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Beam Forming Technique to Optimize the Power for the Positioning of Underwater Device

K. SUDARSAN[A*], N. RAMADASS[B], G. A. RAMADASS[A]

[a]National Institute of Ocean Technology, Chennai, India
[b]Professor, Department of ECE, Anna University, Chennai, India
[*]Corresponding Author: K. SUDARSAN

Abstract-

Power management is the major key factor for the design and development of underwater devices. Special care has to be taken for development of an underwater instrument to work in the oceanographic environments. Installation and frequent retrieval of the system is more challenging and expensive. Locating the position of the device is a crucial task for the researchers. Long-Base Line system (LBL), Short BaseLine system (SBL) and Ultra-Short BaseLine system (USBL)[1] are the most wildly used in underwater positioning and navigation. However, the ambient noise and natural change in the climate will lead to negative impact on the positioning accuracy, which results large positioning error[2], [3]. In some cases USBL positioning system with kalman filter is integrated along with the Inertial Navigation system and Doppler velocity log (DVL) for improving the accuracy of the positioning system. The proposed technique is inexpensive and less complex, for positioning of the underwater objects. We simulate the proposed technique using Matlab and extend it for beam forming, Beam angle adjustment and amplitude of transmitting signal power with respect to the position of the underwater device. The simulation also shows that the power can be optimized based on the range and angle of the underwater device.

Keywords — *Data buoys, Beam forming, LBL, SBL, USBL, hydrophones, and DVL*

Introduction

Exploration of sea involves deployment of buoys for data collection at various depths. These devices are battery operated deployed in underwater[4], [5]. The data collected by these underwater devices are stored locally. The stored data are collected by the ship on the surface of the sea periodically. The buoys are not stationary and drift over time due to various external factors. There are buoys, which are allowed to drift and collect oceanographic data. Hence it is necessary for the ship to locate the buoy and read the data from the underwater[4]–[7]. Currently, the systems used by the ships are complex and expensive.

Most of the oceanographic researchers has been focusing on design and development of sensor array network to finding the underwater positioning systems. Primarily it has developed varies array types linear, non-linear, orthogonal, non-orthogonal, traditional way of arranging the sensor array elements for detecting the underwater instrumentation. The important of the ocean exploration towards oceanographic application and the natural impact on the ocean, the developers deigned three types baseline systems.

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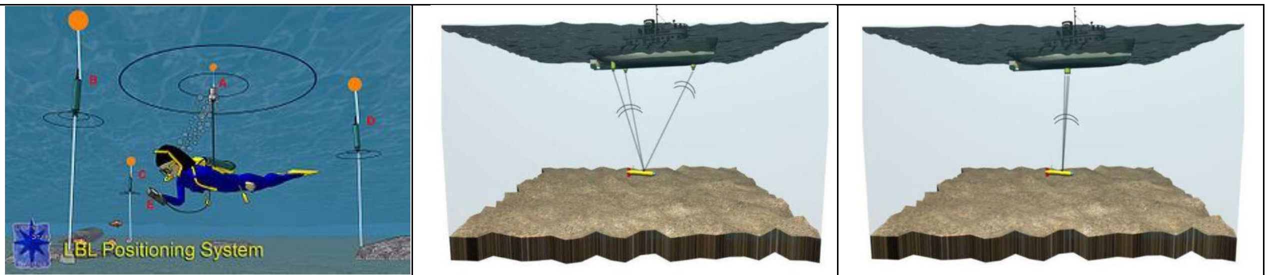

(a) LBL System | (b) SBL System* | (c) USBL System*

Figure 1. LBL, SBL and USBL systems
*Figure 1(b) & 1(c) used with permission (Alcocer, Oliveira, and Pascoal, 2006)

