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A METHOD OF SIMULTANEOUS MEASUREMENT OF DIRECTIONAL WAVE SPECTRA, SURFACE CURRENT AND RIG MOTION

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1. SUMMARY.

The MIROSMc is a new system for full scale verification of the rig response amplitude operators. This paper reviews the basic principles of operation of MIROSMc. Wave and motion data collected by the system during the winter '85 - '86 are presented and theoretical and measured transfer functions are compared.

2. INTRODUCTION.

The lack of convenient, reliable and accurate instrumentation has been a severe limitation for the full scale evaluation of rig performance.

Combining microwave remote sensing principles and inertial navigation techniques the recently developed MIROSMc concept represents a new and powerful tool for full scale determination of the rig response operators.

This paper reviews the basic MIROSMc concept and presents comparisons of theoretical and measured transfer functions based on data collected during the winter '85/'86 from the Deepsea Bergen semisub (type: Aker H3.2). The rig is owned by Odfjell Drilling and was operated by Statoil a.s. in the North Sea.

The results presented in this report originate from a development project sponsored by Statoil a.s and Saga Petroleum a.s. In addition to the sponsors the following parties participated in the project: Odfjell Drilling, Marintek a.s and MIROS A/S.

3. SYSTEM DESCRIPTION.

In the following a brief description of the MIROSMc system and the rig installation is given.

A comprehensive review of the basic measurement principles of the MIROS system is given in appendix 1.

3.1 MIROSMc

Floating structures are exposed to environmental forces due to wind, waves and current. MIROSMc (Microwave Remote sensor for the Ocean Surface, motion compensated) measures the directional wave height spectrum, surface current and the resulting rig motion due to the environmental forces. A block diagram is presented in fig 3.1.1. The system comprises:

- SENSOR HEAD containing the microwave transceiver operating at 5.8 GHz and the antenna assembly.
- MIREF (Marine Inertial Reference) measuring the rig motion with six degrees of freedom.
- CENTRAL PROCESSOR containing the signal processing electronics the system computer and the cassette tape logger.

In a typical installation, the sensor head is mounted about 50m above the sea, and scans the sea surface at a radius of 500m over a 180 degree arc, in six 30 degree sectors.

The sensor head receives echo from the sea surface containing information about the dynamic processes of the upper layer of the ocean. This information is processed in the central processor giving the wave height spectrum and the radial surface current for each sector. Integration over all sectors provides the conventional nondirectional wave spectrum and parameters such as the significant wave height and peak period. The total current vector is calculated from the radial components using a least squares algorithm.

MIREF is a compact inertial navigation unit providing information of the rig motion with six degrees of freedom. The rig heading is obtained from the gyro compass. The motion data collected by MIREF and the wave and current data collected simultaneously by the sensor head give the basis for the calculation of the response amplitude operators of the floating structure for any sea state and loading condition.

The unwanted effect on the received echo due to the antenna motion is compensated for in software by using the high performance rig motion information provided by MIREF.

3.2 Rig installation.

During December '85 and January '86 a MIROSmc was tested out on the Deepsea Bergen semisub (type: Aker H3.2). The installation comprised the following:

- A sensor head mounted in the derrick 52 meter above the mean sea level.
- A marine inertial reference (MIREF 1) mounted close by the sensor head.
- A central processor installed in the rig chart room.
- A second marine inertial reference (MIREF 2) mounted in the forward starboard corner of the rig.
- A stand alone logging system for simultaneous logging of MIREF 1 and MIREF 2 provided by MARINTEK. This logger was a part of the test equipment and is not included in the standard MIROSmc package.

The actual installation is shown in fig 3.2.1 specifying the coordinates of MIREF 1 and MIREF 2. The reference coordinate system has the X-Y plane located at the bottom of the pontoons with origo underneath the center of gravity. The center of gravity is located at (0, 0, -34.5). Note that the positive Z - axis is pointing downwards.

The Marintek logging system and the extra marine inertial reference (MIREF 2) were installed for test purposes since this experiment represented the first real life offshore test of the MIREF unit. By logging the two units simultaneously, off line checking of the accuracy and noise properties can be carried out.

4. DATA PRESENTATION.

Representative wave and motion data collected from Deepsea Bergen are presented in this section. Data collected simultaneously with the two MIREF units are compared and theoretical and measured rig transfer functions are shown.

