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Ultra Wide Swath Deep Sea Interferometric Multibeam Echo Sounder with Sea Bottom Imaging System

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Abstract

The SIMRAD EM12 is a new full ocean depth multibeam echo sounder, operating at 13 kHz. By use of interferometric signal processing techniques it will acheive an ultra wide swath geometry of 150 degrees, corresponding to 7.5 times the depth of water. The system will in addition to the bathymetry produce a fully corrected sidescan sonar image of the seafloor.on to the depth soundings, the EM12 has the capability to generate a sidescan image of the seabed.

Introduction

For mapping of the seabed, multibeam echo sounders are rapidly coming into general use, displacing the singlebeam echo sounders which have been available for several decades. The multibeam echo sounder gives a much higher depth sampling density than the singlebeam sounder, allowing a larger line spacing and thus significantly decreasing required ship time and cost. Important benefits of the multibeam are the detailed charts it can produce, and the 100% coverage without gaps in the data coverage between lines.

SIMRAD has for the last few years delivered the EM100 multibeam echo sounder with a depth capability of 600 m [1]. The new EM12 described here is a multibeam echo sounder with full ocean depth capability. Its design builds on the experience gained with the EM100 and utilizes its unique phase measurement principle for bottom detection. This has allowed a design with an ultrawide swath coverage with a 150° sector and 1° beam spacing, and the inclusion of a seabed imaging capability with meter resolution.

Basic Concepts

In hydrographic echo sounders beamwidth is an important parameter in determining the quality of the measurements. A narrow transmission beam increases the source level and thus depth capability, and also increases accuracy on a rough or sloping bottom due to a smaller footprint (insonified area). A narrow reception beam reduces the received acoustic noise and, if narrower than the transmission beam, may also increase the accuracy. In a singlebeam sounder the transmit and receive beamwidths are usually the same as determined by the transverse dimensions of a common transducer.

In a multibeam echo sounder the transducer is configured as an array of separate transducer elements. By controlling the phasing of the different elements beams with different pointing angles may be formed. In a multibeam hydrographic echo sounder, multiple beams are usually only formed during reception, and the beamforming process has the capability of forming the individual beams simultaneously.

The transmit beam of a multibeam echo sounder is usually narrow alongship and very wide athwartship. The multiple receive beams span the athwartship transmit sector while the alongship receive beamwidth depends upon the roll/pitch stabilization method implemented. The accuracy and depth capability in the outermost beams of conventional systems not using phase information will be inferior compared to the center beams. The decrease in accuracy is due to the increase in footprint and the stretching of the returned echo, leading to uncertainty in where the bottom actually is in the echo.

Interferometric signal processing

Hydrographic applications of interferometric signal processing has been treated in a recent paper (4). The principle is to transmit a short pulse, and during reception of the backscattered signal, to trace the direction to the scattering point as function of time, see fig.1. The direction is measured by comparing the electrical phase of the received signals on 2 transducer surfaces mounted with a known distance. Simple application examples are the different sidescan sonar systems with bathymetric capability, such as the Seamarc II and Bathyscan systems.

Because of their wide opening angle in the atwartships direction, these systems have problems measuring the correct angle whenever 2 signal contributions arrive at the same time at the antenna from different directions, see fig. 2. The interferometric multibeam systems EM100 and EM12 solve this problem by forming receiver beams, and then apply angular tracing of the scattering point inside each beam. The situation illustrated in fig. 2 is thus not a problem anymore, since the multiple reflection signal will appear in a different beam. In this beam it will do no harm either, since it will have a completely different time of arrival than the true bottom return.

Existing multibeam systems

Multibeam echo sounders have been in use for some years to map the ocean bottom. Examples are the General Instrument "Sea Beam" [2], the Krupp Atlas "Hydrosweep", and the Simrad "EM100". The two former systems have full ocean depth capability, while the latter has a depth capability of 600 m.

