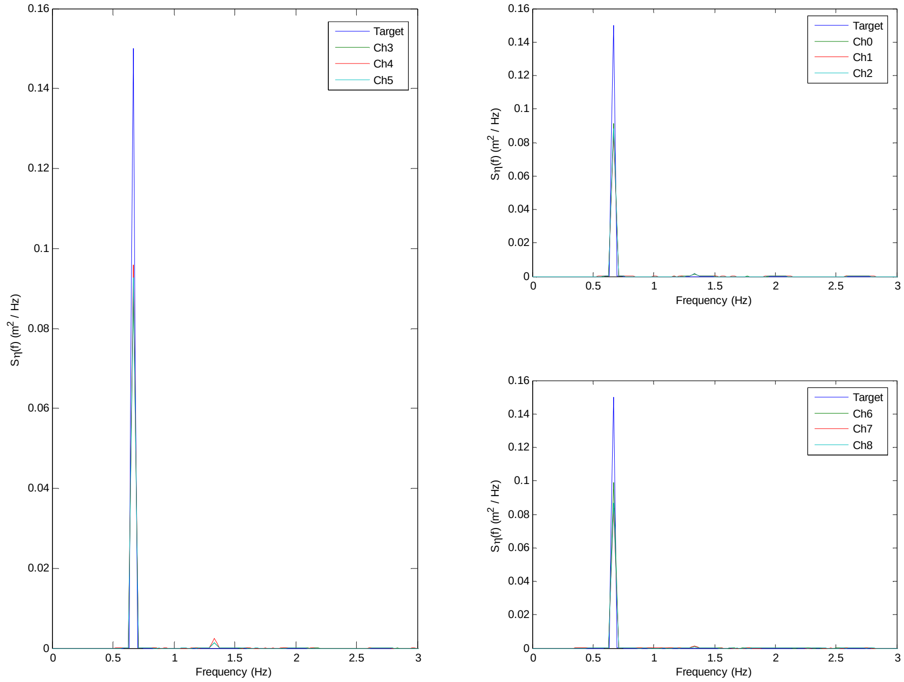

Figure E- 45: Test 32, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec

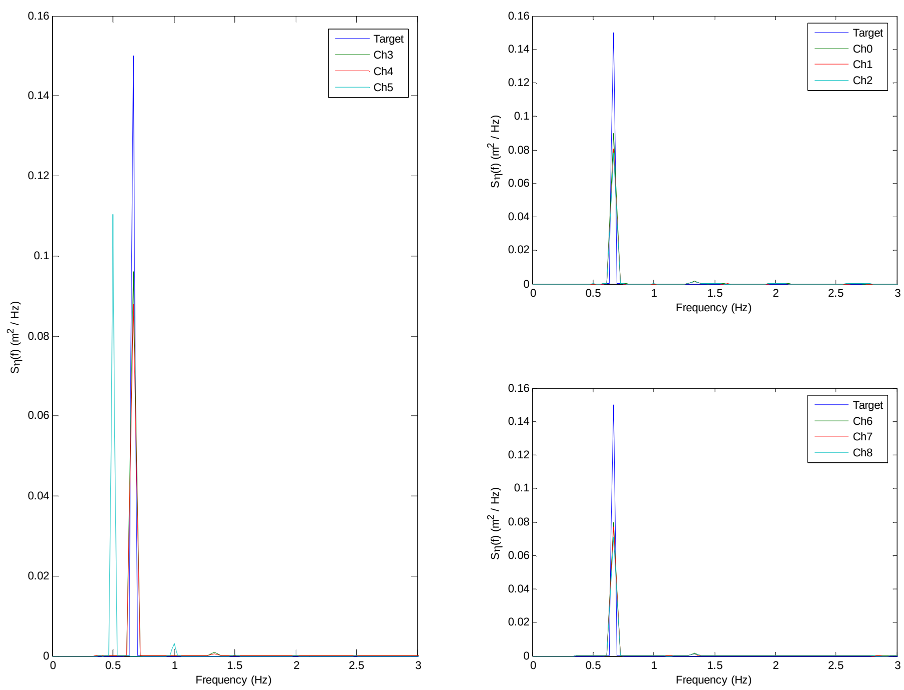

Figure E- 46: Test 32 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 1.5 sec

