CHARACTERISATION OF A DIGITAL THIN LINE TOWED ARRAY – EXPERIMENTAL ASSESSMENT OF VIBRATION LEVELS AND TOW SHAPE

Venugopalan Pallayil[a], Sabu Sebastian Muttuthupara[b], Mandar A Chitre[a] , Kiran Govind V[b] and Naveen R Chandhavarkar[a]

[a]Acoustic Research Laboratory, Tropical Marine Science Institute, National University of Singapore, Singapore -119223
[b]Naval Physical and Oceanographic Laboratory, Defence Research and Development Organisation, Thrikkakkara, Cochin-682021

Venugopalan Pallayil, Acoustic Research Laboratory, Tropical Marine Science Institute, National University of Singapore, 12A Kent Ridge Road, Singapore-119223. Fax No. 68748325, email: venu@arl.nus.edu.sg

Abstract: *Development of light-weight and small diameter arrays has gained importance in recent years primarily because of their ability to operate from small and autonomous assets such as AUVs and USVs. Like conventional arrays these arrays are also subjected to platform vibrations, even though the levels could be small, which may tend to limit its acoustic performance. Similarly, knowledge of the hydrodynamic behaviour of the array, such as snaking of the array, is also important because such effects would result in undesirable performances during array beamforming and bearing estimation. Hence it is important to study these effects so that necessary compensations can be applied. For example, to suppress the vibration, suitable vibration isolation module can be built and if the array snakes, then it could be instrumented with suitable sensors for estimating the array shape. In this paper we describe an experimental approach to study the vibration levels experienced by a thin array under tow while simultaneously videoing the array for its hydrodynamic behaviour in a tow tank facility. The array was instrumented with three 3-axis accelerometers, one each at the array ends and one at the middle. The platform vibrations were monitored using another 3-axis accelerometer and the information was used to correlate the signals from the array accelerometers. Processing of data from the array accelerometer provided the information on how the disturbances were propagating along the array. The array was also equipped with acoustic 'super-elements' to measure the noise couple to the array at different tow speeds. The analysis of results showed that there is a low frequency component propagating along the array which increases with tow speed and decreases in amplitude from the tow end to the tail end for any given speed. It* *was also observed that different low frequency components at certain tow speeds were propagating as if in a dispersive medium. The video recording showed that the array was being towed with minimal snaking and the measured values of drag showed much lower values compared to the computed ones.*

Keywords: *Digital thin line array, towed array, vibration isolation, tow shape*

1. INTRODUCTION

Conventional towed arrays, which are hundreds of meters long and a few tens of mm in diameter, have been built to operate from ships and submarines for underwater sound detection and localisation of suspected objects. Autonomous Underwater Vehicles (AUVs) and Un-manned Surface Vehicles (USVs) are now being extensively used as underwater sensing platforms. There is a strong interest among the underwater research community to build scaled down versions of the conventional towed arrays so that they could be operated from autonomous assets such as AUVs and USVs [1-4]. The Acoustic Research Laboratory (ARL) under Tropical Marine Science Institute (TMSI) of National University of Singapore (NUS) has been engaged in building thin line towed arrays for the past 7 years and built the first proof of concept array in 2002 [5]. In 2007, ARL built the world's smallest Digital Thin Line Array (DTLA) and was tested in the field using an AUV similar to REMUS100 class. The array was 10.5mm in (external) diameter and 12m long with 20m of tow cable. The DTLA with its associated software programmes was able to detect and estimate the bearing of acoustic transmitters located a few hundreds of meters away from it while being towed by the AUV [6].

Even though the DTLA concept has been tested out and the array performed its basic functions, such as detection and estimation of bearing of a suspected underwater object, there was no information available on how the array performance was being impacted by the platform vibration. For example, there was no special Vibration Isolation Module (VIM) used in the above DTLA and whether VIM is necessary at all was a question that remained to be answered. Through a comparison of the heading sensor outputs in the array and the AUV, it was estimated that the array remained horizontal during the tow. However, the heading sensor in the array was located very near the tow end and hence the results could not verify whether the array was subjected to snaking towards the tail end.

