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# BISTATIC SIMULATION IN GSM

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8) ABSTRACT

This report describes how bistatic modelling in the Generic Sonar Model (GSM), has been taken into use at FFI for modelling of sonar performance. The emphasis in the description of GSM is the differences from the monostatic case. A tool for doing automatic simulations is also described.

In the simulations a hull mounted sonar is used as the transmitter and a towed array is used as the receiver. The results show gain in signal excess for deep target when the receiver is lowered but it would probably be even better if also the source was lowered into the water volume.

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# CONTENTS

Page

APPENDIX

# BISTATIC SIMULATION IN GSM

## 1 INTRODUCTION

The Generic Sonar Model (GSM) (1) has been used for modelling of sonar performance at FFI. All modelling so far has been for the monostatic case. This report describes how bistatic modelling (2) in GSM has been taken into use at FFI and some few simulations results will be shown.

In the offers for the new Norwegian frigates of March 1 1999, bistatic sonar operation was included by one of the manufacturer. The simulations were done only for the bistatic geometry specified in the offer. The different sonar suites offered were modelled at FFI to be able to do comparisons. Results from the monostatic modelling are given in (3).

The outline of this report is a description of how do to the bistatic simulation, given in chapter 2, with emphasis on the differences from the monostatic case. In chapter 3 tools for automatic simulations are described. A few examples of simulation results are given in chapter 4. The report ends with a short conclusion in chapter 5.

## 2 BISTATIC SIMULATION IN GSM

The differences and supplements that need to be added in GSM when doing bistatic simulation as compared with monostatic simulation are commented in this chapter. The main difference is definition of geometry because there is one path from the transmitter to target and a different path back to the receiver. This results in different transmit and receive beampatterns, more complicated calculation of pressure, reverberation and signal excess. GSM commands used for the simulation are stated in appendix A. Comments are added into these GSM commands to make it more readable.

With a bistatic system the transmitter and receiver of the sonar system are separated in distance. Therefore the position of the transmitter, receiver and target is referred into a co-ordinate system. All the definitions in the polar co-ordinate system for the transmitter, receiver and target are shown in Figure 2-1, Figure 2-2 and Figure 2-3. The user must be careful when defining the geometry. The horizontal beam of the transmitter must overlap with the beampattern of the transmitter to insonify the target. The target also has to be placed in the horizontal beam of the receiver. If either of this fail no signal excess will be calculated by GSM.

