AWP-24
Wave Height Gauge
Test Results

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Prepared by
Akamina Technologies Inc.

Revision History

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1. Introduction

A suite of tests were carried out to validate the performance of the AWP-24 under controlled conditions. The test suite included:

- calibration tests,
- background noise tests,
- short-term drift tests,
- long-term drift tests and
- interference tests.

This document describes the set up and results for these tests.

1.1. Test Set Up

The tests were carried out using two AWP-24 wave height gauges in a container of fresh water. The 20-cm wave probe heads were outfit with double-strung KSW 30-gauge wire. Both wave height gauges were mounted on the same support structure. Each wave height gauge was set up for the capacitance range of the wave probe head following the procedure outlined in the AWP-24 User's Guide.

The wave height gauges were powered from a common DC power supply. The output signals were connected to a National Instruments NI SUB-6221 data acquisition system. The first wave height gauge (WHG-1) was connected to analog input channel 0 and the second (WHG-2) was connected to analog input channel 1. Both analog input channels were configured for +/- 10 V, differential input voltage signals. The 16-bit resolution analog-to-digital converter resulted in each bit representing 0.305 mV. Wave height gauge WHG-1 was connected to the data acquisition system with a 1 m length of cable; wave height gauge WHG-2 was connected to the data acquisition system with a 60 m length of instrumentation cable. The cable connections were as described in section 4 of the User's Guide.

The data acquisition hardware has a maximum aggregate sampling rate of 200,000 samples per second or 100,000 samples per second for each of the two channels. The data acquisition software allowed data to be stored in an output file in csv format. The data were typically resampled at a lower rate before writing into the output file to keep the number of data points to less than the maximum of 64 k samples.

For all tests, both wave height gauges were in the same 30 cm diameter container of water. The tests were carried out in a room where the temperature fluctuated between 15 °C and 24 °C.

2. Tests

2.1. Calibration

Calibration of the wave height gauges involved acquiring a data set of known wave elevations (water depths) and voltages to compute the linear relationship between voltage and wave elevation. By collecting more than the minimum of two data points, we were able to compute the error between the measured calibration points and the best-fit straight line through the points.

2.1.1. Calibration Procedure

The following procedure was used to calibrate the wave height gauges:

1. Submerge the wave probe head in the water to the maximum height that is to be measured.
2. Acquire data for 10 seconds.
3. Record the mean output voltage and wave elevation.
4. Insert a shim of known length to raise the wave probe head out of the water by the length of the shim.

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5. Repeat steps 2 through 4 recording a number of data pairs that span from the maximum to the minimum wave elevation.
6. Compute the best-fit straight line through the data points and compute the error for each point. The error is the difference between the measured wave elevation and the wave elevation predicted using the best-fit straight line and the voltage measured during calibration. The errors are typically presented as a percent of the range of the calibration.

The results for the calibration of the two 20-cm wave height gauges are shown in Table 2-1 below.

	Gauge WHG-1				Gauge WHG-2			
Elev (cm)	Voltage (V)	Best Fit (cm)	Error (cm)	Error (% of range)	Voltage (V)	Best Fit (cm)	Error (cm)	Error (% of range)
0.0	4.449	-0.055	0.055	0.28%	4.537	0.025	0.025	0.12%
-2.5	3.381	-2.504	0.004	0.02%	3.483	-2.485	0.015	0.08%
-5.0	2.311	-4.960	0.040	0.20%	2.428	-4.994	0.006	0.03%
-7.5	1.215	-7.473	0.027	0.13%	1.364	-7.527	0.027	0.13%
-10.0	0.121	-9.982	0.018	0.09%	0.307	-10.042	0.042	0.21%
-12.5	-0.971	-12.486	0.014	0.07%	-0.728	-12.506	0.006	0.03%
-15.0	-2.065	-14.994	0.006	0.03%	-1.780	-15.010	0.010	0.05%
-17.5	-3.171	-17.532	0.032	0.16%	-2.826	-17.497	0.003	0.01%
-20.0	-4.253	-20.013	0.013	0.06%	-3.862	-19.963	0.037	0.19%

Table 2-1: 20-cm Probe Calibration Results

A client calibrated a series of 10 AWP-24 wave height gauges over a range of -0.5 m to +0.5 m. The results passed on to us showed that all 10 gauges calibrated extremely well. Seven of the ten gauges had a maximum error of 0.05% or less and the other three gauges had a maximum error of between 0.10% and 0.12%. These calibrations suggest that the measurement error for 7 of the ten gauges should be less than 0.5 mm over a 1 m range while the measurement error for the other 3 gauges should be less than 1.2 mm over a 1 m range.