In the following sections we describe the approach, instrumentation and experimental procedures employed to study the vibrational levels experienced by the DTLA when towed at different speeds. The results and conclusions based on the analysis of data from the experiments have also been given. A video recording of the array, while under tow, was also performed to see whether there is any appreciable snaking on the array.

2. DESCRIPTION OF DTLA INSTRUMENTATION

The DTLA employed for this experiment was very similar to the one that was used in our 2007 experiments. However to measure the vibration levels along the array, three 3-axis accelerometers were added. The accelerometers were placed with one each at the tow-end, tail-end and the third one at the centre of the array.

The objective was to measure how an induced vibration at the array tow point was propagating through the array as it was being towed at different speeds. The array measured about 12m in length and 10.5mm in external diameter. There were 11 acoustic sensors, but only three were acquiring the data and were mounted next to the accelerometers. This arrangement provided a direct measurement of the level of coupling of the vibrations to the acoustic sensors through a comparison of their signal output with those of the accelerometers next to it. The nine other acoustic sensors, even though were dummy, were still retained in the array so as to duplicate as faithfully as possible the original array and to ensure similar weight distribution. The array configuration used is illustrated in figure 1.

The accelerometers used in the array were ADXL330, from Analog Devices. With no external capacitors connected to their output, these accelerometers have a frequency response of 1200 Hz along the X & Y axis and 600Hz along the Z-axis. The accelerometer can sense typically a full scale range of ± 3g accelerations and has a sensitivity of 300 mV/g. The unit can be used both for static (tilt) and dynamic applications. The accelerometers were aligned inside the array in such a way that their Y-axes were along the length of the array. The acoustic sensor used in the array was named as a 'super-element' and was formed by connecting six EDO micro-linear sensing elements in series. Each sensing element had a sensitivity of ~ -217 dB re 1V/µPa. The six elements connected in series provided ~ 15dB array gain and thus the overall sensitivity of the super-element was -202 dB re 1V/µPa. A preamplifier with ~60 dB gain provided a final sensitivity of -142 dB 1V/µPa per super-element.

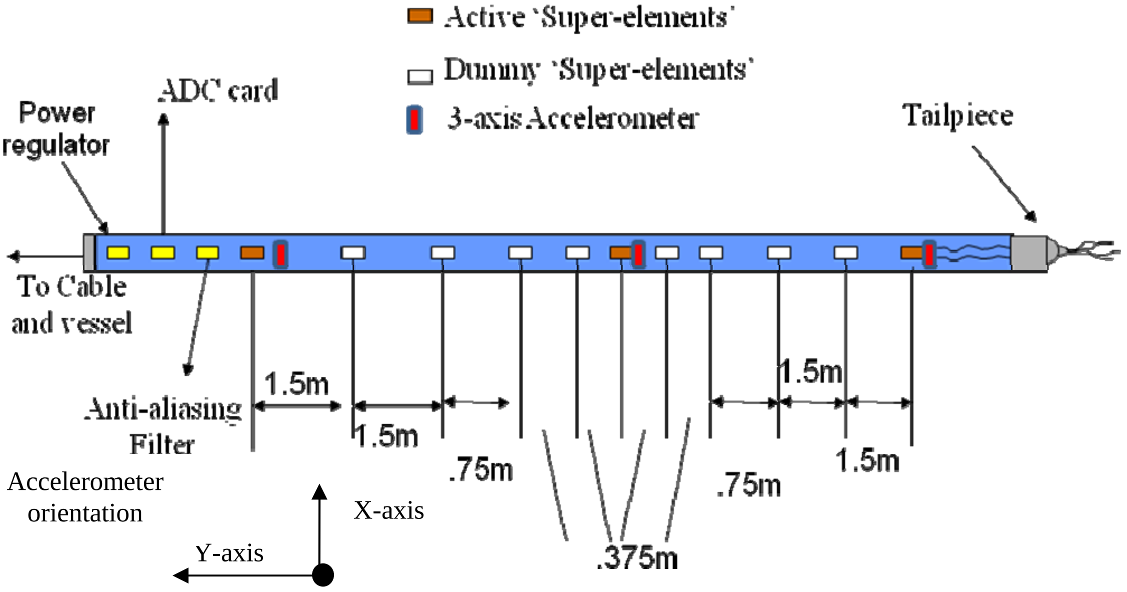

Fig. 1: Sketch of the array showing the layout of sensors and electronics

3. EXPERIMENTAL SET UP AND PROCEDURES

The experimental set up employed is shown in figure 2. The experiment was performed in a high speed tow-tank facility which was about 500 m long, 8 m wide and 8 m deep.