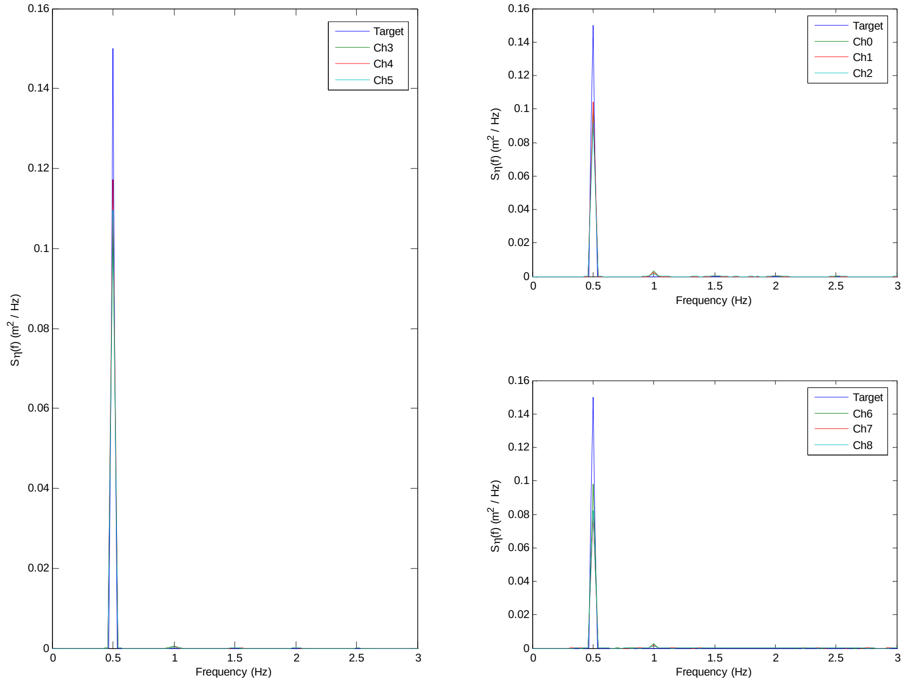

Figure E- 47: Test 33, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec

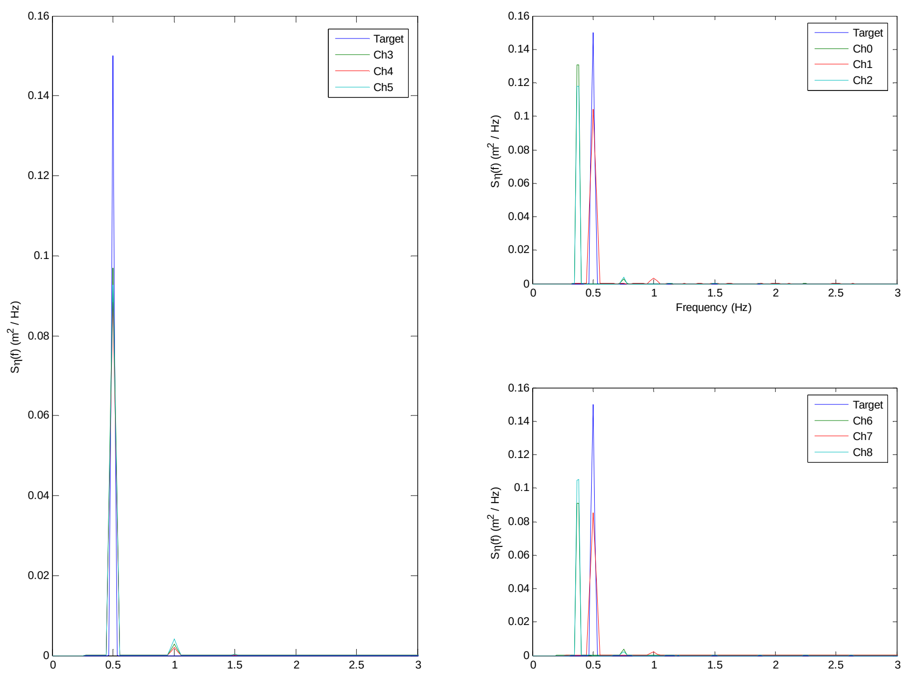

Figure E- 48: Test 33 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.0 sec