The calibration data for the wave height gauge with the smallest calibration error and for the wave height gauge with the largest calibration error are shown in Table 2-2 below.

	Gauge with lowest % error				Gauge with highest % error			
Elev (m)	Voltage (V)	Best Fit (m)	Error (m)	Error (% of range)	Voltage (V)	Best Fit (m)	Error (m)	Error (% of range)
-0.50	-4.496	-0.4998	-0.0002	-0.02%	-4.441	-0.5002	0.0002	0.02%
-0.40	-3.605	-0.4003	0.0003	0.03%	-3.585	-0.4010	0.0010	0.10%
-0.30	-2.707	-0.3000	0.0000	0.00%	-2.712	-0.2997	-0.0003	-0.03%
-0.20	-1.813	-0.2001	0.0001	0.01%	-1.850	-0.1998	-0.0002	-0.02%
-0.10	-0.917	-0.1001	0.0001	0.01%	-0.987	-0.0997	-0.0003	-0.03%
0.00	-0.020	0.0001	-0.0001	-0.01%	-0.126	0.0002	-0.0002	-0.02%
0.10	0.875	0.1001	-0.0001	-0.01%	0.742	0.1008	-0.0008	-0.08%
0.20	1.772	0.2003	-0.0003	-0.03%	1.598	0.2001	-0.0001	-0.01%
0.30	2.664	0.2999	0.0001	0.01%	2.463	0.3004	-0.0004	-0.04%
0.40	3.562	0.4002	-0.0002	-0.02%	3.322	0.4000	0.0000	0.00%
0.50	4.453	0.4997	0.0003	0.03%	4.174	0.4988	0.0012	0.12%

Table 2-2: 1-m Probe Calibration Results

The maximum error measured during the calibration of the 20-cm probes was 0.55 mm or 0.28% of the 20-cm range. This was nearly identical to the maximum absolute error that was measured during the calibration of the 1-m probe. Sub-millimetre errors can be caused by meniscus effects that change the effective length of the wire under water. These effects can be reduced by decreasing the diameter of the wire. Other sources of error include non-linearities caused by variations in the thickness of the dielectric material on the wave probe head wire and errors due to the calibration process itself.

The calibration data show that the relationship between wave elevation and output voltage is highly linear. Sub-millimetre accuracy is possible even for longer wave probe lengths.

2.2. Background Noise Test

This series of tests involved obtaining a 1-second sample of data and computing the difference between the minimum and the maximum of the sample (delta) as well as the standard deviation (stdev) of the sample. We completed this test on the wave height gauge attached to a 1 m length of instrumentation cable as well as on the wave height gauge attached to a 60 m length of instrumentation cable. This provided a view of the gauge noise as well as the effect of cable length on noise.

The noise measurements are summarized in Table 2-3 and are shown in Figure 2-1.

Wave Height Gauge	*1 m Cable Length*		*60 m Cable Length*	
	Delta (mV)	*Stdev (mV)*	*Delta (mV)*	*Stdev (mV)*
WHG-1	1.94	0.26	6.82	0.87
WHG-2	2.61	0.29	6.17	0.87