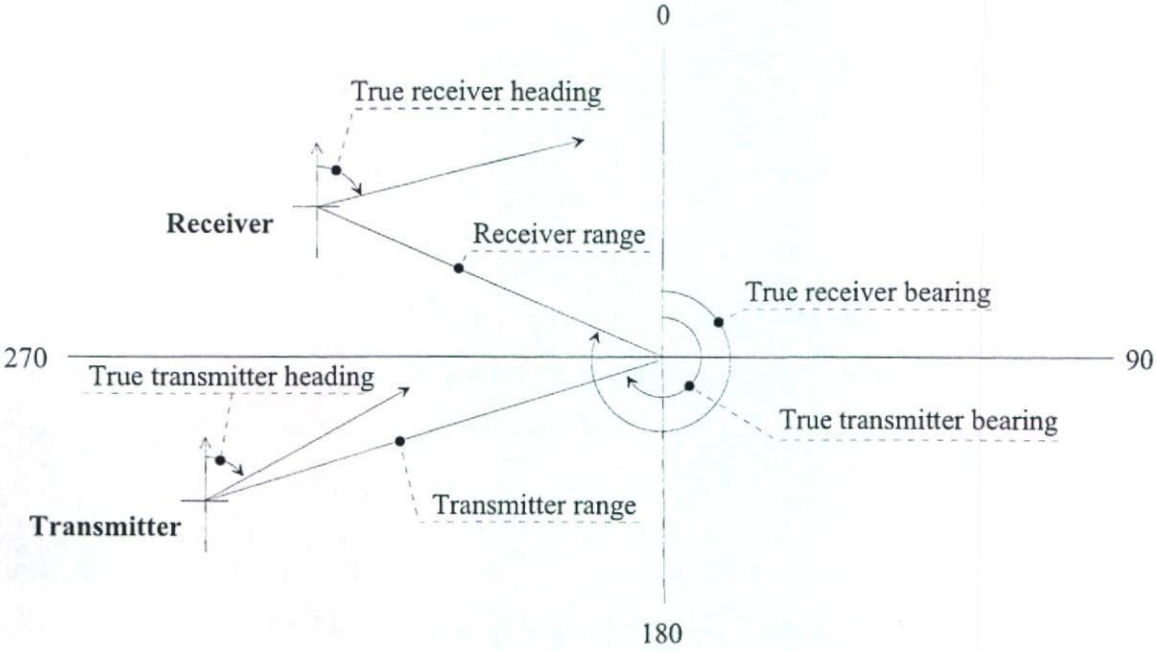

*Figure 2-1Transmitter and receiver positions*

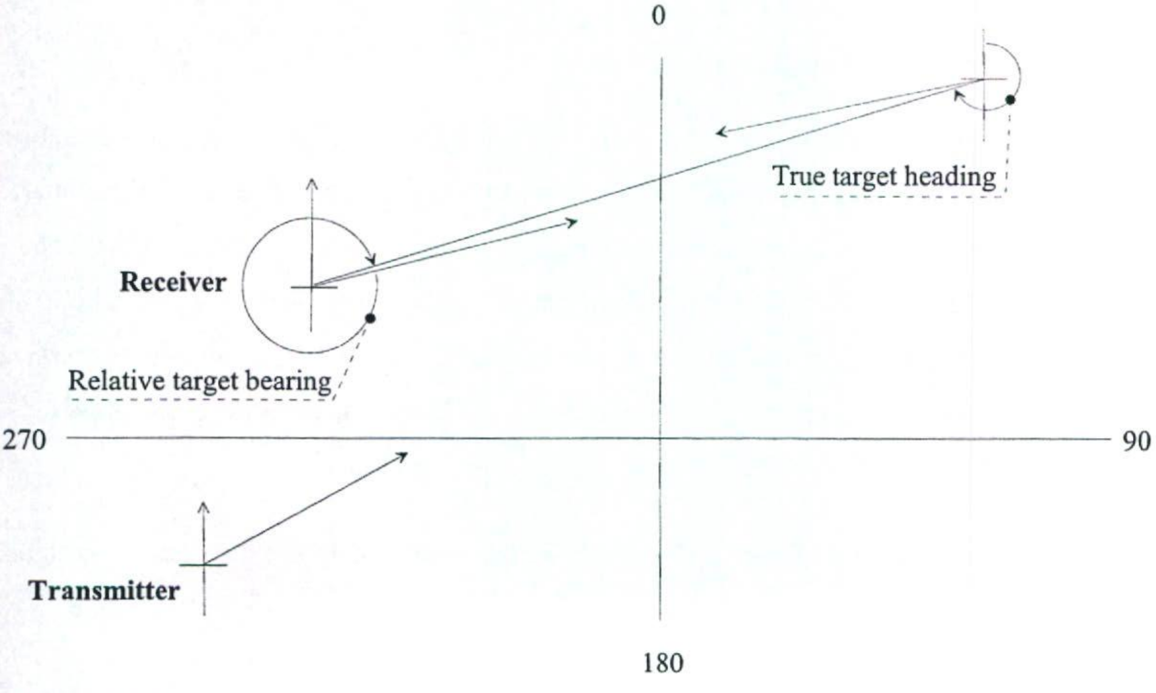

*Figure 2-2Target position*

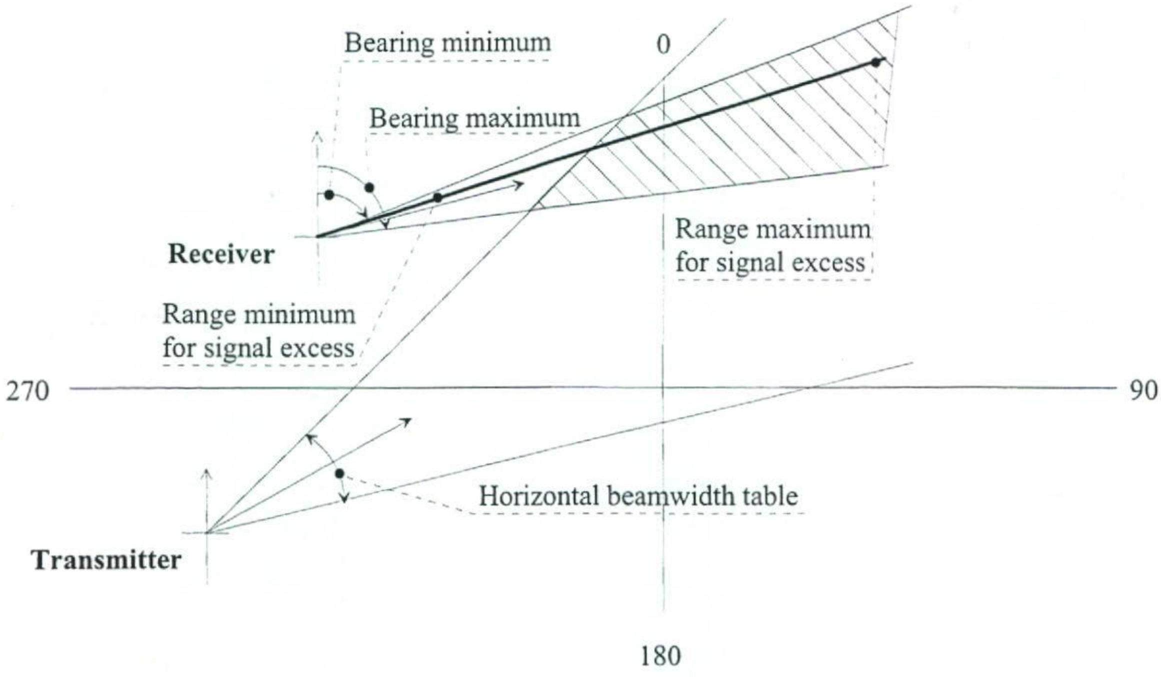

*Figure 2-3Transmitter and receiver horizontal beampatterns and target path for signal excess computation*

Both reverberation and signal excess calculation require a special bistatic model. For the reverberation model a horizontal separation between the transmitter and receiver is necessary. The calculations use two sets of eigenrays. One set from the transmitter to the target and the other set from the target back to the receiver. These two sets of eigenrays must be stored on files named by the user and recalled when appropriate. For the sound-pressure calculation the use of vertical beampattern is also more complicated. The first calculation step is from the transmitter to the target. The target is considered as the receiver with no directionality. The next step is pressure calculation from the target to the receiver. Now the target is considered as the transmitter with no directionality and the receiver as the actual receiver with its directionality.

## 3 IMPLEMENTATION OF THE SIMULATIONS

A system exist which allows one to do multiple set of simulations automatically(4). This is written in the script language PERL. This system has been modified to do bistatic simulation. There is also one change in use of models in GSM. A built in model for calculation of beampattern for a line array is used instead of reading a pre-calculated beampattern from an external program. In addition some small Matlab programs have been written to generate set of text files needed by the PERL script. Input to GSM is a specially formatted text file. The PERL script build up this text file for each set of wanted parameters and can then do a set of simulations automatically, including storing of the results to file. The parameters can be different location for measured sound velocity profile, time of year, seastate, or transmitter, receiver and target depth. Further documentation of the script system is found in appendix B.

