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Extension of MATLAB Active Sonar Modelling Tools

Ron Stockermans
Ron Stockermans Consulting
30 Allenby Drive
Stillwater Lake, Nova Scotia
B3Z 1G6

Contract #W7707-08212

Scientific Authority James A Theriault

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Defence R&D Canada

Contractor Report
DREA CR 2001-131
August 2001

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Defence Research Establishment Atlantic

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Signed for the Author

James A. Theriault

Approved by

Dave Chapman

Head Naval Sonar Section

Approved for release by

Kirk Foster

Chair ~~Document~~ Review Panel

Abstract

The Defence Research Establishment Atlantic has a requirement to evaluate the performance of an active monostatic sonar that can employ a vertical or horizontal projector array and a horizontal receiver array. To facilitate this effort, several tools have been developed for managing the multiple files input parameters and which use the Generic Sonar Model (GSM) as the performance prediction engine. The software languages used are MATLAB and PERL.

This report provides a description of Active Sonar modelling tools as developed by the author. This report is divided into a number of sections including: general description, methodology, results, and conclusions.

Résumé

Le Centre de recherches pour la défense Atlantique a le mandat d'évaluer les performances d'un sonar monostatique actif pouvant utiliser un réseau projecteur vertical ou horizontal et un réseau récepteur horizontal. Afin de faciliter cette évaluation, on a mis au point plusieurs outils permettant de gérer les paramètres d'entrée de fichiers multiples et recourant au Generic Sonar Model (GSM) comme motae de pridction des performances. Les langages de programmation utilisés sont MATLAB et PERL.

Ce rapport donne une description des outils de modélisation de sonar actif mis au point par l'auteur. Il se divise en un certain nombre de sections : description générale, méthode, résultats et conclusions.

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Executive summary

The Defence Research Establishment Atlantic has undertaken numerous studies of active-sonar detection performance in recent years. A number of tools are available to carry out the task. An important tool for studying the performance of active sonars is the US Naval Undersea Weapons Center (NUWC) Generic Sonar Model (GSM). Unfortunately, using this model for such task tends to consume significant effort, especially when considering a complex system such as the DREA Towed Integrated Active-Passive Sonar (TIAPS).

In the case of TIAPS, the source and receiver have vertical and azimuthal directionality. Though a single transmit direction can be assumed for executing a model prediction, the azimuthal coverage available by considering all receive beams is the desirable performance metric. GSM does not directly produce such results. The inputs and outputs must be manipulated in order to achieve the desired predictions.

A contract was undertaken to develop a software package that would allow the researcher to make such predictions with much less effort. Several tools, written in MATLAB and PERL have been produced to manipulate the input and output.

This report is provides a description of Active Sonar modelling tools as developed by the author. This package is being used for a current TIAPS study and will be available for future work.

Stockemans, RJ. 2001. Extension of MATLAB Active Sonar Modelling Tools.
DREA CR 2001- 131
Defence Research Establishment Atlantic.

Sommaire

Au cours des dernières années, le Centre de recherches pour la défense Atlantique a entrepris de nombreuses études portant sur les performances de détection des sonars actifs. Un certain nombre d'outils sont disponibles pour exécuter cette tâche. Un outil important d'étude des performances des sonars actifs est le Generic Sonar Model (GSM) du Naval Undersea Weapons Center (NUWC) aux Etats-Unis. Malheureusement, l'utilisation de ce modèle à cette fin tend à exiger des efforts importants, surtout lorsqu'on considère un système complexe comme le sonar remorqué intégré actif et passif (TIAPS) du CRDA.

Dans le cas du TIAPS, la source et le récepteur se caractérisent par une directivité verticale et azimutale. Bien qu'on puisse supposer une seule direction d'émission pour l'exécution d'une prévision à l'aide du modèle, la couverture azimutale disponible, établie par l'examen de tous les faisceaux de réception, constitue la mesure des performances souhaitables. Le GSM ne produit pas directement de tels résultats. Il est nécessaire de manipuler les entrées et les sorties pour obtenir les prévisions souhaitées.

