R/V Falkor Multibeam Echosounder
System Review

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<td>Very Deep CW – Single swath SN</td>
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<td>Very Deep CW – Single swath NS</td>
<td>55</td>
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<tr>
<td>Extra Deep FM – Single swath, SN</td>
<td>56</td>
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<td>Extra Deep CW – Single swath, SN</td>
<td>56</td>
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Introduction

RV Falkor is equipped with Kongsberg Maritime (KM) EM302 and EM710 multibeam echosounders (MBES). Both systems underwent Sea Acceptance Trials (SATs) in May 2012 in Sognefjord, Norway. The bathymetric and topographic constraints imposed by the fjord limited the ability to fully test the EM302. Additional system testing was conducted during a second set of trials while in transit from Newcastle-upon-Tyne, UK to Nuuk, Greenland in July 2012. It is the intent of this report to document the outcome of both trials and to provide an assessment of the capabilities of both systems with respect to their advertised abilities.

System Overview and Ancillary Instrumentation

The EM302 is a 30 kHz MBES capable of full ocean depth mapping though it is most optimally used in depths from 1,500 to 3,000 m. The EM302 system is available in a number of transmit/receiver configurations; the system aboard Falkor provides 1°x1° angular resolution, yielding seafloor sounding resolution on the order of 1.7% of oblique range. Though the system is nominally 30 kHz, the full frequency range is 26.5-33.6 kHz.

The EM710 frequency range spans 73-97 kHz; the system aboard Falkor is capable of 0.5°x1.0° transmit and receiver angular resolution, respectively. The EM710 system is well suited for continental shelf mapping with maximum coverage being achieved at depths typically between 500-1,000 m. Maximum depth performance is typically less then 2,000 m.

Both systems allow for seafloor mapping over a swath of 140°, giving a roll stabilized coverage up to 5.5 x water depth (w.d.). The systems are capable of multiple sector transmission, this allows for pitch/yaw motion stabilization and also multi-ping capabilities. The latter functionality doubles the along-track sounding density and permits surveying at higher speeds without loss of data density.

The ancillary components of the two mapping suites are listed below:

- SeaPath 320 heading, attitude and positioning sensor
- CNAV positioning correction service
- Seabird 19+ Conductivity Temperature Depth (CTD) profiler
- Valeport SV profiler
- Turo XBT
- Valeport miniSVS surface velocimeter
- SBE38 and SBE45 thermostalinograph
Sensor Geometry Verification and Calibration

System calibration was done during the Sognefjord trials in Norway with both systems being calibrated simultaneously. Prior to calibration procedures, the ship survey report was reviewed to establish the geometry of the various sensors and sensor components used in support of seabed mapping. Linear and angular offsets of all seabed mapping system components were established from the ship survey report and were compared with the current configuration of the MRU and multibeam echosounder systems. Linear and angular offsets agreed in all cases with the exception of the water line Z offset from the reference point (a discrepancy of 0.10 m, this was corrected in the EM710 and EM302 configurations).

A standard “patch test” procedure was used to determine the residual angular misalignment angles between the MRU and the EM710/EM302 arrays. Calibration lines were run with both systems operating simultaneously without synchronization. Residual angular offsets were nearly negligible (<0.05° for roll, pitch and heading). The data acquired in support of pitch and heading alignment were suboptimal due to limited availability of seafloor targets in the fjord. Given the small magnitude of the offsets, the uncertainty in the estimated pitch/heading offsets will have minimal impact on bathymetry data accuracy. Final system installation results are summarized in Table 1 below.

Table 1. Summary of Installation Geometry.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EM710</th>
<th>EM302</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter X</td>
<td>18.84 m</td>
<td>18.89 m</td>
</tr>
<tr>
<td>Transmitter Y</td>
<td>-2.12 m</td>
<td>-1.32 m</td>
</tr>
<tr>
<td>Transmitter Z</td>
<td>6.09 m</td>
<td>6.09 m</td>
</tr>
<tr>
<td>Transmitter roll</td>
<td>0.13°</td>
<td>0.05°</td>
</tr>
<tr>
<td>Transmitter pitch</td>
<td>0.25°</td>
<td>0.21°</td>
</tr>
<tr>
<td>Transmitter heading</td>
<td>359.74°</td>
<td>359.85°</td>
</tr>
<tr>
<td>Receiver X</td>
<td>17.45 m</td>
<td>16.94 m</td>
</tr>
<tr>
<td>Receiver Y</td>
<td>-2.28 m</td>
<td>-1.61 m</td>
</tr>
<tr>
<td>Receiver Z</td>
<td>6.10 m</td>
<td>6.11 m</td>
</tr>
<tr>
<td>Receiver roll</td>
<td>-0.07°</td>
<td>0.10°</td>
</tr>
<tr>
<td>Receiver pitch</td>
<td>-0.39°</td>
<td>0.49°</td>
</tr>
<tr>
<td>Receiver heading</td>
<td>179.95°</td>
<td>359.82°</td>
</tr>
<tr>
<td>MRU X</td>
<td>0.00 m</td>
<td>0.00 m</td>
</tr>
<tr>
<td>MRU Y</td>
<td>0.00 m</td>
<td>0.00 m</td>
</tr>
<tr>
<td>MRU Z</td>
<td>0.00 m</td>
<td>0.00 m</td>
</tr>
<tr>
<td>MRU roll</td>
<td>0.00°</td>
<td>0.00°</td>
</tr>
<tr>
<td>MRU pitch</td>
<td>0.00°</td>
<td>0.00°</td>
</tr>
<tr>
<td>MRU heading</td>
<td>0.00°</td>
<td>0.00°</td>
</tr>
<tr>
<td>Waterline Z</td>
<td>0.57 m</td>
<td>0.57 m</td>
</tr>
<tr>
<td>Positioning time latency</td>
<td>0.00 sec</td>
<td>0.00 sec</td>
</tr>
</tbody>
</table>
**Accuracy Testing**

Accuracy testing was conducted in as many modes as possible within the limited range of depths available during both cruises. These are discussed separately by cruise below with plots from all testing being presented in Appendix A and B.

