Environment and Sustainable Development
(ESD)
PROGRAMME

Contract for: Shared-cost RTD

24 Month Report

Proposal number: **EVK3-2001-0078**
Project acronym: **EMCOMMS**

Project full title: **Underwater Communications using Electromagnetic Waves**

Duration: 36 Month (1 January 2002 – 31 December 2004)

Project
Co-ordinator: Professor James Lucas
The University of Liverpool

Contractors:

The University of Liverpool	(UOL)	UK
Bonn Elektronik	(Bonn)	D
Norwegian Underwater Intervention	(NUI)	N
Stenmar Ltd	(Sten)	UK
FS Antennentechnik	(FSA)	D

<u>Document Revision Date:</u> **April 2004**

Contents

1 Section 1: Management and Resource Usage Summary, Related to the Reporting Period (24 Months)

1.1 Objectives of the Reporting Period

The objectives during the reporting period 18 to 24 months were to complete Workpackages WP4, WP5 and WP6. As specified on page 2 of the DOW these are as follows:

WP4	System Testing (Vertical Water)	The transmitter will be lowered vertically into the water and the receiver will be placed just below the barge. The signal strength will be measured as a function of distance for comparison with Maxwell's equation. A time of flight velocity measurement will be obtained by using command signals generated using fibre optics communications.
WP5	Large Power Electronics	Power amplifiers with antenna matching circuits to deliver up to 1000W to a transmitting antenna. This will allow horizontal water ranges up to 1000m to be investigated.
WP6	PCM Signal Electronics	The ability to transmit and receive pulse code modulated signals with a low error bit rate and error correction facilities

1.2 Scientific/Technical Progress Made in Different Workpackages According to the Planned Time Schedule

During the period 18 to 24 months activities on three workpackages have been undertaken. These are:

WP4 System Testing (Vertical Water).
WP5 Large Power Electronics.
WP6 PCM Signal Electronics.

The Gantt chart is given in table 1.

The specific details are as follows:

- The Manpower chart in table 2.
- The details of the activities undertaken in Workpackages WP4, WP5 and WP6 are given on separate pages.
- All three tasks have been completed to allow a smooth transition into the final workpackages WP7 and WP8. One item WP5.5 is ongoing and is the EM screening activities. Presently the EM interference is low because all the electronic items are battery operated within a single metal container.

WORKPACKAGE/DURATION BARCHART				
Workpackage description	**YEAR 2**			
WP4: System Testing (Vertical Water)				
4.1 Validation of transmitter on the barge				
4.2 Validation of receiver on the same barge				
4.3 Investigate carrier signal system performance at distances varying by approximately 0.2m over a distance of 30m over the frequency range 1 to 5MHz				
4.4 Investigate PCM signal performance up to 30m distance. Examine the data rate integrity for sensor signals and video images				
4.5 Investigate the effect of sea surface and seabed reflections and ranging experiments				
WP5: Large Power Electronics				
5.1 Impedance matching circuit between antenna and rf power supply				
5.2 Integration with the 1000W signal amplifier				
5.3 Crystal oscillator and pre-amplifier				
5.4 Dock testing with antennae				
5.5 Integration with PCM signal electronics				
5.6 Electrical screening framework for barge mounted system				
WP6: PCM Signal Electronics				
6.1 Establish pulse code modulation (PCM) with error coding				
6.2 Selection of binary modulation frequencies				
6.3 Detector system amplifiers				
6.4 Signal processing to aid signal recovery				
6.6 Signal output using fibre optics				
WP9: Management and exploitation				
9.1 Management				
9.2 Exploitation				
Reporting Period	**12**	**15**	**18**	**21** **24**
Major Deliverables and Milestones (M1 to M7)				

Table 1 The Gantt Chart (12 to 24 months)