## 4 EXAMPLES FROM THE SIMULATIONS

The geometry used in the simulations is shown in Figure 4-1. The transmitter is at 5 meter depth. The simulations were done for targets at both 30 and 150 meter and the receiver array was placed at either 5, 50, 100 or 150 meter depth. The transmitter and receiver had a horizontal separation of 1000 m. This geometry was used for simulations at two different locations, at four different seasons with seastates 2 and 5 and 0 dB selfnoise from the ship. The sonar frequency was 5500 Hz.

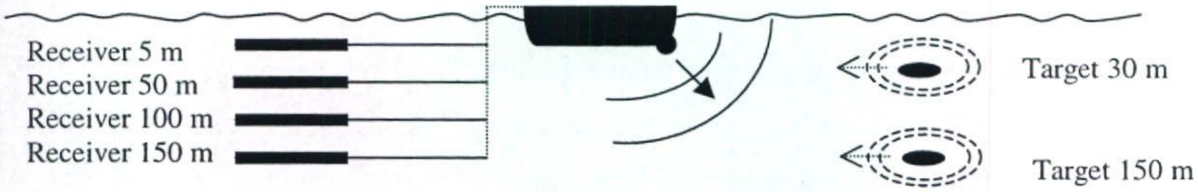

*Figure 4-1 Geometry for the simulations*

Here only results from one location at one season at seastate 2 will be shown. The raytrace diagram is shown in Figure 4-2. The real source is situated at 5 meter, but in the bistatic simulations the path from the target back to the receiver is calculated as an independent path and the raytrace diagram for a "source" at the target depth at 30 and 150 meter are therefore included. The sound velocity profile is nearly constant for the upper 20 meters, and the sound velocity profile has a maximum for 76 meter and a minimum for 122 meter. The positive gradient from 20 to 76 meters depth tends to bend the rays upward, this is seen in the ray diagram for the source at 5 and 30 meters. The minimum in the sound velocity profile at 122 meter will create a sound channel and this is seen in the raytrace diagram for the source at 150 meter depth. The raytrace diagrams are plotted in Lybin since it is very inconvenient to export plots from GSM.

As stated before a bistatic module is used for calculation of reverberation. The output is reverberation level as a function of time as for the monostatic case. The calculated reverberation levels are plotted in Figure 4-3 for the four receiver depths. Due to the different receiver depth and paths involved in the reverberation calculation the contribution from the

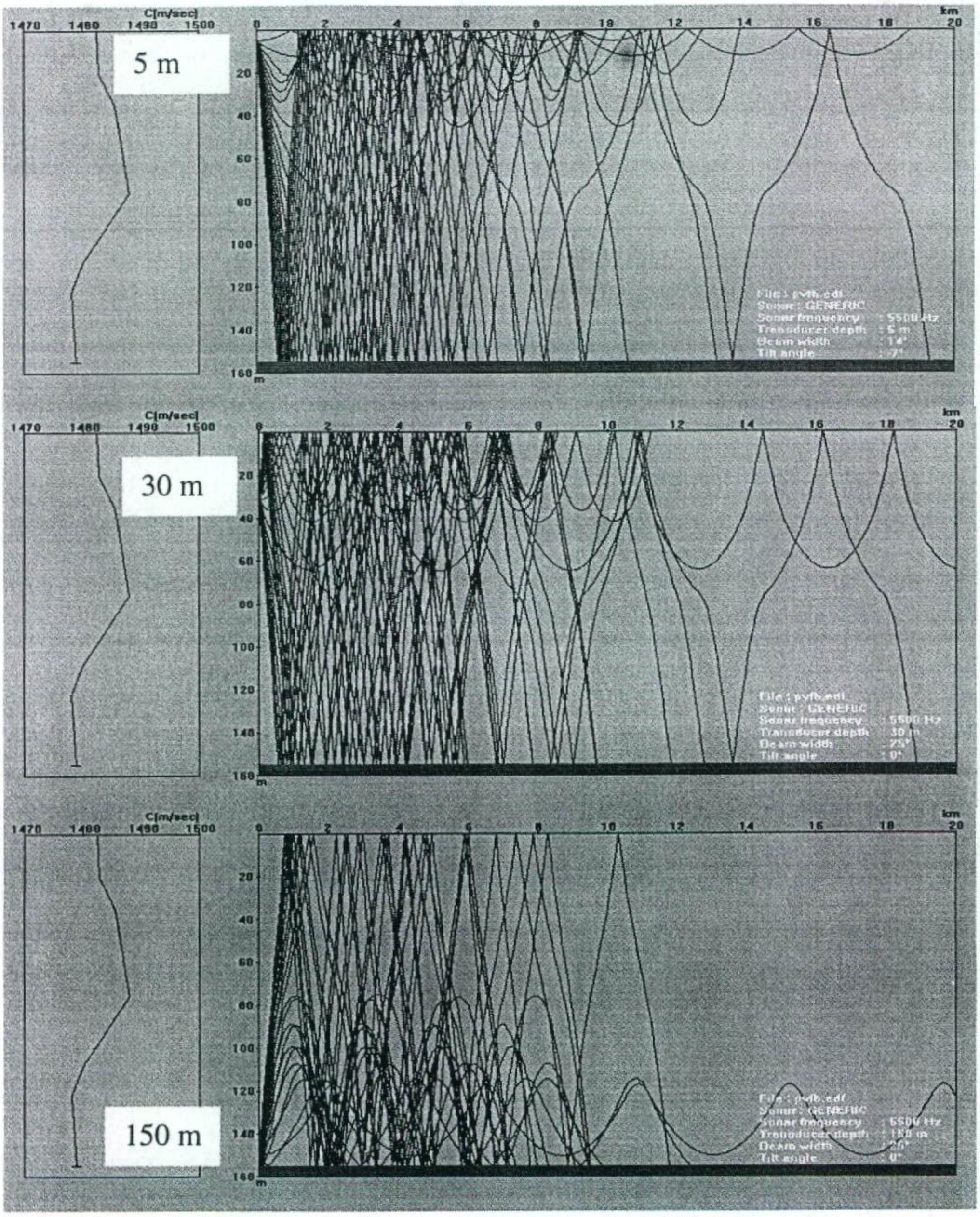

*Figure 4-2 Raytrace diagram for source at 5 m, 30 m and 150 m depth.*

different reverberation categories vary. For the two deepest receiver depths the bottom reverberation is dominating. For the two shallow receiver depths the bottom reverberation dominates early in the time series before the volume reverberation starts to dominate. The overall reverberation level is highest for the receiver at 150 meter, which is very close to the bottom.