**Sognefjord, Norway**

Accuracy testing was conducted in two separate areas with differing depths. The first area, approximately 1,200 m deep, provided suitable testing ground for the EM302 system as the system is able to track the seafloor over its entire angular sector (+/-70°) in these depths. The EM710 was only able to track the seafloor to +/-45° (this is expected due to the higher frequency of the system; this particular model typically begins to lose outer swath coverage at water depths of ~500 m).

Accuracy testing was done by conducting a seabed survey with survey lines parallel to the long-axis of the fjord with line spacing of 600 m (300% coverage for EM302 and 200% for EM710). Cross lines, run orthogonally to the main lines, were acquired with soundings from the cross lines being compared to a reference surface constructed from the main lines. Both systems show beam depth biases less than 0.05% w.d. across the majority of their achievable swaths; standard deviations about the mean bias are within +/-0.10% w.d (1-σ) across the majority of the swath with higher uncertainties at the limits of the swath as expected. Both multibeam systems provide bathymetric measurements that are in agreement with the expected performances of the systems for DEEP mode (EM302) and EXTRA DEEP mode (EM710). This must be tempered with the cautionary note that there was very little vessel motion during the survey due to very calm sea conditions in the fjord.

The second area, with depths of approximately 250 m, provided the opportunity to test the shallower mode functionality of both systems. The procedure used in the deep-water test area was repeated with three long main survey lines oriented with the long axis of the fjord and spaced at 400 m, yielding better than 200% coverage. Five cross lines, running orthogonally to the main lines, were collected at 500 m line spacing. Both systems were operated in SHALLOW mode.

The EM710 performed within expected tolerances. A small depth bias (0.1% w.d.) was observed across the swath; this bias increased systematically with each cross line and is consistent with an uncorrected water level shift, likely due to the tide (<1 m range, according to the pilot). The sounding uncertainty about the mean bias was less than 0.1%w.d. (1-σ) over a sector of +/-50°, reaching 0.2%w.d. at 65°. Discounting the depth bias due to uncorrected tide, the system performs within expected tolerance levels in SHALLOW mode.
Despite running in shallow mode, the EM302 data suffered from sub-bottom mistracking artifacts, predominantly in a +/-30° sector centered on the nadir region. This is typical for the EM302’s 30 kHz operating frequency and the soft sediment on the floor of the shallow fjord; in these water depths it is preferable to use the EM710 for this reason and also for the EM710’s superior angular and range resolution. On average, the EM302 mistracked too deeply across the entire swath as compared to the EM710. Uncertainties were dominated by the poor tracking at nadir and the usual high uncertainties at the edge of the swath (+/-0.25%w.d. and 0.5%w.d. bias, respectively, both reported at 1-σ confidence level). In the off nadir regions around +/-45°, however, the sounding uncertainties improved, dropping to 0.15%w.d. (1-σ). It is expected that this system would have improved performance in these water depths over harder grounds. Real-time data filters are available in SIS to deal with sub-bottom penetration; their use should be explored when using the EM302 in soft sediment areas to mitigate mistracking artifacts observed in the shallow water test area. It is also possible to steer the transmit beam in the fore-aft direction to reduce the specular nature of the bottom and sub-bottom returns at nadir; this should be used with caution (Beaudoin and Schmidt, 2010).

The easternmost and deepest of the cross lines was chosen for repeat runs in order to assess as many of the other operational modes as possible. Observed uncertainty levels were consistent with expected performances despite the small data set collected for this. The EM302 suffered from mistracking in the nadir region due to the relatively low operating frequency (30kHz) and the soft seafloor sediments. Pronounced nadir mistracking was observed when operating the EM710 in Very Shallow and Shallow modes when the EM302 was also running (in Shallow and Medium mode, respectively). This mode of operation is not representative of how the systems would be used during mapping operations and is of little concern but is noted regardless. It should be also noted that the systems were synchronized with the Ksync unit. Results for the shallow water testing are summarized in Tables 2 and 3.

Table 2. EM710 Bathymetric Performance.

