The Design of the New
RCM-9 MkII and RCM-11
Doppler Current Sensor

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Introduction

The Doppler Current Sensors (DCS) 3500 and 3620 are both current sensors with integrated compensation for tilt and magnetic orientation. The 3620 is used as the main sensor in the RCM-9 and the 3500 is delivered as a sensor unit in a buoy system or as a standalone device. The 3500 is rated for 500 meters of water depth and the 3620 is rated for 2000 meters.

The DCS has gained a reputation for being a rugged sensor with adequate specifications. Initially it had some trouble when working in clear waters, but after the release of a modified version in the autumn 1998, the feedback from the customers has been very positive.

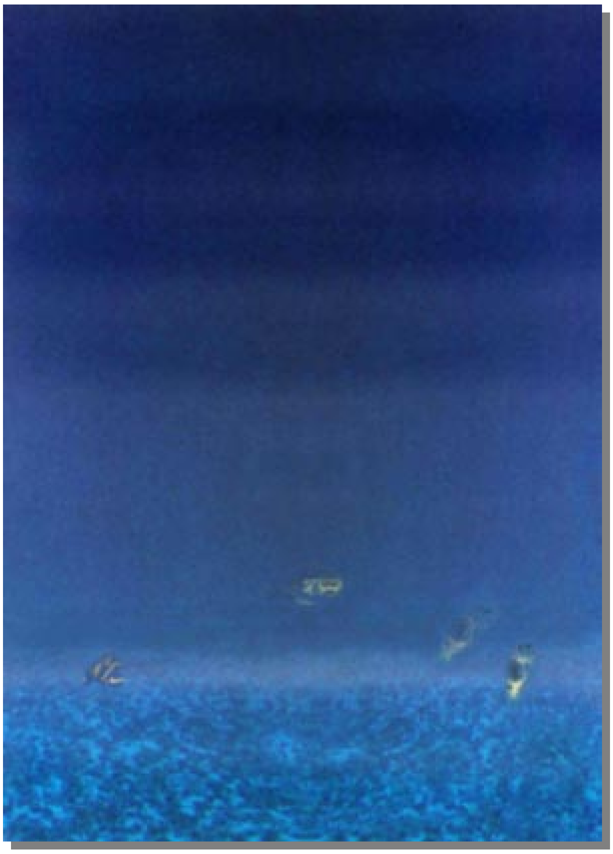
A demand for a deep-water (6000m) version quickly emerged. However, it was clear from the beginning that the present design would not stand the high pressure present at such depths. This design employs an open solution with all components are exposed to the full pressure.

As a consequence, we decided to design a new device from scratch. This device incorporates all recent technology advances in addition to being able to withstand 6000 meters water depth. The work led to two devices sharing the same electronics:

- The DCS 3920, supplied with the RCM-9 MkII.
- The DCS 3820, supplied with the RCM-11.

The first unit has the same depth rating as the previous sensor for the RCM-9, the 3620.

Design Goals and Motivation



The deep-water current meter RCM-8 has for long been the benchmark product for use in water depths down to 6000 meters. It has been, and still is, a reliable instrument for exploring unknown secrets at large depths. The RCM-8 is, however, based on the design of the RCM-7 and employs a mechanical rotor system to extract sea current information.

Even though the rotor based design has proven adequate for most applications, the release of the Doppler based RCM-9 has led to a demand for a similar product for use in deep-water moorings. This is natural, since the RCM-9 has several advantages when compared to the RCM-8 (e.g. no moving parts and no lower current speed threshold).

At the first glance it may seem to be a simple task to enhance the depth capability of the RCM-9: Just pack the instrument into a pressure proof container that will withstand the enormous pressure that exists at such depths. However, using backscatter based Doppler current meters at great depths will put additional demands on the instrument.

The first problem to arise is linked to the amount of scattering obtained. It is expected that the water volume at very deep waters will be very clear with almost no suspended particles. The back-scatter based Doppler current meters rely on particles in the water volume to reflect some of the acoustic energy transmitted. If the water volume is clear, little scattering takes place and the signal-to-noise ratio becomes poor and inadequate.

The second challenge is linked to the low current speeds that are common at great water depths. It is expected that most current speeds measured will be in the range from 0 to 10 cm/s. This is a problem for the RCM-8 due to the speed threshold of the rotor design. The RCM-8 will not measure current speeds below 1.5 cm/s, and even at somewhat higher speeds, the vane based direction measurement may degrade the accuracy. A back-scatter based Doppler system will in theory manage such low speeds, but practical designs will be limited by the ability to measure in low scattering situations and by the performance of the Doppler processing system. Typically, the measured data are too noisy to explore low current speeds, and are as such useless.