Un contrat a été lancé en vue de la création d'un logiciel qui permettrait au chercheur d'effectuer de telles prévisions avec beaucoup moins d'efforts. On a produit plusieurs outils, écrits en MATLAB et en PERL, pour manipuler les entrées et les sorties.

Ce rapport donne une description des outils de modélisation de sonar actif mis au point par l'auteur. Le logiciel est utilisé pour l'étude actuelle du TIAPS et sera disponible pour des travaux futurs.

Stockemans, RJ. 2001 Extension of MATLAB Active Sonar Modelling Tools.
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Centre de recherches pour la défense Atlantique.

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General

Outline

This report is provides a description of MATLAB Active Sonar modelling tools as developed by the author. This report is divided into a number of sections which are briefly described.

- General Description of the Tools – A complete description of the tools developed under this contract.
- Methodology – This section describes the modelling components and steps needed to perform a detection and how the tools are used to
- Results – An example case of the tools as used and the results described.
- Conclusions – This section describes a number of areas which remain to be addressed and future work that may be considered.

General Description of the Tools

The purpose of this contract was to build the tools required to carry out a modelling study of a Low Frequency Array. The active sonar system to be modelled included two types of projector arrays: a Horizontal Line array of Omni-directional projectors (HLO) and a Vertical line array of two omni-directional Projectors (VP2); and a Horizontal Line array of Omni-directional receivers (HLO).

The tools are organised around a structure of directories shown below in Figure 1.

```
GSMF
  ├─ENVRNMNT
  ├──LFA
  │   ├─BEAMPAT
  │   ├─HLOHLO
  │   └─VP2HLO
  └─MFILES
```

Figure 1. Structure of Directories

The GSMF directory is used as the 'Root' directory for the tools and may be located anywhere on the users hard drive. The gsmf_4.exe application is located in the GSMF directory. There are three main sub-directories below the GSMF directory: ENVRNMT, LFA, and MFILES. The ENVRNMT directory is the repository of all the environmental parameters; the MFILES directory is the repository of all the MATLAB related scripts (called m-files because of the *.m extension that is commonly used to identify them); and the LFA directory is used to store all the project specific files including PERL scripts, templates, and the results of all GSM runs and post-GSM data reduction for a particular project.

There are four main tools that were built for this contract. They are 'vp_hl_tx.m', 'reverb.pl', 'se.pl', and 'planviewer.m'. The MATLAB script 'planviewer.m' was late replaced by a set of PERL scripts that carry out the same function. These later tools are 'rad2cart.pl' and 'finalPlan.pl'. A requirement for calculating the Transmission Loss for counter-detection modelling was introduced to the project and a set of PERL scripts were written to deal with that requirement. These scripts are 'cd.pl' and 'rad2cart_cd.pl'. The execution method of all software scripts is identified by their extension. Those with '*.m' extensions are MATLAB scripts and those with '*.pl' are PERL scripts. All these tools use the 'lfa_globals.m' (see Annex A), which contains all the initial parameters for the desired run. It is located in the MFILES directory.

vp_hl_tx.m

This is a MATLAB script located in the MFILES directory that is used to generate the array beam patterns required by GSM. It generates both the 3D and azimuthally integrated beam patterns required for Signal Excess and Reverberation Level calculations.

The beam pattern files generated by 'vp_hl_tx.m' are stored in the BEAMPAT repository as shown at Figure 2. The directory name indicated the type of transmitter or receiver array and the type of beam patterns the directory contains. The first letter indicates whether the array is for a Transmitter, 'T', or Receiver, 'R', arrays. The next letter indicates whether the array is aligned Horizontally, 'H', or Vertically, 'V'. The third letter has no significant meaning, however, 'L' stands for Line Array, and 'P' stands for Projector Array. The fourth letter for a horizontal array indicates whether the beam pattern has been Integrated, 'I', or not. Since a vertical array's beam pattern is already azimuthally independent and does not require integration. The fourth letter in the directory name is a number which indicates the number of elements in the array.

```
GSMF
 └──LFA
     └─BEAMPAT
            ├─RHLI
            ├─RHLO
            ├─THLI
            ├─THLO
            ├─TVP2
            └─TVP4
```