4.1 Wave data.

On Deepsea Bergen the MIROS antenna covered a 180 degree arc from 65 deg. to 245 deg. as shown in figure 4.1.1 corresponding to the following antenna pointing directions : 50, 20, 350, 320, 290 and 260 deg.

A set of wave data collected during the 10th. of January 1986 is shown in figure 4.1.2 in graphical form. The upper six windows represents the power spectra of the approaching and receding wave fields within 30 degree sectors around the antenna pointing directions. As can be seen from figure 4.1.2 the dominating wave direction is shown in the fourth spectrum corresponding to a northerly swell from 350 deg. The lower spectrum in figure 4.1.2 represents the nondirectional wave height spectrum obtained by integrating over all the six spectra above. The wave situation shown represents a significant wave height of 7.7 meter and a peak period of $1/0.078 = 12.8$ seconds.

4.2 Rig motion data.

Time series of rig motion measured by MIREF1 and MIREF2 are shown in figure 4.2.1 with the corresponding auto spectra. The sampling rate is 2 Hz. The data shown are referred to a global coordinate system (i.e. X: North, Y: East). For these comparisons the MIREF2 output is transformed to the MIREF1 position, and the output data is highpass filtered with a cutoff frequency equal to 0.008 Hz. As can be seen from figure 4.2.1 the outputs from the two sensors are highly correlated.

These motion data and the wave data shown in figure 4.1.2 are recorded practically during the same time interval.

4.3 Transfer functions.

The theoretical rig transfer functions available for this comparison are derived on the basis of long crested waves (i.e. all wave energy is associated with one direction.). This represents, however, a somewhat idealized situation seldom occurring in the real life. In order to satisfy the idealized assumption as well as possible, only highly directive wave situations lining up closely with the heading of the rig are used for comparison purposes.

This is equivalent to assuming that all the wave fields are going in the same direction and that their spectrum is given by the nondirectional wave spectrum.

For the analysis carried out in this paper the wave situation shown in figure 4.1.2 is an example which is considered acceptable for the comparison of transfer functions.

The modulus of the measured transfer functions is derived as follows:

$$H(\omega) = \sqrt{\frac{S_{ii}(\omega)}{S_w(\omega)}}$$

where: $S(\omega)$ is the auto spectrum
ii of the motion parameter
in question.

$S_w(\omega)$ is the nondirectional
w wave spectrum.

Examples of theoretical and measured transfer functions are shown in figure 4.3.1. Measured transfer functions are shown for two data sets (run 212 and 215) collected the 10th. of January 1986. Both data sets representing highly directional waves situations hitting the rig head on. Only transfer functions for heave, surge and pitch are shown since they are the most interesting ones for head on wave situations.

Measured values are shown for frequencies down to 0.079 Hz. Below this frequency no significant wave energy is present for the selected wave spectra.

As can be seen from figure 4.3.1 the theoretical and measured transfer functions are highly correlated. The measured transfer function for heave is typically offset with a factor of two relative to the theoretical function.

Presently the authors do not want to draw any conclusions regarding the validity of the measured or theoretical data.

However, the high degree of correlation is encouraging and the research and data analysis will be continued.

5. CONCLUSION.

Wave and motion data measured with MIROSmc on a Aker H3.2 semi-submersible rig has been processed to give the rig transfer function.

The general shape of the theoretical and measured transfer function show a good correspondence.

Despite the observed deviations between the measured and theoretical data the results are considered to be very encouraging and they form a good basis for further research.

An important scope of the continuation of this work is to utilize the directional wave information for deriving measured rig responses for short crested irregular waves.

Appendix A

MIROS PRINCIPLES OF OPERATION

Miros operates in two different modes:

- the pulsedoppler mode for directional wave measurement,
- the dual frequency mode for surface current measurement.

The wave and current measurements are performed simultaneously.

Both modes utilize the doppler information in the radar echo from the sea surface. This doppler information is determined by the relative motion of the target (i.e. the sea surface) and the radar antenna.

A.1 Compensation of antenna motion

On a floating rig the radar antenna will follow the rig motion. This means that a compensation must be applied to the detected signal in order to obtain the correct wave and current information. It can be shown that the critical motion components are the time varying antenna position and velocity in the antenna look direction.