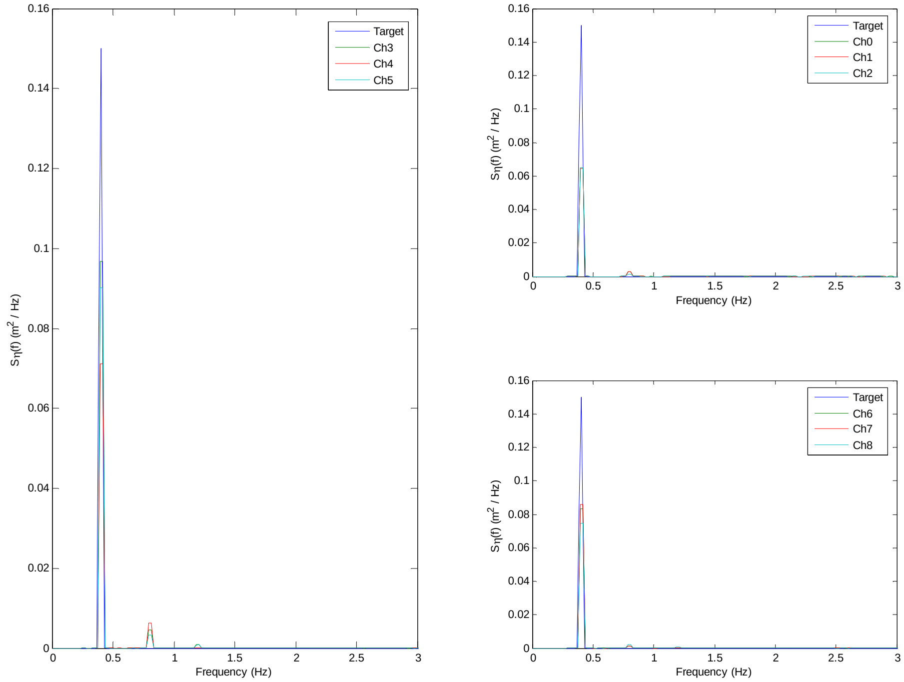

Figure E- 49: Test 34, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec

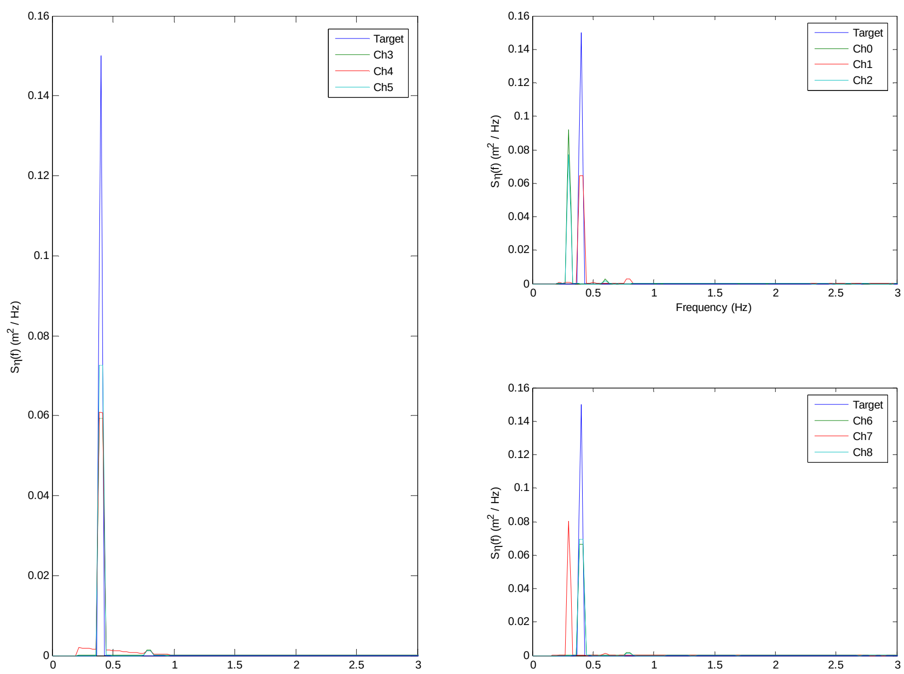

Figure E- 50: Test 34 with Buoys, Monochromatic, h = 1.0 m, H = 0.2 m, T = 2.5 sec