The New RCM-11 and RCM-9 MkII Electronic Unit

The RCM-9 MkII and the RCM-11 share the same basic electronic design. Later this year a new version of the DCS 3500 based on the same design will also be launched.

The analog as well the digital part is brand new and employs the most recent developed technology. Most sections have been optimized by means of computer simulation. It is an extremely compact design. Surface mounted components are used whenever possible. It comprises a highly efficient transmitter, an ultra-sensitive receiver, a tilt sensor, a compass sensor and a 100 MIPS (million instructions per second) digital signal processing system.

The new electronic unit supports several input and output interfaces, including:

- SR-10 (standard Aanderaa digital sensor format)
- RS-232C (with full compliant voltage levels)
- CAN-Bus (a future standard Aanderaa interface)

The firmware is located in Flash memory, and the unit may be re-programmed without opening the unit. The programming takes place by means of the CAN-Bus.

The compass and tilt sensors are used to adjust the actual current measurement so that it refers to magnetic North and to the horizontal plane. The tilt and compass readings are usually not available for outside use.

New, ultra sensitive transceiver

As the scattering level becomes low due to clear water, the received signal will also appear noisy and result in a noisy current estimation.

Several contributors cause the noise. The typical one is caused by improper impedance matching between the sensor and the pre-amplifier system. Another is caused by pick-up noise from digital circuits working together with the amplifier system. These noise sources may be almost totally removed by proper design procedures.

Another contributor is the natural acoustic background noise in the sea. At high frequencies this background noise is caused solely by thermal activity. At low frequencies weather conditions and manmade activity introduce additional noise.

The latter type of noise can not be designed out of instruments and represent a kind of limit for how sensitive an acoustic underwater system can be.

The new pre-amplifier employed in the RCM-9 MKII and the RCM-11 is a result of extensive computer simulation where SPICE models have been developed for both the piezo-electric transducer and the electronic circuit. The result is a design with an electronic self-noise as low as 0.5nV/√Hz and an almost perfect impedance match. In addition to low electronic noise, this also ensures a short settling time. Together with proper damping of the acoustic energy radiating out from the rear of the transducer, a short illegible zone is also achieved.

New, advanced signal processing system

The RCM-9 MkII and the RCM-11 also include an all new digital signal processing system. A new processing algorithm has been developed. It combines several statistical and spectral estimation algorithms and achieves excellent frequency resolution even when the signal-to-noise ratio is poor. The frequency resolution is further improved by utilizing a shaped transmit pulse with little side lobe leakage.

The new algorithm is carried out in a new, low power Digital Signal Processor (DSP) capable of 100 MIPS. Putting the DSP to sleep between each ping calculation reduces power consumption. As a result, the new high capacity processing system is no more power hungry than the counter system employed in the old RCM-9.

As before, each ping is compensated for tilt and compass orientation by means of an integrated tilt and compass sensor.

"Upstream" Measurement Technique Yield Highest Performance

2-D single point current meters will, by nature, introduce a measurement error when put into the water volume in which they are supposed to measure. The presence of the instrument itself will upset the current and modify it such that the current measured will be slightly different from what it would have been if the instrument were not present.

The major reason for this is the flow disturbance of the water as it passes by the instrument. The disturbance dominates in the downstream section of the water flow. As a rule of thumb, a distance of approximately 20 times the diameter of the instrument is disturbed by the presence of the instrument. The upstream section is, on the other hand, only affected in the volume up to one diameter from the instrument.

There are several possible ways to overcome this problem:

- It can be adjusted for in the software algorithm.
- The measurement could take place in a water volume above the transducer that is not upset by the instrument.
- The measurement could take place in the upstream section of the water volume (the section that holds waters flowing towards the instrument).

The first approach is difficult to achieve with acceptable accuracy since the disturbance is speed dependent and vary with time. The compensation would have to consider the actual current speed and take into account the effect of possible turbulence that could be present.

The second approach would indeed measure in an undisturbed water volume, but not in the one in which it is supposed to measure. When installed at large depths and far away from the bottom or the surface, this should not lead to major errors. But, if the measurement takes place close to the surface or the seabed, the current situation measured above the instrument could be completely different from the one at the level of the instrument.

Another disadvantage with this solution is the degradation of the signal-to-noise ratio. In order to measure horizontal current above the instrument, the acoustic beam must be angled. If the angle were 45^{o}, vector decomposition would lead to a signal that is only 0.7 of what it would have been if the measurement took place normal to the current direction. As a result, the noise in the estimated current speed will increase by 3dB.

The RCM-9 and the RCM-11 employ the third solution. By constantly monitoring if the Doppler shift is negative (the current flows away from the transducer – downstream), or positive (the current moves towards the instrument – upstream), the system selects the two transducers that are pointing towards the direction of the current. In this way, each measurement takes place in the undisturbed, upstream section of the water volume. This eliminates the error caused by the presence of the instrument, while still measuring the water volume in question with optimal signal-to-noise ratio.