Table 2-3: Noise Measurements

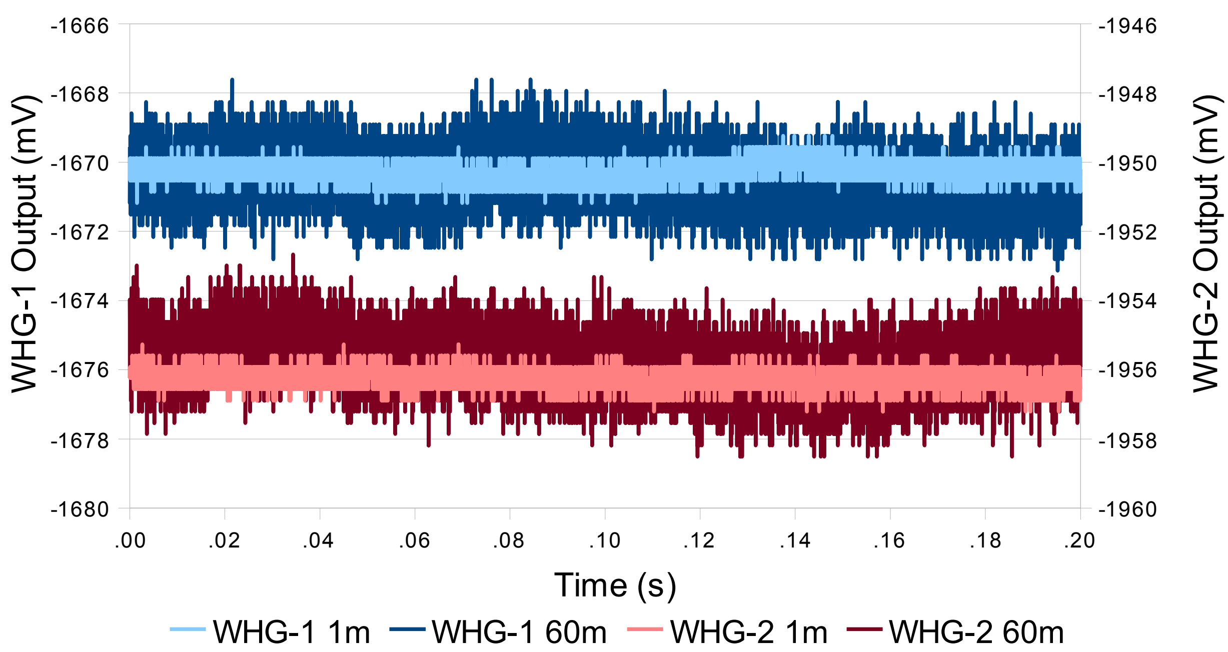

Figure 2-1: Wave Height Gauge Noise Measurements

The figures and data indicate that noise increases with cable length. The noise, however, is acceptable even for the longer cables where the noise range represents less than 7 parts in 9000 or 0.08% of the output range.

2.3. Short-Term Drift Test

This test involved placing a wave height gauge in very still water and acquiring a data sample for a period of 1 hour. As long as temperature remains constant during the test, the measured wave height should also be constant over the hour.

The results of the 1-hour sample are shown in the Figure 2-2 and Figure 2-3 below. Wave height gauge 1 (shown in blue in the figures) and wave height gauge 2 (shown in orange in the figures) both exhibit extremely low drift of approximately 0.01 cm (0.04 % of the range of the probe). The higher noise present in the data from wave height gauge 2 is the result of the 60 m of cable between the wave height gauge and the data acquisition system.

The elevation data shown Figure 2-2 is magnified 600 times over Figure 2-3 to show the drift and the noise in the signal. In Figure 2-3, the elevation range in the figure has been adjusted to the range over which the wave height gauge is intended to be used (+/- 10 cm). It is clear in Figure 2-3 that the noise and short-term drift become negligible when considering the range in which the wave height gauge is intended to measure.