WORKPACKAGE/MANPOWER BARCHART	Partners Person-Months					
Workpackage description	**UOL**	**Bonn**	**NUI**	**Sten**	**FSA**	Total (pm)
WP4: System Testing (Vertical Water)	Lead					
4.1 Validation of transmitter on the barge	2		1	1	1	
4.2 Validation of receiver on the same barge	2		1	1		
4.3 Investigate carrier signal system performance at distances varying by approximately 0.2m over a distance of 30m with the frequency range 1 to 5MHz	2		1	1		
4.4 Investigate PCM signal performance up to 30m distance. Examine the data rate integrity for sensor signals and video images	2		1	1		
4.5 Investigate the effect of sea surface and seabed reflections and ranging experiments	2		1	1		**21**
WP5: Large Power Electronics		Lead				
5.1 Impedance matching circuit between antenna and rf power supply					2	
5.2 Integration with the 1000W signal amplifier		1			1	
5.3 Crystal oscillator and pre-amplifier	1	1				
5.4 Dock testing with antenna	1					
5.5 Integration with PCM signal electronics	1	2			1	
5.6 Electrical screening framework for barge mounted system		1	1	1	1	**15**
WP6: PCM Signal Electronics	Lead					
6.1 Establish pulse code modulation (PCM) with error coding	1					
6.2 Selection of binary modulation frequencies	1					
6.3 Detector system amplifiers	1	1				
6.4 Signal processing and signal recovery	1					
6.5 Signal output using fibre optics	2		1	1		**9**
Total: Person Months/Partner	19	6	7	7	6	**41**

Manpower Usage												
Partner	**UOL**		**Bonn**		**NUI**		**STEN**		**FSA**		**Totals**	
	Plan	**Used**	**Plan**	**Used**	**Plan**	**Used**	**Plan**	**Used**	**Plan**	**Used**	**Plan**	**Used**
WP4	10	10	0	0	5	5	5	5	1	1	21	21
WP5	3	3	5	4	1	0	1	0	5	4	15	11
WP6	6	6	1	1	1	0	1	0	0	0	9	9
Totals	**19**	**19**	**6**	**5**	**7**	**5**	**7**	**5**	**6**	**5**	**45**	**41**

Table 2 The Manpower Usage

1.2.1 Work Package WP4 System Testing (Vertical Water)

Starting Date Month 12 Duration 6 Months Total Effort 21pm

Partners Involved WP4	R&D Task/Activity of Partner	Effort (pm)
UOL LEAD	Organisation of scientific and technical activities of sea trials	10
NUI	Responsible for mechanical system in sea trials	5
Sten	Organisation of barges and logistics for sea trials	5
FSA	Responsible for antennae in sea trials	1

Objectives

To undertake sea trials on the transmission and receiving of EM waves over a vertical distance of 30m. The integrity of transmission of both data and video signals in shallow water will be investigated.

Overview of Technical Progress

The transmission and receiving of rf signals has been achieved over the full frequency range of 0.5 to 5MHz. Measurements have also shown that higher carrier frequencies are suitable for achieving propagation of CCD camera images. The research has been more difficult than anticipated because detailed measurements over a 9 month period have shown that the antennae performance is strongly affected by the water conductivity and temperature. Therefore this has been solved by online automation using a variable frequency source, Direct Digital Synthesiser (DDS) to allow antennae resonant frequency to be optimised to the water conditions. Hence, a series of high quality transmissions have been attained with signal strengths well above the S/N level of 140dBm when using a 10W amplifier. Such results are summarised in figure 1