The array was attached to a tow post which was then towed using a tow-carriage. A 3-axis reference accelerometer, with a sensitivity of 100 mV/g, was attached to the tow post near the cable termination to measure the vibration levels induced at the cable end of the array. Figure 3 shows a snapshot of the array with carriage about to be towed. A Nexus preamplifier was used to amplify the signals from the reference tri-axial accelerometer and the data were recorded on to a PC using National Instruments NI6115 four channel data acquisition system. The receiver system for the DTLA was custom built using a STR-912 micro-controller. The SPI interface over 20 m of tow cable between the array and the receiver limited the clock frequency to a maximum of 2 MHz. Each array channel was sampled at 5 kHz rate and in this configuration there were 12 channels (9 accelerometer channels and 3 acoustic channels). Each channel was represented by 16 bits with the first four bits representing the channel ID followed by 12 bits of data. The data packets were sent over the Ethernet interface on to a laptop, where they were later converted to a text file to be processed using Matlab® software.

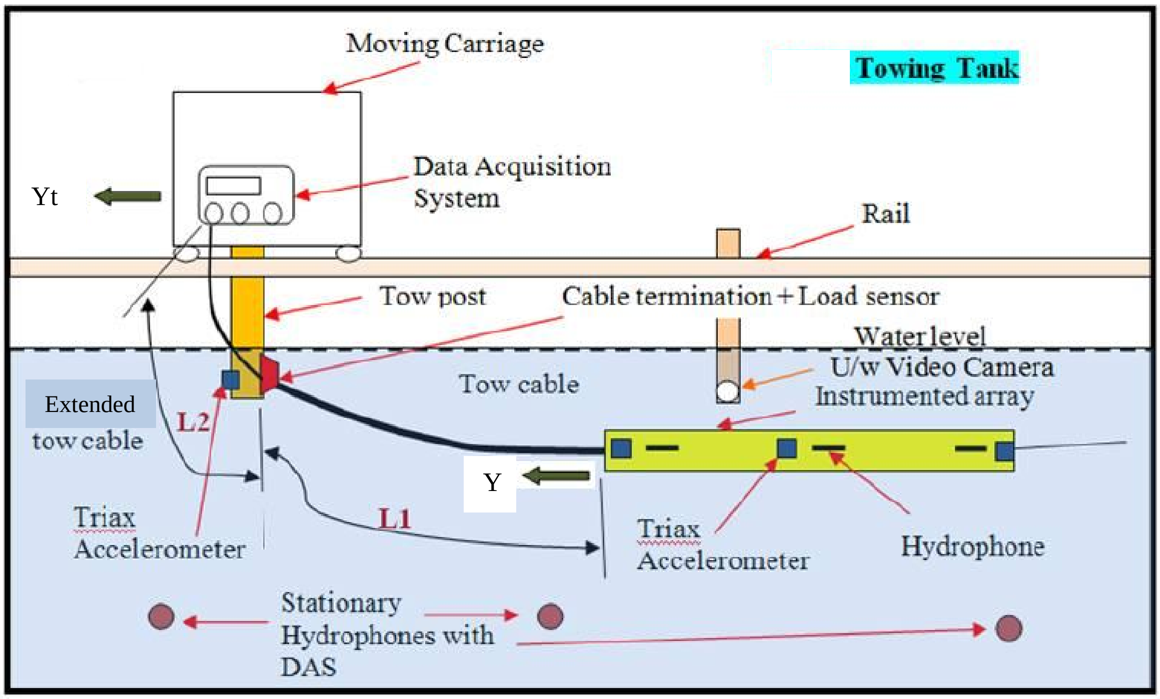

Fig. 2: *The test set up showing the various instrumentations and the array*

An underwater video-camera was positioned in such a way that it can capture the array dynamics during the tow. Later the video was played back to see whether the array was streamlined or was experiencing any snaking.