Ultra-low Power Consumption

The new electronic system achieves benchmarking results while consuming very low power. This is achieved by the use of a highly efficient power amplifier and low power components. In addition, the digital signal processors are shut down between each measurement.

RCM-11 Doppler Current Sensor for High Pressure Environments

The RCM-11 high-pressure sensor is based on the design of the RCM-9 MkII, but the acoustic sensor unit and the sensor electronics are separated. The electronics system is housed in a pressure resistant container with atmospheric pressure inside, while the acoustic sensor is exposed to the full pressure outside. A balanced design ensures that the pressure on all surfaces of the sensor elements remains the same.

The acoustic sensor unit is placed on top of the electronic unit and acoustically isolated to prevent acoustic coupling between the sensor unit and the electronic housing. Initial studies showed that reverberation noise was a main noise contributor when improper de-coupling occurred between the acoustic sensors and the titanium based electronic housing.

The RCM-9 avoids this problem since the acoustic sensors and the electronics are molded into an epoxy resin with excellent reverberation properties.

Performance Figures and Field Results

Improved Specifications

Both the RCM-11 and the RCM-9 MkII offer improved specifications when compared to the RCM-9 MkI. Most enhancements are the result of improved sensitivity and signal processing. The new benchmark figures are achieved without sacrificing the usual benefits associated with a backscatter based Doppler Current Meter. The new generation RCMs is still extremely rugged, insensitive to fouling and easy to deploy.

Improved Accuracy.
The accuracy specification has been enhanced from *2cm/s to 0.5cm/s*. The accuracy is given as a standard deviation figure. As such it is a figure for the expected noise, which will be the main contributor to an error in the measurement. Another contributor could be drift in the oscillator circuit, but since the RCM-9 and RCM-11 employ the same oscillator for the transmitting as the receiving circuit, this contribution will be negligible.

A more dominant, but correctable contributor to degradation in total accuracy is a deviation in the speed of sound from the one used by the RCM. Both the RCM-9 and RCM-11 assume that the speed of sound at the time of measurement is 1500 m/s. If it is not, an error would be introduced. However, the measurement could be adjusted for the actual speed of sound using the formula provided with the operating manual. Or, even more elegant, you can use the Data Reading Program 5059 to automatically adjust the current measurement by calculating the actual speed of sound using corresponding measurements from the optional temperature, pressure and conductivity sensors. This could be achieved using the 5059's virtual sensor feature. In this way, you will have each record adjusted for the actual current speed that was present at the time and position where the current measurement took place[1].

Improved Resolution.
The RCM-9 MkII and the RCM-11 has a resolution of *0.3cm/s* as compared to the old RCM-9 0.5cm/s. The increased resolution is the result of the improved performance and allows for the exploration of even smaller current deviations.

Improved Capability to Measure in Waters with Low Backscatter.
The new generation RCMs is able to operate in even clearer water volumes. For Aanderaa Instruments this has been a major design goal. For us it is not acceptable to state proper functioning at “typical oceanographic scattering levels”. We know the cost and effort involved in deploying a mooring, and we fully understand the disappointment that occurs when the instrument is retrieved one year later with no data.

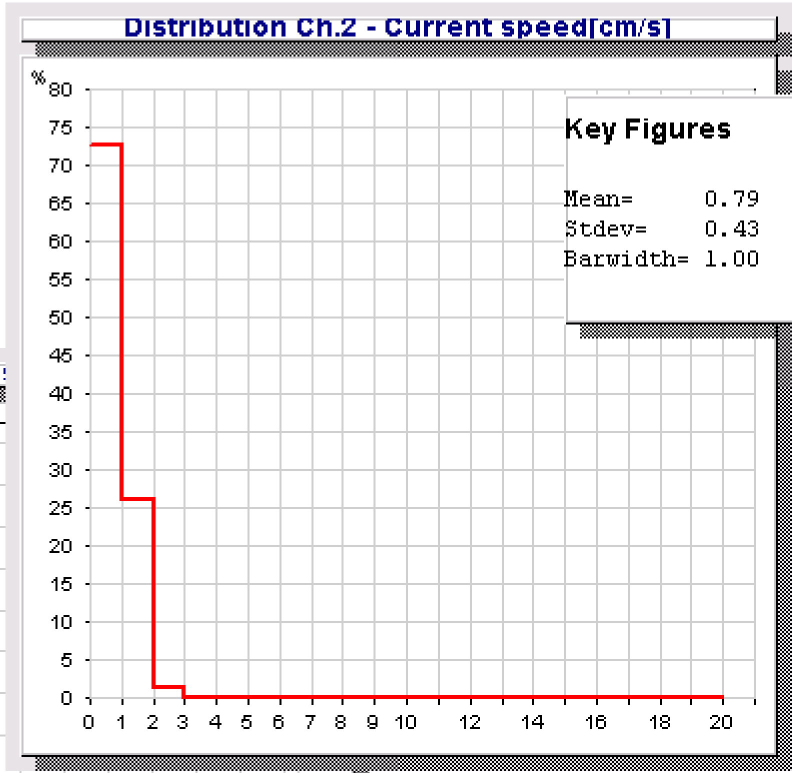
With the introduction of the ultra-sensitive sensor system in the RCM-9 MkII and RCM-11, the customer should retrieve current data equally well in Arctic waters, inland lakes and rivers as in dirty and polluted harbor based waters.