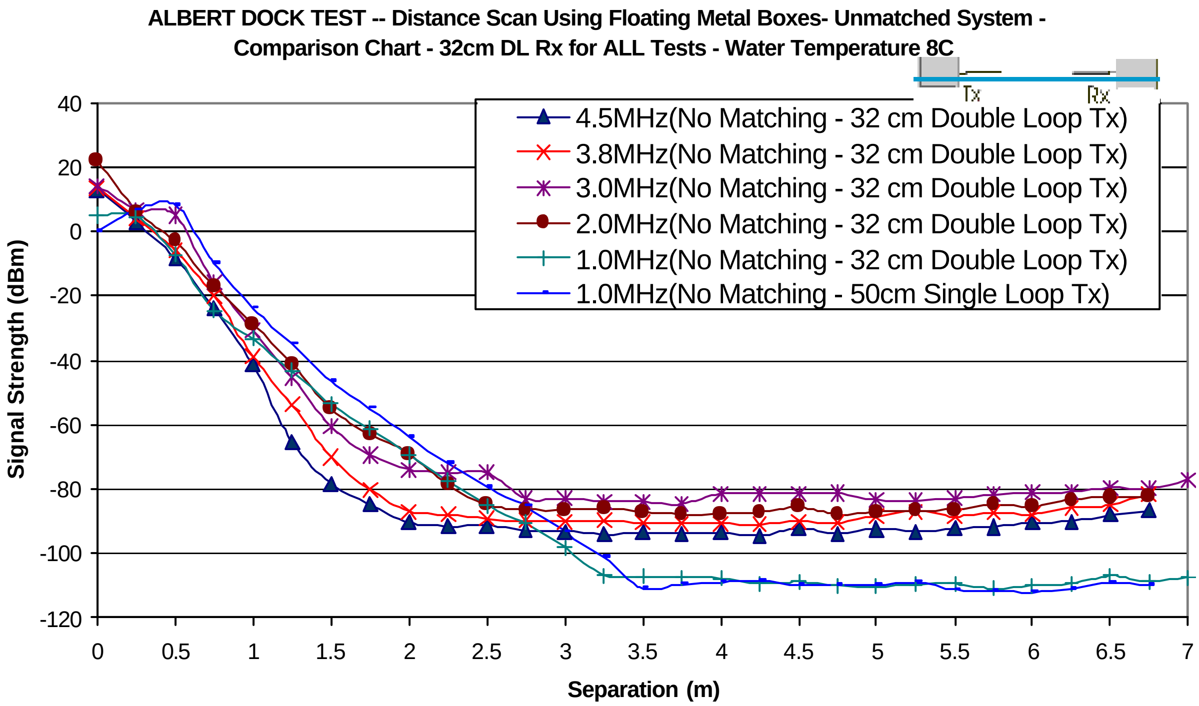

Figure 1 The Transmission from near field to far field

Difficulties

All solved.

Project Status

This workpackage has been successfully completed.

1.2.2 Work Package WP5 Large Power Electronics

Starting Date Month 18 Duration 6 Months Total Effort 15pm

Partners Involved WP5	R&D Task/Activity of Partner	Effort (pm)
Bonn LEAD	Sub-system integration with the amplifier systems	5
FSA	Impedance matching of antenna to power amplifier	5
UOL	Antenna specification and measurements	3
NUI	Barge mounting system	1
Sten	Industrial requirements	1

Objectives:

To interface the antennae to a 1000W power source so as to deliver the optimum power to the antenna in seawater.

Overview of Technical Progress

In WP4 a system has been successfully developed to transmit signals using a 10W amplifier by careful selection of the operating frequency. The signal to noise level is –140dBm and the far field signal is –80dBm at 10m. Hence it is now theoretically possible to transmit 100m with this level of amplifier and hence 1000m with the 100W amplifier. Therefore the next level of amplifiers currently being investigated is given in table 3. The full family can be supplied by Richardson as off the shelf components.

EMPOWER RF SYSTEMS INC, http://www.empowerrf.com

SKU	Model	Freq. Lower (MHz)	Freq. Upper (MHz)	Power Out (W)	Gain (dB)	Vin (DC)	Iin (A)
3001	GCM0K1EFL	0.5	2	30	44	28	4
1081	BBM0A3ERR	0.01	175	500	56	28	85
1020	BBM0D3FK7	0.15	230	100	16	28	17
1038	BBM0D3FO7	0.15	230	250	16	28	3
1057	BBM1C3CKO	1	100	100	50	28	14
1058	BBM1C3CP8	1	100	300	18	28	25

AC Power – complete units

SKU	Model	Freq. Lower (MHz)	Freq. Upper (MHz)	Power Out (W)	Gain (dB)	Vin (AC)	Power (W)
2087	BBS0A3EVT	0.01	200	1200	60	180-260	12000
2073	BBS1C3CUT	1	100	1000	60	180-260	3000

Table 3 DC Power - Modules

Currently the 30W amplifier is being used with the potential of using the 100W and 500W amplifiers if they are necessary. There is a large cost saving in using low power amplifiers and in addition they can always be operated from rechargeable batteries as well the size of the amplifier and its power supply. The 100W amplifier is shown in figure 2. All the none AC amplifiers in table 3 fit within our present electronic containers (shown in figures 16 and 17). If possible, amplifiers with output powers greater than 500W should be avoided because they require AC mains power and hence need to be placed in a separate water proof housing. In addition, the weight of the amplifier is of the order of 35kg and this causes further logistic problems. The specification of such amplifiers is given in table 3.