The calculated transmission losses are shown in Figure 4-4. The transmission loss to and from the target at 30 meter are shown in the upper part of the figure, and the transmission loss to and from the target at 150 meter is shown in the lower part of the figure. For the target at 30 m it is a noticeable increase in the transmission loss when the receiver is lowered to 100 and

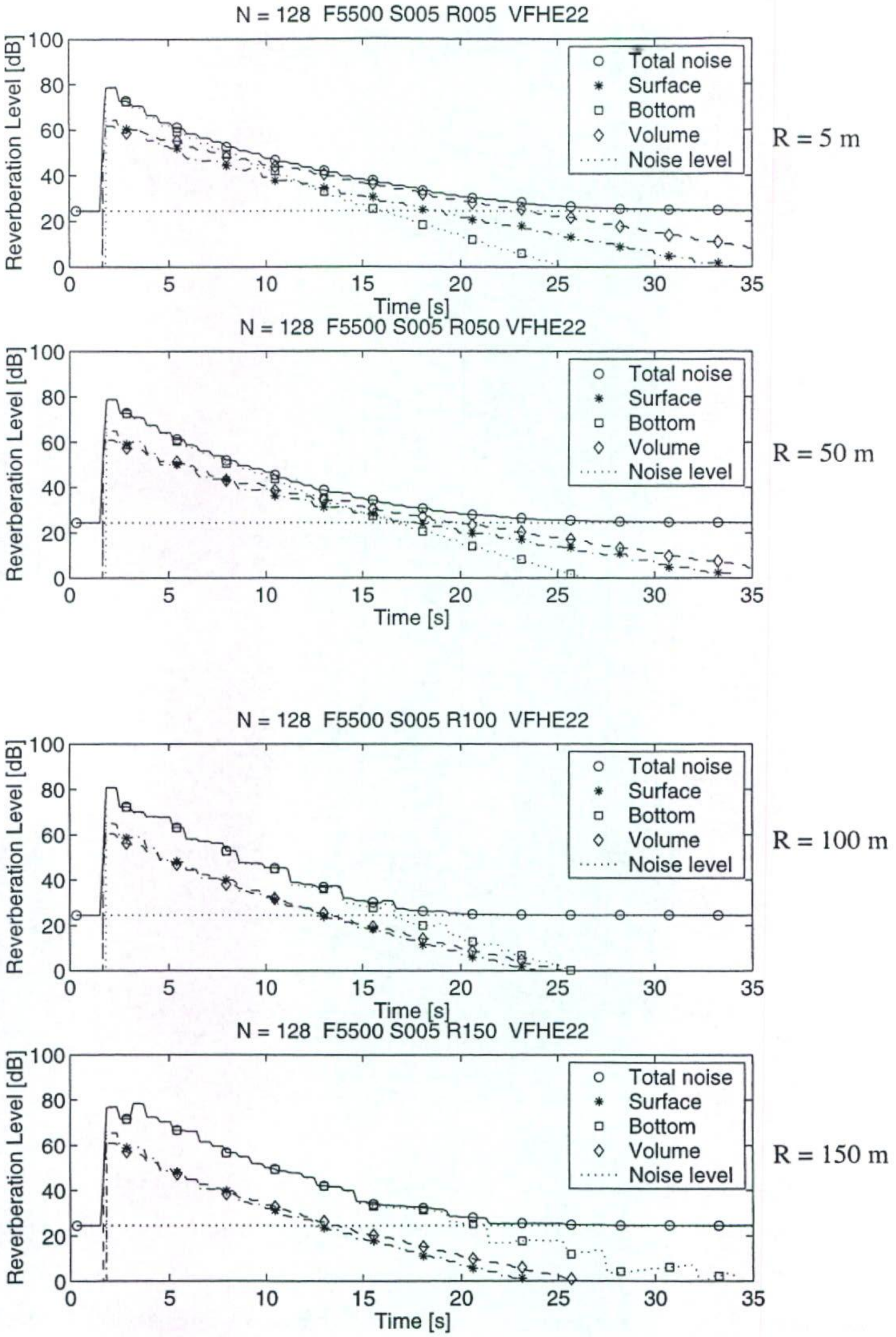

*Figure 4-3 Reverberation level at four receiver depths*

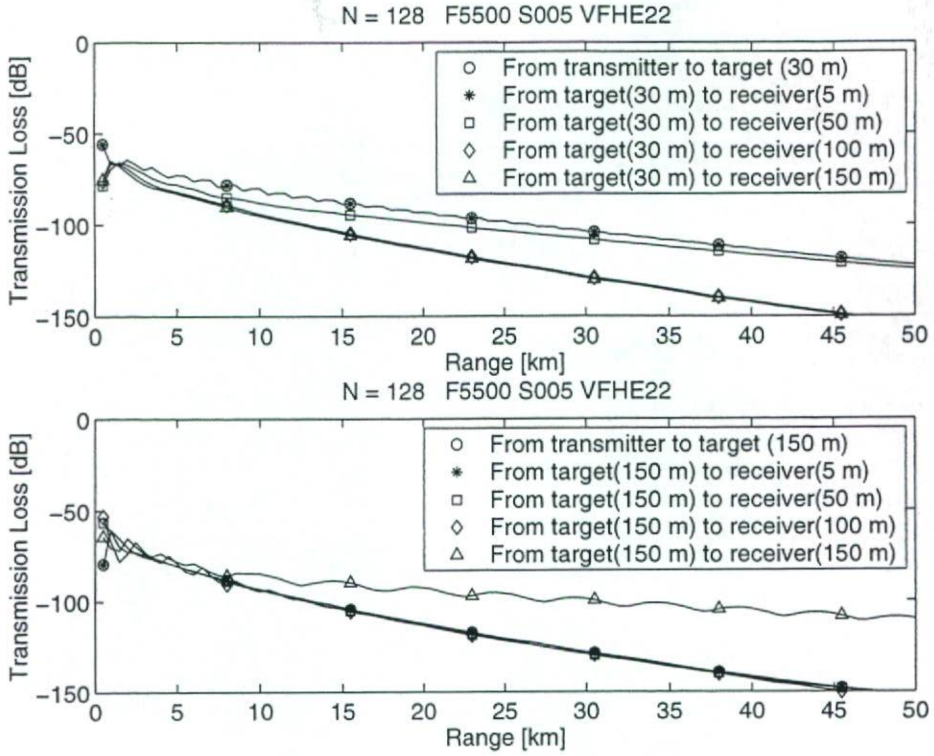

*Figure 4-4 Transmission loss*

150 meters. In the comments to the raytrace diagram in Figure 4-2 it was stated that the sound velocity profile had a maximum at 76 meter and rays from a source above this depth tends to be bent upwards. In the lower part of the figure the effect of the sound channel at 122 m is clearly seen. The transmission loss is significant lower for the receiver at 150 meter than for the receiver at the other depths.

The calculated echo level is shown in Figure 4-5. For the three uppermost receiver positions the targets at 30 meter has an echo level higher than the reverberation level, while the target at 150 meter has an echo level close to or lower than the reverberation level. For the receiver at 150 meter the echo level for targets at 30 and 150 meter almost coincide with the reverberation level.

The last plot to be shown is the signal excess in Figure 4-6. For the target at 30 meter the signal excess decrease as the receiver is lowered below 50 m. For the target at 150 meter the signal excess increase as the receiver is lowered down. The best receiver depth is 150 meter for the target at 150 meter, but the achieved signal excess is not better than the poorest value for the target at 30 meter. The problem is to get enough energy into the deeper part of the water volume with the source at 5 meter as was seen in Figure 4-4 for the calculated transmission loss.