Figure 2. Beam Pattern Repository Tree

The vp_hl_tx.m script performs a function similar to what may be produced by using the SWAMI[1] tools. The conclusion section will comment further on this subject.

reverb.pl

This is a PERL script which is located in the LFA directory. Its purpose is to generate the Reverberation Level values for all transmitter and receiver beam combinations. It reads the run parameters specified in the 'lfa_globals.m' (see Annex A) file and builds a file named 'rvbjob.dat' based on a template called 'rvbTemplate.dat'. The script then calls GSM and submits the file it just created for GSM to run. The output files contain the GSM output for the reverberation levels. These files are saved in the run repository which is located below the LFA directory as shown in Figure 3. The directory name indicated the type of transmitter and receiver array (or system) the repository contains. The first three letters, 'HLO' or 'VP2' in this case, indicates the transmitter array; either a horizontal line array or vertical projector array. The last three letters indicate the receiver array, in this case 'HLO' for a horizontal line array.

```
GSMF
  └─LFA
       ├─HLOHLO
       └─VP2HLO
```

Figure 3. Run Directory Tree

The run repository is further sub-divided by Location, Season, Pulse Type, Transmitter Beam, and Receiver Beam. These parameters are defined in the 'lfa_globals.m' file and will be further described in the Methodology section.

se.pl

This is a PERL script which is located in the LFA directory. Its purpose is to generate the Signal Excess values for all radials of all transmitter and receiver beam combinations It reads the conditions specified in the 'lfa_globals.m' file (see Annex A) and builds a file named 'sejob.dat' based on a template called 'seTemplate.dat'. The script then calls GSM and submits the file it just created. The output file of a single GSM run is the log file that GSM creates. Among other information, the log files contain the Signal Excess results and are saved in the receiver directory of the run directory as described above. For each combination of transmitter beam and receiver beam, the SE.pl script generates the Signal Excess file for all radials defined in the 'lfa_globals.m' (see Annex A) .

cd.pl

This is a PERL script which is located in the LFA directory. Its purpose is to generate the Pressure Level or Transmission Loss values for all transmitter beams. The Transmission Loss is used to later to generate the Counter Detection file. It reads the conditions specified in the 'lfa_globals.m' file (see Annex A) and builds a file named 'cdjob.dat' based on a template called 'cdTemplate.dat'. The script then calls GSM and submits the file it just created. The output file of a single GSM run is the log file that GSM creates. Among other information, the log files contain the Pressure Level results and are saved in the transmitter directory of the run directory as described above. For each transmitter beam, the cd.pl script generates the Pressure Level.

rad2cart.pl

This is a PERL script located in the LFA directory that is used to reduce the multiple Signal Excess radials to a single Cartesian Plan View for each receiver directory. The Signal Excess values from the sonar, in increments out to a maximum range as defined in the 'lfa_globals.m' file (see Annex A), are read in for each radial. These radials identify the Signal Excess values for all ranges and bearings and are converted to uniformly spaced Cartesian co-ordinates by interpolation. This grid of Signal Excess values in range and cross-range is saved to the receiver directory of the run directory as described above. The same is repeated for all receiver beams within a transmitter beam directory.

rad2cart_cd.pl

This is a PERL script located in the LFA directory that is used to reduce the multiple Transmission Loss radials to a single Cartesian Plan View for each transmitter directory. The Transmission Loss values from the sonar, in increments out to a maximum range as defined in the 'lfa_globals.m' file (see Annex A), are read in for each radial. These radials identify the Transmission Loss values for all ranges and bearings and are converted to uniformly spaced Cartesian co-ordinates by interpolation. This grid of Transmission Loss values in range and cross-range is saved to the transmitter directory of the run directory as described above. The same is repeated for all transmitter beams.

finalplan.pl

This is a a PERL script located in the LFA directory that is used to reduce the multiple Cartesian Plan View Signal Excess files to a single Plan View for each transmitter beam. The files for Signal Excess grids, as produced by the rad2cart.pl script, are read in and the maximum value of each point in the grid over all the receiver beam grid files is determined. The result is a single file of the Signal Excess values, for each transmitter beam, in Cartesian co-ordinates, that represents the Plan View of the sonar performance.