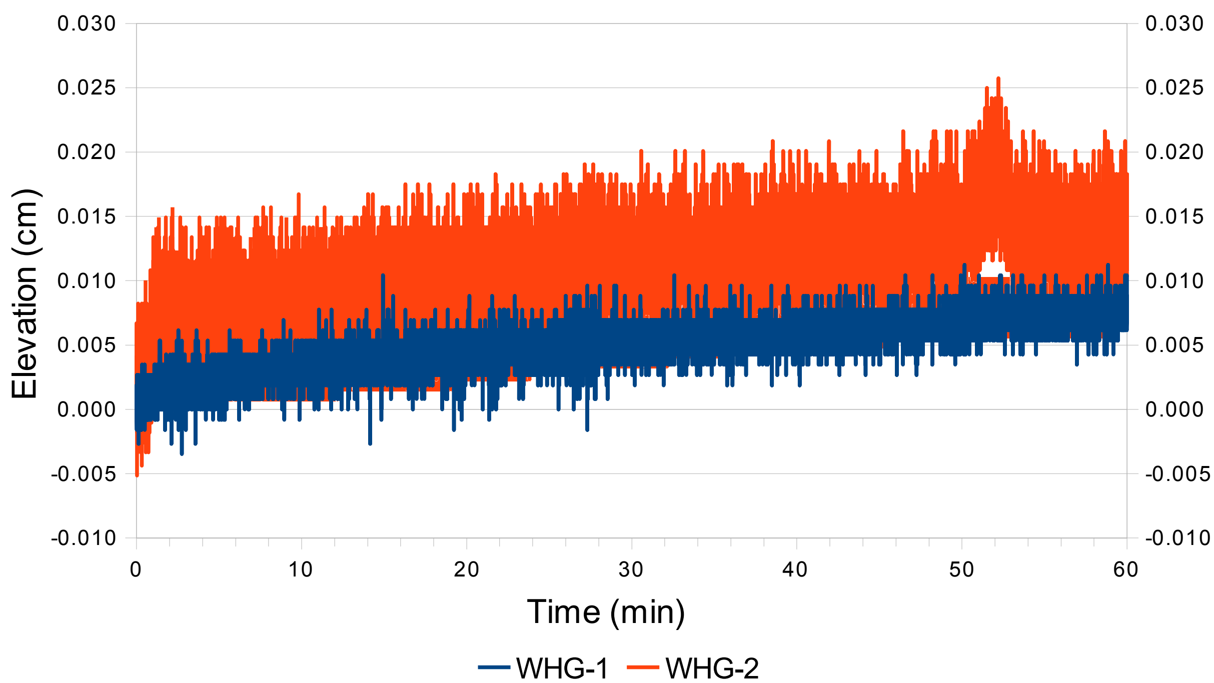

Figure 2-2: One Hour Drift Test (Detail – 600X Magnification)

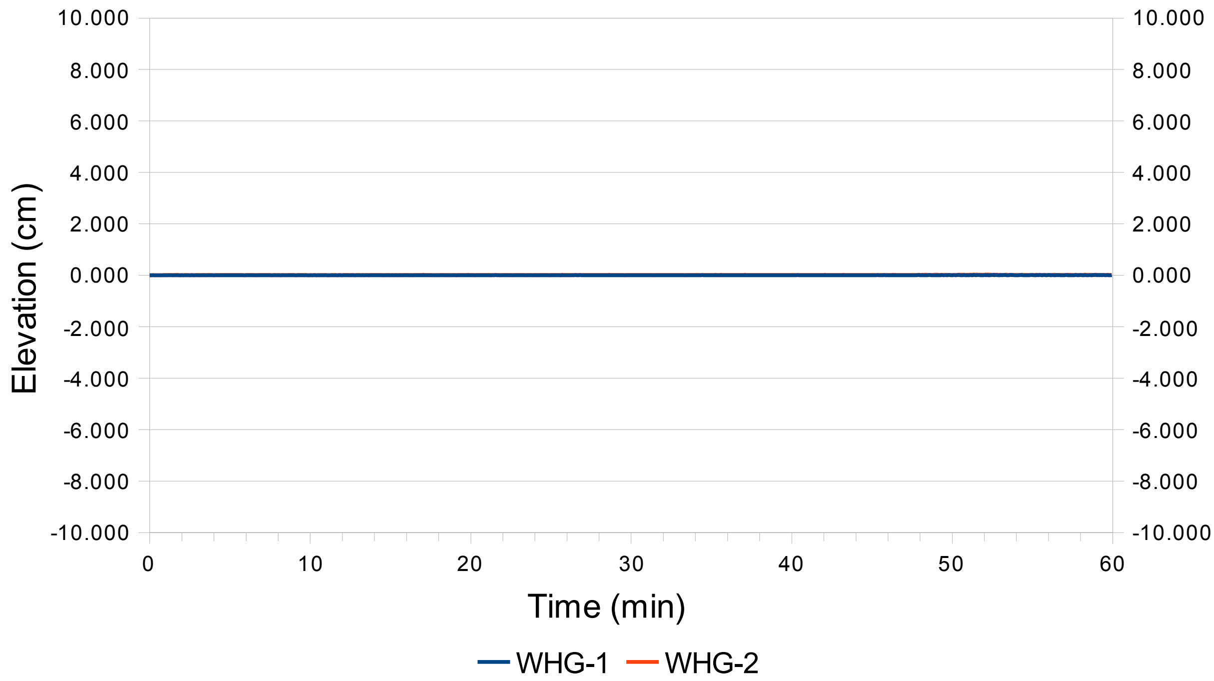

Figure 2-3: One Hour Drift Test (Full Scale)

2.4. Long-Term Drift Test

This test involved placing a wave height gauge in very still water and acquiring data for a 72-hour period. Since the temperature of the electronics varied with the room temperature during the test period, we expect to see a low frequency drift caused by temperature. Temperature was acquired at the same time as the wave elevation so that it was possible to look at the wave elevation change at the same time as temperature. The temperature measurement was made within the wave height gauge enclosure of unit WHG-2.