[1] To utilize the Virtual Sensor feature of the 5059, you need a licensed 5059. The virtual sensor feature is not available in the free, non-licensed version.

Field Results

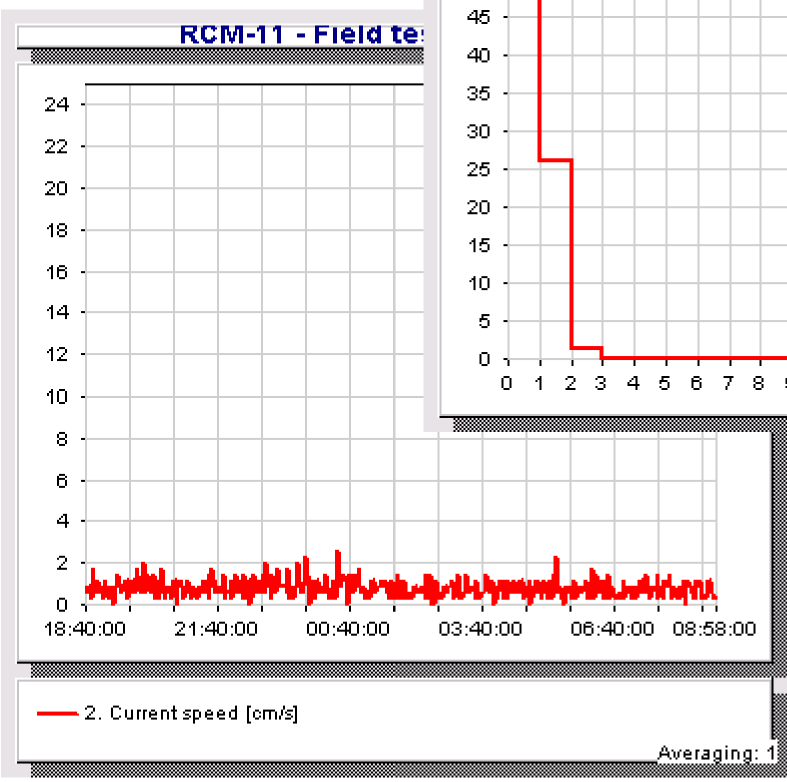
Low Current Situation

The figures below[2] show the result of a deployment of the RCM-11 in a Norwegian winter inland lake with very low scattering levels. Aanderaa Instruments uses this lake for testing purposes because of its low currents and low scattering levels.



The measurement was made in February 2000. Most records took place during the night with an outside temperature close to freezing point. There was no precipitation.

The graph below shows the current speed in [cm/s] as measured by the instrument. The recording interval was set to two minutes.