The 'finalPlan.m' script can also generate a file for Transmission Loss values that can be used in Counter Detection calculations. If the 'counterDetection' variable in the 'lfa_globals.m' file is selected to yes, then the 'planviewer.m' script will automatically generate the Plan View file for the run. These files are annotated with a '_CD' at the end of the file name and are saved in the appropriate transmitter beam directory.

Methodology

Theriault [2] describes a technique that will be used in this report for predicting detection performance of an active sonar using GSM. The first six steps in this technique will provide the Signal Excess prediction and are as follows:

- Define environmental Parameters;
- Define Sonar System Parameters;
- Define the Computational Model Parameters;
- Compute the Reverberation Levels;
- Define the Target Characteristics; and
- Compute the Signal Excess.

Details of each of these steps are available in [2] and only the implementation of the steps will be described in this report.

Environment Parameters

The environmental parameters GSM uses include Sound-speed profile; surface and bottom loss; volume absorption; surface, bottom, and volume scattering; and noise. The tools will either use the models built into GSM and invoke them in the template files or the user may input their own tables, as GSM allows.

```
GSMF
 └─ENVRNMT
    ├─DEEP
    │  ├─SUMMER
    │  └─WINTER
    ├─SHALLOW
    │  ├─SUMMER
    │  └─WINTER
    └─PERSIAN
       ├─SUMMER
       └─WINTER
```

Figure 4. Environment Directory Tree.

The user table files are placed as text data files in the appropriate directory in a repository called ENVRNMT which is located below the main GSMF directory. Each environment repository has a similar structure. The environment location is identified by a directory below the ENVRNMT directory, and each of these has a Season (SUMMER and WINTER) subdirectory. For example, Figure 4 shows the directory tree used for environmental files.

The environmental parameters of Location and Season are also used in directing the output files of the GSM runs. For example, Figure 5 shows the portion directory tree used for locating the GSM output files to the Location\Season level.

```
GSMF
  └─LFA
      └─HLOHLO
           ├─DEEP
           │    ├─SUMMER
           │    └─WINTER
           ├─ SHALLOW
           │    ├─SUMMER
           │    └─WINTER
           └─PERSIAN
                ├─SUMMER
                └─WINTER
```

Figure 5. Run Directory Tree

The ambient noise spectra is defined in the 'SSP.DAT' file as 64.47 dB for deep water scenarios and Table 1 is used for the shallow water case.

kHz	dB
1 2	63 0
2 5	59 0
4 0	55 0
5 0	54 0
10.0	49 0

Table 1: Shallow Water Ambient Noise Spectra

Other environmental parameters used by GSM are included in Table 2.

Computational Parameters	
Ocean Sound Speed Model	CONGRA
Sea State	3
Surface Reflection Coefficient Model	AMOS
Surface Scattering Strength Model	CHAPHA
Surface Scattering Factor	+2 6 DB/YD

Table 2: GSM Environmental Parameters

Sonar System Parameters

The Sonar System parameters GSM uses include Beampattern, Frequency, Signal Type, the minimum and maximum number of steered transmitter and receiver beam directions, the weights applied to the receiver array elements (window), the number of elements and their spacing in the receiver and transmitter arrays the transmitter source level and the receiver processing gain. Several of these parameters are defined in the 'lfa_globals.m' file (see Annex A) in the MFILES directory, however, source level and processing gain are calculated by the 'se pl' file in the LFA directory since they vary with Signal Type