There are Long- Baseline(LBL) system[8], [9], use a sea floor baseline transponder and it is mounded in the corners of the operation site.LBL system designed very good accuracy and are installed in the reference frame of the work site on the sea floor depending upon the water depth. Second Ultra -short-baseline system (USBL) [10]is designed with a tightly integrated transducers array. The USBL transducers array is used to measure the object range and direction. Thirdly short-baseline system (SBL) is designed with three or more transducers integrated with a central control unit. The combination of range and direction will give the position of the targeted vehicle related to the surface vessel. To improve the efficiency, accuracy of these transceiver arrays authors introduced multiple models of calibration, like Kalman filter calibration, dynamic filter calibrations. The underwater targeted devices such as AUVs, remotely operated vehicles (ROV)[11], [12], will have an integrated transponder and it will transmit the acoustic signals to the baseline stations. The baseline station sends back the acoustic signals to the underwater target which records the position. The time of arrival of the acoustic signals from the baseline station is used to estimate the position of underwater devices. Also, the poisoning system for Deep Ocean Navigation (POSYDON)[11], [13], [14] is working the concept of long-baseline systems to allow positioning across ocean basins. However there is much more limitation for all baseline systems, it required detailed and frequent calibration, for improving the accuracy its required additional sensors, the ship's gyro, and vertical reference. It has minimal redundancy needs a large number of transceiver/transducer to have a higher degree of repeatability.

In this paper, a simple and inexpensive way to detect the underwater device using hydrophone array is explained. We simulate the underwater device positioning and beam forming using Matlab. The simulation also shows that the power can be optimized based on the range and angle of the underwater device.

Methodology and simulation:

The underwater object is detected by sending a ping signal towards the ocean floor. A ping signal is a burst of sinusoidal signal of a very small duration. In our simulation, we use 9 KHz sine wave for duration of 2ms with an interval of 300ms. Figure 2 shows the ping signal. If the object of interest is in the search area, the ping signal will be reflected and received by the multiple hydrophone array placed at the bottom of the ship. The transmitted signal is represented by the equation, $f = Asin(\omega t)$, where A is the amplitude and ω is the frequency of the signal.

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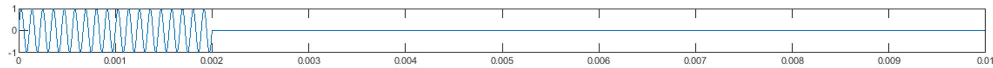

Figure 2. Ping signal

The centre of bottom of the ship is considered as the origin of our space. The hydrophones are at the bottom level of the ship placed randomly. The positions of the hydrophones are known with respect to the center of the ship. The experimental setup is simulated with 16 hydrophones as shown in figure 3.