MIROSmc has a built in motion reference unit, MIREF, providing highly accurate information about rig motion in all 6 degrees of freedom. From this information the MIROS computer calculates the antenna velocity time series which are used for removing the effects of rig motion from the measured doppler time series. Thereby providing undistorted wave and current raw-data for further processing and presentation. The compensation is done in the computer and no mechanical adjustment of antenna pointing direction is needed.

A.2 Wave measurements

Directional wave height frequency spectra are measured in the pulsedoppler mode, basically obtaining water particle velocity information. A wave model is applied in order to transform the velocity spectrum into a wave height spectrum.

The Miros Sensor Head is operating at C-band (5.8 GHz, wave length = 5.17 cm). Hence the actual radar scatterers are the capillary wave field which ride on top of the underlying gravity waves, forming a large number of radar scatterers all moving with the velocity of the water particles. The sea surface is illuminated with a radar pulse short compared to gravity wavelength and the received echo is range-gated to exclude all echoes from the sea surface outside a well defined radar footprint. The instantaneous doppler shift is proportional to the average water particle velocity along the antenna look direction, where the average is with respect to the the illuminated area or radar footprint see figure A.2.1. The azimuth dimension of the footprint is given by the radar antenna beam width.

The sea surface can be described as an infinite sum of plane, harmonic elementary waves see figure A.2.2. The resulting water velocity is therefore to first order just the vector sum of the orbital velocity of each individual elementary wave.

The directional resolution is obtained because the component of the average water-particle velocity in the antenna look direction for a plane harmonic elementary wave soon drops to zero when the ocean wavenumber forms an angle with the antenna look direction greater than the directional resolution of the radar. Hence the radar do not respond to waves arriving from other direction sectors.

To derive velocity information from the radar echo the received signal is frequency to voltage converted, lowpass filtered, sampled with a sampling rate of 2.8 Hz and A/D converted. Velocity raw data are collected as 90 sec (256 samples) time series.

During a measurement sequence observations are taken in 6 directions with an angular increment of 30 degrees. This represents 180 degrees angular coverage, which is sufficient for a complete directional scan since the radar observes both approaching and receding waves simultaneously. Each direction is observed for 90 seconds and the measurement sequence is repeated 8 times giving a total observation time per direction of 12 minutes or 72 minutes for a complete directional scan. The measured wave data presently have an inherent 180 deg. ambiguity with respect to direction. Techniques to resolve this ambiguity is under development and will be implemented in new systems.

A complete frequency spectrum is then formed for each direction sector by averaging 8 periodograms, giving spectrum estimates with 16 degrees of freedom (assuming a Gaussian sea).

The velocity spectrum is then converted into a wave height spectrum using a wave model. Presently a linear deep-water model is used. The performance of this model has proven to be good even for high waves. Improved models taking non linear effects into account will however be investigated.

The complete directional wave spectrum is presented as a two-dimensional array with 40 equidistant frequency bands ranging from 0 to 0.446 Hz and 6 directions. The spectral resolution is 0.011 Hz in frequency and 30 deg. in direction. The spectral values are given as square-meters per Hz for the given direction sector.

Based on the two-dimensional spectrum the nondirectional spectrum is formed by adding the spectral values for each frequency over the 6 directions.

The significant wave height is calculated as 4 times the rms wave height. The rms wave height is calculated taking the square root of the sum of the spectral values of the nondirectional spectrum from 0.033 to 0.446 Hz.

The directional distribution of the total wave energy is formed adding the spectral values from 0.033 to 0.446 Hz for each direction. If the maximum energy is found in direction 1,2 or 5,6 the directions are redistributed to obtain a symmetrical distribution around the peak, bearing in mind the inherent 180 deg. ambiguity with respect to measured wave direction. The peak wave direction is calculated on the basis of the total wave energy directional distribution using a quadratic interpolation. The spread around the peak is also calculated.

A.3 Surface current measurements

Surface current information is obtained by measuring the phase velocity of a gravity wave in the dual frequency mode.

The gravity waves interact with the capillary waves thereby causing a spatial and temporal modulation of the radar cross-section of the sea surface. In addition to amplitude modulation the backscattered signal will also be phase-modulated because the distance between the radar antenna and a particular radar scatterer varies in accordance with the movement of the underlying gravity wave.

Due to this periodic modulation of the backscattered radar signal the presence of a gravity wave component may be established using two radar signals with a frequency or wavenumber difference which is related to the ocean wavenumber equivalent the Bragg resonance condition, see figure A.3.1. Multiplying the radar return on one frequency with the complex conjugate of the other and forming the power frequency spectrum of the product signal, only equal velocity scatterers will give coherent contributions or stable spectral components. This shows up as a line in the product signal power spectrum at a frequency equal to the frequency of the particular gravity wave component see figure A.3.2.