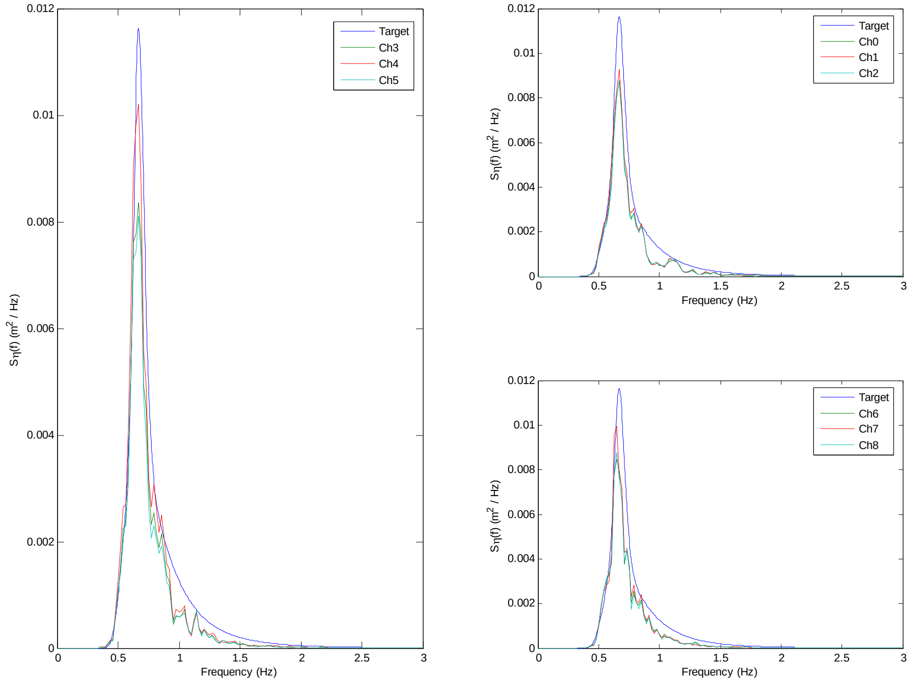

Figure E- 51: Test 35, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec

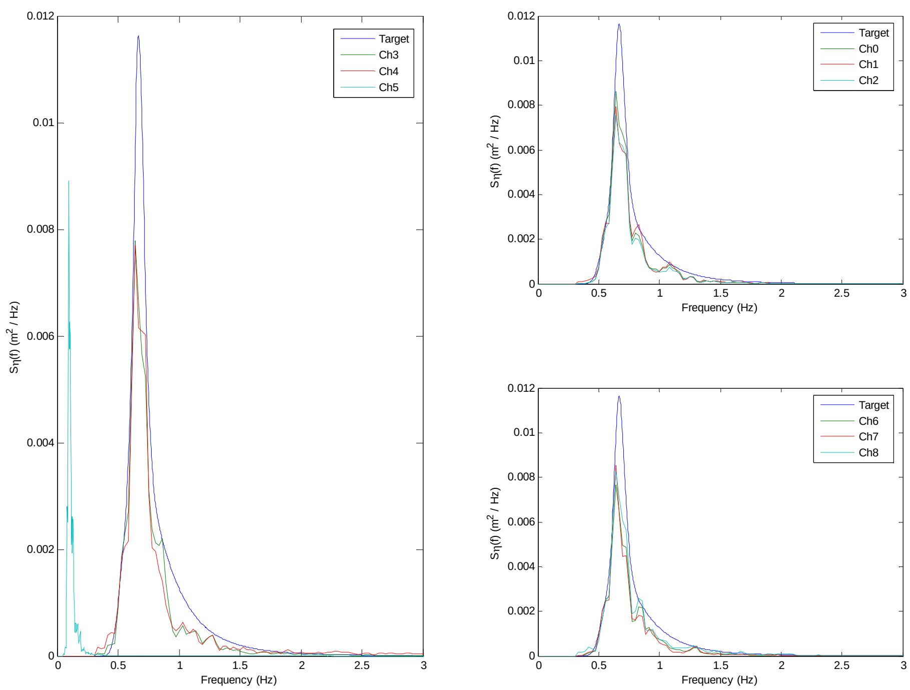

Figure E- 52: Test 35 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 1.5 sec