The conventional full ocean depth multibeam systems typically have a 90° sector coverage with 50 to 60 beams. The signal processing in each beam is similar to the digitizer for a singlebeam echo sounder, and the accuracy capabilities of these systems are thus severely limited in the outermost beams, especially in areas with a rugged or sloping bottom. In contrast, the EM100 uses phase detection to determine the range to the bottom in the exact center of the beam, thus avoiding the drop in accuracy with scan angle. The current EM100 has a 100° sector mode, but experiments have shown that it is possible to expand the sector to 150° with the phase detection principle.

EM12 System Design

A block diagram of the EM12 is shown in figure 3. Its main functional parts are the transmitter with transducer and power amplifiers, the receiver with transducer and preamplifiers, a digital signal processing and control system with bitslice and microprocessors, an operator control system with optical disk data storage and connections to external positioning and postprocessing systems, a Quality Assurance system for seabed map display and system calibration, and a sidescan system for seabed reflectivity display. Mounted beside the transducers is also a sound velocity sensor which is required to have full control of beam pointing angles. The digital signal processors control the transmitter, form the receiver beam, filters the received signal, extracts amplitude and phase information, and do the final bottom detection and tracking.

The EM12 is available in two versions, a single and a dual system. A single system has a set of horizontally mounted transducers with a coverage sector of 90° and 81 receiver beams with a 1.1° spacing. The dual system has two sets of transducers, transmitters, receivers, and digital signal processors with the transducers mounted on each side of the ship, tilted 40° with respect to the horizontal. Each transducer set has a coverage sector of 80° with 81 receiver beams spaced at 1°. A total coverage of 150° is thus obtained with the dual system, with a 10° overlapping sector straight down available for quality control.

The EM12 has an operating frequency of 13 kHz which is a compromise giving good range capability with reasonable transducer dimensions and narrow beamwidths. Two pulselenghts are utilized, 2 msec in a shallow mode and 10 msec in a deep mode. The received signal is sampled with a range resolution of 0.6 and 2.4 m respectively. The shallow mode will be range limited in the outermost beams at a depth in the order of 1000 m for the dual system and 3000 m for the single system (-30 dB backscattering strength). The deep mode has a larger range capability because the longer pulse length gives more energy and also allows narrower filters in the receiver to reduce the noise level.

However, the extra gain this gives is quickly eaten up by the unavoidable spreading loss, and in the EM12 deep mode the source level is therefore also increased by transmitting in five narrow sectors instead of over the whole 80/90° sector as in the shallow mode, see figure 4.

The usual penalty of a sector transmission is a severe decrease in bottom sampling density as the pulse travel time could be up to 20 seconds and five pulses would be needed to cover the whole swath. In the EM12 this is avoided by transmitting the five sector pulses sequentially without delay, and ambiguities in reception due to sector overlap have been eliminated as the sectors have different frequencies spread in a 1 kHz bandwidth around 13 kHz.

The calculated swath width achievable with the EM12 in deep mode is as shown in figure 5. The calculations are for a bottom return loss of -20 and -30 dB straight down, and due account has been taken for the reduction in backscattering strength due to decreasing grazing angle. Full sector coverage is obtained down to 2000 m depth for the dual system and 7000 m for the single system with -30 dB backscattering strength. Note that the swath width is in the order of 15-20 km for the dual system at all depths below 2000 m while the single system swath width is two times water depth almost down to full ocean depth.

Transducers

The EM12 uses separate transducers for receive and transmit due to different requirements on beamwidth and they are mounted in a T configuration. The transmitting transducer has an alongship beamwidth of 1.8° which determines alongtrack resolution. A real time Vertical Reference Unit (VRU) is interfaced to the EM12 allowing electronic roll (±15°) and pitch (±10°) compensation of the transmit sectors to within 1°, with the aim of always insonifying the bottom straight down beneath the ship, thus maximising bottom return and keeping a regular sampling coverage of the seabed. This is achieved by having each of the 384 elements in the transmitter array driven by separate thick film power amplifiers with individual element phase and amplitude under control of the digital signal processors.