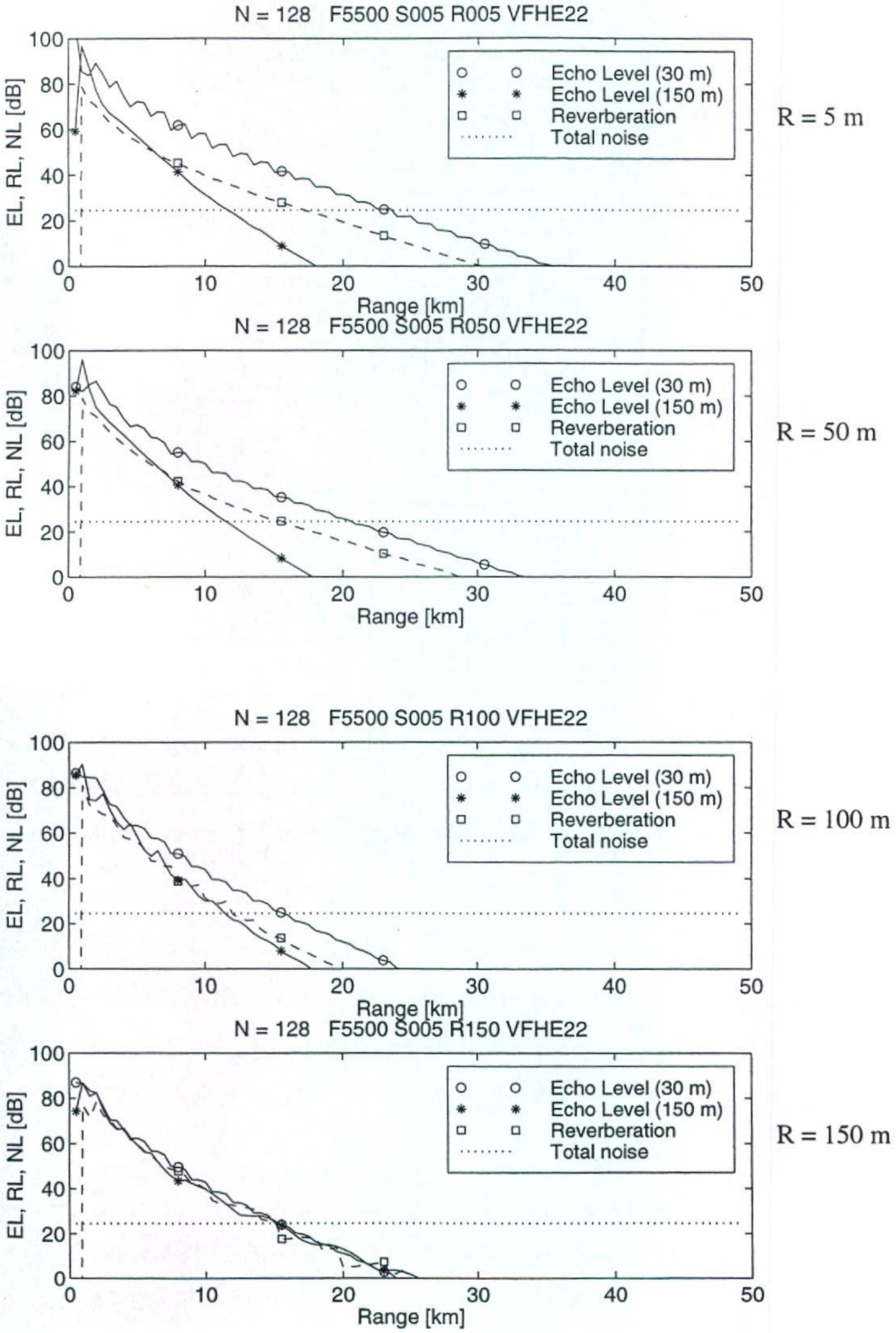

*Figure 4-5 Echo level*

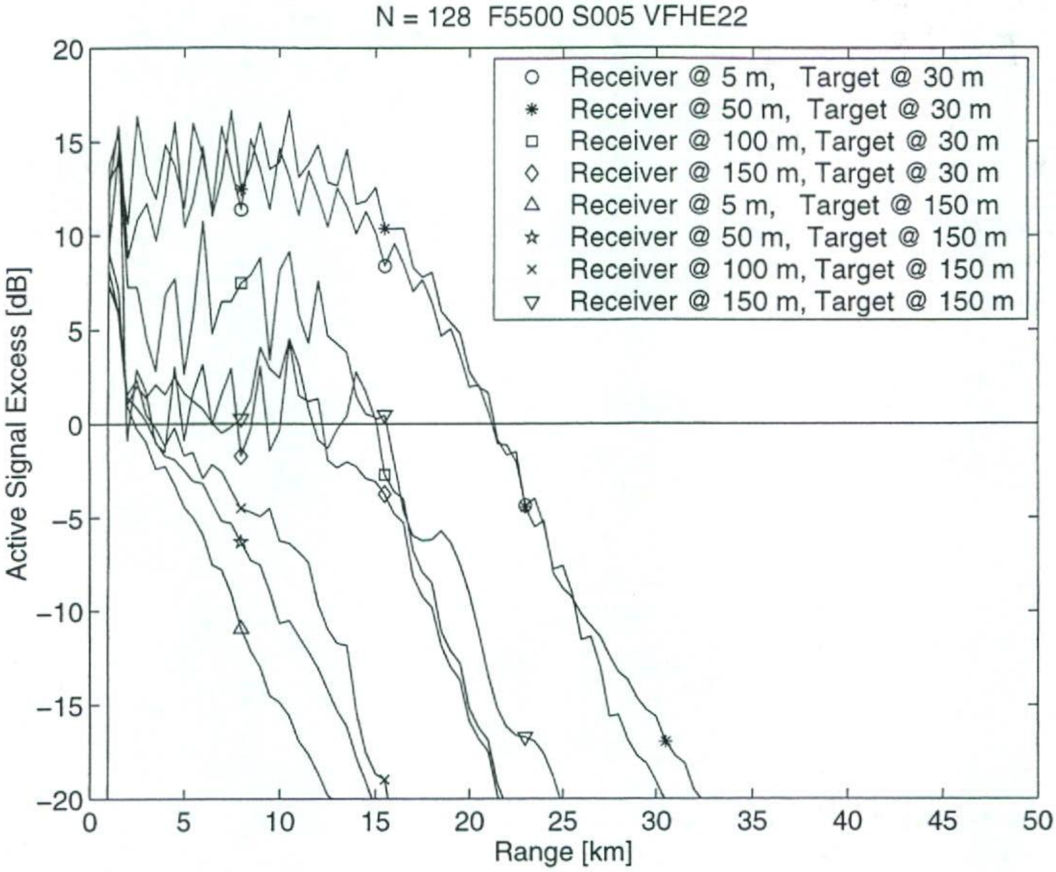

*Figure 4-6 Active signal excess*

## 5 CONCLUSION

The bistatic module in GSM has been taken into use. Existing PERL scripts have been modified to do bistatic modelling in an automatic manner. GSM is not user friendly so it is time consuming to take new parts into use. But the script that has been made will do it much easier to do simulations for an other geometry since a framework exists. In the future the plan is to use Lybin for sonar evaluation but this model has no possibility for bistatic calculations so GSM will still be a candidate for doing bistatic simulation.

The results show gain in signal excess for deep target when the receiver is lowered but it would probably be even better if also the source was lowered into the water volume. How the source is able to distribute the sound energy into the water is dependent of the oceanographic conditions and an ATAS system is more flexible than the bistatic configuration simulated in this report.