The radar can therefore measure the frequency of a particular gravity wave component and thereby its phase velocity by selecting a proper frequency difference. The difference between the measured and theoretical phase velocity gives, by means of the dispersion relation, the radial component of the surface current vector in the radar look direction.

In the dual frequency mode the radar signal is a train of 500 ns long dual frequency pulses. The received signal is range-gated to obtain echo from a 75m long footprint which is optimum for a frequency difference of 10 MHz coupling to a 15 m long gravity wave. The returns on each frequency are then cross correlated, lowpass-filtered, sampled with a sampling rate of 2.8 Hz and A/D converted. Raw data are collected as 90 sec. time-series of (256 samples) of the in-phase and quadrature components of the cross correlated signal.

During a complete directional scan data are collected from all 6 directions. For each direction a power frequency spectrum is formed by averaging 8 periodograms. The presence of a coherent line is then established by a threshold detection technique and the exact frequency estimated by interpolation.

The surface current measurements yields a weighted average of the current of the upper layer of the ocean. The total current velocity will be the sum of the mean ocean circulation, the tidal component and the wave and wind induced currents. The weighing function is assumed to be of the form $\exp(-2kz)$ where k is the wavenumber of the gravity wave and z is the depth. For a gravity wavelength of 15 meters the current measured represents an average down to a depth of approx 1.2 meters.

The total current vector (magnitude and direction) is finally estimated using an algorithm based on the method of least squares. The surface current estimate represents an average with respect to both time (72 minutes) and space (radar footprint, 6 direction sectors).

ACKNOWLEDGEMENT.

The authors want to thank Aker Engineering for providing the rig transfer functions for this paper. We would also like to express our gratitude for the enthusiastic support from the rig owner Odfjell Drilling during the field measurements. Finally we want to acknowledge the importance of the work carried out by mr. Karl Erik Kaasen, MARINTEK, during the preparation and completion of the field test.

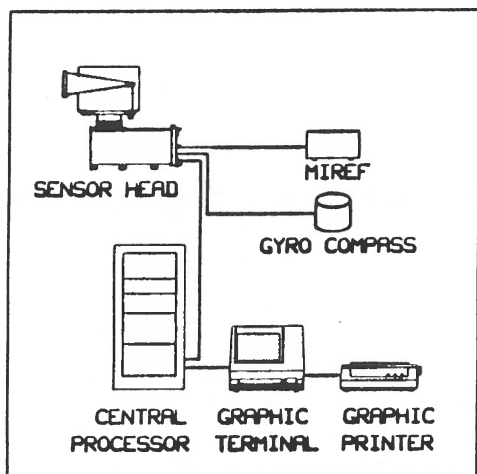


Fig.3.1.1. MIROSmc system components.