The post-processing of the acquired water elevation data included:

- set the starting elevation of the signal to 0.0 cm,
- removal of the 1st order trend of the signal to set the slope of the data to 0.0 and
- low-pass filtering using a first-order digital IIR filter with a corner frequency of 0.0001 Hz.

The removal of the 1st order trend eliminated the change in elevation due to the evaporation of water from the test container. The computed trend was 0.00476 cm/hr or 1.14 mm/day. An independent measure of the overall change in water depth over the test period was approximately 3 mm which compares favourably with the computed slope of 1.14 mm/day.

The elevation and temperature curves are shown in Figure 2-4 below. The figure shows that elevation change over the test period was in the range of +/- 0.25 mm while the temperature variation was in the range of 16 to 24 °C.

There is some correlation between temperature change and elevation change. This suggests that it would be possible to remove some of the low-frequency variation in the elevation data by compensating the data for temperature related effects. The wave height gauge electronics PCB has been laid out to include a temperature measurement IC so that compensation for temperature is possible. A compensation algorithm has not yet been developed but given the processing power available within the device, active compensation of the measured elevation data would be possible to do in real time.

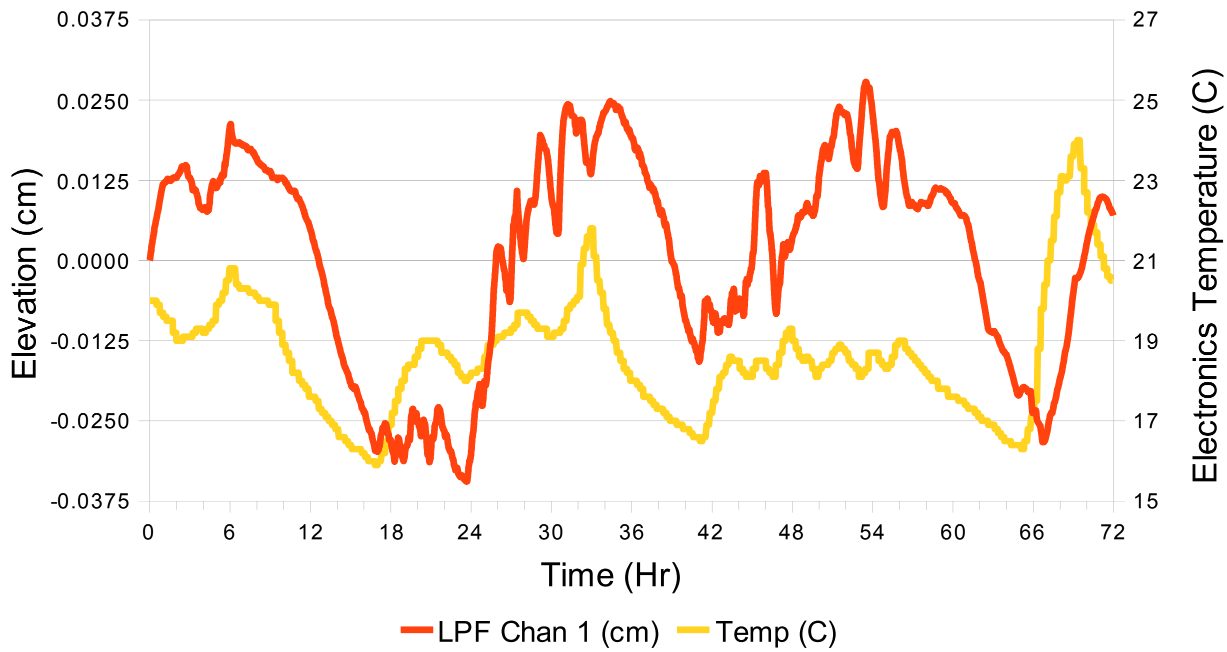

Figure 2-4: Long Term Drift Test

The long-term drift test demonstrates that there is very little drift in the output measurements. The test also shows that there is a correlation between temperature and drift suggesting that long-term drift could be reduced further if active temperature compensation were to be implement.