Figure 2 The 100W Amplifier BBM/C3CKO (size 6.4 x 3.4 x 1.1 inches)

It has been convenient in this workpackage to rebuild all the electronics in modular form on PCBs. Duplicate systems have also been built. This is illustrated in figure 3.

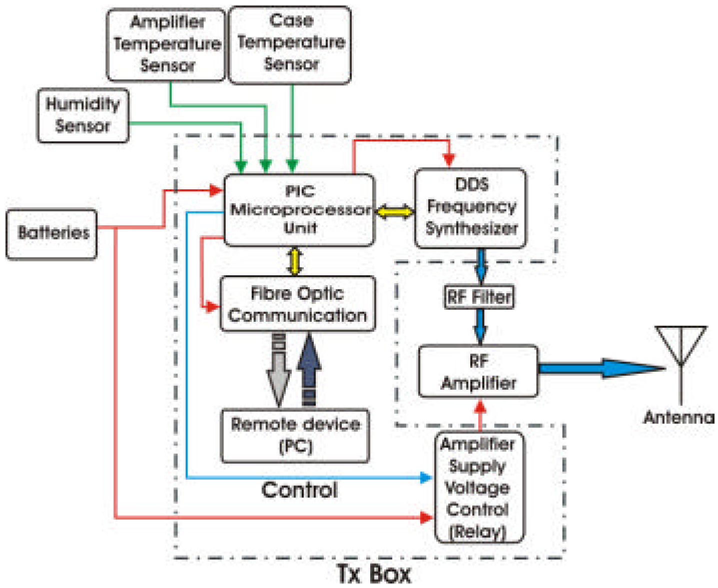

Figure 3 The Electronic Control System

Difficulties

These are being solved as they arise.

Project Status

This workpackage has been completed and the design allows a range of amplifiers to be readily inserted into the electronic package up to a maximum power of 500W.

1.2.3 Work Package WP6 PCM Signal Electronics

Starting Date Month 18 Duration 6 Months Total Effort 9pm

Partners Involved WP6	R&D Task/Activity of Partner	Effort (pm)
UOL LEAD	Design and Construction of PCM Detection System	6
Bonn	Interfacing to Power Amplifier	1
NUI	Marinisation of System	1
Sten	Market requirement	1

Objectives

To set up a pulse code modulation and demodulation system. To aid recovery of signals in the presence of noise

Overview of Technical Progress

The PCM system has been designed and constructed based upon using frequency modulation with the operating frequency being at 2MHz for logic 0 and 3MHz for logic 1. The modulating circuits, both transmitter and receiver, are shown in figure 4.