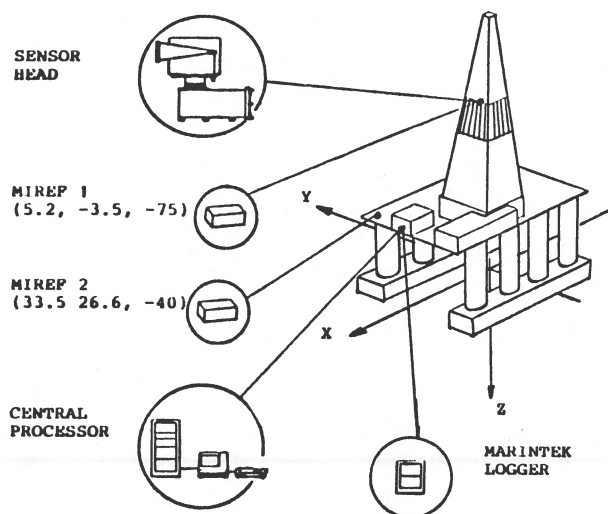


Fig.3.1.2. Installation on Deepsea Bergen

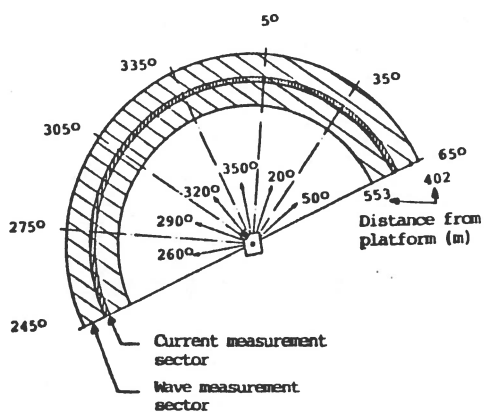
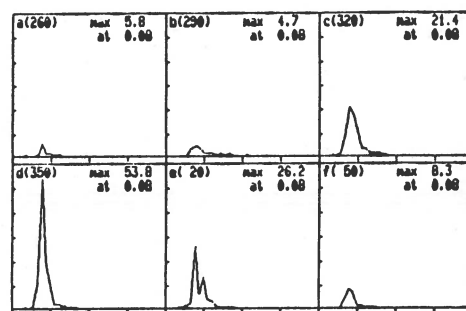
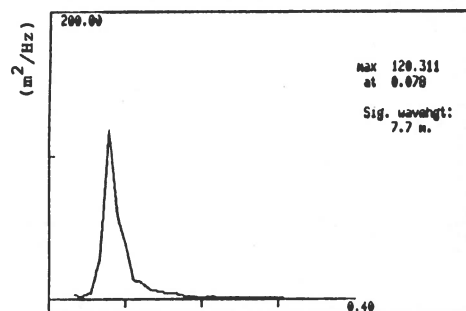


Fig.4.1.1. Geometry of antenna illumination



a) Wavespectra corresponding to each of the six pointing directions of the antenna.



b) Nondirectional waveheight spectrum.