Experiments were conducted for various tow speeds from 2 to 10 knots in steps of 1 knot, even though most AUVs operate in the 4 to 5 knots speed regime. The drag on the array was also measured using a load cell attached to the tow cable near the termination point. Measurements were made after the platform and hence the array had attained a uniform velocity. Recordings were done only for the period when the array was in uniform motion.

4. DATA ANALYSIS AND RESULTS

The data from both the array accelerometers and the acoustic sensors were analysed and also compared with the data from the reference accelerometer for various tow speeds. The analysis was carried out to find out what components of vibrations were prominent and how do they change along the array and at different speeds.

The PSD of the accelerometer signals gave a measure of the frequency components of vibration experienced by the array and their relative amplitudes as they propagate along the array.

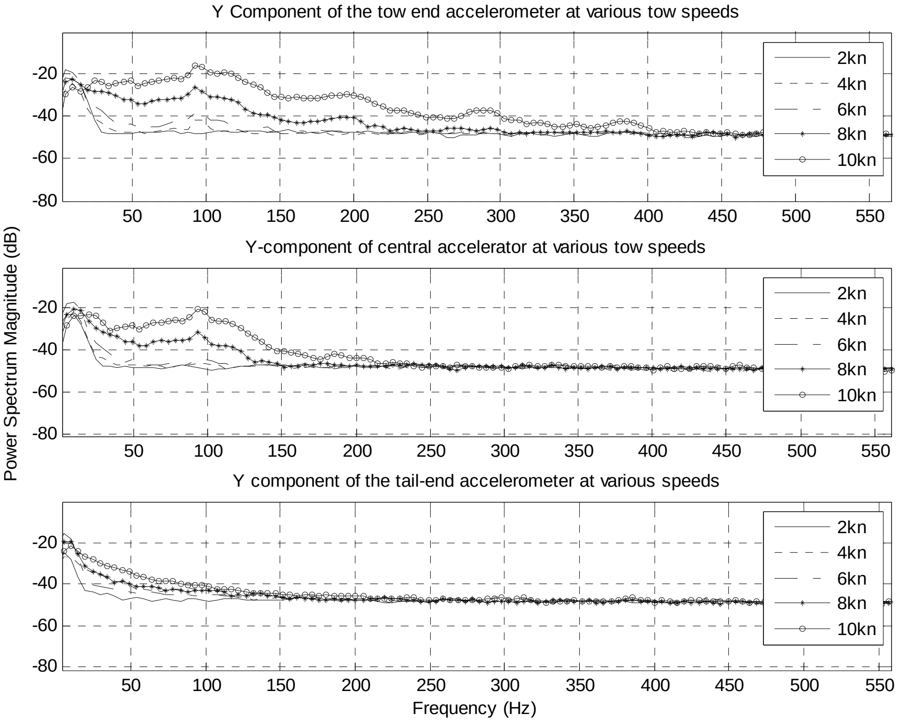

Figure 3 Variation in the PSD of the Y components of the array accelerometers for different tow speeds

Preliminary observations showed that the PSD of the Y component of the accelerometer varied more than the X and Z components for different tow speeds. To get a better understanding, the variation in the PSD of Y components alone of the accelerometers for different speeds were plotted and is shown in figure 3. The energy increase in the accelerometer Y-component with increasing tow speeds is evident from the above plots. The plots also shows that the energy levels decreased from the tow end to the tail end of the array indicating that the disturbances originated from a point closer to the tow end and it was damped as it moved down the array.

The cross correlation of the output of the array accelerometers indicated that the array has some resonance at a tow speed of 4&6 knots. The results of cross correlation of the y-component of the accelerometers for selected tow speeds are given in figure 4. The plot at 10 knots indicates that there are multiple frequencies propagating along the array.