<table>
<thead>
<tr>
<th>Pass</th>
<th>Mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very Shallow,</td>
<td>Depth uncertainties +/-.05%w.d. (1-σ) over central sector (+/-40°) rising to +/-.30%w.d. (1-σ) at 65°</td>
</tr>
<tr>
<td></td>
<td>single swath</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Very shallow,</td>
<td>Similar uncertainties as observed in single swath mode. Pronounced nadir mistracking; most likely from interference from EM302, this behavior was not observed during the standard cross lines when the EM302 was also running, in this scenario the EM710 is in Very Shallow mode and the EM302 is in Shallow mode; the mistracking is only observed in one of the swaths of the dual swath pair, suggesting a frequency selectivity</td>
</tr>
</tbody>
</table>

7
Table 3. EM302 Bathymetric Performance.

<table>
<thead>
<tr>
<th>Pass</th>
<th>Mode</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shallow, single swath</td>
<td>Higher uncertainties relative to EM710, mostly due to sub-bottom mistracking discussed earlier; nadir uncertainty of +/-0.25%w.d. (1-σ), dropping to +/-0.15%w.d. (1-σ) at 45° and back up to +/-0.25%w.d. (1-σ) at 65°.</td>
</tr>
<tr>
<td>2</td>
<td>Shallow, dual swath</td>
<td>Slightly elevated uncertainties relative to Shallow/single swath mode.</td>
</tr>
<tr>
<td>3</td>
<td>Medium, single swath</td>
<td>Similar behavior as observed in Shallow/Single swath.</td>
</tr>
<tr>
<td>4</td>
<td>Medium, double swath</td>
<td>Similar behavior as observed in Medium/Single swath.</td>
</tr>
</tbody>
</table>

Offshore Sognefjord, Norway

After leaving Sognefjord at the tail end of the sea trials in May, an additional test was done just offshore of the mouth of the fjord in order to assess the accuracy of the systems under realistic sea states. A short survey was conducted in 400 m water depth with the EM710 running in DEEP mode and the EM302 running in MEDIUM mode. The DEEP mode for EM710 uses FM pulse waveforms for the outer sectors and CW waveforms for the inner central sector; the FM waveforms allow for increased coverage due to the higher signal-to-noise (SNR) afforded by long FM pulses. The EM302 maintains the use of CW pulses across its entire angular sector while in MEDIUM mode.

The same methodology was used to assess sounding repeatability as was done in previous trials in the fjord. A main line survey consisting of three 4 NM survey lines, spaced at 350 m, was run with both the EM302 and EM710 simultaneously pinging. A set of five cross lines were then run orthogonally to the main line survey scheme. Data were tidally reduced with a global tidal model (Florent et al., 2006).

The EM302 suffered from significant bottom penetration problems at nadir over a sector of approximately +/-30°. This is typical of this system in shallower areas. It
can be remedied somewhat by intentionally tilting the transmit sector fore or aft to reduce the specular nature of returns in the nadir region. This can be done by adjusting the “Along Direction” value in the Transmit Control section under the Sounder Main tab in the Runtime Parameters menu. There are limitations to this method and it is possible to introduce other types of data artifacts, for further discussion see Beaudoin and Schmidt (2010). The sub-bottom penetration data can be removed by hand in a standard swath editor, however, this is extremely tedious in areas of variable terrain. Averaging the data does not help either since the mean values at nadir are biased towards the lower sub-bottom data, producing a trench artifact in this region.

Figure 1. Sun-illuminated terrain model showing outer sector "wobbles" in EM710 DEEP mode. Wobble magnitude is on the order of a few meters and varies with ship pitch/heave. The effect is constant across the FM sector (affects all beams in the sector equally) and appears to be depth independent (does not grow with depth).

The EM710 cross line analysis indicates that the inner CW sectors perform very well with 0.1% w.d. depth uncertainty over the entire inner sector out to 35°-40° with nearly negligible mean bias across the sector once tidal corrections are applied. The outer FM sectors were contaminated by a significant time-varying depth bias shift
across the entire sector that is correlated with pitch and/or heave. This introduces a so-called “wobble” in the outer sectors that significantly detracts from data quality (see Figs. 1-2): sounding uncertainty in the FM sectors is on the order of +/-0.35% w.d. (1-sigma), see Fig. 3. This is outside what is typically achievable by such systems when properly configured (Beaudoin, 2012a).

Figure 2. Transition from EM710 DEEP to VERY DEEP mode (which uses all FM sectors). The "wobble" artifact contaminates the entire swath in VERY DEEP mode.
Figure 3. Beam depth bias statistics for EM710 DEEP mode. Bottom plot shows scatter plot of beam biases with mean bias (per 1° bin) plotted as solid colored lines with color coding indicating swath number in dual-swath geometry and sector number. Dashed lines indicate 1-sigma standard deviation, also plotted in the upper plot.
This artifact, which has a peak-to-peak range reaching a few meters at times, was witnessed again during the later sea trials and was found to exist in all three modes that use FM signal waveforms: DEEP, VERY DEEP and EXTRA DEEP. It was not noticed during the Sognefjord trials due to the very low vessel motion.

In its current state, the FM waveforms severely limit the usability of the EM710 data and effectively restricts its depth range to that achievable in MEDIUM mode, the last mode in which CW pulses are used across the swath. This depth mode is typically meant for depths between 200-300 m, however it can be used in deeper water depths but at the cost of limited coverage compared to what would have been achievable with FM pulse waveforms in the outer sectors.

As there are no other motion correlated artifacts, the source of the problem can be likely isolated to the additional calculations required for modes of operation that use FM waveforms. FM pulse waveforms require the calculation of the transducers vertical velocity through the water during transmission and reception in order to account for the Doppler shift due to vertical motion through the water (pitch/heave). The Seapath calculates the information necessary for these corrections and provides them to both the EM302 and EM710 via UDP messages separate from the traditional serial line motion data stream. Both the EM302 and EM710 systems were verified to be receiving these corrections and that the corrections were identical for both systems. The EM302 is likely suffering the same problems however it does not use FM waveforms until it reaches DEEP mode at 750-3,300 m depth and the small, depth independent heave artifact is likely drowned out by other sources of depth dependant uncertainty.