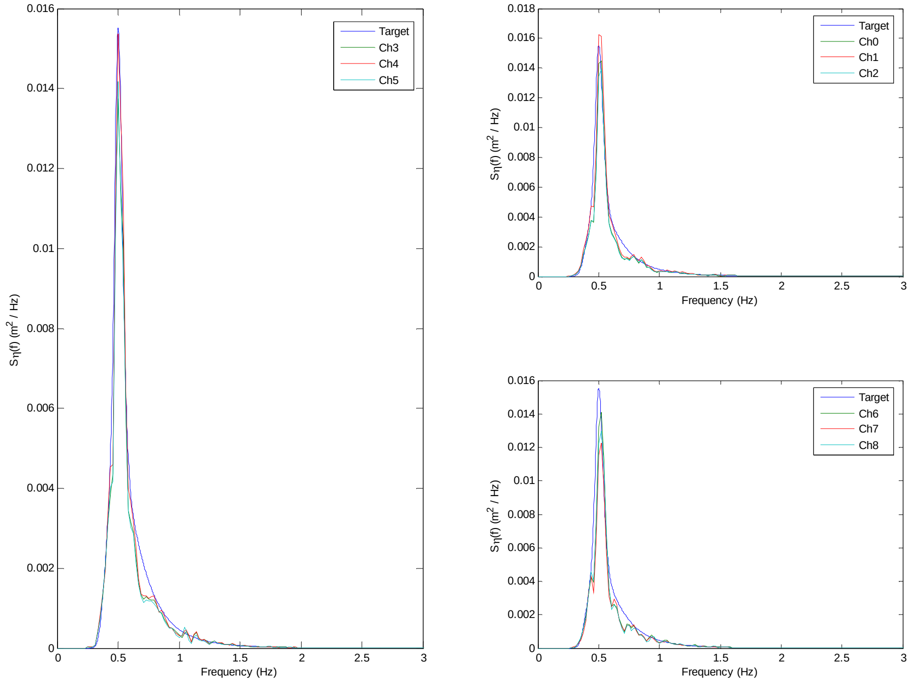

Figure E- 53: Test 36, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec

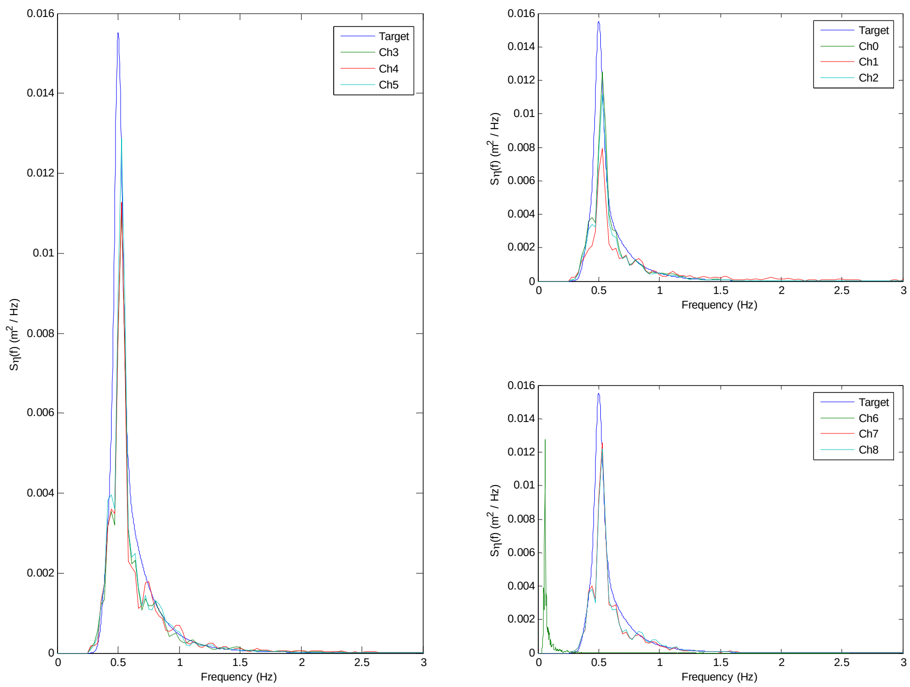

Figure E- 54: Test 36 with Buoys, JONSWAP, h = 1.0 m, H = 0.2 m, T = 2.0 sec

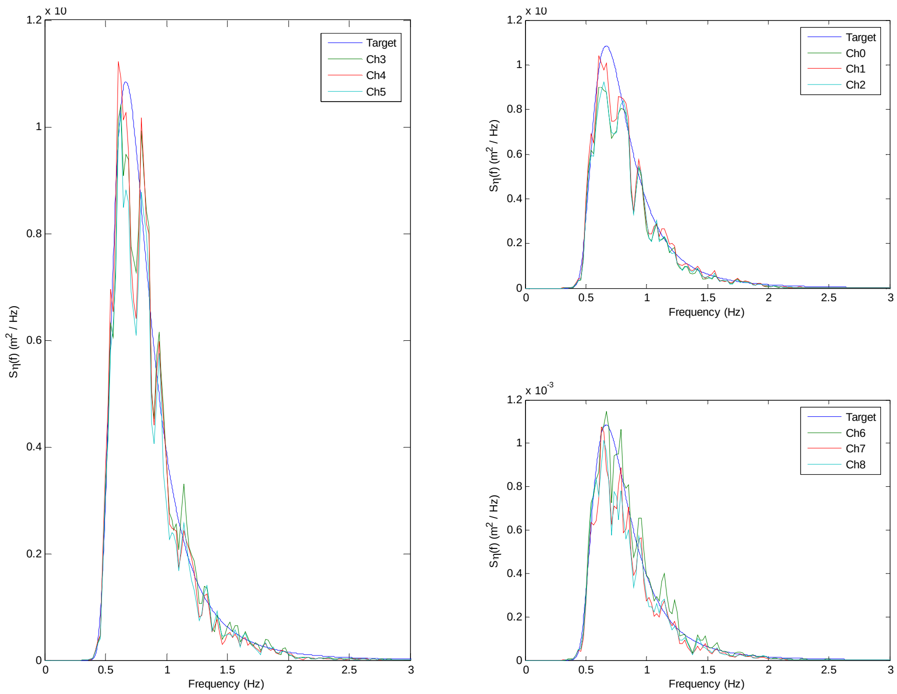

Figure E- 55: Test 37, PM, h = 1.0 m, T = 1.5 sec