## APPENDIX

## A GSM CODE FOR BISTATIC TOWED ARRAY

```
*****  Start sub GSM_SSP   ********
*MT oct
BOTTOM DEPTH = 294 M
OCEAN SOUND SPEED TABLE
M         M/S
  0.0     1488.4
   .
   .
294.0     1481.7
EOF
OCEAN SOUND SPEED MODEL = CONGRATS
FIT OCEAN SOUND SPEED
*****  Slutt sub GSM_SSP   ********


*****  Start sub GSM_GEO   ********
* DEFINERER BISTATISK GEOMETRI
TRANSMITTER RANGE = 0.0 KM            *målt fra origo
TRUE TRANSMITTER BEARING = 0. DEG
TRUE TRANSMITTER HEADING = 2.50 DEG   *satt for å få bearing min/max 0-2.5
                                      *grader for mottaker

RECEIVER RANGE = 1.0 KM            *målt fra origo
TRUE RECEIVER BEARING = 0. DEG
TRUE RECEIVER HEADING = 2.50 DEG
BEARING MINIMUM = 1.25 DEG
BEARING MAXIMUM = 3.75 DEG
BEARING INCREMENT = 1.25 DEG

RELATIVE TARGET BEARING = 0. DEG
TRUE TARGET HEADING = 0. DEG
*****  Slutt sub GSM_GEO   ********


*****  Start sub GSM_T_AXES   ********
RANGE UNITS = KM
DEPTH UNITS = M

* def range sep. for kilde mottager
TIME MINIMUM = 0.3378 S
TIME MAXIMUM = 70.0 S
TIME INCREMENT = 0.1689 S
RANGE REFERENCE = 1.0 M
*****  Slutt sub GSM_T_AXES   ********


*****  Start sub GSM_SCAT   ********
*>!GENERIC PARAMETERS FOR BOT/SURF/VOLUME SCATTER
SURFACE REFLECTION COEFFICIENT MODEL = MARSH
BOTTOM REFLECTION COEFFICIENT MODEL = MGS
SURFACE SCATTERING STRENGTH MODEL = CHAPHA
SURFACE SCATTERING FACTOR = +2.6 DB/YD
BOTTOM SCATTERING STRENGTH MODEL = TABLE
```

```
BOTTOM SCATTERING STRENGTH TABLE
DEG        DB/YD
   2.0     -36.3
   5.0     -36.3
  10.0     -36.3
  20.0     -36.3
  30.0     -33.0
  50.0     -29.3
  60.0     -28.2
  90.0     -27.0
EOF
*>!GENERIC PARAMETERS
VOLUME SCATTERING STRENGTH MODEL = DPTTBL
VOLUME SCATTERING STRENGTH TABLE
M          DB/M
0.0        -80.0
250.       -80.0
EOF
*****  Slutt sub GSM_SCAT   ********

*+++++++++++++++++++++++
SEA STATE = 5
BOTTOM PROVINCE = 2
*+++++++++++++++++++++++

*****  Start sub XAD_NSE   ********
*>!Ambient noise
TOTAL NOISE SPECTRA MODEL = ISOTRO
AMBIENT NOISE SPECTRA MODEL = NUSC
SHIPPING LEVEL = 3
RAIN RATE = NONE
AMBIENT NOISE COMPONENT = TOTAL
*>!Self noise
SELF NOISE SPECTRA TABLE = 0 DB
*****  Slutt sub XAD_NSE   ********

*****  Start sub XAD_SOURCE   ********
SOURCE LEVEL TABLE = 0.0 DB
FREQUENCY MINIMUM = 5.50 KHZ
FREQUENCY MAXIMUM = 5.50 KHZ
PULSE LENGTH = 0.002000 S
AMBIENT DIRECTIVITY INDEX TABLE = 23.00 DB
SELF DIRECTIVITY INDEX TABLE = 0.00  DB

**** BEREGNE SENDER OG MOTTAKER EGENSTRÅLER, MÅ LAGRES PÅ FIL TIL SENERE
**** BRUK (SE-BEREGNING)MÅ FØRST SETTE SUB-MODELLER FOR Å BEREGNE
**** EGENSTRÅLER
*
**** DISSE AVSTANDS PARAMETRENE ER FOR SENDER, KILDE DYP = SENDER DYP. MÅL
**** DYP = MÅL DYP
RANGE MINIMUM = 0.5 KM
RANGE MAXIMUM = 50.0 KM
RANGE INCREMENT = 0.5 KM
EIGENRAY FILE = TREISX
SOURCE DEPTH = 5 M
TARGET DEPTH = 150 M
COMPUTE EIGENRAYS
SORT EIGENRAYS
*
*** VERTIKALT STRÅLEMØNSTER SENDER
TRANSMITTER BEAM PATTERN MODEL = PISTON
TRANSMITTER PISTON DIAMETER =  2.15 M
TRANSMITTER TILT ANGLE = 7 DEG
*
```

```
*** TRYKK BEREGNING SENDER ( OPTIONAL)
COHERENCE = RANDOM
EIGENRAY FILE = TREISX
PRESSURE FILE = TRPTST
HORIZONTAL BEAMWIDTH TABLE = 14.0 DEG
BANDWIDTH TABLE =    1 HZ
INTEGRATION TIME =    0.00 S
COMPUTE PRESSURE
PRINT PRESSURE VS RANGE
*** For å beregne trykket ved mottager, må det vertikal strålemeønsteret til
*** sender fjernes fordi målet er antatt som den nye kilden med
*** omnidirektionalt sendemønster
TRANSMITTER BEAM PATTERN TABLE = 0. DB
*
*** Nå kommer avstandsparametre for mottageren. Kilde dyp = mottaker dyp.
*** Mål dyp = mål dyp ved resiprositet
RANGE MINIMUM = 0.5 KM
RANGE MAXIMUM = 50.0 KM
RANGE INCREMENT = 0.5 KM
EIGENRAY FILE = RCEISX
SOURCE DEPTH = 150 M
TARGET DEPTH = 150 M
COMPUTE EIGENRAYS
SORT EIGENRAYS
*  frek= 5500,   N= 128,  0.47 lamda,  Hamming vekt
HORIZONTAL BEAMWIDTH TABLE = 2.5 DEG
RECEIVER BEAM PATTERN MODEL = TABLE     ** leses inn fra fil av script
RECEIVER BEAM PATTERN TABLE
DEG