Further investigations during the second sea trial found that the Seapath data output rate for this correction was 1 Hz when it should be typically delivered at a rate of 50-100 Hz. It is our understanding that the Seapath was configured in this manner by the manufacturer. This particular problem was unfortunately not resolved until the last day of the cruise and thus could not be tested to verify that it is indeed the source of the FM data artifacts. Instructions were provided to the Marine Technicians (MTs) to allow them to conduct verification tests upon reaching suitable water depths after leaving from Nuuk for the next cruise.

**Greenland**

Accuracy trials in deep water (~2,900 m) off the coast of Greenland allowed for deeper testing of the EM302 system. The same assessment methods from Sognefjord were used with a reference surface being constructed with seven long (14 NM) main line survey lines spaced at 3,000 m, yielding 200% coverage. A single cross line was planned over the flattest portion of the area and was run repeatedly eleven times, allowing for accuracy assessment in the deeper modes of operation as
Several permutations of EM302 configuration parameters were investigated for the purpose of seabed imagery calibration over the eleven cross lines. From an accuracy analysis point of view, many of the permutations investigated were redundant and the results can be summarized by the sounder’s depth mode.

DEEP mode

CW mode is less than 0.2% w.d. over +/-55° with nadir region uncertainties as low as 0.05%w.d. for the central CW sectors. FM mode has slightly higher uncertainty levels in the outer two sectors but was able to track to +/-60° in the same water depth as compared to the CW modes where all sectors use CW pulses.

VERY DEEP mode

CW mode is less than 0.2%w.d. over +/-55°. FM mode has slightly higher uncertainty levels across all sectors but still maintained the same performance of less than 0.2%w.d. over the same angular sector.

EXTRA DEEP mode

The EXTRA DEEP mode is limited in angular coverage to +/-35°. It maintained nearly constant level of 0.1%w.d. depth uncertainty across this swath in FM mode with slightly better improvement in at nadir and at the outer edge of the swath in CW mode: 0.07%w.d.

None of the modes of operation suffered from any large biases or systematic bottom mistracking however, a slight (<0.02°) roll residual bias does appear in some, but not all, of the investigations. The residual varied in magnitude from line to line and was sometimes not present at all; this could be explained by a small misalignment of the MRU axes that would allow for crosstalk between the pitch and roll signals (whenever the vessel takes on a static change in trim due to change of speed through the water, for example, the measured pitch signal bleeds through as a small roll signal, see Hughes Clarke, 2003).

The EM710 system was test in an operational sense during a grid search for the wreck of SS Terra Nova just off the coast of Greenland. Very good results were achieved and the fact that the wreck was positively identified using the EM710 in depths of 160 m is evidence of the quality of data achievable with the EM710 system in shallower water. It should also be noted that the system was operated in VERY SHALLOW mode even though this mode is meant for water depths less than 100 m (recall that the depth was 160 m). Despite using a shallower than recommended setting, the system resolution and performance was observed to be quite good.
**Achievable Coverage**

Sognefjord provided little opportunity to exercise the full range of depths capable by both systems. Early assessments from the fjord data set indicated that the EM302 was able to maintain a full +/-70° swath over the entire range of depths in the area of operations. The EM710 coverage was observed to be attenuation limited at a depth of typically 500 meters.

The North Atlantic crossing provided several opportunities to push the coverage testing further under a range of realistic conditions. The EM710 was able to track the seafloor to a depth of 2,200 m, which is typical of this system, see Figs. 4 and 5. The system became attenuation limited at depths around 500 m, this varied slightly with seafloor scattering strength as did the achievable swath coverage below this depth (see Fig. 5, note color coding of soundings and extent of coverage achieved).

![Figure 4. EM710 depth/coverage/mode during crossing of North Atlantic. The EM710 was unable to track the bottom for the majority of the crossing. Note the mid-Atlantic ridge at 108 hours. Acoustic interference from other sounders early on during the cruise caused significant mistracking and loss of coverage, e.g. hours 0-4 and 22-24. Modes 0-5 correspond to VERY SHALLOW, SHALLOW, MEDIUM, DEEP, VERY DEEP and EXTRA DEEP. The system successfully auto-tracked and changed depth mode for most of the cruise and required little user intervention. FM waveforms were enabled.](image-url)
Figure 5. Scatter plot of EM710 outermost soundings for the entire North Atlantic crossing. Color coding depicts seafloor backscattering strength. Stronger scattering seafloors permit increased coverage beyond the attenuation limit depth of ~500 m.

Similar plots for the EM302 are shown in Figs. 6 and 7. The system became attenuation limited at depths of 1,000-1,500 m, depending on the seafloor’s backscattering strength. Coverage grew more slowly with depth beyond this point and is consistent with expected results. Coverage curves like those of Figs. 5 and 7 can be used to predict performance during survey planning stages. Modeling by Lurton can be used to predict the coverage performance of the EM302 for deeper depths until deeper ocean depths are encountered, refer to Ifremer report titled “Coverage & Performance Predictions for Multibeam Echosounders” for additional details and discussion. It should be noted that sea conditions during the crossing were remarkably good and the systems have yet to be tested under heavier sea states.
Figure 6. EM302 depth/coverage/mode for North Atlantic crossing. Compare to EM710 performance in Fig. 4. The mode codings are equivalent to those of the EM710; note that the sounder remained in DEEP mode for the majority of the crossing with only short deviations to deeper modes during coverage testing by Lurton (hours 72-82). Acoustic interference from other sounders early in the cruise impacted on coverage, e.g. hours 18-24, 40-42.
Figure 7. Scatter plot of outermost EM302 soundings indicating achieved coverage during North Atlantic crossing.