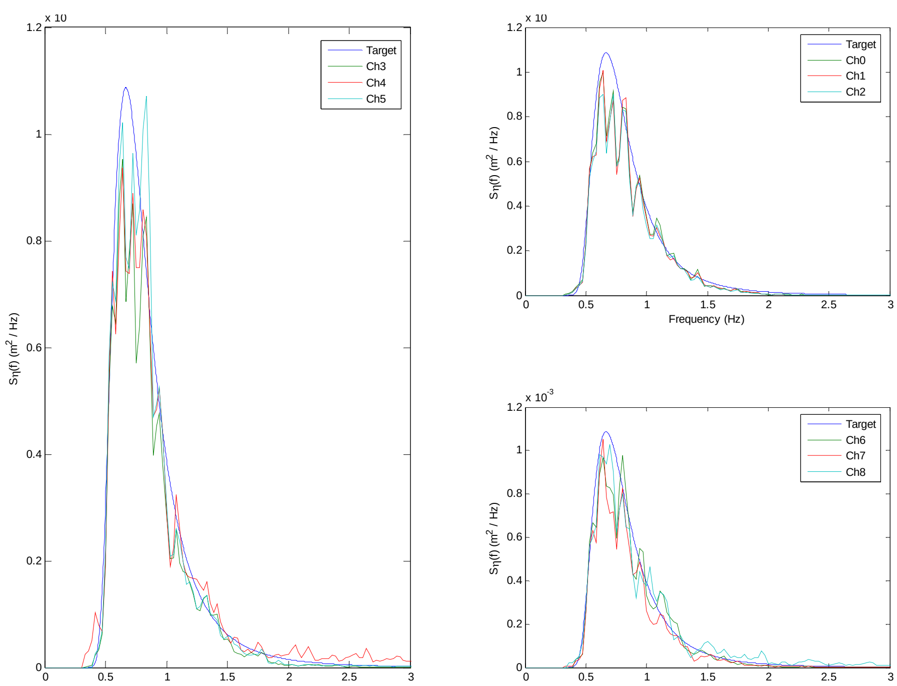

Figure E- 56: Test 37 with Buoys, PM, h = 1.0 m, T = 1.5 sec

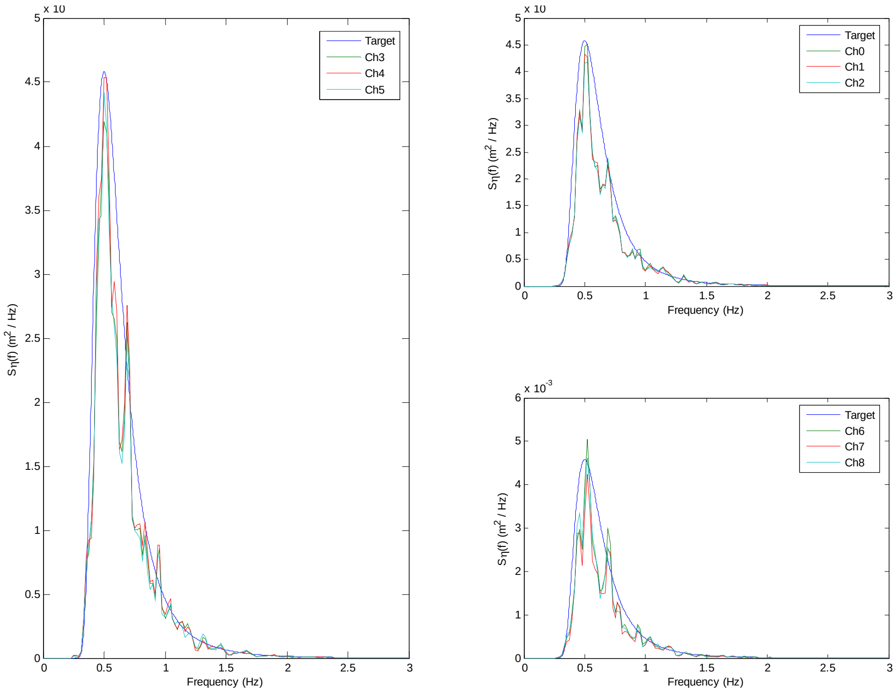

Figure E- 57: Test 38, PM, h = 1.0 m, T = 2.0 sec

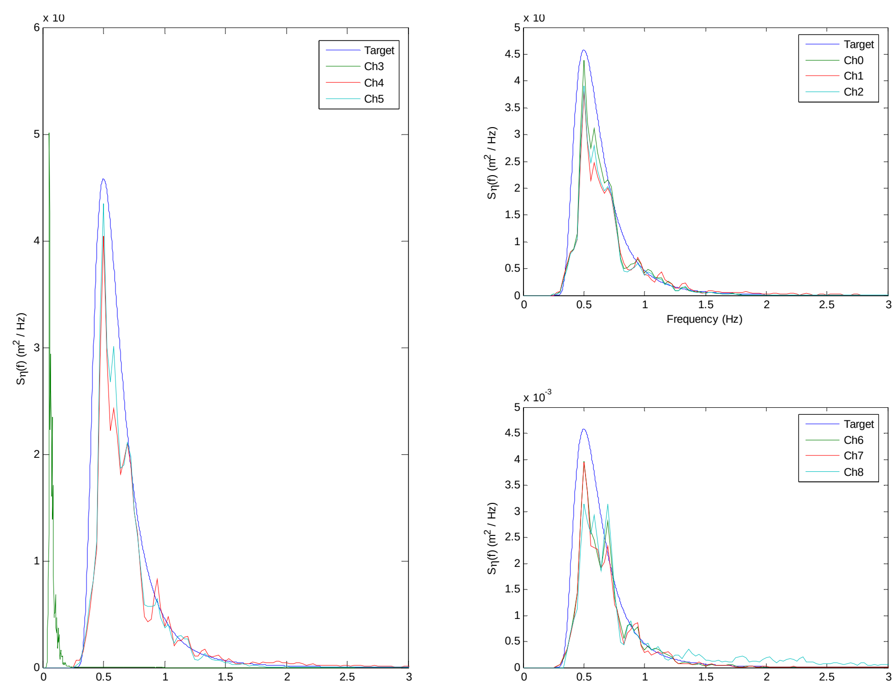

Figure E- 58: Test 38 with Buoys, PM, h = 1.0 m, T = 2.0 sec

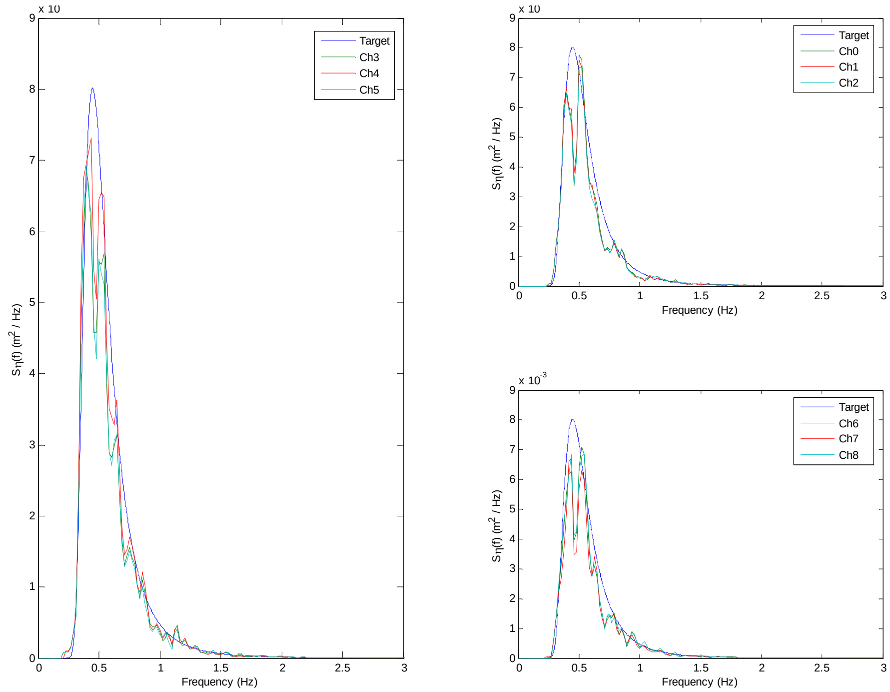

