SACLANTCEN MEMORANDUM
serial no.: SM-298

SACLANT UNDERSEA RESEARCH CENTRE MEMORANDUM

THE JOINT SACLANTCEN/USA TOWED VERTICALLY DIRECTIVE SOURCE TVDS

G. Murdoch, L. Gualdesi, L. Troiano, J. Monti, C. Dubord

July 1996

SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

tel: +39-187-540.111
fax: +39-187-524.600

e-mail: library@saclantc.nato.int

NORTH ATLANTIC TREATY ORGANIZATION

The joint SACLANTCEN/USA Towed Vertically Directive Source- TVDS

G. Murdoch, L. Gualdesi, L. Troiano,
J. Monti and C. Dubord

The content of this document pertains to work performed under Project 041-1 of the SACLANTCEN Programme of Work. The document has been approved for release by The Director, SACLANTCEN.

David L. Bradley
Director

intentionally blank page

The joint SACLANTCEN/USA Towed Vertically Directive Source - TVDS

Murdoch, L. Gualdesi, L. Troiano, J. Monti [1] and C. Dubord [1]

Executive Summary: For some years SACLANTCEN has conducted environmental studies utilizing a low-frequency sound source. Operating at frequencies around 400 Hz and 960 Hz, a comprehensive data base has been built up which has been used by scientists at SACLANTCEN and national research centres to refine theoretical treatments of low frequency sound transmission, to validate work on forward and back scattering, and to investigate geological factors giving rise to discrete reflectors in an attempt to assess the potential of low frequency active sonar adjuncts. Though these studies have been extremely successful, by 1993 it was clear that the scope of the work was being curtailed by limitations of the sound source. The acoustic power was too low for wide area reverberation research, the inability to transmit more than a single frequency at any one time and the limited transmit bandwidth were severely hampering several studies. The wide transmit beam width was also not well matched to the environment or the potential operational user, particularly in shallow water.

Simultaneously, though quite independently, in 1993 the US Office of Naval Research was examining the practicalities of developing a new source for low-frequency research. The US authorities involved were confident that a suitable source could be constructed but they lacked a research vessel with suitable shipborne winching capability and the cost of purchasing or building such a capability was so great that it could have endangered the whole programme. In May 1993, SACLANTCEN was approached by workers from the Naval Underwater Warfare Center, New London Detachment, to explore the possibility of joint research and to identify the technological difficulties inherent in such a proposal.

In what has turned out to be a classical example of modern collaborative research where neither could afford the total cost involved but each had provision to build part of the system, the source construction talents of NUWC were brought together with the sea-going experimental and ocean engineering expertise of SACLANTCEN to produce an equipment suite which would be used for future scientific research on board the NRV *Alliance*.

This report describes the development of the source, the Towed Vertically Directive Source (TVDS), together with the ship-handling deployment scheme adopted. It also outlines some of the lessons learned. This extensive programme was completed on time and the full suite of equipment was put to sea on NRV *Alliance* in July 1994 for the first engineering trial. The trial had been planned precisely for that period of time some two years earlier, a remarkable achievement by all concerned. The report is intended as an overview; technical details are available on request.

[1] Naval Undersea Warfare Center

intentionally blank page

The joint SACLANTCEN/USA Towed Vertically Directive Source - TVDS

G. Murdoch, L. Gualdesi, L. Troiano, J. Monti and C. Dubord

Abstract: This report is the text of a paper presented at Undersea Defence Technology, Cannes, 1995 (UDT 95). It outlines the development of the Towed Vertically Directive Source (TVDS) and the associated ship-handling and winching scheme adopted. This was an extensive programme of cooperative development between SACLANTCEN and the Naval Undersea Warfare Center, New London Detachment sponsored by the Office of Naval Research. It was completed on time and the full suite of equipment was put to sea on NRV *Alliance* in July 1994 for the first engineering trial.

Keywords:

Contents

1 Introduction

In the early 1980's, SACLANT Undersea Research Centre developed a low-frequency sound source capable of being towed at speeds up to 10 kn. The source body and the ship winching equipment were designed and constructed by the engineering and workshop staff of SACLANTCEN. The compact design of the source and the winch equipment allowed them to be moved in their entirety to the Centre's research vessel *Alliance* when it was commissioned in 1988, (Fig. 1). By 1993, it was realized that research work was being curtailed by limitations in the acoustic characteristics but the cost of an alternative source was unlikely to be affordable by the Centre in the foreseeable future.

Simultaneously, though quite independently, in 1993 the Naval Undersea Warfare Centre, Detachment New London under the sponsorship of the US Navy, was examining the practicalities of developing a new wide band source for low-frequency research. The US authorities involved were confident that a suitable source could be constructed but they lacked a research vessel with suitable handling capability and the cost of purchasing or building such equipment was so great that it could have endangered the whole programme. In May 1993, SACLANTCEN was approached by workers from NUWC to explore the possibility of joint research and to identify the technological difficulties inherent in such a proposal.

In what has turned out to be a classical example of modern cooperative research where neither could afford the total cost involved but each had the knowledge and expertise to build part of the system efficiently, the source construction talents of NUWC were brought together with the sea-going experimental and ocean engineering expertise of SACLANTCEN to produce an equipment suite which would be used for future scientific research.

This report will first describe the original source and the ship-borne handling system, the forerunners of the new Towed Vertically Directive Source (TVDS); then TVDS itself will be described. This was an extensive, complex programme which was completed on time. The full suite of equipment was put to sea on NRV *Alliance* in July 1994 for the first engineering trial, a trial which had been planned precisely for that period of time some two years earlier.

2
Source

The original SACLANTCEN source consisted of two low-frequency transducers operating at a resonant frequency of 390 Hz and producing an acoustic power output level of 212 dB re 1μPa at 1 m. A second independent pair of transducers operated at a resonant frequency of 960 Hz produced 210 dB re 1 μPA at 1 m. Both transducer pairs had 3 dB down bandwidths of 100 Hz; however it was not possible to transmit simultaneously at both frequencies due to hardware constraints.