**System Selection**

Having access to two mapping systems extends the operating range of depths over which *Falkor* can effectively work however some considerations must be made when choosing the optimal system for a particular range of depths. There is no clear answer to this as the performance of either system can be specific to the seafloor scattering environment (e.g. sub-bottom mistracking is not always present with the EM302 in shallow water), the oceanographic conditions, and also end-user specific requirements for a particular operating frequency, etc.

Some comments can be made regarding the hardware that can provide a good starting point when deciding on which sonar to choose from:

- The EM710 allows for greater spatial resolution due to its 0.5° transmitter beam (the EM302 has a 1.0° degree beam).
- When operating in the correct depth mode for a given depth, the EM710 always allows for greater range resolution due to its smaller pulse lengths. Finer range resolution allows for improved definition of seabed targets, such as wrecks, in the seabed imagery data (why the EM710 was optimal for the *SS Terra Nova* search).
When operating shallower than \(~500\) m, both systems provide the same across track coverage. When operating deeper than this, the EM302 will provide greater coverage.

The use of FM waveforms allows for increased range performance but at the price of increased sounding uncertainty in those sectors using these waveforms. This is a recognized limitation of this particular mode of operation. Sounding uncertainty can increase by as much as 50% in sectors using FM as compared to their CW counterparts.

Both systems use CW pulse lengths in their shallower depth ranges of operation and reserve the use of FM waveforms for use at greater depths. See Table 4 for a summary.

<table>
<thead>
<tr>
<th>MODE</th>
<th>EM710</th>
<th>EM302</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth range (m)</td>
<td>Waveforms</td>
</tr>
<tr>
<td>Very Shallow</td>
<td>0-100</td>
<td>CW</td>
</tr>
<tr>
<td>Shallow</td>
<td>100-200</td>
<td>CW</td>
</tr>
<tr>
<td>Medium</td>
<td>200-300</td>
<td>CW</td>
</tr>
<tr>
<td>Deep</td>
<td>300-500</td>
<td>CW+FM*</td>
</tr>
<tr>
<td>Very Deep</td>
<td>500-1,000</td>
<td>FM*</td>
</tr>
<tr>
<td>Extra Deep</td>
<td>1,000+</td>
<td>FM*</td>
</tr>
</tbody>
</table>

* In these modes, FM cannot be disabled. When “FM disabled” is chosen, the system switches to Medium mode.
** In these modes, it is possible to disable the use of FM waveforms and to use CW waveforms instead.

The EM710 is clearly preferred for depths less than 300 m with FM pulse waveforms disabled. This will allow the sounder to be run in “AUTO” depth mode, but it will restrict itself to only CW modes, i.e. it will NOT switch to Deep mode even if the water depth warrants this. The EM710’s Medium mode can, of course, be used for greater depths. In this operating mode, the system may not be able to maintain full coverage to its typical depth of 500 m as it will typically be using Deep mode at this point, i.e. the depth at which the system becomes attenuation limited will get smaller.

It should be noted that both sonars could be operated simultaneously with the K-Sync without only minor interference between the two systems when configured to ping simultaneously in shallow water (< 250 m, based on results observed in shallow testing area in Sognefjord). The drawbacks to using both systems simultaneously are (1) the cost of additional data storage media, and (2) increased data processing and data management work.
Seabed Imagery Quality and Normalization

Introduction

Having correct measurement and display of the seafloor imagery data is indispensable for using MBES in seafloor imaging and seabed characterization applications. This was most evident during the search for SS *Terra Nova* during the FK003 cruise: the wreck was seen in the real-time imagery display quite easily but was barely discernible in the bathymetry displays. To maximize utility of seabed imagery data, calibration of a sounder’s intensity output is necessary.

An *absolute calibration* of the recorded levels is today still out of reach considering the current state of the art - although a first attempt has been done by the UNH/Ifremer team onboard *Falkor* during the Norway cruise, taking the opportunity of using the calibration system installed for the single-beam sounder calibration. This first trial gave interesting preliminary results, and the data are presently being analysed by a PhD student in Brest. It is expected that this data set will contribute in the years to come to the progress on this particular topic – which is indeed an important current concern for the MBES community.

On the contrary, a *relative calibration* is today a realistically feasible operation. The purpose is to ensure that:

1. The response of the system is homogeneous across a given swath, meaning that all the biases introduced by the directivity patterns of the sounder are properly compensated;

2. The measured seafloor echo strength intensity is the same whatever the working mode of the sounder (“Shallow”, “Medium”, “Deep”, etc), meaning that the various parameters that typically vary with working mode, such as the source power, pulse duration, etc., are properly accounted for.

Though the manufacturer of *Falkor*’s mapping systems applies relative calibrations to the sounders prior to delivery, the calibration parameters are common to all echosounders of the same model and do not allow for the slight differences between systems. Furthermore, the intensity calibration of an MBES can be subject to drifts over time due e.g. to the aging of transducers. Current practice is either to apply the corresponding calibrations in post-processing, or to modify a set of configuration parameters (named *BSCorr.txt* in the Kongsberg systems) such that output data are calibrated in real-time. The relative calibration operations have been applied to EM 302, and are described below.