To get a better understanding of the frequency components and the velocity with which they were propagating down the array, wave-number analysis was applied. The y-components of the three accelerometer outputs were summed after applying appropriate delays corresponding many different velocities of propagation. The PSD of the summed output was then plotted against the speed of propagation and for different tow speeds, and the results are shown in figure 5. The results showed that there are indeed some low frequency components propagating down the array with their speed increasing with increasing frequencies. The higher frequencies were found being attenuated at a faster rate compared to the low frequencies. The figure also shows that there is an increase in the velocity as the tow speed is increased this is consistent with our understanding that an increased tension would results in a higher velocity.

Efforts were made to see whether there is any correlation between the accelerometer reference data and the array accelerometer data. Even though a PSD plot of the signals

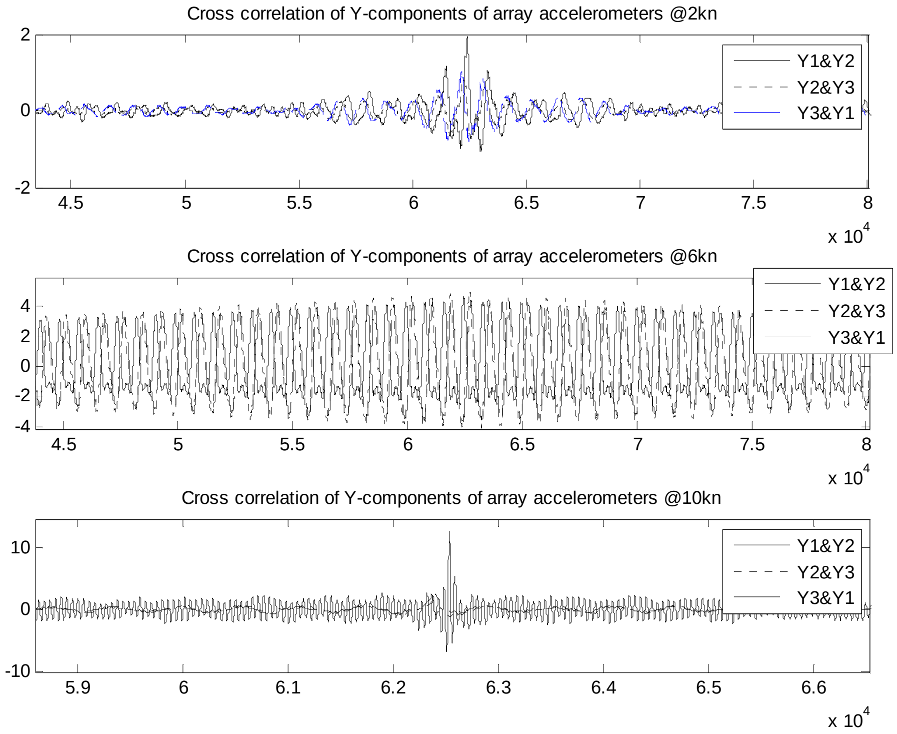

Figure 4 Cross correlation output of array accelerometer Y component at various tow speeds