The underwater tow body is of aluminium with a torpedo -like shape. The transducer pairs are housed in a pivoting arm. As the body falls from the cradle, gravity causes the arm to rotate to the vertical, its tow position underwater. There is no locking mechanism; the arm is free to move when towed, (Fig. 2).

The technique for recovering the body into its cradle was not automated; catching the body in the cradle was done manually and it was to the great credit of the operators that successful retrievals were achieved in sea-state 7 though this was regarded as the upper limit for safety to both equipment and personnel. Once 'hooked' the body was pulled up into the cradle using the tow cable, the arm swung back into the body, and the 1000 kg of weight was rotated back through 180° by the winch pinion gear into its rest position. This arrangement of retrieval and storage was extremely economical in terms of space and very safe after retrieval as there was no equipment outboard of the ship during transit or in bad weather, (Fig. 3).

By 1992, it was clear that the source characteristics were limiting its usefulness. Its relatively low acoustic power output, the limited transducer bandwidth and the lack of simultaneous low-and high-frequency transmission were restrictive in some studies and its large vertical beam width was not well matched to the environment, (Fig. 4). In 1993 cooperation talks began with the US.

At the outset it was clear that for any body likely to produce marked performance improvements there would be an increase in size and weight compared to the existing body. Careful consideration had to be given to this point because the space on board NRV *Alliance* could not be increased substantially for any new equipment. Even if the size of a new body could be managed, any substantial increase in weight might eliminate the use of the *Alliance* winch and handling system and resources at *SACLANTCEN* precluded the purchase of a completely new on-board system. A finite element study of the cradle body and an examination of the associated winch hydraulics showed that changes could be made which would allow for a maximum body weight of 4500 kg.

For programme reasons the first engineering trial had to take place in August 1994. RV *Alliance* was committed to an experiment in May of that year which involved the use of the handling equipment, and therefore only two months were available for the mechanical alterations to the ship and installation of new wiring necessary to carry the 400 ampere at 440 volts, necessary to drive the upgraded source.

3
Display

It was anticipated that data display on-board NRV *Alliance* would not be a problem area. A new sonar information display suite had been proposed in 1993 and the equipment was scheduled to be delivered in early 1994. The suite was to be based on a group of Alpha workstations known as the 'Alpha Farm', which could be implemented to independently process information received from more than one transmitted frequency and display this information on a set of independent monitors in real time, (Fig. 5). As commercially available equipment was being used, the approach was low risk; the only concern was that it had not been done before and little was known of the architectural procedures required to ensure data throughput at the correct rate. A feature of this equipment was the inclusion of a geographical mapping facility developed at SACLANTCEN on a separate Macintosh system. This addition would allow the real-time presentation of own ship position and sonar information directly into a Geographical Information System (GIS). This allowed the acoustic returns to be related to geophysical features. This schedule was ambitious but fortunately it was successful and the display suite and associated software were taken to sea complete and working by mid April 1994.

4 Receiver

A difficulty did exist with the towed receiving array if it was intended to operate at frequencies substantially above 1500 Hz. The available SACLANTCEN towed array had 256 elements nested in three apertures of 128 channels at spacings of 2.0, 1.0 and of 0.5 m, (Fig. 6). This combination corresponds to an upper frequency of operation of 1500 Hz. With the planned new source, the upper frequencies would exceed this value and a new receiving array would have to be employed. The current array could not be modified for a higher frequency of operation and it became clear that the requirement could only be fulfilled by constructing and towing a second array. From materials available at SACLANTCEN, it would be possible to construct a 32-element array with an internal element spacing of 0.18 m. This would be the first time that three systems would be towed simultaneously from NRV *Alliance*.

The principle concern was that the equipment components would be geographically separate during production and modification. Alterations to the ship's winching and handling equipment would be carried out in La Spezia while the body was to be made in the USA. There could be no provision for checking the design with the equipment before the handling gear and the body were brought together for the first time at the start of the engineering trial.

The system is a complex one, with many contributing agencies (Fig. 7), but it was decided to proceed and to impose on the programme a completion date of August 1994 - 20 months from the first planning meeting. This time scale was met and in August 1994 the ship changes had been completed and the winch and handling cradle were ready to accept the new source, the Towed Vertically Directive Source (TVDS), (Fig. 8).

5
Towed Vertically Directive Source - TVDS

The Towed Vertically Directive Source was designed as a scientific tool to examine problems associated with sound propagation and reverberation in shallow and deep water. The aim was to produce a wide-band high-power acoustic source capable of being towed from NRV *Alliance*.

The use of open architecture hardware in conjunction with commercially available items reduces the complexity of upgrades and costs. Two requirements for the source were that the design should allow the equipment to be used for the scientific investigation of areas by tailoring the available pulse types to the experimental needs over more than one frequency of operation and that the stringent weight constraints imposed by the method of deployment should be met, even if this necessitated using newly developed lightweight transducers and composite materials as yet not fully tried at sea.

It was decided that the frequency requirements would be best met by using two separate sets of transducers, one operating at a resonant frequency of 600 Hz and a second separate set with a resonant operating frequency of 3000 Hz. To have sufficient acoustic power output and maintain a narrow vertical beam width at low frequencies, a stack of five transducers was necessary. Two transducers were in fixed positions above and inside the body while the remaining three transducers were located inside the lower arm. This arm operated a similar swing arm design as the previous source. The resulting vertical beam width of this grouping of transducers was 16° steerable between $+45^{\circ}$ and -45° in 5° increments. The maximum transmit acoustic power at resonance is 230 dB with a bandwidth of 200 Hz at the -3 dB down points. However with these transducers it is possible to operate at frequencies from 200 Hz to 2000 Hz.