**EM 302**

**Intra-mode angular calibration**
The basis of the relative calibration is to have backscatter data recorded on a flat and homogeneous area, featuring a high enough number of pings (so that a statistical analysis is meaningful) and recorded over the relevant variety of sounder configurations. This can be done ideally by running the same line under the various modes; alternatively this can also be done along one same line over a seafloor expected to be homogeneous and changing the settings along the line.

The processing method for identifying the directivity biases applicable to the EM 302 data was the following (all these functionalities are available in the SonarScope® software suite developed by Ifremer, which was used along the cruise):

- Compensation of the Time Varying Gain function applied by the echosounder, and application of another function with a higher accuracy. After this step, the “reflectivity”, now expressed as a function of the angle at the sonar array, is as close as possible of the physical value of the angular backscattering strength.

- Plot of the average backscatter level as a function of angle, in order to emphasize the various transmission sectors.

- Fine-tuning of offset values to apply to each sector in order to homogenise the sounder response over the complete angle span. This is done by visually checking the continuity of the sectors and the symmetry of the response around the Nadir direction.

- At the end of the tuning operation, the parameters obtained can be used either for a post-processing operation of the complete sonar images obtained with this particular sounder, or for modifying the parameters stored in the echosounder’s imagery calibration file (the BSCorr.txt file).

Figures 8 and 9 illustrate the process for two modes of the EM 302. Each figure shows:

- The original seabed image
- The angular response curves from the original data
- The angular response after fitting for continuity and symmetry (and, for the second example, level agreement with a reference level – in this case the FM measured level)
- The modified seabed image (obtained equivalently by post-processing of the data or by modification of the BSCorr parameters).
Figure 8. Angular equalization of the Deep FM Dual mode of EM 302 (16 sectors). (a) Original reflectivity data; (b) angular average response; (c) angular response after compensation; (d) equalized reflectivity data.
Figure 9. Angular equalization of the Deep FM Dual mode of EM 302 (16 sectors). (a) Original reflectivity data; (b) angular average response; (c) angular response after compensation, and compared to the FM curves (taken as a reference); (d) equalized reflectivity data.

Inter-mode relative calibration

For the inter-mode calibration, the goal is to obtain the same average backscatter value on a given seafloor whatever the sounder working mode. This is obtained by comparing the average reflectivity values obtained under the various modes, and computing the differential values usable for compensation as shown in Fig. 10.

During this second analysis, large intensity offsets were indentified between the modes with some as high as 5 dB, which is quite large considering the system is supposed to be at least factory-calibrated. This observation is presumably evidence of some problem in the algorithm of reflectivity estimation applied by the
manufacturer inside the sounder processing. A report of these observations will be sent to Kongsberg.

The discrepancies between the various modes have been integrated as far as possible in the calibration file (BSCorr.txt) to adjust for the inter-mode offsets in real-time.

Towards absolute calibration

During analysis to derive these corrections, it was noticed that there is a non-negligible, nearly constant signal level offset between CW and FM sub-modes of the depth modes, typically 2-3 dB. The FM mode values were used as a reference point for the inter-mode normalization procedures primarily since they were acquired first, however, we tend to trust the imagery processing of CW pulses (it is a more mature technology) and would prefer to use these as the reference points instead of the FM pulses. A corrective shift has been applied to all EM 302 modes to compensate for this effect by setting the **system gain offset** to -3 dB in the EM 302 "System Parameters" tab of the installation parameters window. Alternately, this could be embedded directly into the calibration file (BSCorr.txt) by adding 300 (equivalent to 3 dB) to all the figures of the first column.

As the intent of this corrective shift is to bring the signal levels closer to true acoustic backscattering strength estimates, a verification procedure was done dockside in Nuuk with the EM710 to ensure that all signal imagery data products are updated by the system gain offset (too shallow to test with EM302). Testing confirmed that the system gain offset that is specified in the Installation Parameters in correctly applied to:

1) Water column data
2) Seabed imagery data
3) Beam averaged reflectivity measurements

The gain offset does not appear to be applied to the raw stave data. We also note that SIS limits the range of the system gain offset to -10 to +10 dB.

The system gain offset was confirmed to be recorded in the standard output file format (.all) in the Installation Parameters datagram as field GO1 (Gain offset, sonar head 1).

It should be noted, however, that the corrections applied by the bscorr.txt file are not preserved in the ".all" data file output by the sounder. If users are interested in recovering the true seabed backscatter then additional files should be recovered from the system:

- bscorr.txt from the TRU
- attenuation profiles used in compensation
Figure 10 Example of processing for a line featuring 10 different modes of the echosounder. The upper plot displays the complete backscatter recording, with the ping number plotted vertically. The lower plot is the average backscatter level measured for each ping. (a) Deep FM Dual; (b) Deep FM Dual –10 dB; (c) Deep FM Dual –20 dB; (d) Deep FM Dual –10 dB; (e) Deep FM Dual max; (f) Very Deep FM; (g) Very Deep FM –10 dB; (h) Very Deep FM –20 dB; (i) Medium Dual max; (j) Medium Dual –10 dB. One can observe the very clear steps in measured backscatter, especially with the Very Deep mode. The strong peaks at the mode changes are due to the time needed by the sounder electronics to adapt to the new settings.
The first is stored on the server with the EM302 configuration files. It can also be retrieved from the EM302 TRU via FTP through the following steps:

1. Ensure that the TRU is energized.
2. Open a command prompt on the EM302 computer.
3. Type the following commands:
   a. `ftp 157.237.14.60`
   b. `get bscorr.txt`
   c. `exit`

The file will be found in the directory in which the FTP command was typed.