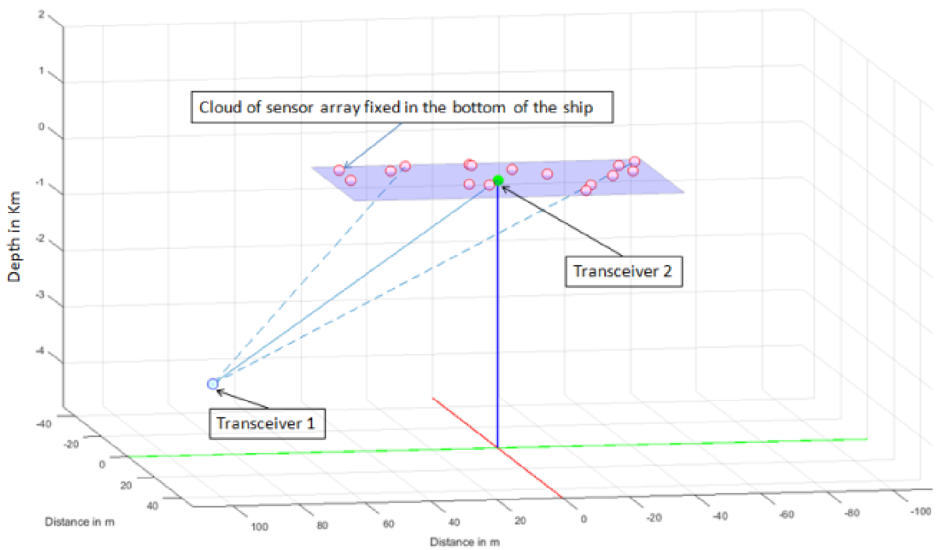

Figure 3. Experimental setup

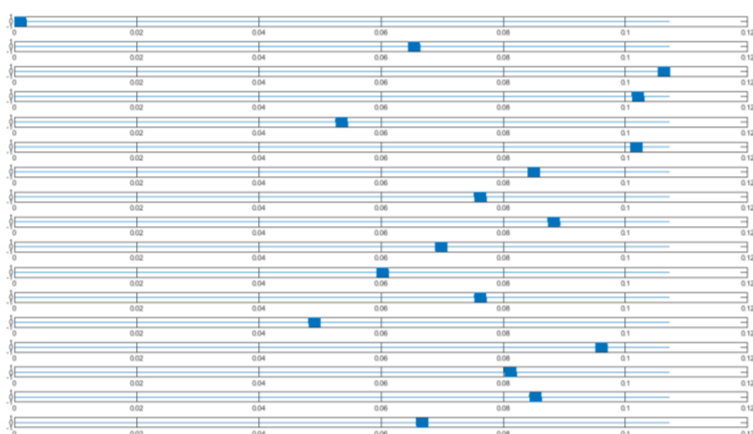

Figure 4. Transmitted and received signals

The blue plane represents the bottom of the ship or the sea level. The green dot is the centre of the bottom of the ship and the red dots are the randomly placed hydrophones. The blue dot is the object of interest. The X, Y and Z axes are represented by the green, red and blue lines

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respectively. The signal reflected by the object is received by the hydrophones on the bottom of the ship. Figure 4 shows the transmitted and the received signal. The blue patch in each graph is the 2ms ping signal shown above in figure 2. The first graph is the transmitter and the following graph represents the signal received by the hydrophones.

In a real-time scenario, two-way time for the ping signal to get reflected by the object of interest is known. We have simulated this condition and proceed to determine the location of the underwater object. From the time taken for the signal to get reflected by the underwater object and the velocity of the sound (C) in salt water we calculate the range of the object from the centre of the ship.

$$d_n = C * \frac{t_n}{2}$$

where, d_n represents the distance of the underwater object from the hydrophone n.

t_n is the time taken by the ping signal to get reflected with respect to n^{th} hydrophone. If the transmitted signal is represented as $f(t,\theta)$, where, t is time and $\theta$is the phase of the signal f. The signal received by the sensor, $\overline{f(t,\theta)}$, is represented by the following equation.

$$\overline{f(t,\theta)} = \begin{bmatrix} f_{p_0}(t) \\ f_{p_1}(t) \\ \vdots \\ f_{p_{N-1}}(t) \end{bmatrix} = \begin{bmatrix} f(t-\tau_0) \\ f(t-\tau_1) \\ \vdots \\ f(t-\tau_{N-1})) \end{bmatrix}$$

Where N is the total number of array elements and τ is the time delay associated with corresponding hydrophone element[15]. To position the underwater object, which is in 3D space, it is necessary to calculate the spherical co-ordinates $P(\rho,\theta,\varphi)$ of the object with respect to bottom of center of the ship. The spherical co-ordinates of the point$P$, is calculated by considering the distance between any two sensors with the point$P$.

To identify the range and direction of the targeted point "P" with respect to the center of the ship, we will consider any three hydrophone point in the sensor array. The distance between the selected hydrophone and the target is calculated as follows.