At the higher frequency, the transducers would be located in the fixed tail section. At the higher frequency, two transducer staves are used, producing an acoustic power output of 226 dB at a resonant frequency of 3000 Hz with 800 Hz of bandwidth at the -3 dB down points. The vertical beam width is 20° but there is no steering. The source is designed to have a maximum operating depth of 200 m and a tow speed of up to 16 kn.

6
Seneca Lake Tests

In April 1994, the near complete body was transported to the Naval Undersea Warfare Test facility at Seneca Lake to begin the acoustic testing. No major design faults were found and the LF transducers and the individual HF staves met their design goals. Testing continued through May when the TVDS was prepared for transporting to SACLANTCEN to begin the engineering trials on board NRV *Alliance*.

7
Tow cable

Experience with the previous towed source had shown that cable strumming could be a problem and therefore care was required in the cable design both from the electrical and mechanical standpoints.

TVDS has an electro-mechanical cable consisting of a 32 mm diameter electrical core surrounded by a double layer of torque-balanced armour resulting in an outer diameter of 40 mm. The electrical core has a total power capacity of 260 kVA which powers the five low-frequency (600 Hz) transducer, the two mid-frequency, 3000 Hz staves, the engineering sensors (pitch, roll, depth) and a reference hydrophone. The power loss in the 300 m of tow cable is 5 kw, (Fig. 9).

The breaking strength of the cable with its armour is 40 t while the smallest bending diameter is 90 cm. A short section of the cable was put through a series of tests including cyclic bending. The cyclic bending consisted of 5000 cycles before a failure occurred.

It was considered necessary to have some form of fairing on the cable to reduce strumming to a minimum. The overall rolled volume of the cable however could not be increased substantially because the winch drum size was fixed and this fact eliminated several forms of fairing usually used on tow cables. The cable manufacturer De Regt eventually suggested a ribbon fairing and this was adopted. This hairy ribbon fairing is braided on to the cable as the last step of the manufacturing process. It proved to be a fairly inexpensive means of apparently eliminating cable strum with only a slight increase in drag observable. The 300 m of tow cable was sufficient to meet all the depth requirements for this initial experimental system.

8
Engineering tests

The body was slightly heavy at 4300 kg; however this was within the tolerance of the handling equipment and it made an excellent fit with the cradle. There were five main aims for the engineering tests:

1) To conduct static trim measurement.

2) To determine the optimum deployment and recovery scenario.

3) To study the tow body dynamics at a range of towing speeds.

4) To compile curves of cable scope and depth achieved for a range of towing speeds.

5) To perform full power acoustic testing.

8.1. STATIC TRIM

The static trim test was conducted and after removal of some buoyancy foam in the tail, the nose-down towing angle was measured to be 2°. This was considered acceptable based on a ±5° guideline determined from earlier model tests.

8.2. DEPLOYMENT AND RECOVERY

Many deployment/recovery scenarios were examined during the trial and of these, the most successful (later taken to be the standard operating procedure) was to deploy at a ship speed of 3 kn. To recover the body, it was found that it should be brought to the sea surface at a ship speed of 5 kn; the ship should then cut power to both propellers and when the ship's forward momentum was reduced in speed to 2.5 kn, the tow body should be hauled into the chute. This process eliminated propeller turbulence at the surface and allowed for a smoother recovery. The procedure, similar to that used for the previous source, is illustrated in (Fig. 10).

8.3. TOW BODY DYNAMICS

In general, at the towing speeds of interest (4-16 kn), the tow body behaved in a very stable manner. Measurements were made with both active flap-control and fixed flap positions. With the flaps fixed in the horizontal position, it became apparent that the tow body exhibited a slight port bias. This bias was eliminated by setting the flaps for a roll to starboard. The final result was that at low tow speeds (4 kn) the body rolled to starboard (5°), at 8 kn, roll was zero, and at 10 kn, roll was 8° to port. The body pitch remained steady throughout being between 0-3° for all conditions. Given the attraction of reducing weight and considering that the tow body was stable for all towing speeds of interest, the active flap control electronics pod was removed.

8.4. DEPTH/ SPEED/CABLE SCOPE CURVES

Curves were obtained during the trial for a range of tow speeds. At 5 kn towing speed, the tow speed for many experiments, a towing depth of 100 m was achieved at full cable scope.

8.5. ACOUSTIC TESTING

Acoustic testing concentrated on establishing safe drive levels at various signal bandwidths. The parameters to consider were maximum VA of amplifier, maximum ceramic volts, and maximum drive current to the cable/tuning and transducer assembly. Derived source level corrections over the bandwidths measured for both LF and MF transducers are presented (Fig. 11).

Elaborate control software ensures that on transmit, the system cannot be damaged inadvertently by over-driving with a rogue signal. The transmit controller utilized a depth gauge on the body to accurately regulate the level fed to the transducers and thereby ensure that the correct power was delivered as a function of depth, only allowing maximum drive current and voltage when the body is at a depth in excess of the non-cavitation depth of 65 m. In addition to the control network the transmit signal characteristics are fed to the SACLANTCEN processor for automatic replica generation. It is also possible to feed this transmit signal to any other processor. Either all or part of the transmit signal can be processed in this way; the limit is on the processor not the transmitter, provided that the duty cycle is adhered to correctly. The transmit controller is shown (Fig. 12).

9
SWAC (Shallow Water Active Classification) experiments

The first sea trial with the complete suite of equipment took place in October 1994 and a second trial followed in June 1995. These trials were very successful particularly in relating reverberation features to the geophysical map of the area. The first experiment related the returns to the geographic features and sediment type by transferring the returns from the sonar displays to the GIS display. Here returns that could not easily be related to bathymetry were explained in some instances when the sediment type was overlaid, (Fig. 13). In the second trial the bathymetric data is overlaid directly on to the real-time sonar display where some of the reverberation returns and features are instantly recognizable, (Fig. 14).