The receiving transducer has an alongship beamwidth in the order of 20°, thus no further pitch stabilization is needed in the receiver. Athwartship beamwidth of the receiver is 3.5° normal to the transducer. The receiver beams are roll compensated within ±15° with an accuracy as given by the VRU (typically 0.1°). Each receiving transducer has 42 staves with individual thick film preamplifiers with digitally controlled TVG.

The transducer dimensions and beamwidths have been carefully selected to ease installation problems and to fully exploit the phase detection principle. The transmitting transducer which is mounted along the ship keel, is very long (4.8 m) to give a narrow alongship beamwidth thus increasing accuracy with an alongship bottom slope. The receiving transducer which is mounted normally to the keel, has a length only half that of the transmitting transducer.

In the dual system this lessens the problem of aeration due to the bow wave and allows more freedom in placement on the ship bottom for the single system. The shortening of the receiving transducer gives a larger beamwidth which would have unacceptable in a conventional echo sounder using amplitude detection only, but is not detrimental when phase detection is used. The array configurations are such that no grating lobes exist and sidelobes are generally below -25 dB.

Digital Signal Processing

The beamformer in the EM12 is a digital beamformer using a combination of time delay and phase shifting. To allow phase to be used in the bottom detection the beamformer forms two separate so called halfbeams for each receiver beam. Each halfbeam is formed from the received signals on the 30 staves to each side of the transducer and both signal amplitude and phase is derived. The element shading in the beamforming has been designed so that the total receiver beams or fullbeams can be formed by a simple addition of the two halfbeam signals with low sidelobes in both half- and fullbeams.

The phase difference between the two halfbeams is a measure of the angular direction to the reflecting point on the seabed, i.e. the interferometric principle. At the center of the fullbeam the phase difference will be zero. As the direct phase of a received echo from the seabed will usually be quite noisy, the EM12 preaverages the received signal over a beam dependent number of samples before extracting the phase difference.

For each range sample in every beam the EM12 will thus have both echo amplitude and angular direction available. In the bottom detection process, range to bottom is calculated based on both amplitude and phase information. The calculated range is in the amplitude detection given by the return echo center of gravity, while in the phase detection it is given by the beam center.

In the latter calculation a third order function is fitted to the phase and the zero crossing of this function is used, thus further improving the algorithm's immunity to noise. Simulations have shown that a good estimate of bottom depth can be obtained from the phase measurements even with very low signal to noise ratios (less than 5 dB), see figure 6 which shows the returned signals before and after averaging when the grazing angle is 20°. Note that while a zero phase crossing may be very accurately derived for this data set, no bottom detection is possible from the echo amplitude.

The phase detection (interferometric processing) principle collapses at normal or nearly normal incidence of the beam with the seafloor. This will always be a certain section of the swath. For this section, however, the conventional bottom detection methods such as the center of gravity of the return pulse envelope or similar, will work very well. In the EM12 both bottom detection methods are implemented for all beams as the grazing angles are not known a priori, and quality measures are calculated for both. Based upon the quality measures, a choice is made upon which method is finally used or if a combination is appropriate.

Operator Interface and Data Storage

The operator presentation and control is based upon the well proven concept of the EM100. The operator controls the EM12 through a menu system, and on the operator console along and acrosstrack depths profiles are shown. The depths are calculated with full corrections for the raybending due to a varying sound velocity through the water column, which if not taken into account would lead to errors both in depth and in horizontal distance to the bottom. The sound velocity is partly taken from a probe which gives measured sound velocity values down to 1000 m depth, and for deeper layers, sound velocities may be manually entered from existing sound velocity tables. Both probe and manually entered values may be updated at any time.

The bathymetry is automatically stored on write-only optical disk, thus ensuring the safekeeping of the measured data. Along with the bathymetry, positioning data which is transferred to the EM12 via a serial line, may also be stored. The EM12 is also prepared for transfer of data out of the system, either via serial line, but also on an Ethernet using the standard TCP/IP protocol family. Thus the depth data may in real time be transferred to a postprocessing system such as the SIMRAD Neptune system for immediate onship map production.