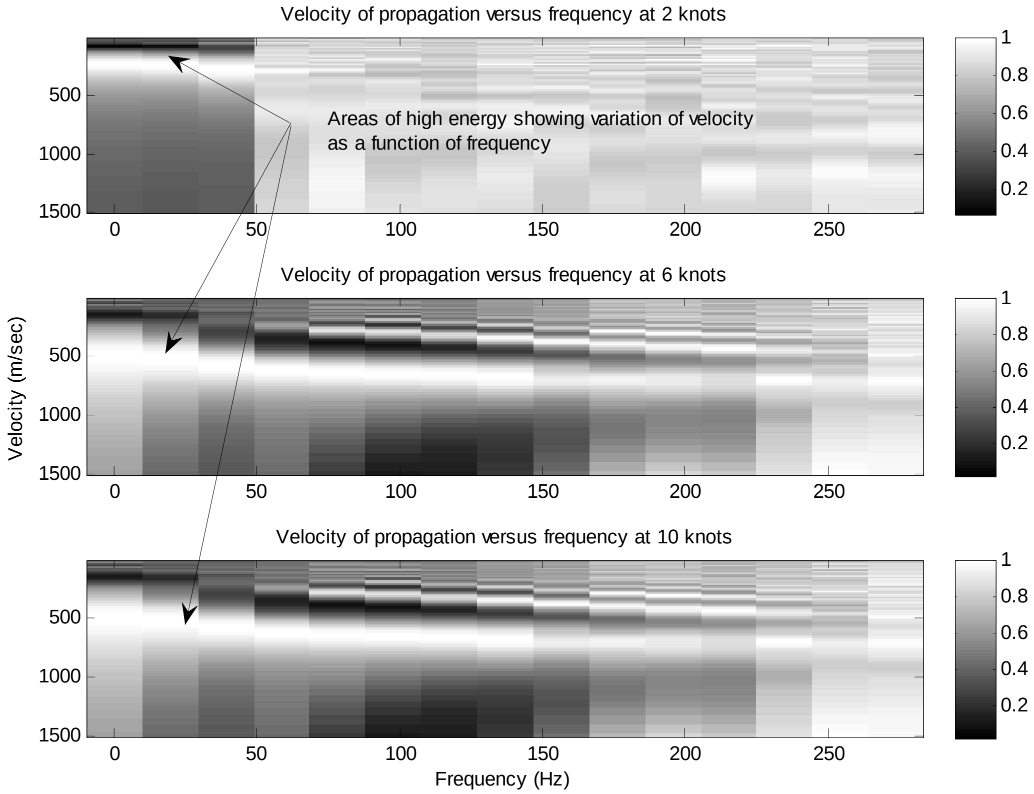

Figure 5 Variation in velocity with frequency suggesting a dispersive propagation of waves

from the y- component of the reference accelerometer showed some increase in energy with tow speed around the same frequency band as those of the array accelerometers, a cross correlation of the array accelerometer and reference accelerometer components did not show much correlation. This is believed to be may be because of the non-linear or dispersive nature of the transmissions of the waves propagating along the array as brought out earlier.

The outputs of the 'super-elements' were analysed to see how do their acoustic outputs change for different tow speeds. Figure 6 shows the PSD plots for various tow speeds. An ambient noise recording, when the array was stationary, is also included in the plot. It is evident that the noise floor is going up when the array is being towed and increasing further with the tow speed. Both the array accelerometers and acoustic sensors were also picking up 50Hz noise and its odd harmonics as can be seen from the figures.

5. CONCLUSIONS

In this paper we have described an experimental set up to measure the vibrations and other acoustic disturbances that may arise when a thin line towed array is being towed at various speeds. Even though this may not be a substitute for the actual scenario where an AUV will be towing the array, this experiment has provided insight into the complex wave propagations along the array at various speeds.

