[Online Journal of Space Communication](https://ohioopen.library.ohio.edu/spacejournal)

Volume 5
Issue 9 *Global Navigation Satellite System (Winter 2006)*

Article 25

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## BIOGRAPHY

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## ABSTRACT

In case of positioning by GPS, the direct signal from the satellite to the receiver is ordinarily utilized, but the multipath signal is regarded as one error source that deteriorate the positioning accuracy. In this paper, we focus on characteristics of the reflected signal, and had a few simulation tests. The correlator output signals are checked out and compared to the change of wave height and the wave period.
In this paper we describe that in sufficient long wave compared with reflection area size we can measure an accurate wave height, and by pointing antenna beam center from two directions we can obtain the characteristics of wave which are height, direction and period.

## 1. INTRODUCTION

Generally, a multipath signal in GPS positioning is often considered as undesired signal and it is too complicate to eliminate all of it. Especially in GPS positioning at sea, the degradation of receiver signal due to the multipath signal reflected from the sea surface is a well-known phenomenon. Consequently, if setting up an antenna at sea, lowering the antenna height will limit the effect of sea surface reflection of multipath signal. At ION NTM 2004, we already proposed a system configuration on measuring the ship draught using the typically undesired sea surface reflected signal. Also, from the results of basic experiment, we pointed out the possibility of GPS Draught Measuring System and its issues [1]. There were some research papers on characteristics of the multipath signal and its use as a different tool. Attila Komjathy and others suggested that GPS sea surface reflected signal to be a new tool for remote sensing [2]. They were also investigating a technique to estimate the wind speed and force based on reflected signal properties. Manandhar and others pointed out the multipath signal properties using antenna with RHCP for direct waves and LHCP for reflected waves [3]. Moreover, Rheem and others demonstrated the dispersion properties of microwaves on sea surface as experimental and simulation results. In this paper, we measured the direct signals using RHCP antenna and multipath signals with LHCP antenna at comparatively near the sea surface level.

Measuring the multipath signals from the sea surface as sea surface wave height, we proposed a system to measure the wave height change successively. We evaluated to what extent the height of the antenna and the directional characteristics should be to have an accurate wave height meter by performing some simulations for several types of sea surface conditions. As result, when directivity of receiving antenna is 4 degrees beam width, correlation results (delay distance from direct signal) are measured less than about 10 cm as dispersion around theoretical value. Then, we find that it has enough accuracy to measure sea surface wave height by giving statistical process. Using this system constructed by these conditions, we have known the possibility of simple and low-cost wave height measurement. By using this system in the future, setting a number of points for measurement near same area, we will be able to measure by array configuration. And using the MUSIC method to process the array signals, we can estimate the wave height precisely.

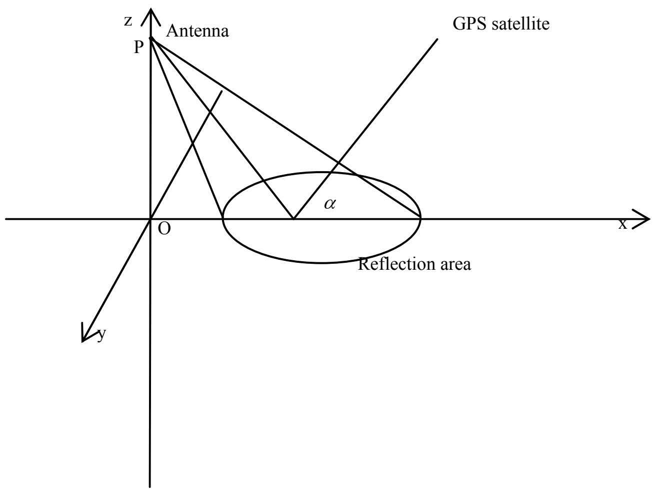


Fig. 1 Outline of simulation

## 2. SIMULATION TEST

We applied simulation method in order to confirm that it is possible to measure the wave height. Fig. 1 shows the outline of this system for measuring wave information using two GPS receivers. In the case of actual system, at the point P, the RHCP antenna is used to receive the direct waves from satellite and the LHCP antenna is used to receive the reflected waves on the sea surface. As a distance between two antennas is fixed, we can calculate this distance by means of a satellite elevation angle. Accordingly two correlator output signals of each receiver that are connected with each antenna depend on characteristics of the antenna and the reflected surface. For our feasibility study, some simulation tests were carried out and this simulation condition is shown as follows.