Fig.4.1.2. Wave data collected 10th of December 1985

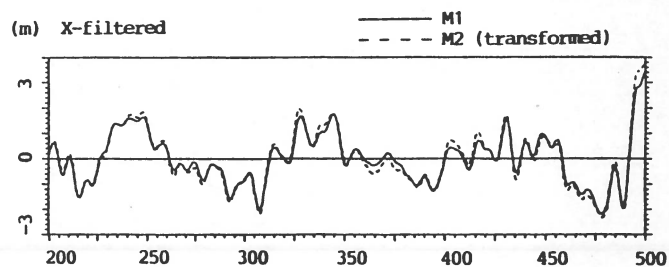


Fig.4.2.1.a) Time series of north-south motion

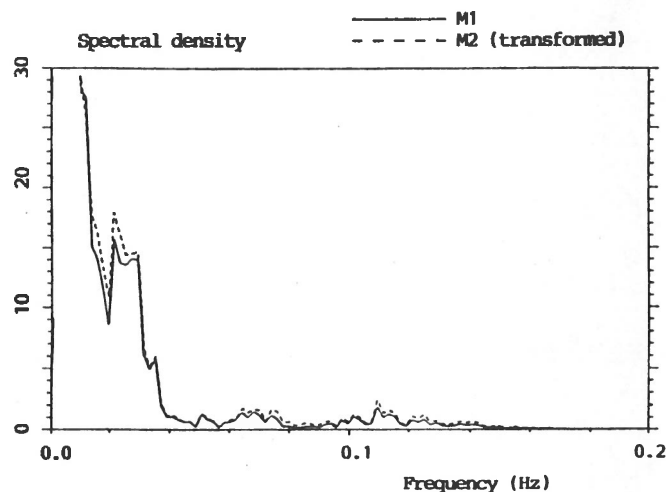


Fig.4.2.1.b) Autospectra of north-south motion

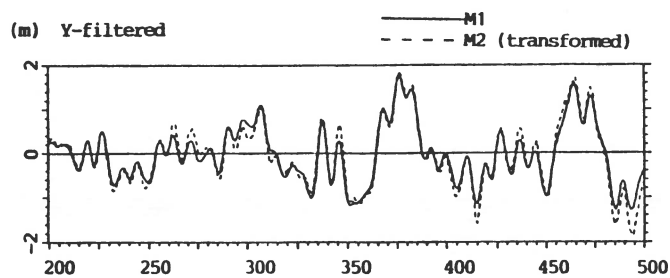


Fig.4.2.1.c) Time series of east-west motion

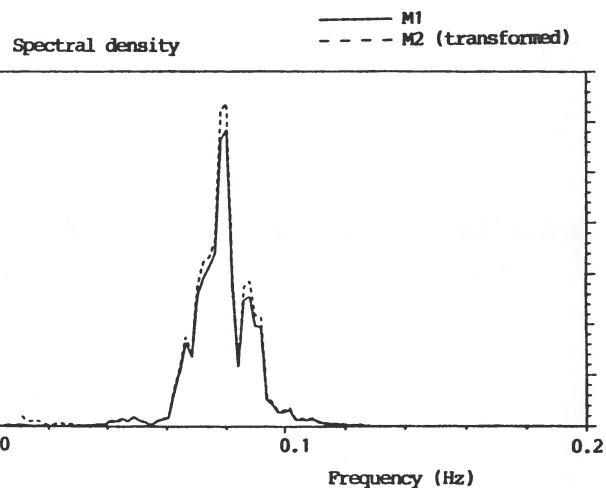


Fig.4.2.1.f) Autospectra of heave

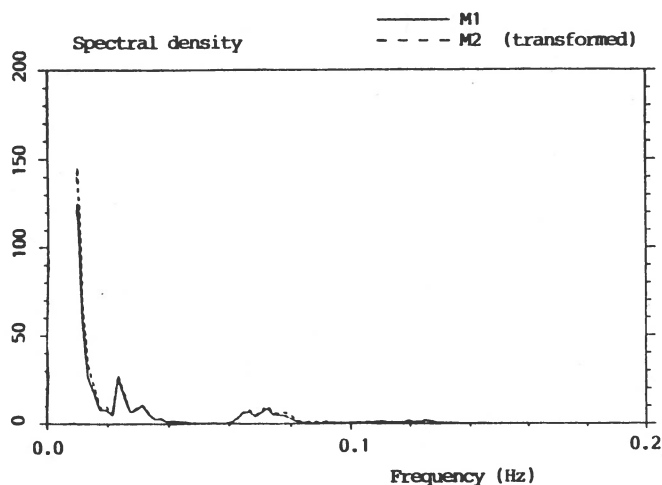


Fig.4.2.1.d) Autospectra of east-west motion

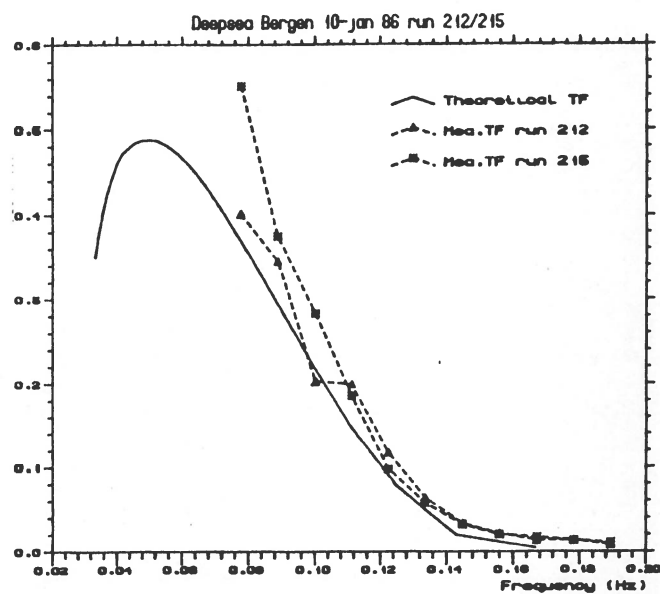


Fig.4.3.1.a) Transfer function of pitch