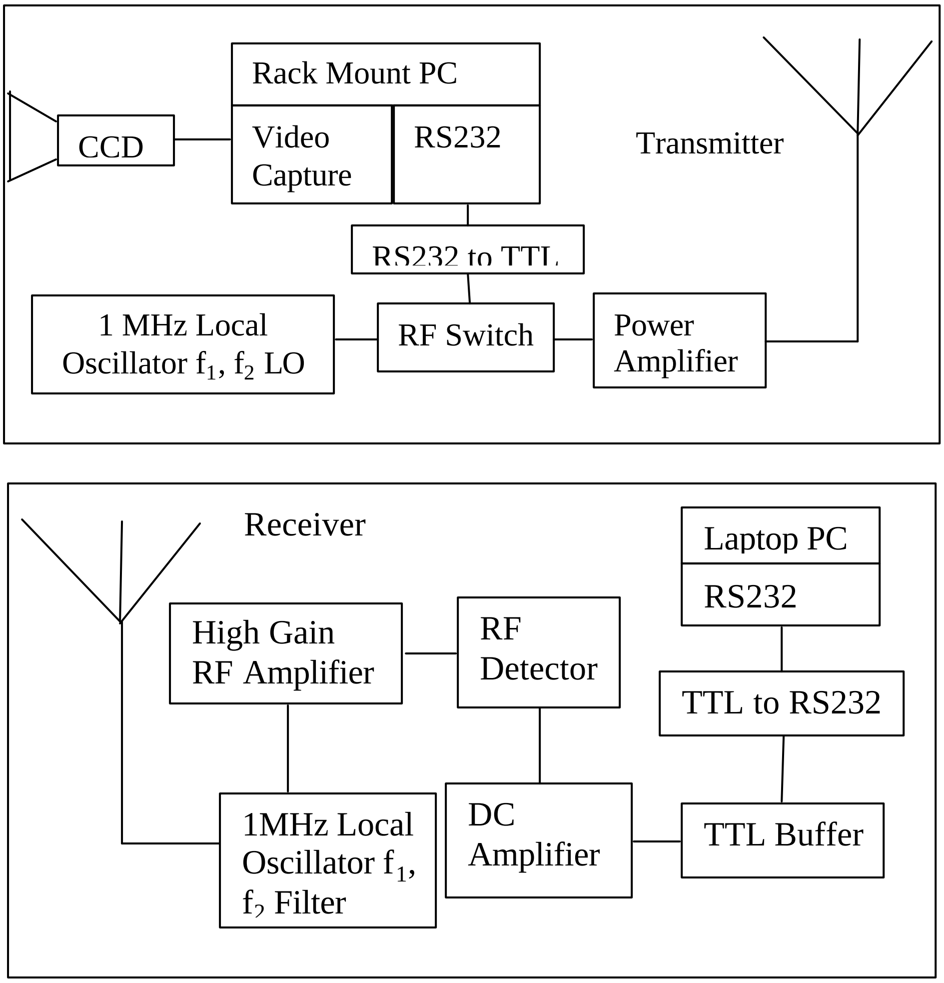

Figure 4 The PCM System

A standard commercial CCD camera and capture board has been used as shown in figure 5.

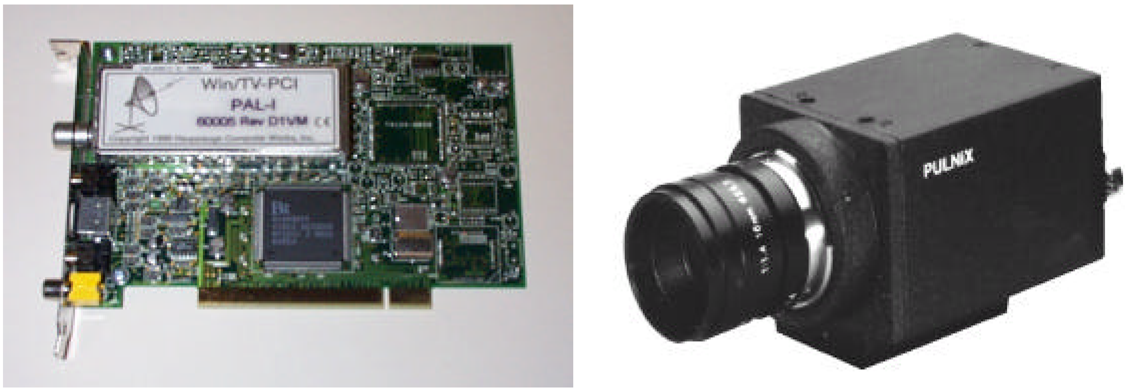

Figure 5 The CCD Camera System

The test card has a simple structure of wide band black and white stripes. The system is also capable of transmitting ASC II codes to examine the level of transmission. Provision has been made for a noisy environment, producing transmission errors, by using the Hanning error detection and correction codes. The fibre optic link has been set up for velocity trials. Tank trials have been successfully completed at both Liverpool and Stenmar.

Difficulties

None. This workpackage benefits from the quality system developed in WP5.

Project Status

This workpackage has been completed.