Let us consider the sensor C_1, C_3, C_7 as first three hydrophone components in the sensor array.
Let C_3 be consider as origin,
dx = distance between the sensor in the x direction
dy= distance between the sensor in the y direction

The υ be the velocity of sound wave in water, in our test setup the velocity of sound wave is consider as 1506m/s. Therefore the range of each selected sensor from the targeted object is

ρ_{c3}= υ x t x C_3
ρ_{c1}= υ x t x C_1
ρ_{c7}= υ x t x C_7
Where t is time taken for the signal to receive from the target

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We know that, the distance between C_3&P given by $\rho_{c3}$is also equals to

$$\rho_{c3} = \sqrt{x^2 + y^2 + z^2} \quad ----(1)$$
$$\rho_{c1} = \sqrt{x^2 + (y - dy)^2 + z^2} \quad ----(2)$$
$$\rho_{c7} = \sqrt{(x - dx)^2 + y^2 + z^2} \quad -----(3)$$

From equation 1&3 we get

$$X = \frac{{\rho_{c3}}^2 - {\rho_{c1}}^2 + dx^2}{2dx}$$
$$Y = \frac{{\rho_{c3}}^2 - {\rho_{c7}}^2 + dy^2}{2dy}$$

The spherical coordinates of φ and θ are calculated using

$$\theta = \tan^{-1}\frac{y}{x}$$
$$\varphi = \sin^{-1}\frac{x}{\rho_{c3}\cos\theta}$$

and $$Z = \rho_{c3}\cos\varphi$$

Similarly, for other set of sensor for N elements sensor array[1], [16], finally we have taken a mean value of that combination of sensor network and plotted the resultant value of Range and Direction of the object. The simulation steps can be summarized by the following algorithm.

1. Generate N random points $h_n(x, y, 0)$, within the length and breadth of the ship, where $h_n$represents the n^{th} hydrophone. The center of the ship is considered as the origin of our space
2. A random point $p(x, y, z)$ is generated away from the bottom of the ship
3. A ping signal of 2ms duration is generated and transmitted.
4. The time for the round trip of the signal is calculated. Velocity (C) of sound in salt water is considered to be 1506m/s.
5. Two hydrophones are selected and their distance from the object is calculated using C.
6. The range and position of the underwater object is estimated.
7. Based on the range, the amplitude of the signal is adjusted.
8. With the estimated angle, the beam is formed [10] using the communication array.
9. Estimate the power saved using the algorithm

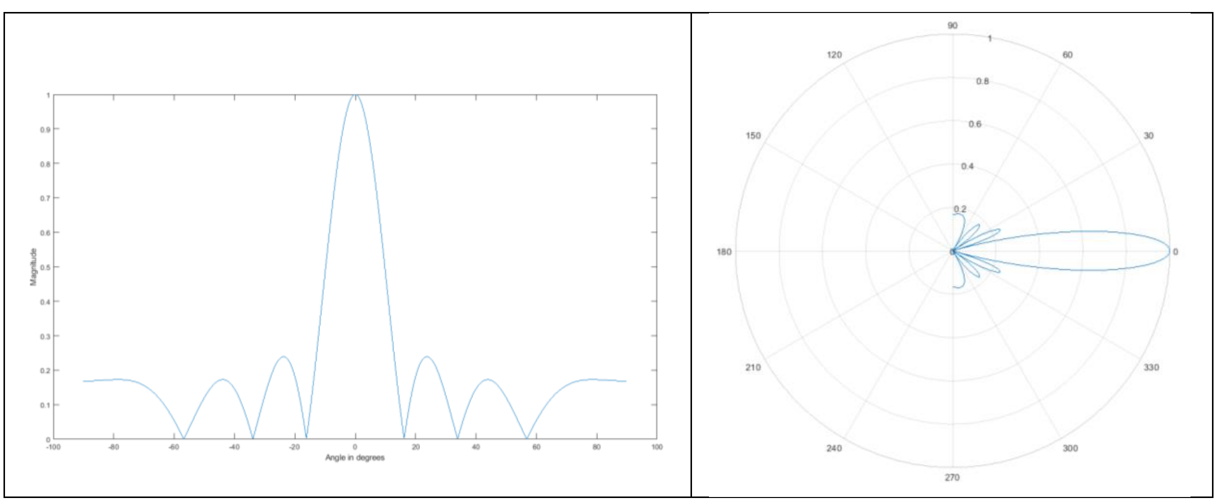

Figure 5. Initial magnitude and phase of the 6 element array, target object located at zero degrees