Figure E- 59: Test 39, PM-Hsig, h = 1.0 m, H = 0.2 m

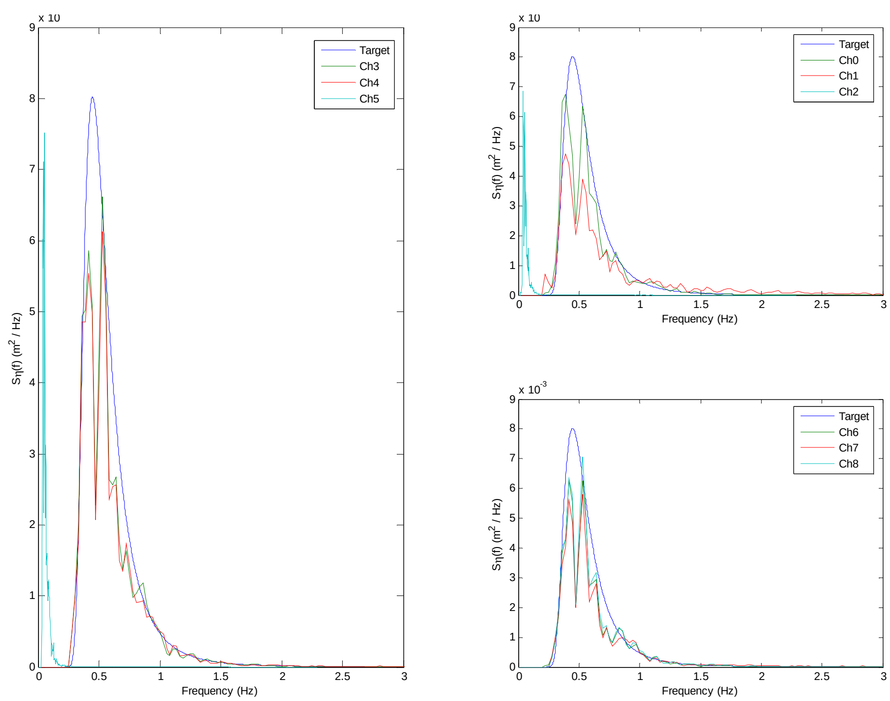

Figure E- 60: Test 39 with Buoys, PM-Hsig, h = 1.0 m, H = 0.2 m

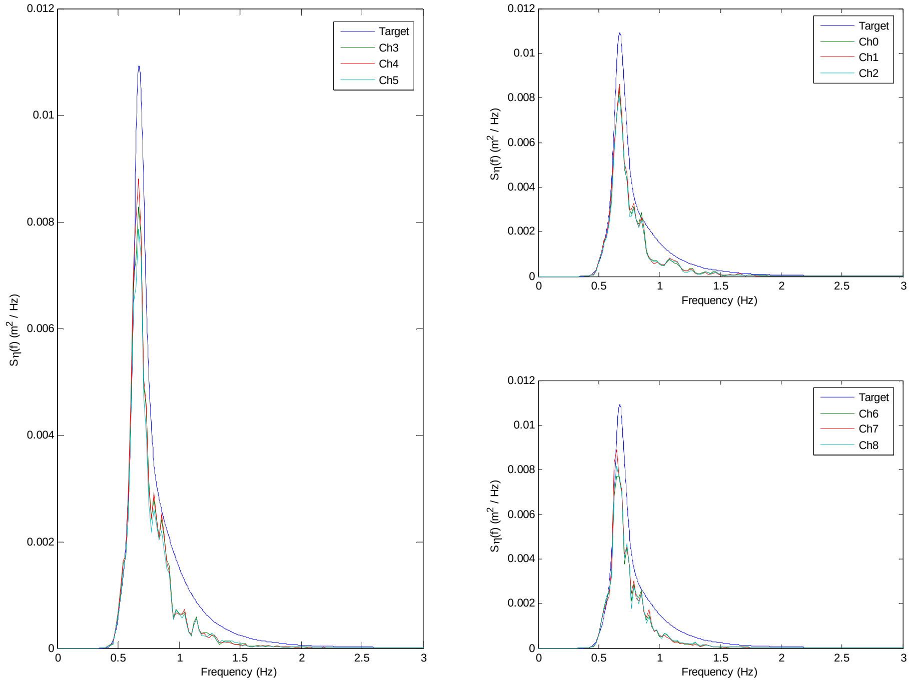

Figure E- 61: Test 40, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec

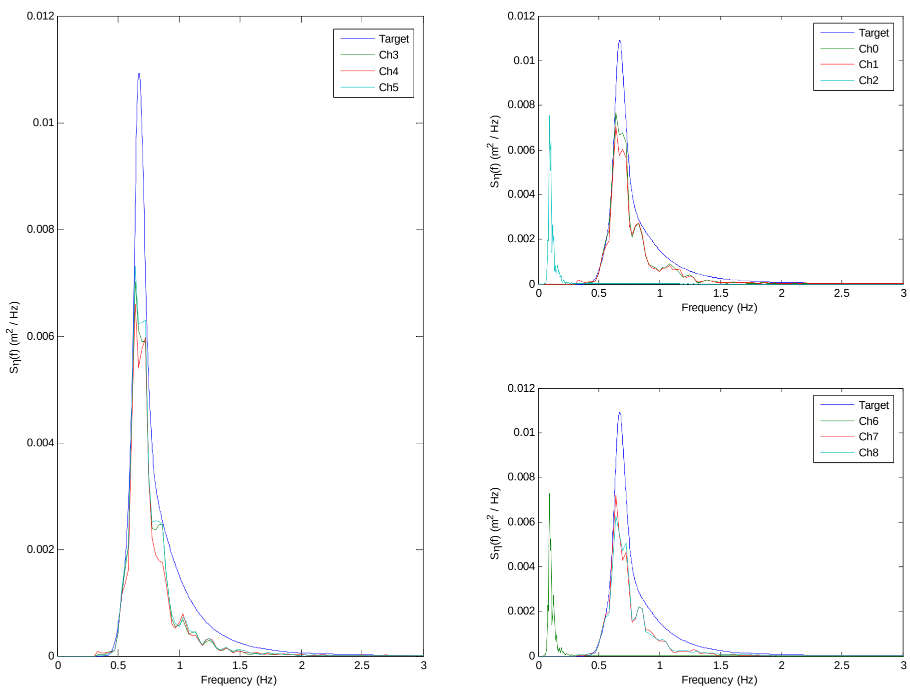