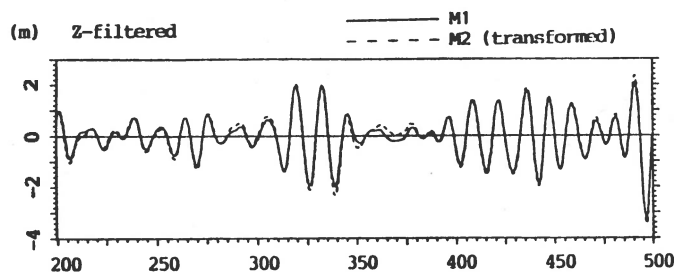


Fig.4.2.1.e) Time series of heave

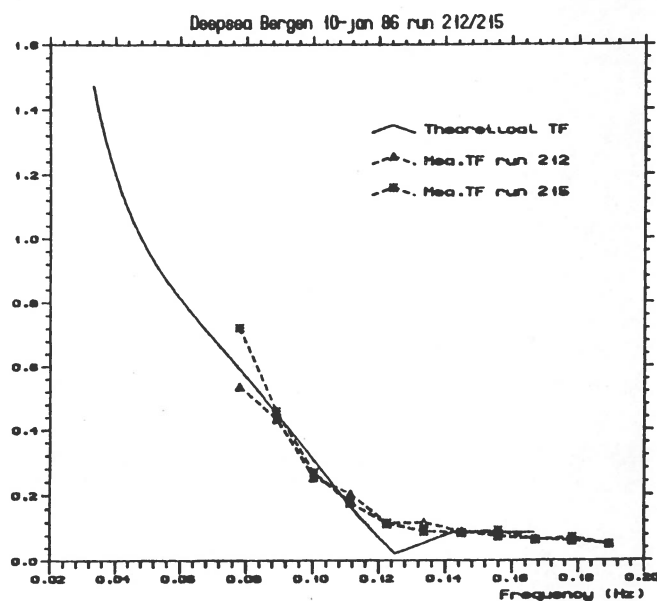


Fig.4.3.1.b) Transfer function of surge

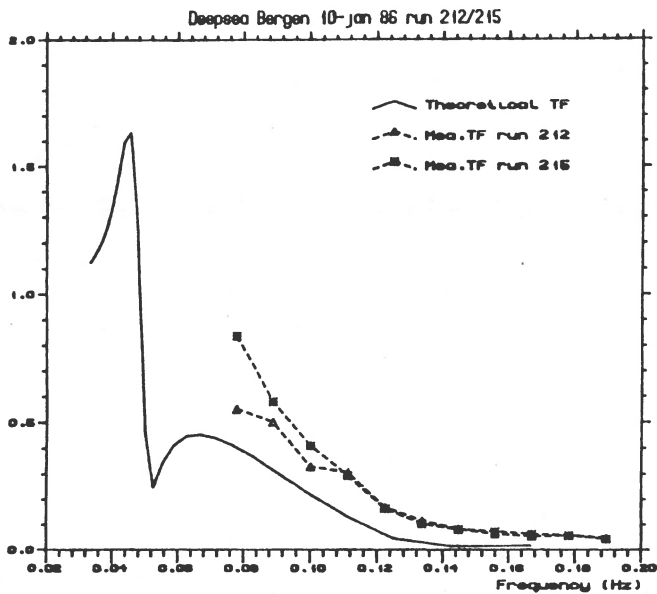


Fig.4.3.1.c) Transfer function of heave

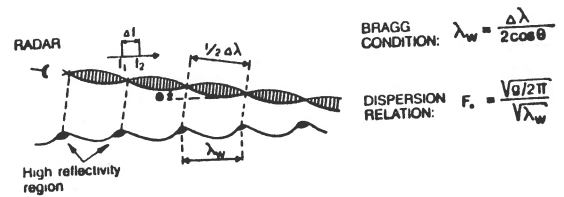


Fig.A.3.1. Dual frequency current measurement

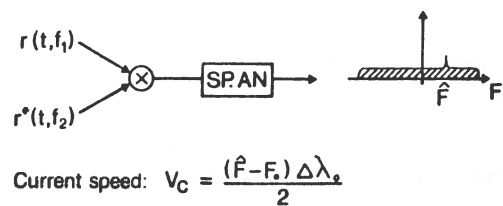


Fig.A.3.2. Surface current signal processing

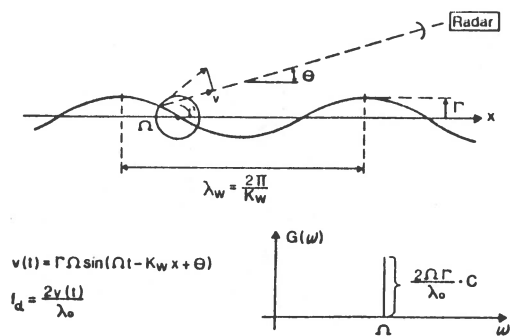


Fig.A.2.1. Pulsedoppler wave height measurement

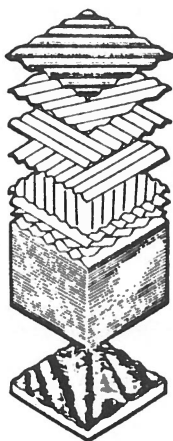


Fig.A.2.2. Sea surface model