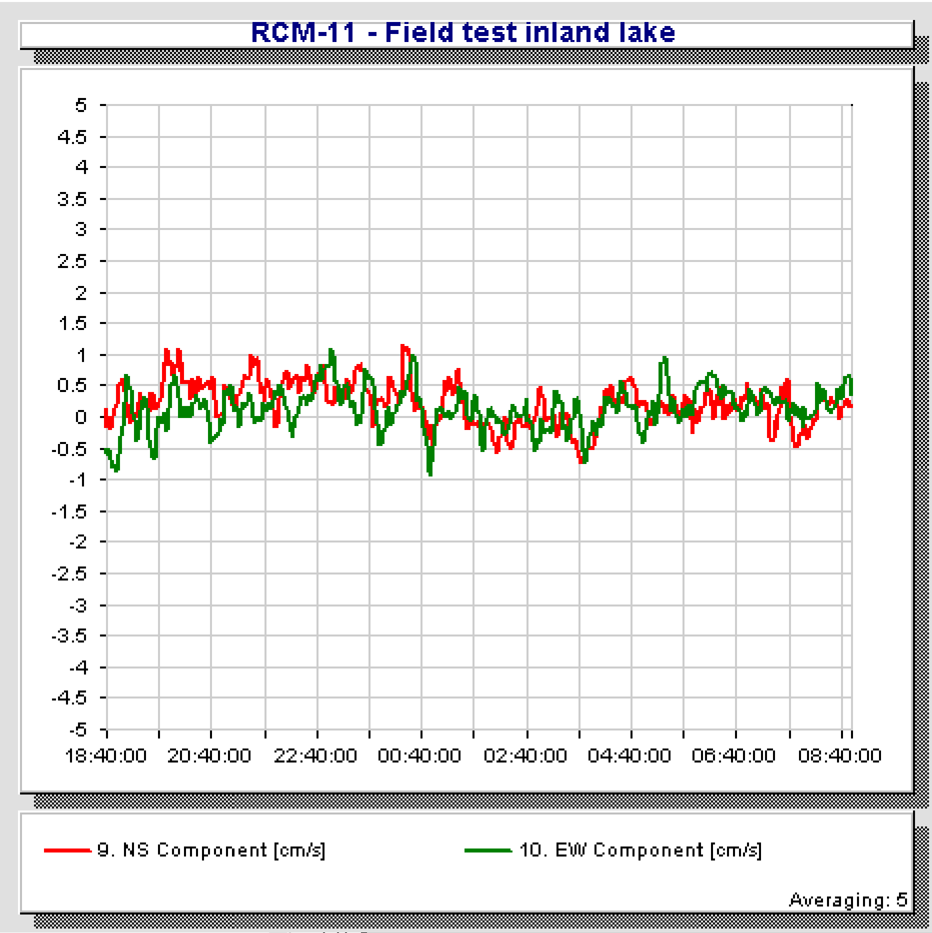


A statistical view of the measurement is shown in the graph above. The key figures show an average current of 0.79cm/s and a standard deviation of 0.43cm/s.

This figure is well within the given specification of 0.5cm/s. In reality, the noise introduced by the instrument is even lower.

Although the anticipated current speed is close to zero, it is not completely zero. If we employ a moving average filter (size 5) to the current speed records, the result will be as shown in the graph on the next page.

[2] The graphs are produced using the Data Reading Program 5059 available from Aanderaa Instruments.

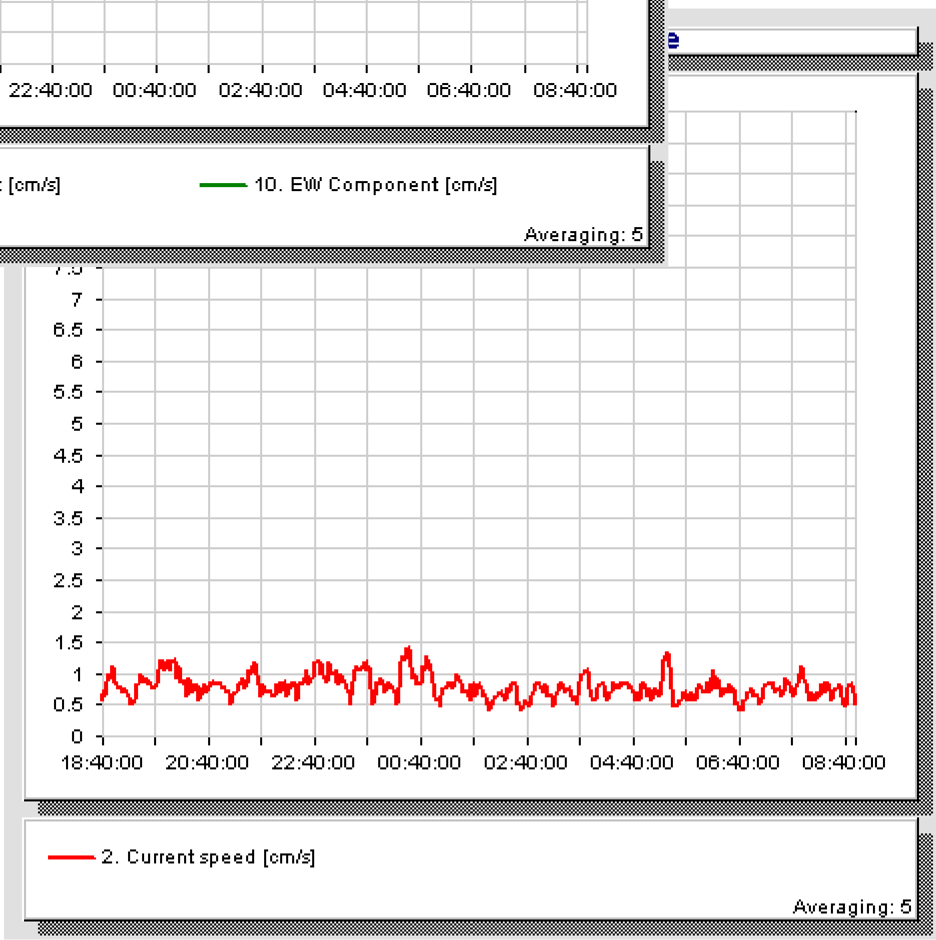


The graphs on this page show the same measurement when treated with a moving average filter of size 5.