10 Summary

In summary this project has been an excellent example of international cooperation. Using a combination of commercially available and specialized hardware, an imposed time scale of 2 years and the demanding requirements of the low frequency active acoustic research programme has been met.

Figure 1 SACLANTCEN Research vessel NRV ALLIANCE

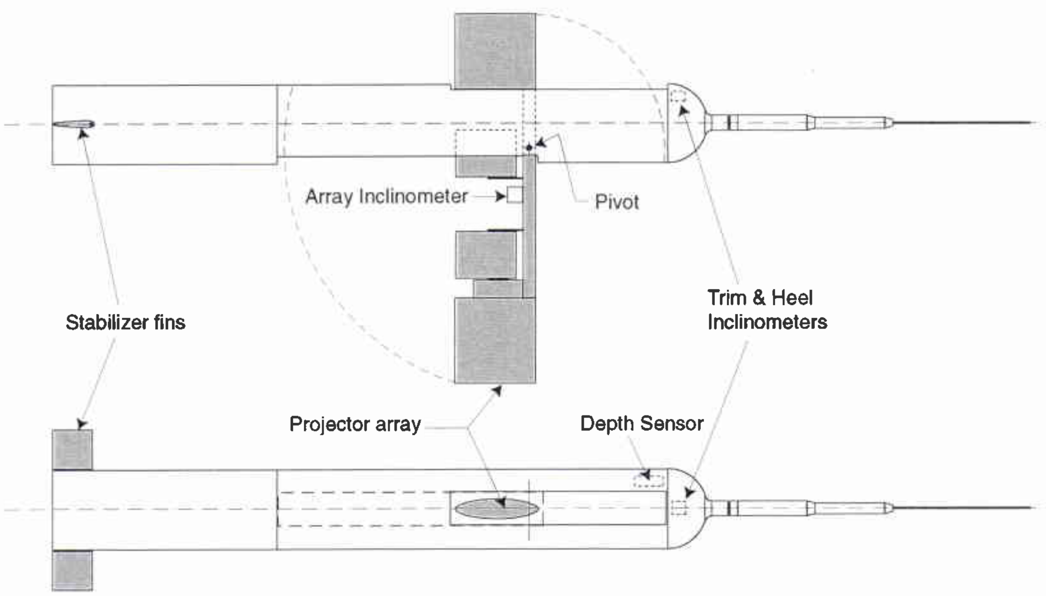


Figure 2 *Schematic of the salient features for the SACLANTCEN pivot arm arrangement in the low frequency towed sound source.*

Figure 3 *Retrieval procedure for towed body*

SOUND SOURCE

Weight = 1000 kg (air), 300 kg (water)

Vertical dipole: LF transducer spacing = 1.9 m.
HF transducer spacing = 0.7 m.

Fundamental design frequencies = 400,900 Hz

Max source levels= 212 dB re 1µPa at 1 m @ 400 Hz
209 dB re 1µPa at 1 m @ 960 Hz

Vertical directivity= +/- 60°

Handling - max tow speed = 10 kn
max tow depth = 100 m.

Figure 4 *SACLANTCEN towed sound source general characteristics.*

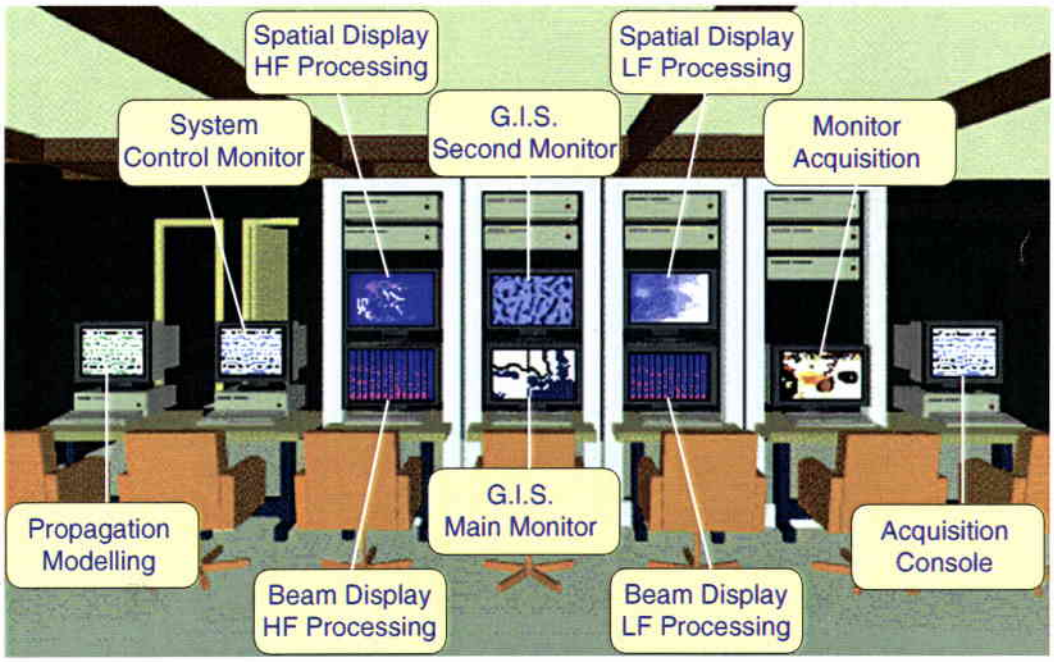
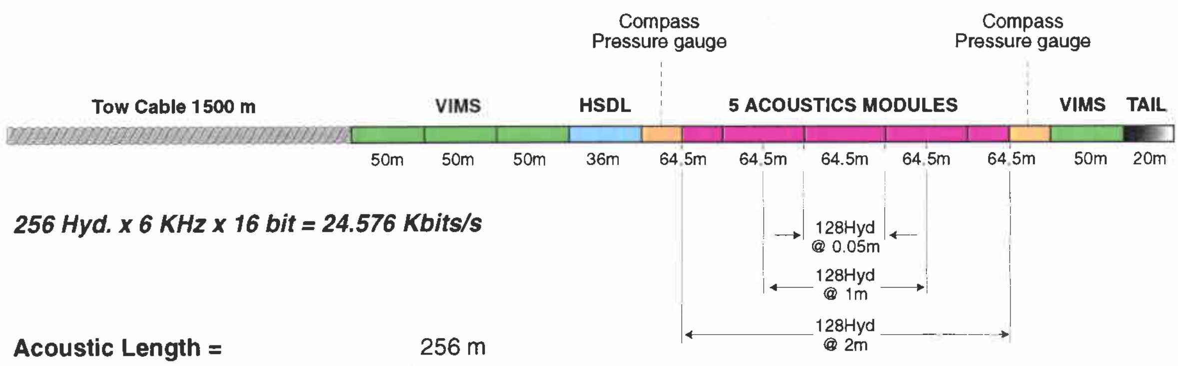