### 2.1 Antenna

Our proposed system has two GPS receivers. One is used for the direct signal and the other is for the reflected signal. The direct signal antenna is usual GPS receiver's antenna, but the reflected signal antenna is a special antenna. The directional characteristic of this RHCP is selected as the cosine pattern with respect to each direction and the beam width is defined as usual -3 dB point. In this simulation test, three beam widths (4, 20 and 40 degrees) are selected. And each antenna height is 5 meters. The simulation conditions of two antennas are shown in Table 1.

Table 1 Antenna conditions

| | Polarization | Beam width (deg.) | Antenna height (m) |
|---|---|---|---|
| Direct wave | RHCP | 180 | 5 |
| Reflected wave | LHCP | 4, 20, 40 | 5 |

### 2.2 Reflective surface

The reflective surface is supposed to sea surface, and characteristics of it is decided the wavelength, direction and displacement. The simulation conditions of the reflective surface are shown in Table 2.

Table 2 Characteristics of reflective surface

| Wave | Length (m) | direction (deg) | Displacement (wavelength) |
|---|---|---|---|
| Surface | 1, 2.5, 5 and 10 | 0 | 0.1 |

The size of the reflective surface is a function of the beam width and the height of antenna and the satellite elevation angle. Our simulation test has one condition of the antenna height and three conditions of the antenna beam width. The satellite elevation angle is 60 degrees. Table 3 shows three sizes of the reflective surface length according to three beam widths.

Table 3 Size of reflective surface

| Beam width (deg.) | 4 | 20 | 40 |
|---|---|---|---|
| Surface length (mm) | 465.8 | 2375.6 | 5077.2 |

### 2.3 Change of wave phase

Wave phase changes by additional phase which is 1/20 wavelength per one time simulation executed. Simulation is executed in 20 times, and then we could obtain time series of output correlation for one period of each wave. Additional wave phase per one time simulation is shown in table 4.

Table 4 Wave phase

| Wavelength (m) | 1 | 2.5 | 5 | 10 |
|---|---|---|---|---|
| Wave phase (mm) | 50 | 125 | 250 | 500 |

### 2.4 Simulation Flow

In this simulation, the simulation flow was executed as follows,

1. Generate sea surface wave according to wavelength and height.
2. Calculate delay distance of reflection path from the direct signal at divided plane.
3. Calculate receiving gain according to antenna receiving pattern.
4. Make histogram for receiving gain per 1 mm that is delay distance from direct signal. Receiving gain is proper for correlation value.

## 3. SIMULATION RESULTS

### 3.1 Correlator output

Fig. 2, 3, 4 show the correlator output signals by 4, 20, 40 degrees beam width respectively. In these figures, the horizontal axis is the delay distance from the direct wave in millimeter scale and the vertical axis is the output power of correlator, and the value means a scale factor of an ideal mirror reflection in percent figure. Fig. 5 means the three relationships between beam width and wavelength.

When it is assumed that ordinary receiver processes the correlation output in Fig. 2 to Fig. 4, since such receiver outputs peak value of the correlation, in Fig. 2 the delay from direct signal is 9068 mm using 4 degrees beam width, in Fig. 3 the delay is 9100 mm using 20 degrees beam width and in Fig. 4 the delay is 9100 mm using 40 degrees beam width. The relation of antenna height $h$ and the delay is followed.

$$h = \frac{\delta}{2\sin(elv)} \quad (1)$$

When the delay is 9068 mm, $h$ = 5235 mm in 4 degrees beam width and wave height converted from the delay which is amplitude from sea surface level is -235 mm, since antenna height from sea surface level is 5 m. In the same way at 20 degrees beam width, $h$ = 5254 mm, wave height is -254 mm. And at 40 degrees beam width, $h$ = 5254 mm, wave height is -254 mm. At this time wave height pointed by beam center is -235 mm. By this means conversion from the delay to wave height performs up to one period of generated wave, next results of wave height at beam center and results of 3 kinds of beam width are shown.