The Sonar System parameters of Signal Type and Transmitter Beam, and Receiver Beam are also used in directing the output files of the GSM runs For example, Figure 6 shows the continuation of the Figure 5 directory tree used for locating the GSM output files to the Signal Type \Transmitter Beam\Receiver Beam level

```
GSMF
   └─LFA
          └─HLOHLO
                 └─DEEP
                      └─SUMMER
                           ├─CW
                           │   ├─ TBEAM001
                           │   │    ├─ BEAM001
                           │   │    ├─ BEAM002
                           │   │    ├─ BEAM003
                           │   │    ├─ ...
                           │   │    └─ BEAM051
                           │   ├─ TBEAM002
                           │   ├─ TBEAM003
                           │   ├─ ...
                           │   └─ TBEAM017
                           └─FM
                               ├─ TBEAM001
                               │    ├─ BEAM001
                               │    ├─ BEAM002
                               │    ├─ BEAM003
                               │    ├─ ..
                               │    └─ BEAM051
                               ├─ TBEAM002
                               ├─ TBEAM003
                               ├─ ...
                               └─ TBEAM017
```

Figure 6: Run Directory Tree

Computational Model Parameters

The Computational Model parameters GSM uses include sonar depth, and self-noise levels. These parameters are defined by the 'se.pl' file in the LFA directory since they vary with the Depth and sound speed profile of the Environment. The sonar depth is placed at the best depth for detection, usually the minimum sound speed, to a maximum of 300m and a minimum of 25m (assumed cavitation depth). In the deep water scenarios, the sonar is placed at 300m, in the shallow/summer scenario at 75m and the shallow/winter scenario at 25m.

The self-noise table is stored in the file 'slfNoise.dat' in the ENVRNMT directory. The shallow water self-noise data is derived from the median curve of the family of curves shown in Figure 7 which was derived from Theriault[3]. For deep water environments, the same curve is used except for the portion between 30° and 60° relative bearing. This portion is replaced with values representing a straight line between the value at 30° and the value at 60°.

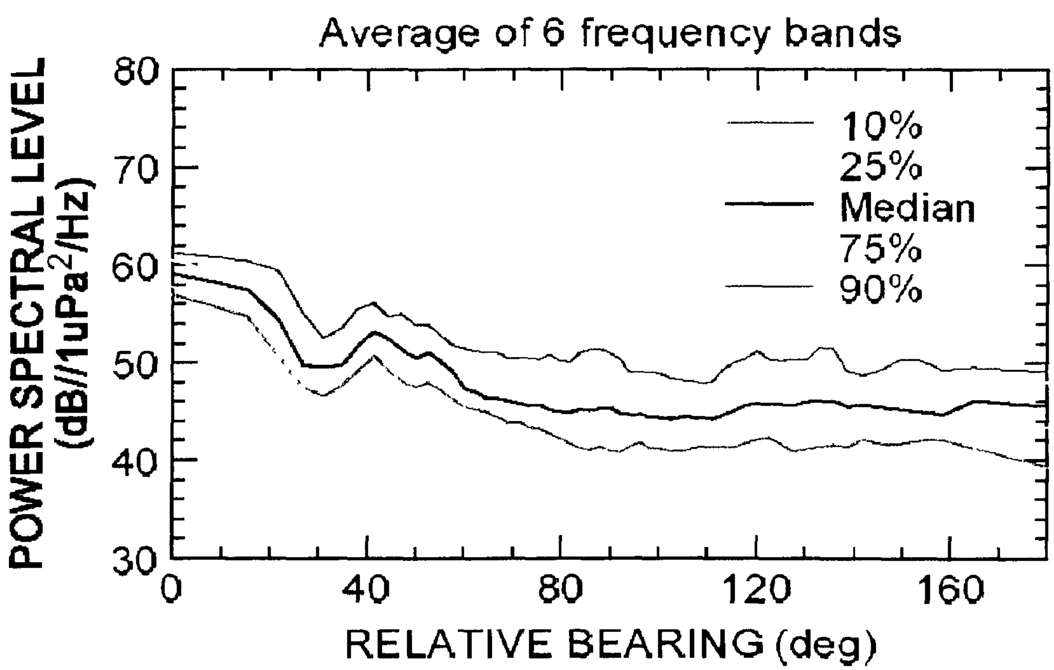


Figure 7: Family of Self-Noise Curves in Shallow Water.