Figure 5 *SACLANTCEN new sonar display suite including the Geographical Information System (GIS) - this complete system was used for the first time at sea in April 1994.*



Acoustic Length = 256 m
Number of hydrophones = 128 spaced at 0.5, 1 or 2 m
Fundamental design frequencies = 1500, 750, 375 Hz
Max Tow Speed = 10 Knots
Max Tow Depth = 1000 Knots
HSDL = High Speed Data Link
VIMS = Vibration Isolation Module

Figure 6 *SACLANTCEN towed receiving array showing the nested configuration HSDL = High Speed Data Link. VMS = Vibration Isolation Modules*

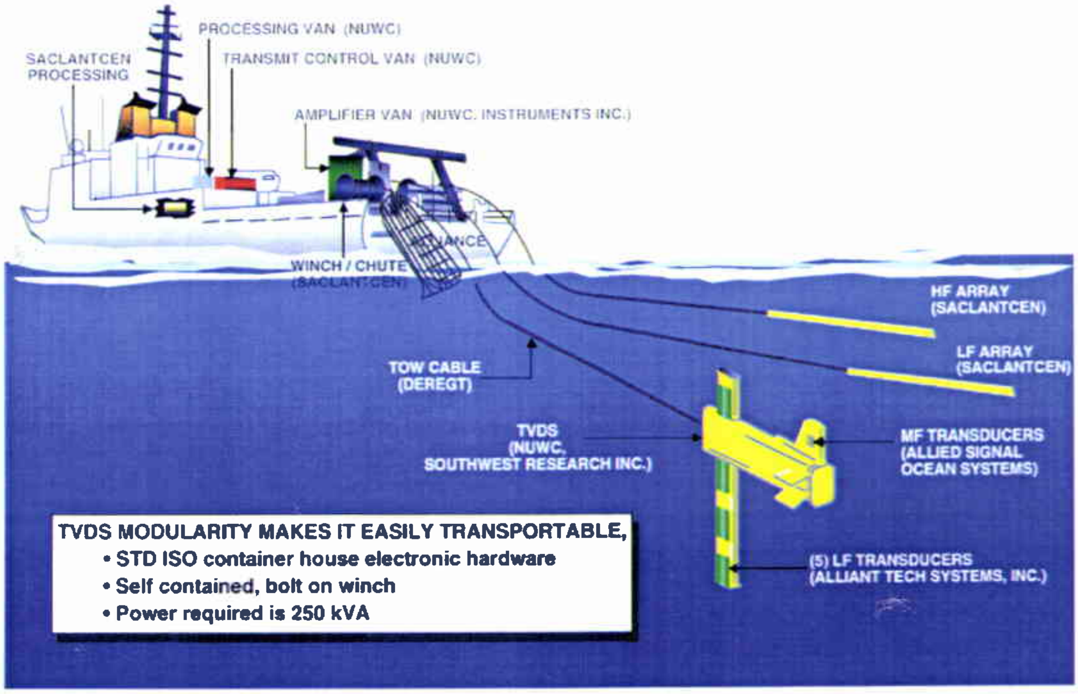


Figure 7 *Impression of source and receiver towing configuration on RV Alliance showing the principle contributors.*