1.3 Milestones and Deliverables Attained

Work Package Deliverables

No	Delivery Date Month	WP	Brief Description	Comment
D1	6	1	Loop and Folded Dipole sub-sea antennae operating with optimum performance.	Completed
D2	6	2	Medium power amplifier with output matched to the antenna.	Completed
D3	12	3	On-board barge mounted transmitter and receiver system with motor drives and position instrumentation.	Completed
D4	18	4	rf PCM transmission through vertical seawater.	Completed
D5	24	5	Large power amplifier with output impedance matched to the sub-sea antenna.	Partially completed. Widened to include 30W, 100W and 500W
D6	24	6	Pulse code signal modulation and demodulation system with error correction.	Completed

Project Reports and Deliverables for the Commission

Report Number	**Delivery Date (month)**	**Type**	Comment
1	6	Management Report	Completed
		Scientific and Technical Progress Report	Ongoing
2	12	Annual Scientific and Technical Progress Report	Completed
		Draft Technological Implementation Plan (TIP)	Ongoing
		Periodic Cost Statements	Ongoing
3	18	Mid Term Report	Completed
		Mid Term Review	Ongoing
4	24	Annual Scientific and Technical Progress Report	Completed
		Draft Technological Implementation Plan (TIP)	Ongoing
		Periodic Cost Statements	Ongoing

Project Milestones and Decision Criteria

No	Due Date Month	Brief Description of Milestone Objectives	Decision Criteria for Assessment	Comment
M1	6	Development of both loop and folded dipole sub-sea antenna.	To be able to transmit and receive a 30mW signal within a testing tank with nominal frequencies of 1, 3 and 5MHz.	Completed
M2	6	Development of a rf transmitter matched to both the dipole and loop antenna.	To be able to transmit a 10W signal within a dock complex over a distance of 10m.	Completed
M3	12	Transmission of carrier signals between barge mounted transmitter and receiver	Development of a mechanical structure to support a transmitter and receiver to allow the distance between them to be varied up to 30m	Completed
M4	18	Transmission between a barge and a sub-sea transmitter	To transmit and receive accurately over distances of 30m carrier signals in the frequency range 1 to 5MHz	Completed
M5	24	Development of a 1000W rf amplifier matched to a sub-sea antenna	Transmission of 100W of power over a distance of 100m in a dock complex	Completed
M6	24	To establish a PCM system between transmitting and receiving antenna.	To be able to transmit and receive digital data using a 10mW signal in a dock complex using PCM	Completed

1.4 Deviations from work plan or/and time schedule and their impact on the project

Leading up to the Mid Term we encountered a problem with the workpackage WP4 System Testing Vertical Water. This occurred because as the water depth increased, both the conductivity and temperature changed as given in figure 6. This caused the signal strength to rapidly attenuate because the optimum operating antenna resonant frequency was detuned with drastic loss of signal.