   -90.0   1.00000
         .
         .
    90.0   1.00000
EOF
RECEIVER TILT ANGLE = 0.0 DEG
*
*** TRYKK BEREGNING MOTTAKER ( OPTIONAL)
EIGENRAY FILE = RCEISX
PRESSURE FILE = RCPTST
COMPUTE PRESSURE
PRINT PRESSURE VS RANGE
*
*** Må sette tilbake sender strålemønster slik at riktig mønster brukes i
*** gjenklang og signal overskudd beregninger
TRANSMITTER BEAM PATTERN MODEL = PISTON
TRANSMITTER PISTON DIAMETER =  2.15 M
TRANSMITTER TILT ANGLE = 7 DEG
*
*** Beskytt den siste lydtrykksfila,
PRESSURE FILE
*****  Slutt sub XAD_SOURCE   ********

*****  Start sub GSM_REVERB   ********
*** Bistatisk gjenklang krever to tilleggsfiler for egenstråler, med egne
*** navn
SOURCE LEVEL TABLE = 221 DB
TRANSMITTER EIGENRAY FILE = TRNEIG
RECEIVER EIGENRAY FILE = RCVEIG
*
*** Model COOKIE sjekker hvis det horisontale strålemønster til sender er
*** innenfor det horisontale strålemønster til mottaker under berenging av
*** bistatisk gjenklang og signal overskudd modellen er ikke dokumentert ut
*** over kildekode.
TRANSMITTER BEAM PATTERN MODEL = COOKIE
```

```
REVERBERATION FILE = RVTST
REVERBERATION MODEL = BISTATIC
FATHOMETER RETURN MODEL = BISTATIC  * krever horisontal seperasjon på sender
                                    * og mottatter
RESET REVERBERATION
*
*** Bistatisk fathometer return model beregner direkte vei egenstråler fra
*** kilde til mottaker. kildedyp = sender. måldyp = mottakerdyp. Døp om
*** egenstrålefil for å unngå interferens med sist definerte egenstrålefil.
*** Egenstråler for fathometer trengs ikke sorteres. Avstandsparametre er
*** for sender til mottaker.
SOURCE DEPTH = 5. M
TARGET DEPTH = 150. M
RANGE MINIMUM = 0.5 KM
RANGE MAXIMUM = 50.0 KM
RANGE INCREMENT = 0.5 KM
EIGENRAY FILE = EIGRAY
COMPUTE EIGENRAYS
COMPUTE FATHOMETER RETURNS
*
*** Overflategjenklang
SOURCE DEPTH = 5.0 M
TARGET DEPTH = 0. M
EIGENRAY FILE = TRNEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
*  mottaker
SOURCE DEPTH = 150.0 M
TARGET DEPTH = 0. M
EIGENRAY FILE = RCVEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
COMPUTE SURFACE REVERBERATION
*
*** Bunngjenklang
SOURCE DEPTH = 5.0 M
TARGET DEPTH = 294 M
EIGENRAY FILE = TRNEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
*  mottaker
SOURCE DEPTH = 150.0 M
TARGET DEPTH = 294 M
EIGENRAY FILE = RCVEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
COMPUTE BOTTOM REVERBERATION
*
*** Volumgjenklang, en slik blokk for hvert dybdeintervall det regnes for
***** sender del
SOURCE DEPTH = 5.0 M
TARGET DEPTH = 14.7 M
SCATTERING LAYER THICKNESS = 29.4 M
EIGENRAY FILE = TRNEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
***** mottaker del
SOURCE DEPTH = 150.0 M
TARGET DEPTH = 14.7 M
SCATTERING LAYER THICKNESS = 29.4 M
EIGENRAY FILE = RCVEIG
COMPUTE EIGENRAYS
SORT EIGENRAYS
```

```
COMPUTE VOLUME REVERBERATION
*
PRINT REVERBERATION + NOISE VS TIME
*****  Slutt sub GSM_REVERB   ********


*****  Start sub GSM_PODFAC   ********
*>!The following pulse length has no influence on the result
*>!PULSE LENGTH = 1.0 S
DETECTION THRESHOLD MODEL = SQUARE
PROBABILITY OF DETECTION = 50 %
PROBABILITY OF FALSE ALARM = 0.01 %
COMPUTE DETECTION INDEX
SYSTEM LOSS = 8 DB
*>!FLUCTUATION INDEX = 0 DB
*****  Slutt sub GSM_PODFAC   ********


*****  Start sub GSM_COMPUTE   ********
TARGET STRENGTH TABLE = 5. DB
TARGET DEPTH =   150 M

*** Sett signal overskudd modell. Sett egenstrålefilnavn til miljø
*** (lydtrykk)filer brukt tidligere. Navngi signal overskudd fila.
*** Avstandsparametre trengs ikke å gis siden de allerede er lagret på
*** egenstrålefilene.
ACTIVE SIGNAL EXCESS MODEL = BISTAT
RESET SIGNAL EXCESS
TRANSMITTER EIGENRAY FILE = TREISX
RECEIVER EIGENRAY FILE = RCEISX
SIGNAL EXCESS FILE = SGXTST

ADDITIONAL INFORMATION = REVERB
COMPUTE ACTIVE SIGNAL EXCESS
PRINT SIGNAL EXCESS VS RANGE
ADDITIONAL INFORMATION =
COMPUTE PROBABILITY OF DETECTION
PRINT PROBABILITY OF DETECTION VS RANGE
*****  Slutt sub GSM_COMPUTE   ********

END
```