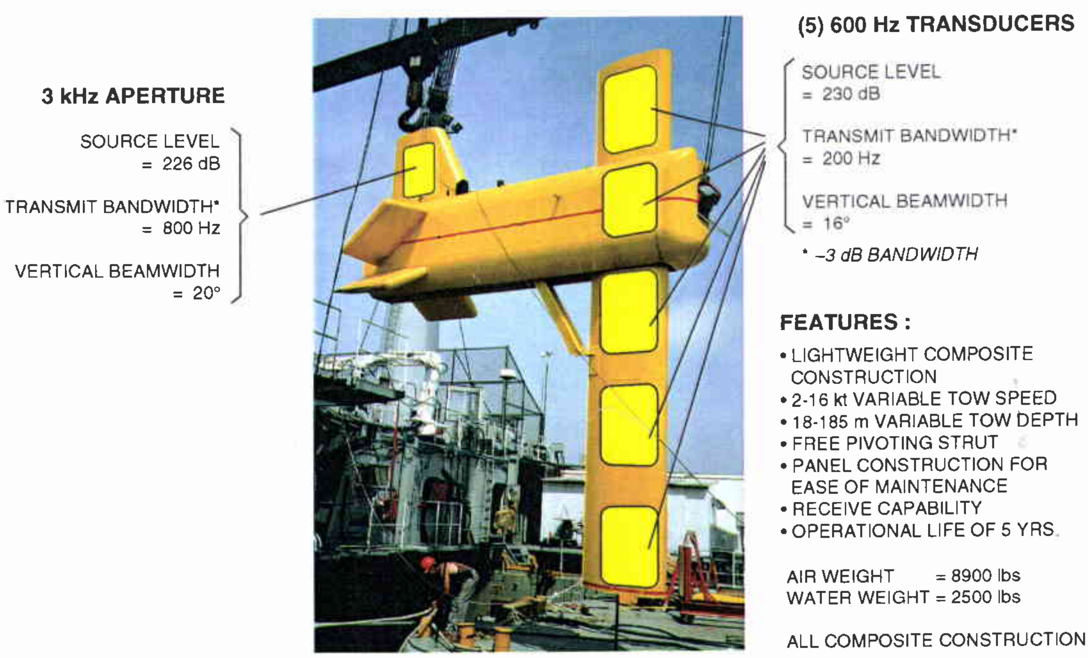


Figure 8 *NUWC Towed Vertical Directive Source (TVDS) with swing arm fully extended.*