In the upper graph, the current is split into a North and East component, and the lower graph shows the current speed vector.

The actual current speed now stands out better. It has varied from 0.5 to 1.5cm/s.

This variation is included in the 0.43cm/s standard deviation figure given on the previous page.



Consequently, the noise introduced by the instrument itself is in fact even lower.

It is an interesting graph, showing that even small current variations may be explored using the RCM-9 or the RCM-11.

The RCM-11 and RCM-9 is also free from any offset error, which is inherently present in some other designs.

Comparing the RCM-11 with the RCM-7

Many customers have relied on the RCM-7 and the RCM-8 (the deep-water version of the RCM-7) for gathering current data. Over the years, they have built up an extensive library that includes data from a variety of sites.

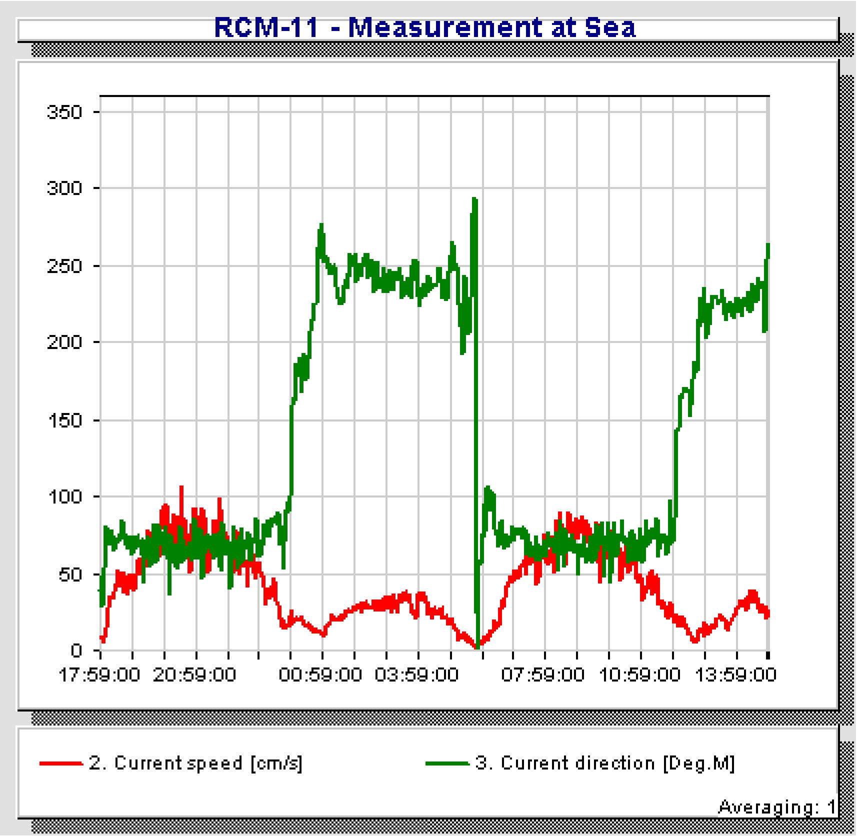
Often measurements are performed repetitively to track changes in the sea current situation at the same location. For these applications, it is important that new measurements may be compared with older measurements.

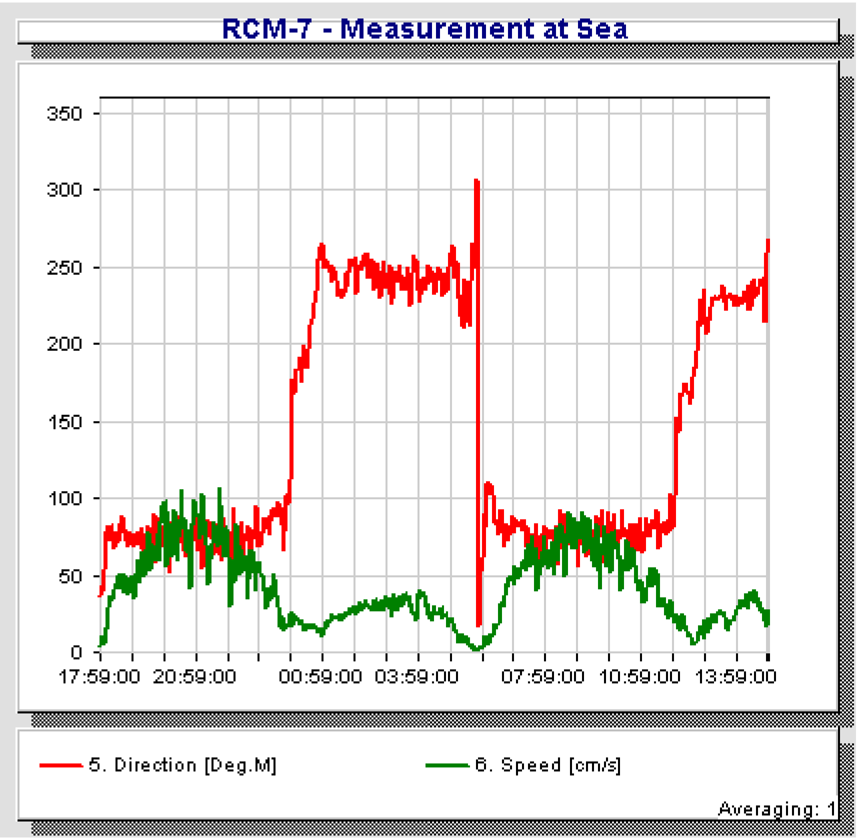
The two graphs on the right hand side are the result of a comparison test between the RCM-11 and the RCM-7. The deployment took place in the open sea at approximately 15 meters depth. The distance between the RCM-7 and the RCM-11 was 1.5m, and the deployment duration was almost one day.