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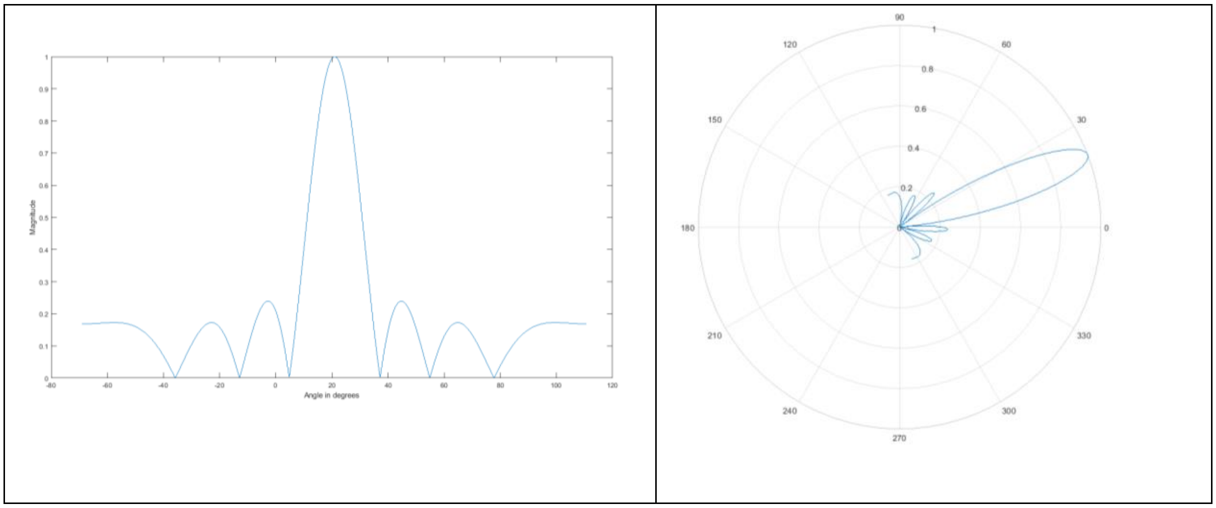

Figure 6 : Beam angle rotated according to the position of the target object,20.94degress

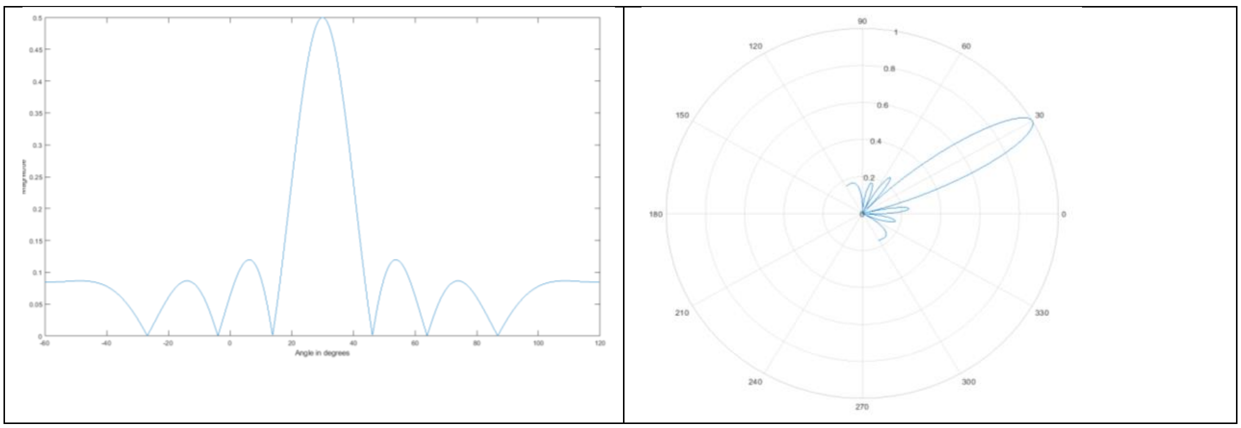

Figure 7: Beam angle rotated according to the position of the target object is at 30 degree