**EM 710**

The same methodology described for EM 302 imagery was applied to EM 710. The principle of definition and computation of the angular response curves is exactly the same.

However an important difference is that the sounder is not equipped with the BSCorr functionality, meaning that the real-time compensation cannot be applied by the sounder. Hence all the image equalization has to be done in post-processing.

During the Sognefjord cruise, the methodology of investigation of the mode-dependent modulations was applied. Areas supposed sufficiently homogeneous were surveyed with the sounder set in all the various modes successively. Unfortunately, it appeared to be difficult to find areas meeting the criteria of sufficient extent (considering the sounder’s swath width) and a flat and homogeneous seafloor. This is caused by the very particular bathymetric relief of the Sognefjord – usually finding such areas is not a problem.

It was, however, possible to identify the corrections to be applied to most modes. Figure 11 gives an illustration of the post-processing results for EM 710 data (Medium mode, 3 sectors) presented in the raw conventional “Ping/Beam” geometry. Figure 12 presents comparable data displayed in a geo-referenced framework.
For now, nothing more can be done regarding the intrinsic calibration of EM 710 in terms of backscatter measurements and all the compensations must be done in post-processing. Several software packages offer such functionality: the imagery processing performed along the cruise used SonarScope®, but similar results can be obtained using GeoCoder.

It should be noted that the shortcoming of EM 710 in this respect is not a serious limitation in its use for sonar image acquisition and exploitation, provided that the angle compensation is applied in post-processing. For instance the wreck search conducted in the South Greenland area provided imagery of excellent quality, which proved to be very well adapted to the purposes of its use.

The manufacturer Kongsberg has been asked to provide the EM 710 MBES with a BSCorr functionality similar to the one available in EM 302. It is not known today what is the schedule for this improvement.
Figure 12. Application of the backscatter compensation to EM 710 data (Shallow mode) in mosaic geometry

Configuration Management

An optimal base configuration was established for both echosounders and saved to configuration files by exporting the PU parameters. These files document the following:

1. Communication configurations of the various input instrumentation
2. Installation geometry (locations and angular offsets of instrumentation)
3. Run-time parameters (sonar settings that can be modified at run-time)

The configuration imposed by these files will not provide optimal configuration under all circumstances. They are meant, instead, to provide a safe starting point from which settings can be modified to accommodate the needs of a particular mapping cruise. They also provide safe default parameters to support unattended data acquisition while in transit as they will allow the sounder to automatically adapt to changing depth conditions.

These files can be imported to bring the sounders to a good working condition in case of accidental misconfiguration or restoration after a system crash. They can
also be used to restore the system to a known operating state after cruises where many operators have had the chance to tweak the system without documenting what has been changed. The MTs have been shown how to export and import these parameters and have been advised to store these configuration files in a safe backup location to allow for system recovery. The configuration file that normalizes the backscatter imagery for the EM302 has also been supplied to the MTs with the advice to store the file on an alternate drive.

Software and Documentation Installation

SVP Editor

SVP Editor is an application that provides pre-processing tools to help bridge the gap between sound speed profiling instrumentation and multibeam echosounder acquisition systems. This software was developed and is maintained by the Multibeam Advisory Committee (MAC) under NSF grant 1150574 (Beaudoin, 2012b). The software is freely available online at http://mac.unols.org. This software has been installed on the CTD processing machine and training has been provided to all MTs.

The software supports all sensor formats available on Falkor (XBT, Valeport SVP, and Seabird CTD) and provides for graphical data interaction in which the operator can validate measurements, remove outliers and extend profiles beyond their maximum sampling depth using oceanographic databases. It is recommended to use this software to process and upload all sound speed information for both MBESs.

Once data management procedures are place, it is encouraged that SOI operate the mapping echosounders whenever possible to help support the seabed mapping community efforts to increase high-resolution mapping coverage of the world’s oceans (e.g. GMRT). The SVP Editor has a “Server” mode in which sound speed profiles, used for refraction correction of the multibeam data, can be delivered to the mapping systems. The sound speed profiles are derived from oceanographic databases and provide reasonable depiction of average temperature and salinity for the world’s oceans. This facilitates underway, opportunistic mapping without the additional burden of acquiring XBTs.

Cookbook Documentation

Cookbook style documentation has been provided to the MTs to facilitate operation, configuration and system backup/recovery:

1. SIS Configuration Backup
2. SIS Software Uninstall
3. SIS Software Install
4. SIS Startup

These provide detailed, step-by-step instructions that allow those who are not necessarily intimately familiar with the system to undertake essential software tasks. These documents have been developed in support of the U.S. academic fleet under the same NSF grant that enabled the SVP Editor. These documents are continually updated and newer versions can always be found on line at http://mac.unols.org.

**Conclusion**

The two systems EM 710 and EM 302 gave very satisfying results all along the cruise. The data quality was found to be very consistent with the manufacturer’s nominal specifications, with SOI expectations, and with our own experience of MBES performance at sea on comparable platforms. The EM710 data are of poor quality when operating in FM mode, this is very likely due to a misconfiguration of the output data rates in the Seapath. We have provided the MTs with instructions on how to verify that it has been remedied.

The system installation documentation was found to be insufficient during the first set of trials in Sognefjord and it is our understanding that this remains the case. The information regarding the wiring installation detailed drawings and the transducers directivity is incomplete. This still needs to be rectified.