The measured data from the RCM-11 is shown in the upper graph, and the data from the RCM-7 is shown in the lower graph.

The colors used for current speed and current direction are interchanged in the two graphs. This is due to the DRP 5059's color assignment procedure and the placement of the current data channels in the RCM-11 and the RCM-7. The 5059 assigns red to the first visible channel and green to the next visible channel.

The two graphs show unprocessed data exactly

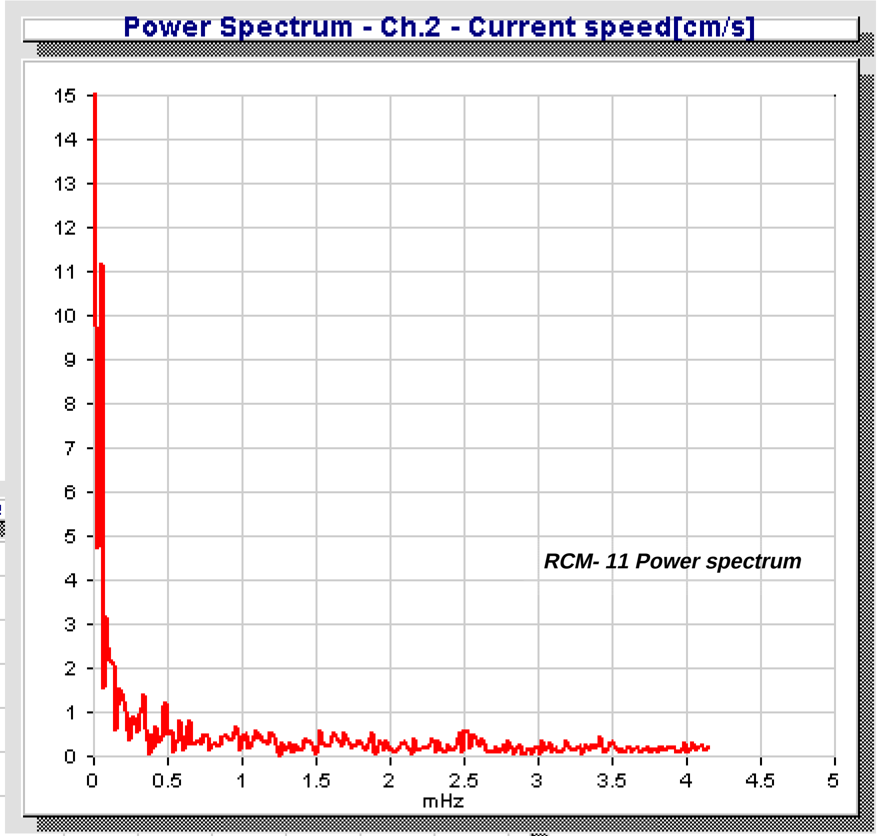


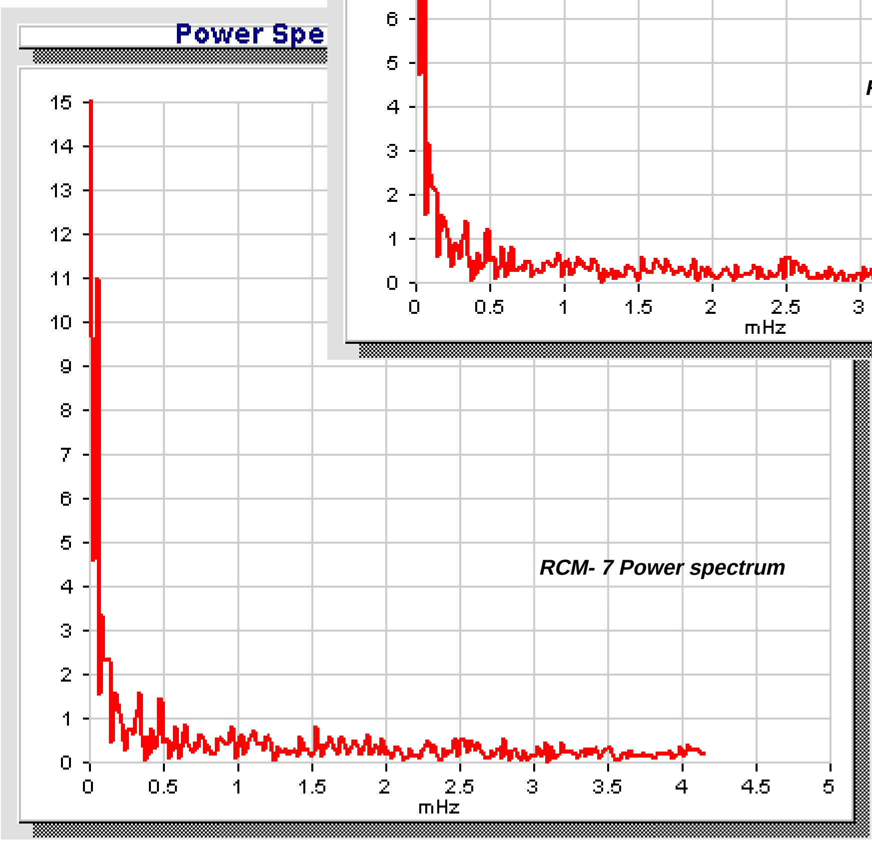


as they were read from the Data Storage Unit.

Another interesting observation from the comparison test between the RCM-11 and the RCM-7, is the lack of noise generally associated with backscatter based Doppler Current Meters.

The RCM-7 is rotor based and therefore does not have statistical





noise in the current estimation. Backscatter based Doppler current meters usually have statistic noise. The amount of noise is specified as a standard deviation figure.

The RCM-11 is optimized for low statistic noise. This can be clearly seen from the two power spectrum graphs shown above and to the left.

The *upper* graph shows the power spectrum for the RCM-11 measurement series, and the lower graph shows the power spectrum associated with the RCM-7 measurement series.

As can be seen from the two graphs, the RCM-11 does not add any significant amount of noise to the measurement series when compared to the RCM-7. This is also confirmed by the key statistical figures outlined in the table below:

Key Figures – Sea Trial:	Mean Current Speed	Standard Deviation - Speed
RCM-7	41.50 cm/s	23.97 cm/s
RCM-11	40.81 cm/s	24.00 cm/s

Conclusion

The new generation of Doppler Current Sensors from Aanderaa Instruments has been designed for improved performance in environments with low acoustic scattering and low currents. Those are qualities that also will enhance the instrument performance in general terms.

Several improvements have been included in the new design:

- The new transceiver electronics achieve extremely low noise figures, and the new transducer design has almost no reverberation noise. As a result, almost all information presented to the digital signal algorithm originates from the acoustic signal picked up by the transducer.
- A new digital signal-processing algorithm has been designed to achieve high resolution in frequency, even when the signal is noisy. The somewhat complex algorithm is carried out in a new Digital Signal Processor (DSP) capable of 100 MIPS with very low power consumption.

The new sensor achieves improved performance when compared to the old RCM-9, while still keeping the "simple to use and operate" philosophy:

- The standard deviation noise (which is the main contributor to degradation in accuracy in the RCM-9 design) is reduced from 2cm/s to 0.5cm/s.
- The resolution has been improved by 60%.
- The sensor has an improved sensitivity in the range of 6dB, allowing it to operate in even clearer water than the old RCM-9.
- The new sensor design employed in the RCM-11 allows for operation down to 6000 meters water depth without noticeable degradation in performance.

In a test deployment together with the RCM-7, the RCM-11 and the RCM-7 produced measurement data that were almost replicas of each other. This shows that the RCM-11 may replace the RCM-7 (and thereby the RCM-8) in most application areas. In deployments where the current speed is expected to be very low, the RCM-11 will achieve improved performance when compared to the RCM-7 or RCM-8.

The second generation of Doppler based current meters, RCM-9 MkII and RCM-11, fully exploit the advantages of backscatter based Doppler Current Meters, while keeping the simple philosophy embedded in all Aanderaa products. The new current meters are extremely rugged, almost insensitive to fouling and designed for easy deployment and use in rough environments. These carefully designed instruments will produce valuable data in almost all environments.

Notes