Results and discussion

The simulation was implemented in Matlab and the results obtained are shown below. For the transmitted and received signals shown in the figure 3, the spherical co-ordinates of the underwater point p is estimated as (109.3, 20.94˚, 88.54˚), which is the same as the set value. This simulation has not introduced any noise models and hence the results coincided with the set value. In the real-time scenario, there are various factors, that introduce noise into the received signal, such as acoustic interference and resistance, rolling and pitching of the sensors, etc., With a 6 element hydrophone array, a beam is formed to communicated with the underwater object and start data transfer. The following figure shows beam formation using a 6 element hydrophone array.

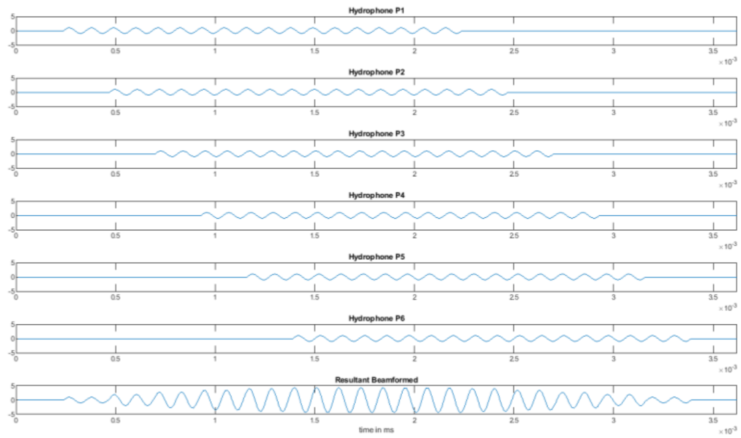

Figure 8. Beam formation using 6 element hydrophone array

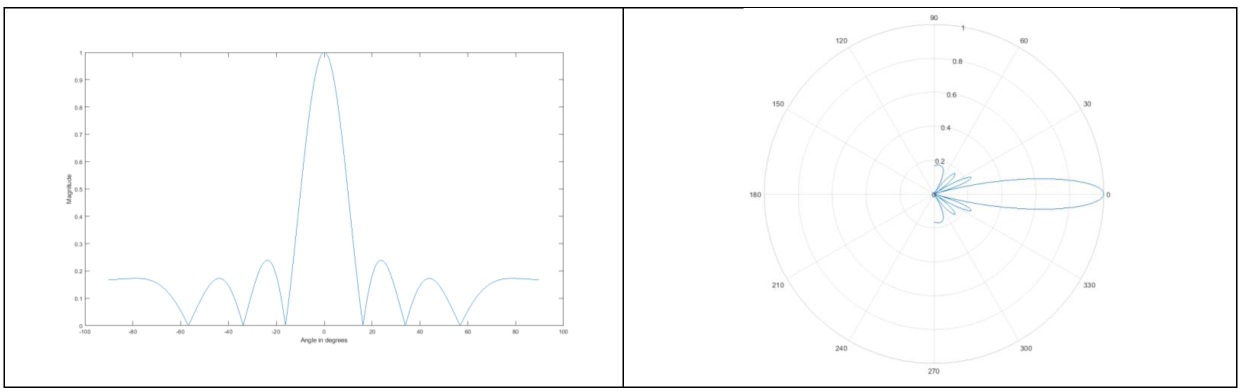

Figure 9. Initial magnitude and phase of the 6 element array, target range is large