A separate Quality Assurance (QA) subsystem in the EM12 displays a contoured map or other presentations such as 3D views of the seabed. A hardcopy of this display may be printed on a color inkjet printer, and a track plotter is also available. The QA system also has facilities for system calibration based upon visualization of depth profiles from tracks run in different directions.

Seafloor imaging

It has been demonstrated earlier (5) that it is possible to generate a sidescan sonar type of image from the beamformed signals of a multibeam echo sounder. In principle this is a good solution, since it is then possible to make a direct comparison between bathymetry and imaging. Because of the beamforming, several artifacts that conventional sidescan sonars have, are minimized or eliminated.

The EM12 multibeam system is the first system to have a built-in capability of visualization of the seabed through a sidescan type of presentation. EM12 is particularly well suited for this, since it is designed with beams that overlap to a high degree with the neighboring beams. In this way the changeover point between one beam and the next will not be visible.

As the angular direction of each range sample is known, the system is able to pick all samples derived from the seabed in non-overlapping portions in every beam, and calculate their correct horizontal position on the seabed. Thus the sidescan display of the EM12 shows the backscattered acoustical energy of the seabed in a geometrically corrected fashion, and by correlating this display with the contour map of the QA system, an onboard scientist will be in a much better position to interpret seabed attributes than with an ordinary sidescan record.

The sidescan display may also be printed on a greyscale or color recorder, and in addition the sidescan data may be stored on a optical disk. Postprocessing of this data which contains the local phase information, will allow the investigation of the microstructure of the seabed, as the effects of local bottom slope on reflectivity strength may be derived from this data.

Conclusion

The EM12 represents a new generation of multibeam echo sounders with full ocean depth capability. The use of interferometric signal processing allows depth measurements to be taken over an ultrawide swath, typically up to 7 or 8 times the depth of water with a dual system. With phase and thus angular direction available for each range sample, the microstructure of the seabed may be investigated thus opening the possibilities for detailed remote classification of the seabed.

The EM12 has already been chosen by three European organizations, IFREMER of France (dual system), WOSL of England, and CSIC of Spain (single systems). Installation of these three systems are taking place this summer and 2 of the systems will be operational by the end of the year.

References

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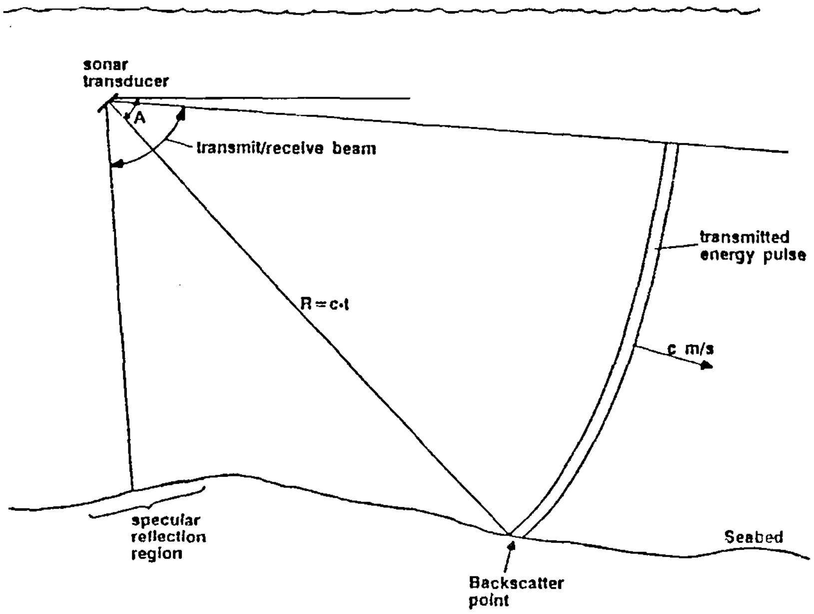