Compute Reverberation Levels

The PERL script 'reverb.pl' is used to direct GSM to calculate the Reverberation Levels. For each transmitter beam and each receiver beam, an azimuthally integrated beam pattern is calculated and saved in the BEAMPAT directory. The 'reverb.pl' script reads in these azimuthally integrated beam pattern tables from the appropriate files, calculates the reverberation associated with that configuration, and saves a binary file in the receiver beam directory (example. TBEAM001\BEAM001) in the run directory defined in Figure 6. These files are used later in the calculation of Signal Excess.

Target Characteristics

The Target Characteristics GSM uses include target depth, and Target Strength. These parameters are defined by the 'se.pl' file in the LFA directory since they vary with the Depth and sound speed profile of the Environment. In the deep water scenarios, the target is placed at 200m, in the shallow scenario at 50m. The target strength is set at 10 dB in the 'seTemplate.dat' file for all scenarios.

Compute Signal Excess

The Signal Excess is computed by using the GSM's Bell Model of matched filter processing gain which allows separation of Noise Signal Differential (NSD) and Reverberation Signal Differential (RSD). In both the FM and CW cases, the pulse length is 2 sec and the NSD is set to 7 dB for 4 pings[4].

In the CW pulse case, one can set RSD to -100 dB and target speed to 0 kts since the target echo is expected to arrive outside the frequency bins containing reverberation returns for a high doppler target (>20 kts). Also, given that the pulse shape is a 0.25 Tukey, source level is calculated by reducing the peak by 20*log(.88) = -1.11 dB, where .88 represents the ratio of coherent processing gain of a 0.25 Tukey shaped pulse with a rectangular window see Harris,

For the FM case, the RSD is calculated as NSD * 10log(pulse length * FM bandwidth) . The Source Level is not reduced

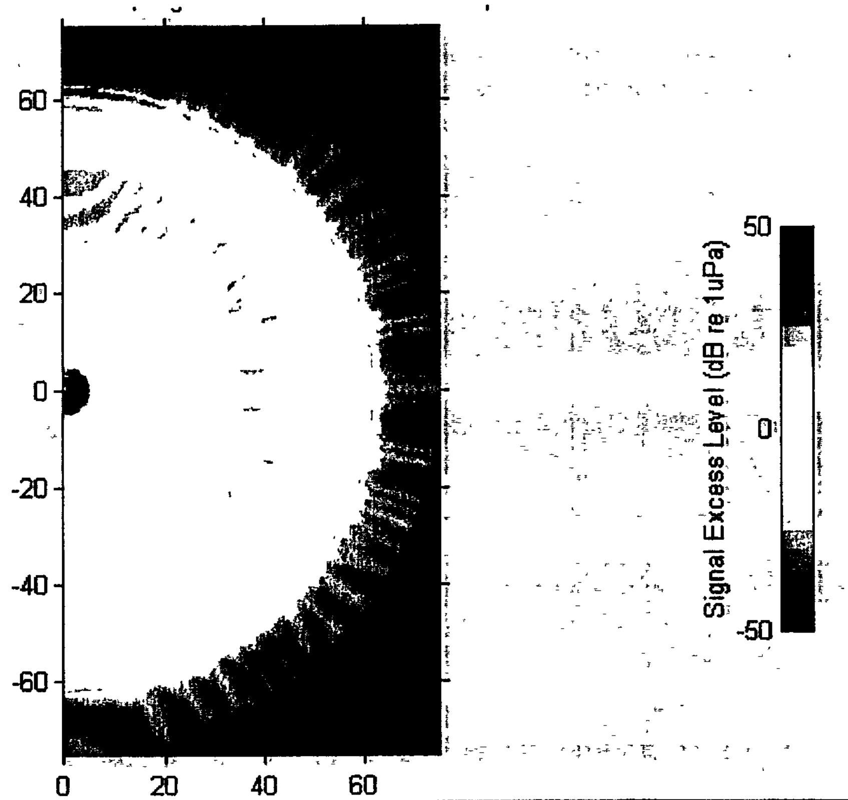
Results

Several configurations of an LFA sonar system have been run and the results are reproduced in this section. The plots show graphically the sonar performance predictions in terms of Signal Excess in range and cross-range. The Horizontal Receiver Array is oriented in a north-south direction with its centre at the origin of the plot. The north-south and east-west scale is in kilometers, while the Signal Excess scale is in dB re 1μPa

The effect of the self-noise from the towing ship, located north of the array, is clearly visible in all plots.