Figure E- 62: Test 40 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 1.5 sec

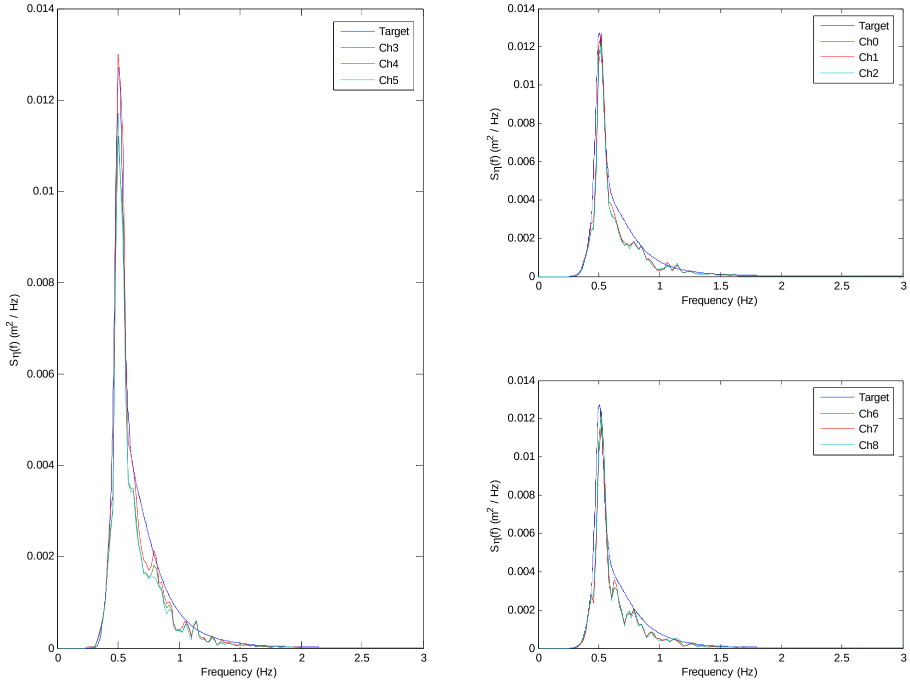

Figure E- 63: Test 41, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec

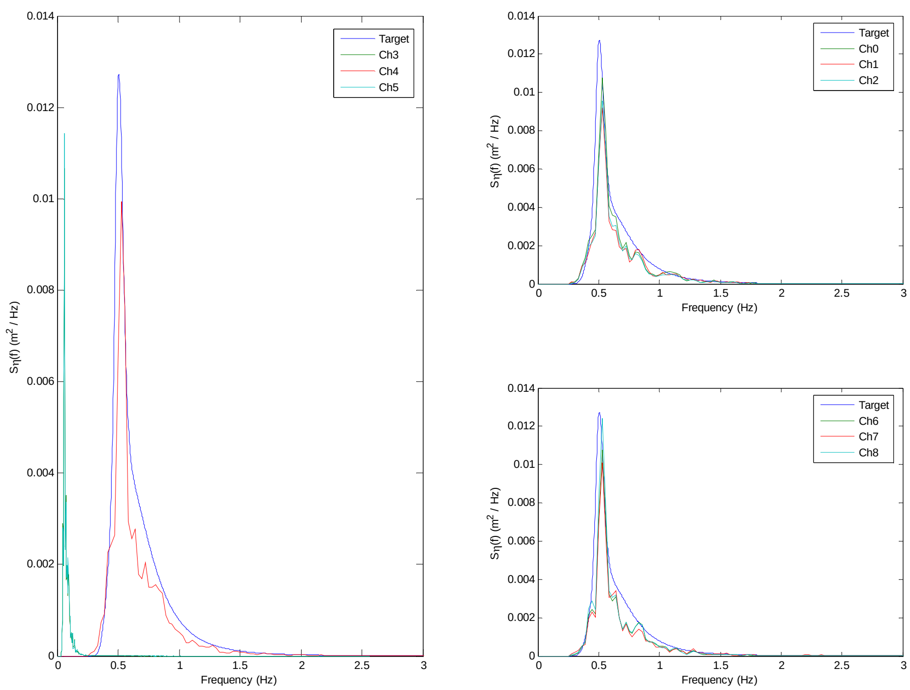

Figure E- 64: Test 41 with Buoys, TMA, h = 1.0 m, H = 0.2 m, T = 2.0 sec

VITA

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