Figure 1
Illustration of interferometric sidescan sonar principle

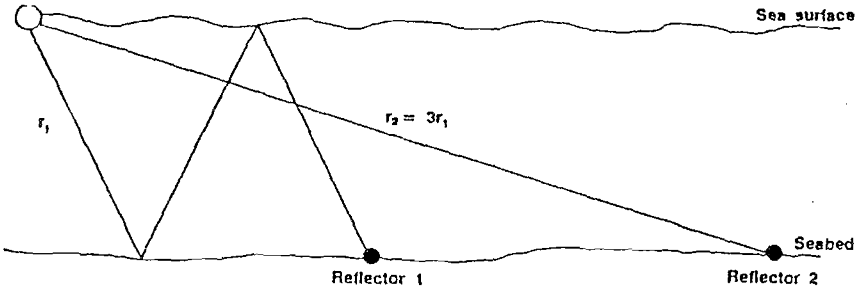

Figure 2
The interferometric sidescan sonar cannot distinguish between reflectors 1 and 2

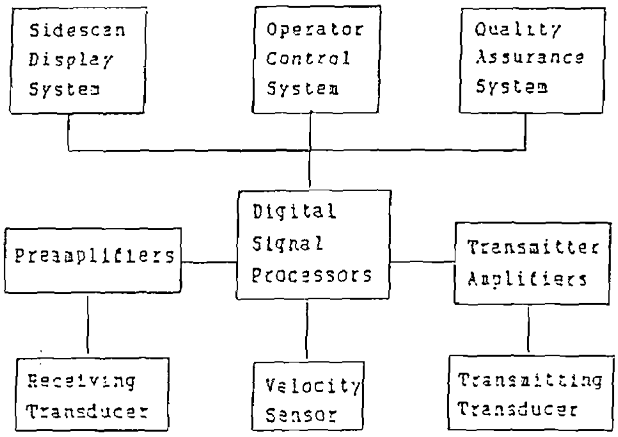

Figure 3, EM12 Block Diagram

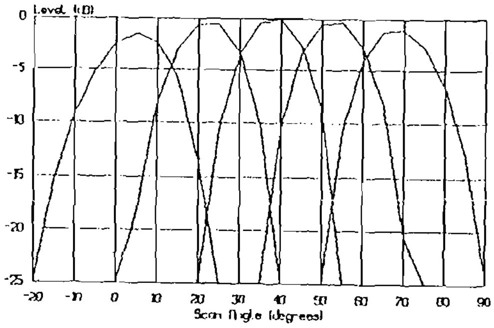

Figure 4. Deep Mode Sector Transmission Dual System (one side).

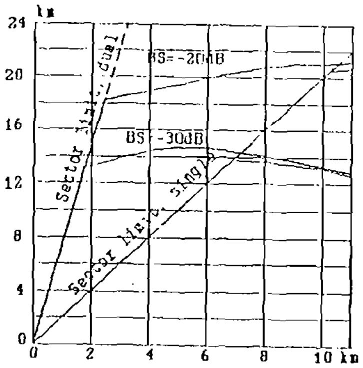

Figure 5. Calculated Swath Width.

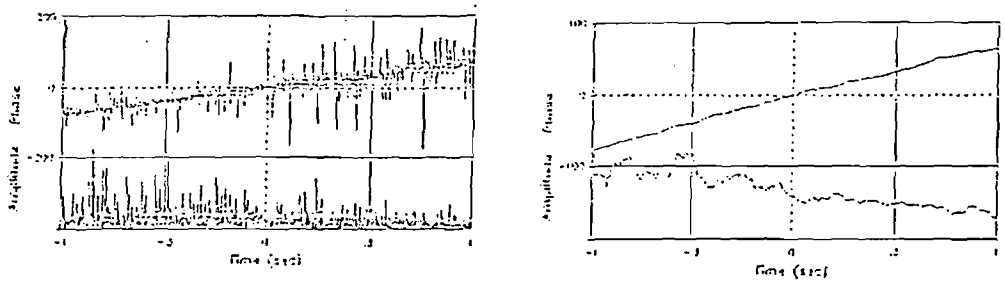

Figure 6
Amplitude and Phase (direction) before and after averaging at 70° Scan Angle