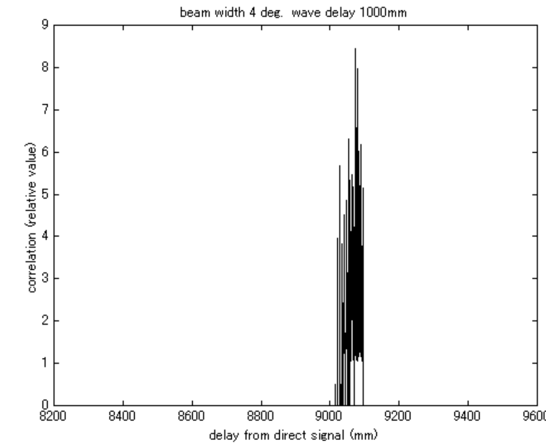


Fig. 2 Correlator output on 4 deg. beam width

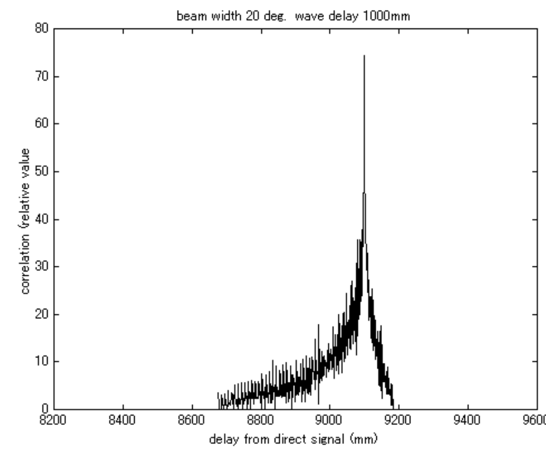


Fig. 3 Correlator output on 20 deg. beam width

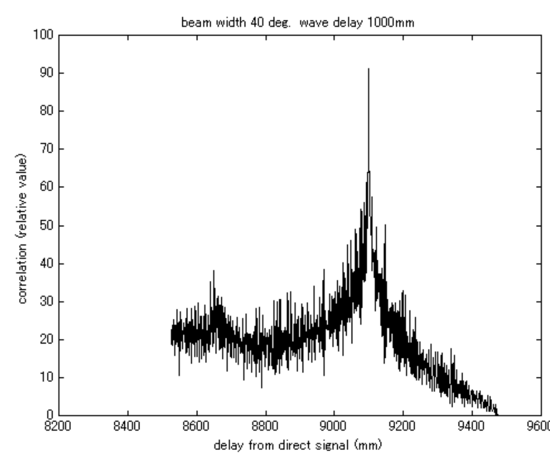


Fig. 4 Correlator output on 40 deg. beam width

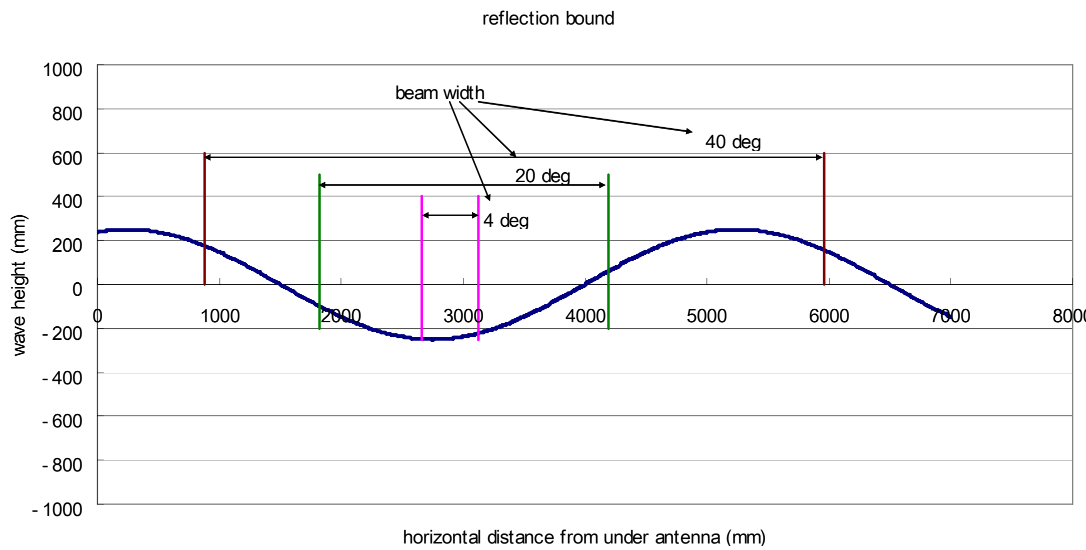


Fig. 5 Three relationships between beam widths and wavelength

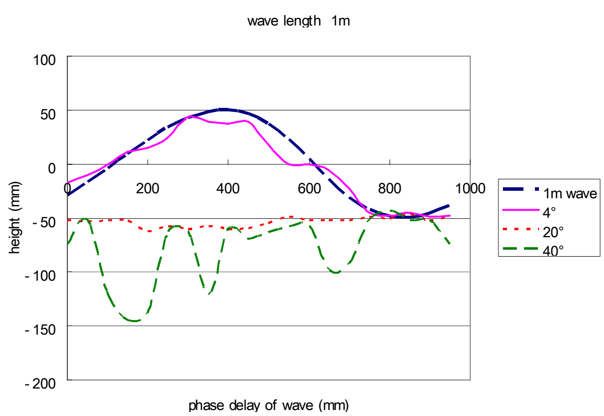


Fig. 6 Result of wave height on 1 m wavelength

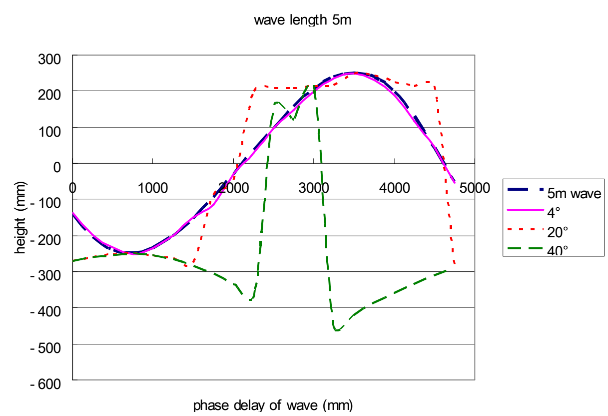


Fig. 8 Result of wave height on 5 m wavelength

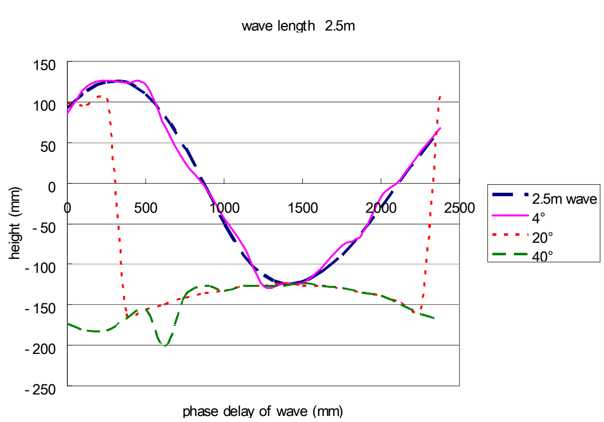


Fig. 7 Result of wave height on 2.5 m wavelength

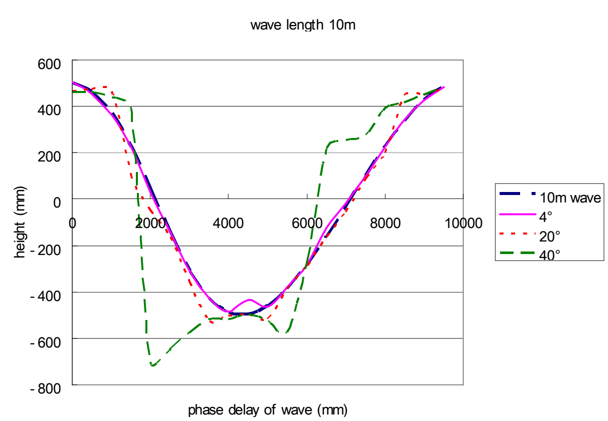


Fig. 9 Result of wave height on 10 m wavelength

### 3.2 Wave height

Fig. 6 shows the simulation result of a 1 m wavelength. This blue dot line means the referred wave height at beam center. Each line means the results of 4, 20 and 40 degrees beam width respectively. The antenna height is obtained by calculating a delay distance. So, in this figure and the case of 4 degrees beam width, the simulation result is coincident with a 10 cm wave height simulated wave. The standard deviation calculated from residual error between simulated wave and the wave height result is about 9.3 mm for 4 degrees beam width. All standard deviations are shown in Table 5. In two results of standard deviation of 20 and 40 degrees beam width, it is trouble to obtain the wave height clearly.