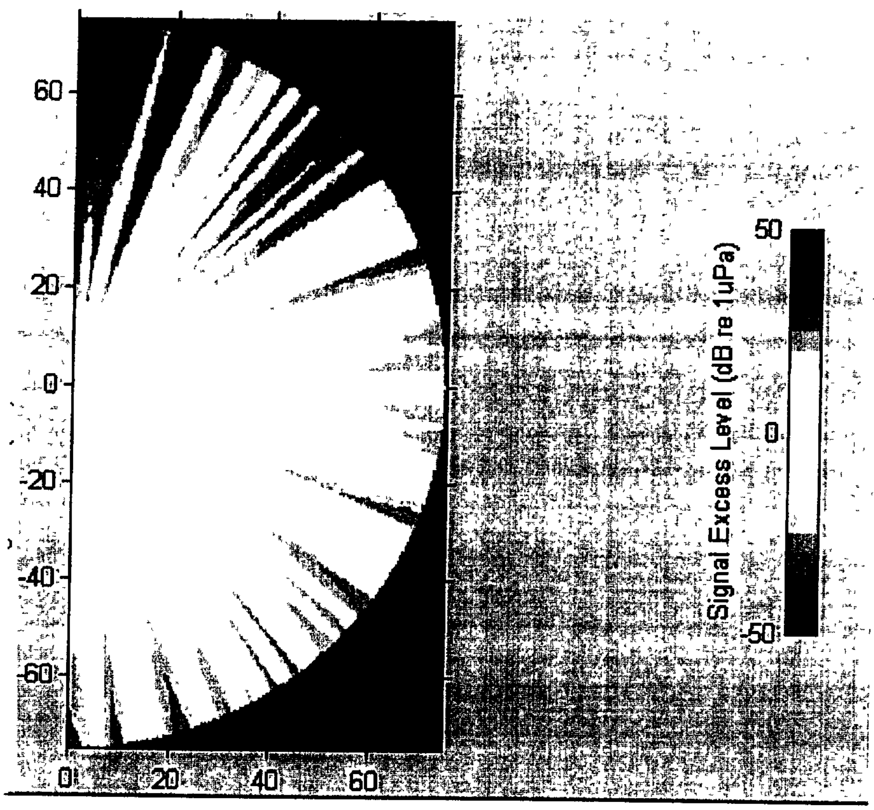
Run #1

- VP2 Projector,
- HLA Receiver,
- Deep\Summer Environment,
- CW Pulse



Run #2

- VP2 Projector,
- HLA Receiver,
- Shallow\Summer Environment,
- CW Pulse



Conclusions

As the results show, the Active Sonar modelling tools discussed in this contract are effective in producing a Plan View of an LFA sonar performance prediction. The results of these runs can be used for further investigation of tactical issues.

Problems

The generation of results for a single HLO-HLO run can take ~60 hrs and one VP2-HLO run can take ~4 hrs on a Pentium 600 PC. The time for each program to run is shown in Table 3 The need for Counter Detection calculations will does increase the time to run. The PERL scripts that can be used in place of 'planviewer m' do run faster, however, their time to was not measured and is not known at the time of writing.

	HPA	VPA
vp_hl_tx2.m	2.5 hrs	10 min
reverb.pl	17 min	1 min
se.pl	15 hrs	51 min
Planviewer.m	41 hrs	2.4 hrs

Table 3. Time to Run the Active Sonar Modeling Tools

Due to the in-availability of MATLAB at the time of delivery and the unsuccessful attempts to employ a MATLAB-like program (OCTAVE) the author elected to re-write the 'planviewer.m' file in PERL.