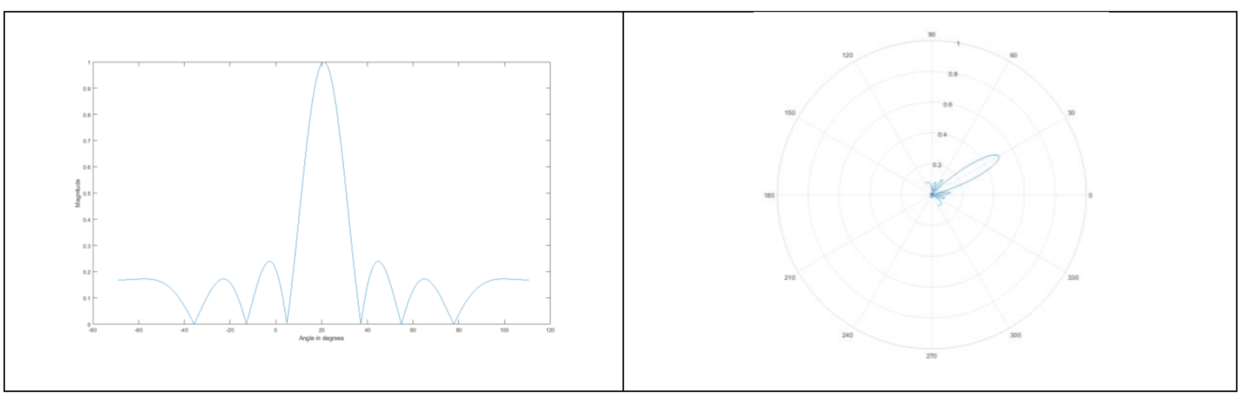

Figure 10. Magnitude and phase of the 6 element array, target range less

The Figure: 9 show the initial magnitude and phase of the communication array. It is at its maximum power of transmission for the range of the targeted objet at maximum distance . Figure: 10 shows the magnitude and phase of the 6 element communication array, power of transmission is half of its maximum value for the targeted objet range is reduced to half of it

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distance from the source. It can be observed that the amplitude has been reduced by 50% and the beam has been formed for the desired angle of 20.94°. As the ship moves on the surface of the sea, the position of the point can be tracked continuously and the parameters can be changed accordingly. The system has become adaptable. With respect to the power, it can clearly be shown that, the amount of power consumed by the system is optimized and hence the battery life has been increased. The system is less complex than the existing system and inexpensive.

Conclusion

A simulation study has been conducted for underwater device detection and power optimization using Matlab. The results show that, the expensive and complex existing systems such as LBL, SBL and USBL can be replaced with an N element hydrophone array for the detection of underwater objects. The study also suggests that, the power can be optimized by beam forming and battery life of the underwater object can be increased. Although, the noise models have not been considered here, the initial study suggests, it is possible to replace the existing system with the proposed system with power optimization.

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Kantipuli Sudarsan is working as Scientific Officer, at National Institute of Ocean Technology, Chennai, India. He has 24 years of experience in the field of design and development of marine instrumentation. He has developed an embedded system based ultrasonicatior for biofouling control, power line communication for remotely operating underwater vehicle and electro flocculation system for extracting the biodiesel from algae.

N. Ramadass is a professor in the department of ECE, CEG, Anna University, Chennai, India. He has 22 years of teaching and 21 years of research and development experience in embedded system design, VLSI Design and Reconfigurable Systems development. In his guidance more than 106 students completed their Projects in Post Graduate degree. He is guiding 12 students for Ph.D.

G.A Ramadass is the director of National Institute of Ocean Technology, Chennai, India. He has completed his Ph. D. at Indian Institute of Technology, Madras, India in the year 1992. He is involved in development of technology towards Manned Ocean mission for underwater biological, geological explorations and engineering intervention of Unmanned Underwater Vehicles, Deep Sea Mining, Deep Water Drilling System and Gas Hydrate Exploration.

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