The two MBES systems EM 302 and EM 710 are considered to be acceptable under their present state, accounting for the reservations made upon documentation.

**Recommendations**

1. A yearly check up on the status of the system should be done either by the manufacturer or by a third party.
2. Maintenance contracts should be sought with the manufacturer if these have not been pursued already.
3. The configuration files should be loaded prior to every survey project to ensure a safe starting configuration. Any changes in system configuration (e.g. changing data ports, etc) should start by the import of the last known good settings, followed by the required changes and followed by an export of the updated settings as a new set of parameters.
4. A project file naming convention should be established for the multibeam data. The following format is suggested: CRUISEID_INSTRUMENT_SEQUENCE_SURVEYNAME
Where:

- CRUISEID is the cruise identifier
- INSTRUMENT is either EM302 or EM710
- SEQUENCE is zero-padded three digit integer that increments with cruise subprojects
- SURVEYNAME is a descriptive name for the particular project

The CRUISEID allows for easy sorting of cruises. The INSTRUMENT field helps manage data by instrument. The SEQUENCE field helps keep cruise sub-projects sorted in the order that they were acquired. The SURVEYNAME helps keep track of the purpose of the survey. Here are some examples:

FK003_EM710_000_PatchTest  
FK003_EM710_001_TransitToArea  
FK003_EM710_002_MainSurvey  
FK003_EM710_003_ReturnTransit

5. An automated backup and data transfer system for MBES data should be implemented. Data are currently copied manually (drag and drop) to the network data drive. This is **HIGHLY** error prone and will eventually result in loss of data. Common errors are: (1) copying data files while they are still actively being written to and (2) forgetting files. Further aggravating this is the fact that hand-made directory structures on the network may differ from the local directory structure. This makes it extremely difficult to ensure that all data have been transferred and backed up. Commercial software does exist to automate these tasks and should be sourced. Backup and transfer scripts, run perhaps from a Linux machine with access to both network directories, are another option but these rely heavily on all personnel being able to understand, modify and update the scripts.

6. MTs should prepare a set of standard operating procedures for the multibeam systems. The familiarity with the mapping systems varied between the technicians and such documentation will prove helpful in maintaining the level of service and knowledge in operating these systems as technicians rotate on and off the ship for crew changes.

7. It was found that the IP addresses of the two multibeam systems had changed between the two cruises. Upon investigation, it was found that the two machines were configured for DHCP network address assignment. This is acceptable, however, it is **strongly** recommended that the science computers be assigned static IP addresses by the DHCP server.

8. The video matrix display has at least on occasion during the FK003 cruise contributed to loss of data. In this particular case, the last operator had left the mouse icon position over the “Logging” button in SIS. When the next operator wiggled the mouse to see what screen was active (a very common occurrence in such an installation), the overly sensitive built-in mouse pad
on the keyboard reacted to the operator’s touch as a mouse click event and subsequently caused the computer to stop logging data without the operator even realizing what they had done. During the second cruise, we all slowly learned to “leave the mouse pointer somewhere safe on the screen” when leaving the video matrix. The video matrix is likely most useful for monitoring of systems during which computer interaction is minimal. If watch standing is to be done with the multibeam systems, or for any other system for that matter, it is recommended to use the dedicated workstations at the aft end of the lab.
References


Appendix A – EM710

Very Shallow – Single swath (Sognefjord)
Very Shallow – Dual swath (Sognefjord)
Shallow – Single swath (Sognefjord)
Shallow – Dual swath (Sogneford)

![Graph showing Depth Std. Dev. (%W.d.) vs. Beam angle (deg) and Depth bias (%W.d.) vs. Beam angle (deg).]
Medium – Single swath (Sognefjord)

Beam angle (deg)

Depth Std. Dev. (%w.d.)

Depth bias (%w.d.)

Beam angle (deg)
Medium – Dual swath (Sognefjord)
Deep – Dual swath (offshore Sognefjord)

![Graph](image)

- Depth Std. Dev (%w.d.)
- Beam angle (deg)

![Graph](image)

- Depth bias (%w.d.)
- Beam angle (deg)
Extra Deep (Sognefjord)
Appendix B - EM302

Shallow – Single swath (Sognefjord)
Shallow – Dual swath (Sognefjord)
Medium – Single swath (Sognefjord)
Medium – Dual swath (Sognefjord)
Deep (Sognefjord)
Deep CW – Dual swath, SN

Depth Std. Dev (%w.d.) vs. Beam angle (deg)

Depth bias (%w.d.) vs. Beam angle (deg)
Deep CW – Single swath, SN

![Graph showing depth standard deviation and depth bias over beam angle]

- **Depth Std. Dev. (%w.d.):** The graph plots the standard deviation of depth measurements over varying beam angles. The standard deviation is relatively low, especially for beam angles around 0 to 10 degrees, indicating good stability in depth measurements.

- **Depth bias (%w.d.):** The depth bias is shown as a range of values, with the graph highlighting a trend where the bias is minimal for beam angles around 0 to 10 degrees, becoming more pronounced at higher and lower beam angles. The shading indicates the variability in depth bias across different measurements.

The overall trends suggest that single swath measurements in this depth range are relatively consistent and accurate, with minimal bias and standard deviation.
Deep FM – Dual swath, SN
Deep FM – Single swath, NS

![Graph showing depth deviation and bias over beam angle](image-url)
Very Deep FM – Single swath NS
Very Deep CW – Single swath NS
Extra Deep FM – Single swath, SN

Extra Deep CW – Single swath, SN