2.5. *Interference Test*

This test was carried out to investigate the amount of interference between adjacent wave height gauges. The test procedure involved placing one wave probe head in very still water and then raising and lowering a second probe head into the water in the immediate vicinity of the first probe. The change in output from the stationary probe is an indication of the amount of interference between the two wave height gauges. The interference includes both electrical interference as well as interference caused by disturbance of the water surface.

The results of the test are shown in Figure 2-5. The elevation measured by the moving probe head is shown on the left Y-axis and the elevation measured by stationary probe head is shown on the right Y-axis. Note that the Y-axis range for the stationary probe head is 100X the range for the moving probe head. This was done to make it possible to see some of the detail in the measurement from the stationary probe head. The results show that range of the measured elevation using the stationary wave probe was 0 to 0.05 cm while the range of the moving wave probe was 0 to 15 cm (approximately 300 times larger). The wave elevation measured using the stationary probe would have been influenced by the oscillations in the water caused by raising and lowering the moving wave probe head.

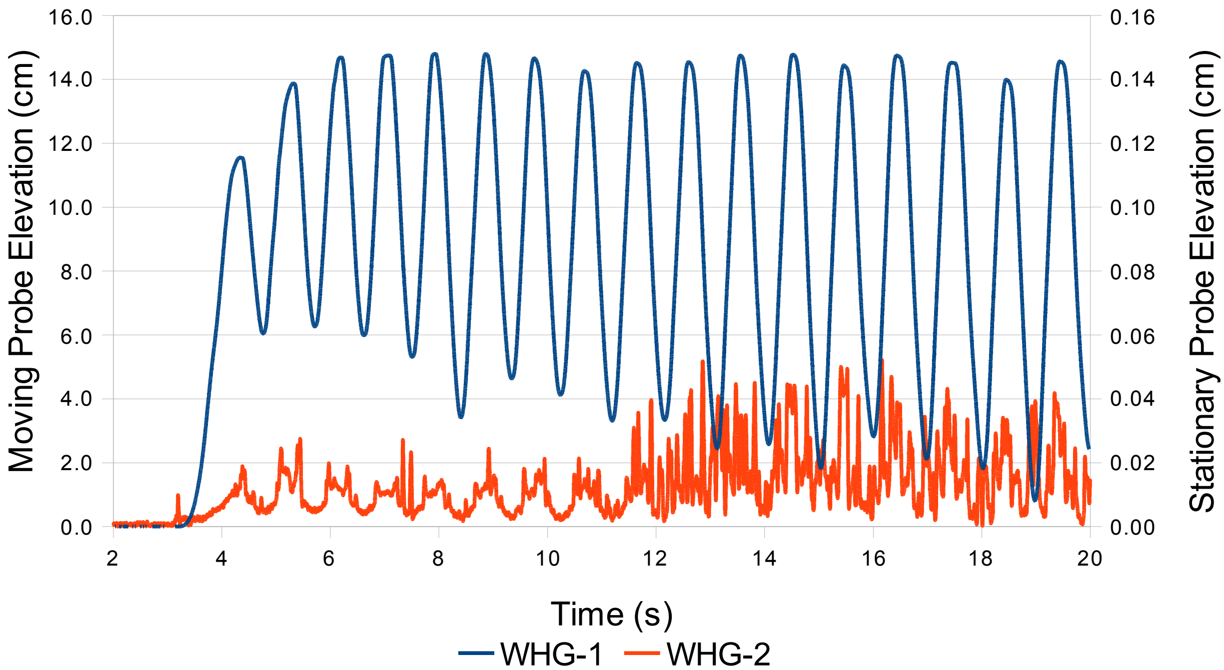

Figure 2-5: Interference Measurement

This test demonstrates that there is minimal electrical interference between adjacent probes.

2.6. Summary

The test series validated that the AWP-24 wave height gauge is an extremely linear, low-noise device with minimal interference between adjacent wave probe heads. Low-frequency drift in the output is also negligible and the change in output due to temperature is minimal over a range of 9 °C.