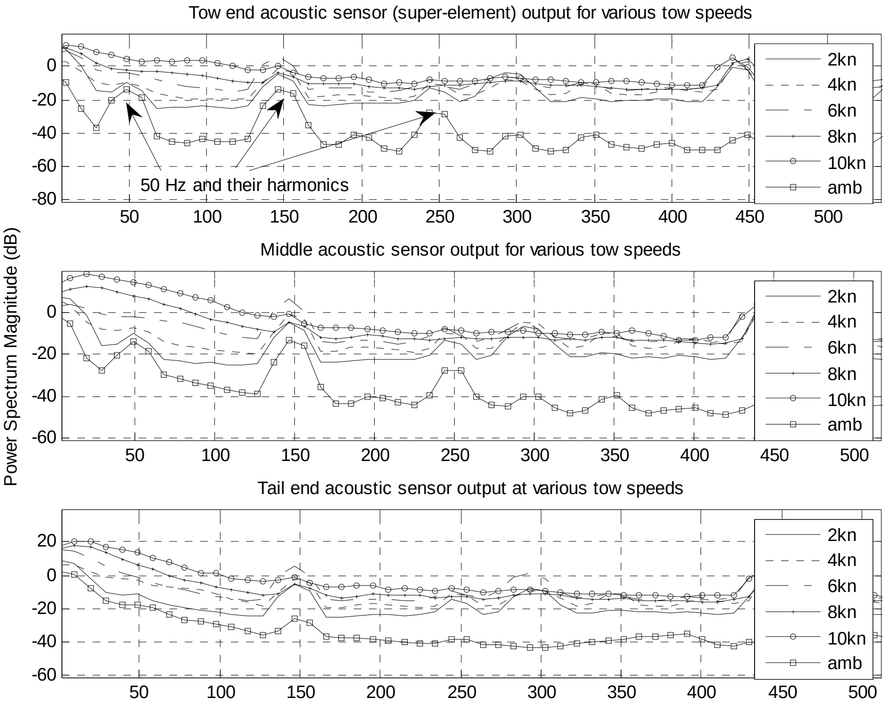

Figure 6 Acoustic sensor output comparison for stationary array and array at various tow speeds

1. There appears to be preferential excitation of certain frequency components depending up on the speed as indicated by the cross correlation plots. For example at 10knots we see that there are at least two main frequency components propagating along the array
2. The array output exhibits resonance near tow speeds of 4 and 6 knots as evidenced from both the autocorrelation and cross correlation plots.
3. For any given speed the frequency of excitation is the same at all accelerometers, but varies in amplitude. In general for a given tow speed the amplitude decreases as the wave travels from the tow end to the tail except for speeds 4 and 6 knots where the second accelerometer has a higher energy content probably due to the resonance and snaking of the array
4. At 10 knots the velocity of propagation seems to be changing as a function of frequency suggesting a non-linear or dispersive behaviour in the wave propagation.
5. The prominent frequencies of the propagating waves were found to be of very low frequencies, with higher frequency components attenuated very fast. This suggest that a VIM is probably required only if one is interested in measuring very low frequencies and the design has to be catered to absorb the low frequencies.
6. The recorded video showed that the array was not subjected to large snaking during the tow. A snap shot of the video recorded is given in figure 7.

7. The measured drag on the array was found to be much lower than the computed values. For example the computed tension on the 12 m array being towed at 1&2 knots are respectively 20 and 42 Newton. However the measured values during the experiment were respectively 6.5&8.7 Newton. The tension measured at the max tow speed of 10 knots was only 33 Newton and the array survived multiple runs at this tow speed.

Figure 7 Snapshots of array when under tow. Tow speed was 4 knots

A field trial employing an AUV platform is planned to be conducted in June 2009. This test would provide a more realistic scenario.

6. ACKNOWLEDGEMENTS

The main authors wish to acknowledge Defence Science & Technology Agencies, Singapore for funding this study. Thanks are also due to the scientists and engineers at NPOL and NSTL in India for providing the facilities and support. Support from Mr Sagar Pai, ARL researcher, who helped to design the receiver system and also from Mr Parijat Deshpande, ex-ARL employee, for trial support are also greatly acknowledged.

REFERENCES

[1] **Jason D Holmes, William M. Cary and James F Lynch**, Results from an autonomous underwater vehicle towed hydrophone array experiment in Nantucket sound, *J.Acoust. Soc. Am*, 120 (2), pp.EL15-19, 2006.

[2] **Jason D Holmes, William M. Cary, James F Lynch, Newhall A.E, Kukulya A,** An Autonomous Underwater Vehicle Towed Array for Ocean Acoustic Measurements and Inversions, Oceans2005-Europe, Vol.2, pp.1058-1061, June 2005

[3] **Andrew J Paulson, Donald P Eickstedt and John P Ianniello,** Bearing Stabilisation and Tracking for an AUV with Acoustic Line Array, Oceans'06, Sept.2006, Boston, MA, USA.

[4] **Maguer Alain, Dymond Rodney, Mazzi Marco, Biagini Stefano, Fioravanti Stefano and Guerrini Piero,** SLITA: A new slim towed array for AUV applications, J.Acoust. Soc. Am, 123(5), pp 3005, 2008

[5] **Pallayil V, Chitre M.A, Deshpande P.D,** A Digital Thin Line Array for Small Autonomous Underwater Platforms, Oceans'07, Sept-Oct 2007, Vancouver B.C, pp 1-9, 2007.