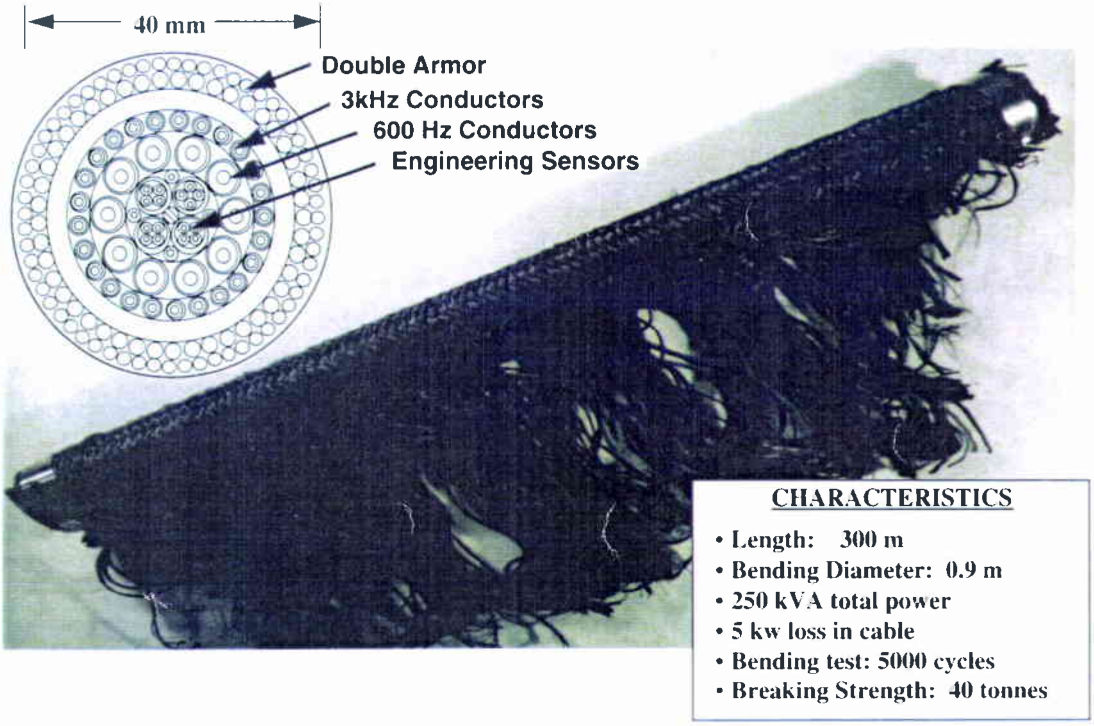


Figure 9 *TVDS tow cable design showing the ribbon fairing.*

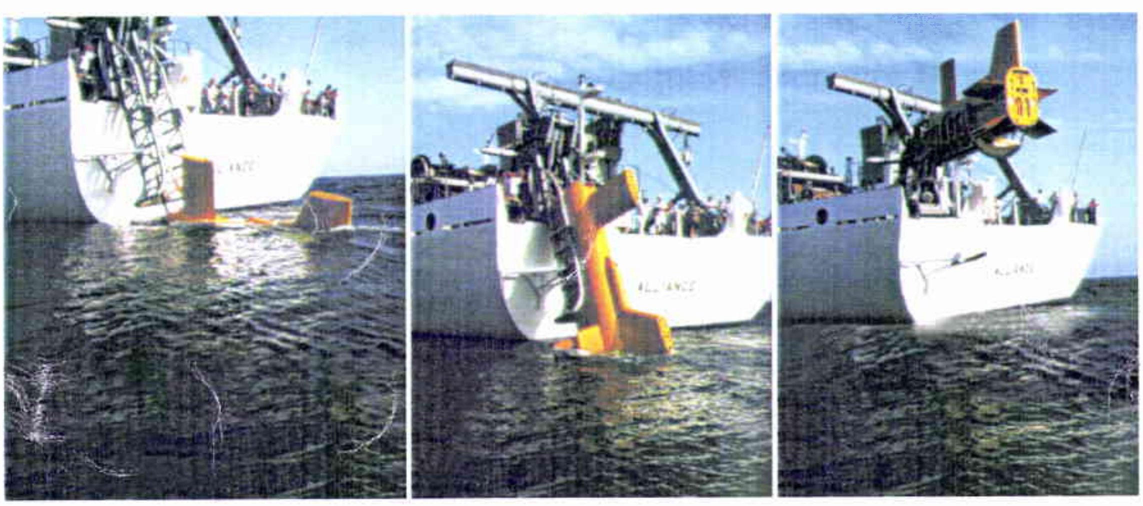


Figure 10 *TVDS retrieval sequence on NRV Alliance.*

Report no. changed (Mar 2006): SM-298-UU

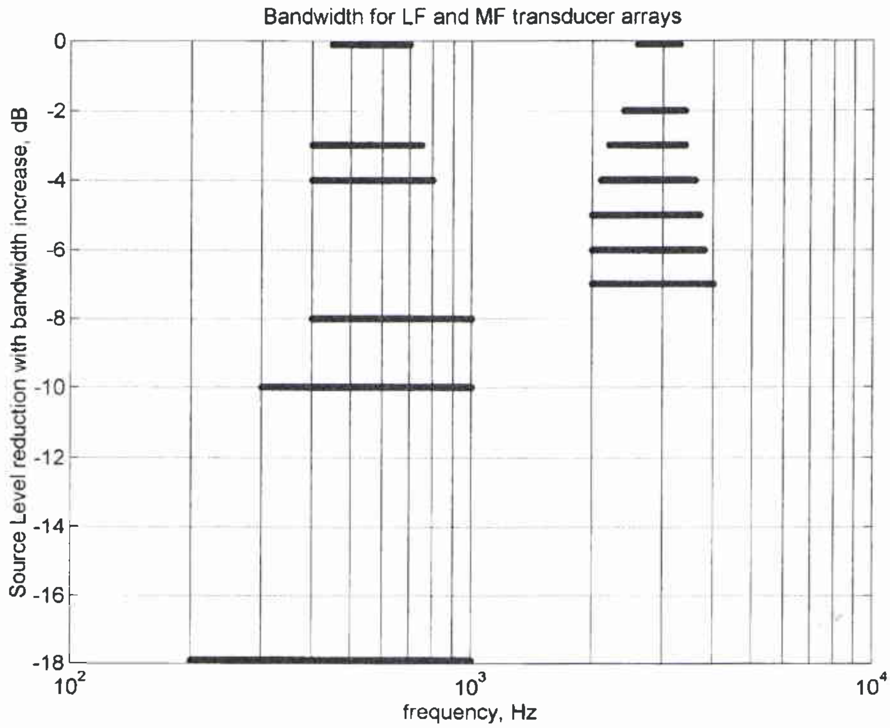


Figure 11 Source level as a function of transmit signal bandwidth derived from transducer drive evel (voltage and current) measurements.

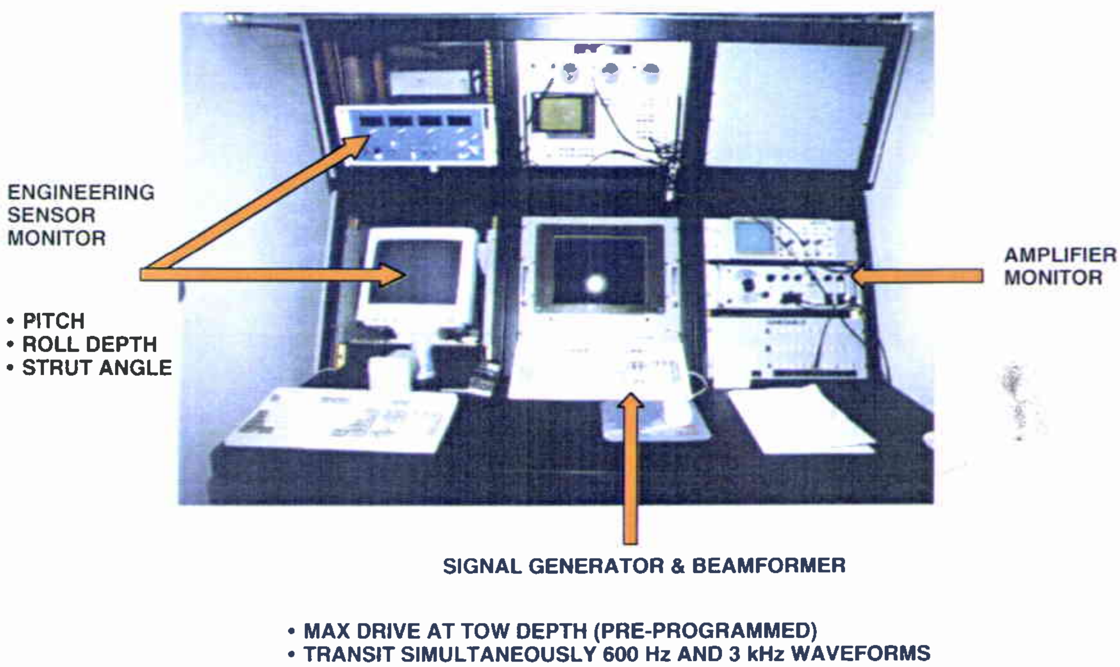


Figure 12 TVDS transmit controller console.