There is a discrepancy between the SWAMI Integrate program and vp_hl_tx.m in the production of azimuthally integrated beam patterns even though both produce identical 3D beampatterns. Since there was insufficient time to debug vp_hl_tx.m, the author elected to use the SWAMI beampatterns, which were readily available, and thus the programming could progress. If a stand-alone capability is a requirement in the future, it is recommended that either the SWAMI Integrate program be ported to Windows, or that the set of PERL scripts be ported to Unix/Linux. The tools used can now be executed independently of MATLAB and, except for some simple system calls, on multiple platforms. This innovation will provide the user with flexibility for future growth and expansion of the tools.

References

1. Theriault, James A., "SWAMI", unpublished.
2. Theriault, James A., "Baseline Modeling Method for Predicting Detection Performance of Monostatic Active Sonars, unpublished.
3. Theriault, James A, Private conversation. Oct 2000.
4. Theriault, James A, Private conversation. Nov 2000.

Annex A lfa_globals.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
%  lfa_globals
%  use this file to set the input parameters for model run
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

titlename = ['AAACABABCA'];

txrModeArray =  ['vp2';'hlo'];
txrMode = (txrModeArray(2,:));

rxrModeArray =  ['hlo'; 'hld'];
rxrMode =  (rxrModeArray(1,:));

locationArray =  char('deep','scotian','persian');
location= deblank(locationArray(2,:));

seasonArray =  ['summer';'winter'];
season= (seasonArray (1,:));

signalTypeArray =  ['FM';'CW'];
signalType =  (signalTypeArray(2,:));

windowArray = ['wboxcar' ; 'hamming' ; 'hanning'];
window = (windowArray(1,:));

counterDetectionArray = [ 'yes' ; 'noo' ];
counterDetection =  (counterDetectionArray(2,:));

f = 1500; %  operating frequency (Hz)
c = 1500; %  sound speed in sea water (m/s)
Nr = 201; %  # Receive sensors;
dr = c/f/2.1; %  Receive sensor spacing (m)
Ns = 32; %  # Source projectors, 2 or 32
ds = c/f/2.1 ;%  Source projector spacing (m)

maxRange = 75; %  maximum Radial Range in km.
nPoints = 150; %  # of points along a radial.
incPoints = maxRange/nPoints; %  points increment in km

azMin = -180;
azMax = 180;
azInc = 2;
vrtMin = -90;
```

```
vrtMax = 90;
vrtInc = 2;
minTxrBeam = 4;
maxTxrBeam = 17;
minRxrBeam = 1;
maxRxrBeam = 51;
minRadial = 1;
maxRadial = 91;  %  maximum number of Radials over 180 deg.
incRadial = 2;  %  Radial increment.
selfNoiseFile = ['SlfNoise.dat'];
```

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
NSD	Noise Signal Differential
RSD	Reverberation Signal Differential
SE	Signal Excess
TL	Transmission Loss
LFA	Low Frequency Active
SWAMI	Shallow Water Active Model
VP2	Vertical Projector, 2 elenments
HLA	Horizontal Line Array
FM	Frequency Modulated
CW	Continuous Wave
GSM	Generic Sonar Model

Bibliography

1. Theriault, James A., "SWAMI", unpublished.
2. Theriault, James A., "Baseline Modelling Method for Predicting Detection Performance of Monostatic Active Sonars, unpublished.
3. Theriault, Jame A, Private conversation. Oct 2000.
4. Theriault, Jame A, Private conversation. Nov 2000.

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The Defence Research Establishment Atlantic has a requirement to evaluate the performance of an active monostatic sonar that can employ a vertical or horizontal projector array and a horizontal receiver array To facilitate this effort, several tools have been developed for managing the multiple files input parameters and which use the Generic Sonar Model (GSM) as the performance prediction engine. The software languages used are MATLAB and PERL.

This report provides a description of Active Sonar modelling tools as developed by the author. This report is divided into a number of sections including: general description, methodology, results, and conclusions.

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