# B SCRIPT PROGRAMS

All the script programs used for running the simulation are located in the following directory: \\freia\home/u1/sonar/ugsmverg/regn_bi.

## B.1 PERL

Two files that contains the main program, *birun_xad.pl*, and a subroutine collection, *bi_xad_gsmstd.ph.*

If among other factors the geometry, the source and receiver characteristics, scattering values or GSM build in models is to be changed the script must be changed. All the following variables are given as parameters into the script: location, season, seastate, source depth, receiver depth, source level, target depth, bandwidth, frequency, directivity index, number of element in the line array.

## B.2 Matlab

Two Matlab m-files writes a set of text files which is used of the PERL script. L*ine_array.m* defines the line array and *reverber.m* writes the necessary commands for reverberation calculation for a given source and receiver depth at a given location.

Matlab is also used to read the results from the GSM output files and for plotting.

## References

(1) Henry Weinberg (1985): Generic Sonar Model, Naval Underwater Systems Center, Technical Document 5971D.

(2) W. J. Powers (1987): Bistatic Active Signal Excess Model -- an Extension of the Generic Sonar Model. Naval Underwater Systems Center, Technical Memorandum. 871025.

(3) Karlsen M., Knudsen T. (1999): Simulated Performance of Sonar Systems Offered to P6088, FFI/RAPPORT-99/02477, Restricted

(4) Nilsen Erik Hamran (1998): Using the script language PERL for Generic Sonar Model simulations, FFI/NOTAT-98/02543, Ugradert