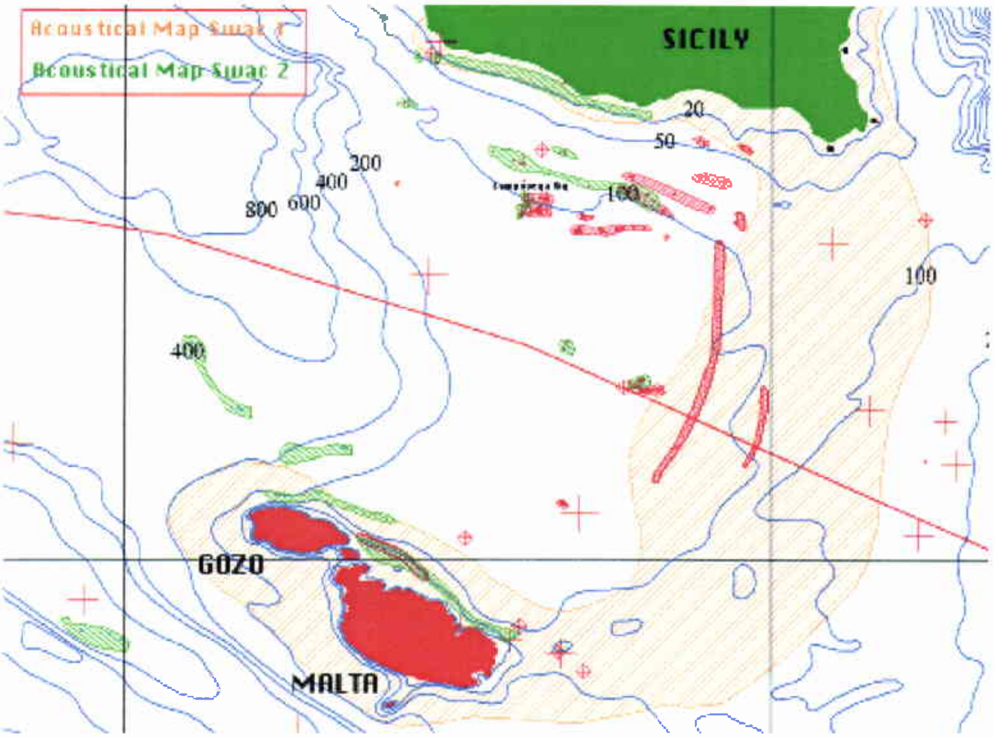


Figure 13 *GIS bathymetric map showing geological features (oblique brown lines) together with sonar reverberation data (oblique green and brown lines) obtained on first two SWAC experiments*

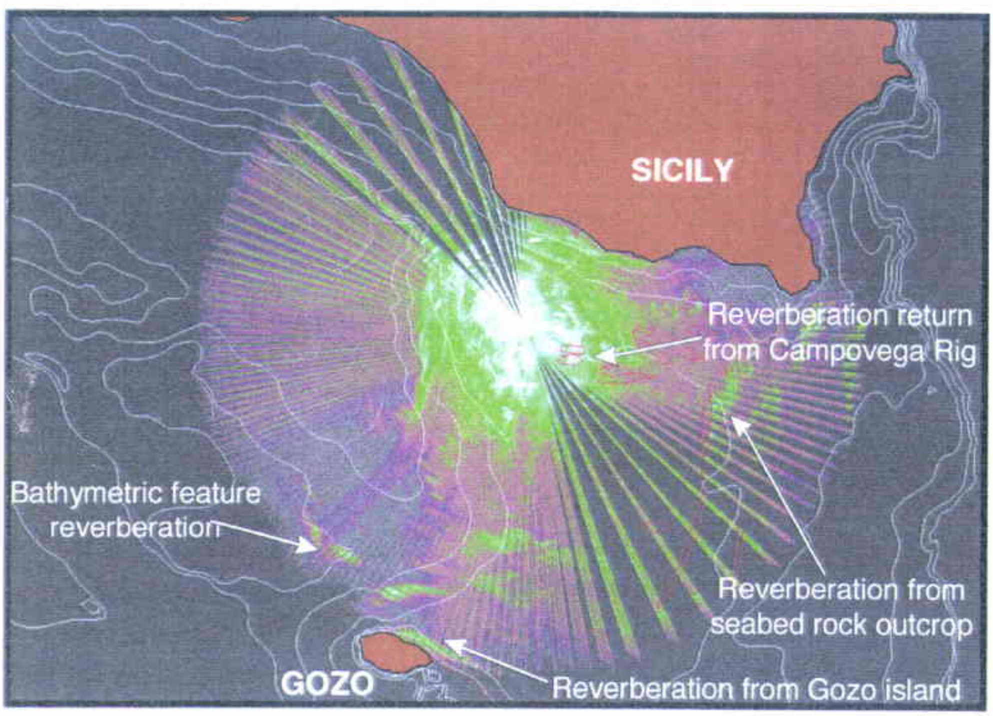


Figure 14 *Recent development showing bathymetric map overlaid dierectly on to the real time single ping sonar data processed and displayed in a geographical format*

Document Data Sheet

Security Classification	Project No.
NATO UNCLASSIFIED	041-1

Document Serial No.	Date of Issue	Total Pages
SM-298	March 1996	24 pp.

Author(s)

G. Murdoch, L. Gualdesi, L. Troiano, J. Monti, C. Dubord

Title

The joint SACLANTCEN/USA Towed Vertically Directive Source - TVDS

Abstract

This report is the text of a paper presented at Undersea Defence Technology, Cannes, 1995 (UST 95). It outlines the development of the Towed Vertically Directive Source (TVDS) and the associated ship-handling and winching scheme adopted. This was an extensive programme of cooperative development between SACLANTCEN and the Naval Undersea Warfare Center, New London Detachment sponsored by the Office of Naval Research. It was completed on time and the full suite of equipment was put to sea on NRV *Alliance* in July 1994 for the first engineering trial.

Keywords

TVDS – Towed Vertically Directive Source

Issuing Organization

North Atlantic Treaty Organization
SACLANT Undersea Research Centre
Viale San Bartolomeo 400, 19138 La Spezia,
Italy

*[From N. America: SACLANTCEN
(New York) APO AE 09613]*

Tel: +39 (0)187 540 111
Fax:+39 (0)187 524 600
E-mail: library@saclantc.nato.int

Report no. changed (Mar 2006): SM-298-UU

Initial Distribution for SM-298

SCNR for SACLANTCEN		*National Liaison Officers*	
SCNR Belgium	1	NLO Canada	1
SCNR Canada	1	NLO Denmark	1
SCNR Denmark	1	NLO Germany	1
SCNR Germany	1	NLO Italy	2
SCNR Greece	2	NLO Netherlands	1
SCNR Italy	1	NLO UK	3
SCNR Netherlands	1	NLO US	4
SCNR Norway	1		
SCNR Portugal	1		
SCNR Spain	1		
SCNR Turkey	1		
SCNR UK	1		
SCNR US	2		
French Delegate	1		
SECGEN Rep. SCNR	1	Total external distribution	34
NAMILCOM Rep. SCNR	1	SACLANTCEN Library	26
SACLANT	3	Total number of copies	60