Fig. 7 shows the simulation result of 2.5m wavelength. The result of 4 degrees beam width is coincident with the wave height change of generated wave. Fig. 8 and 9 show the results of 5 and 10 m wavelength respectively.

Table 5 is briefing results of standard deviation from Fig. 6 to Fig.9. Table 6 is a utility for the trend of each wave height. In table 6, "Available" is to be able to measure the wave height accurately. The accuracy of this measurement is cm level. "Not easy" is possible use for measuring the wave height. "N.A." is not to use for measuring the wave height from the aspect of the measuring accuracy.

Table 5 Result of standard deviation (mm) of four wavelengths

| | Beam width (deg) | | |
|---|---|---|---|
| Wavelength (m) | 4 | 20 | 40 |
| 1.0 | 9 | 40 | 54 |
| 2.5 | 9 | 99 | 112 |
| 5.0 | 7 | 96 | 249 |
| 10.0 | 17 | 54 | 255 |

Table 6 Availability criteria of wave height measurement

| | Beam width (deg) | | |
|---|---|---|---|
| Wavelength (m) | 4 | 20 | 40 |
| 1.0 | A. | N.A. | N.A. |
| 2.5 | A. | N.A. | N.A. |
| 5.0 | A. | N.E. | N.A. |
| 10.0 | A. | A. | N.E. |

"A." is available, "N.E." is not easy, and "N.A." is not available.

## 4. CONSIDERATION

In order to construct the measuring system of the wave information, at the start we confirmed possibility of the wave height measuring system using by simulation method. In this simulation we took notice the relation between beam width and wavelength, and considered that the relation could be derived by altering of these parameters. In results of simulation, when wavelength is short length compared with beam width, it becomes to be difficult detection of wave height. In this simulation, when simulated wavelength is, from 1 m wavelength which is comparatively short wave as sea surface wave, to 10 m wavelength is large grown-up wave as wind wave, antenna with sharp directivity such as 4 degrees beam width is able to measure the wave height in high accuracy. But in the case of 20 degrees beam width it is able to measure wave height at 10 m wavelength which is large wave, and in the case of 40 degrees beam width it is not able to measure wave height at 10 m wavelength.

Using antenna with 4 degrees beam width against basic wavelength is able to measure the wave height in accuracy of 2 cm or less dispersion. This means that the draught measuring system which is our proposal system in previous paper. In the case of selection of wide beam width, there is possibility that it can apply as the wave height measuring system if wave is large in a way. But using wide beam width is possible to enhance the reliability by execution of signal processing which is filtering and so on because wide beam width has a problem of accuracy. It is the problem that is the issue of cost when system will realize in future. In this simulation, it is assumed that the reflection at sea surface is uniform distribution, but in case of actual sea surface, it needs to consider the scattering coefficients on wave surface. In next step of simulation, we will consider the effect of scattering and change beam width adequately. And then, if we derive relational expression of beam width and accuracy, we can decide optimal beam width.

Next, about extraction of the wave characteristics, the wave period is able to measure by recording time difference when the wave height is measured. Against accuracy of wave height measuring which is in z axis, the expectancy of dispersion in x axis which is the direction of wavelength is represented $\sqrt{2}\sigma$ if the time measuring is zero-cross to zero-cross. ( $\sigma$ : Standard Deviation) Consequently, as using 4 degrees beam width, it is considered that it is possible to measure 3 to 4 cm at most. But it is only one direction that is the direction of simulation setting parallel to x axis. It becomes to need continuous measuring of orthogonal two directions for measurement of stereoscopic wave.

## 5. CONCLUSION

In this paper, we proposed the sea surface wave information system to measure and the wave height and the wave phase as a GPS application. In the reflect wave signal that has sufficient long size compared to the wavelength, we can measure an accurate wave height, and the precise wave direction will be able to estimate using two wave height values and MUSIC method. Meanwhile, the reflect wave signal that selected an adequate size compared to the wavelength can estimate the wavelength.

From simulation results, in sufficient long wave compared with reflection area size, we can measure an accurate wave height. According to theoretical consideration, by pointing antenna beam center from two directions, we can obtain the characteristics of wave which are height, direction and period.

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