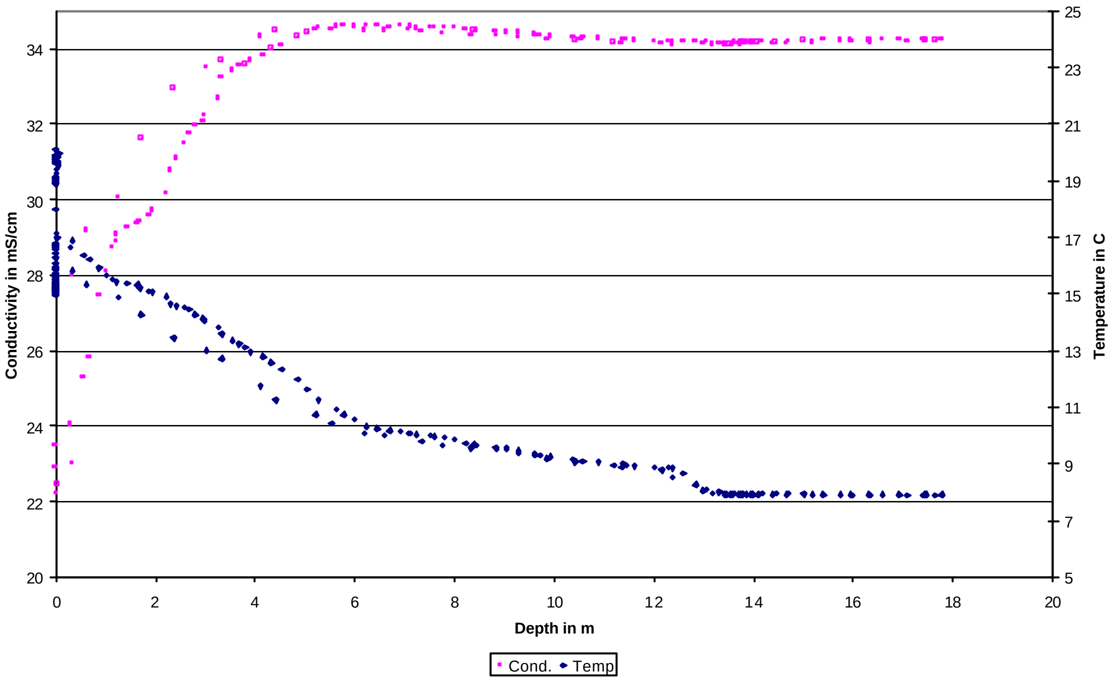

Figure 6 Water Temperature and Salinity at NUI

This has now been completely solved by having a remotely operated tuneable frequency controlled source using the Direct Digital Synthesiser (DDS) with measurements up to 10MHz have been undertaken. Moreover, the far field signals obtained at a frequency of 3MHz have now been found to be stronger than at 1MHz as shown in figure 7 and this has allowed the higher frequency to be used rather than the 1MHz frequency used previously within the trials.

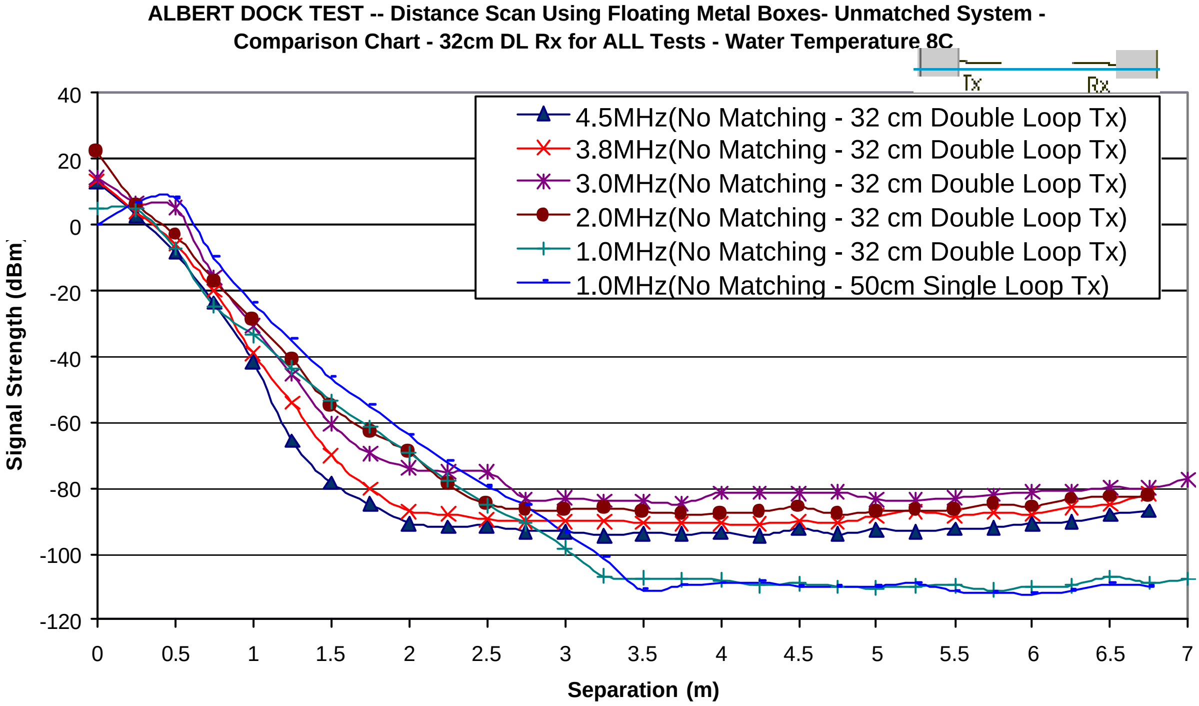

Figure 7 The Transition between near field and far field Propagation

Although this activity delayed the WP5, it was invaluable because there is the likelihood of propagation distances >100m with reduced signal power. If the amplifier power can be kept below 100W then there is a considerable cost saving in cost, weight and operating battery power. The WP6 involving PCM modulation and the transmission of video images has been carried out on schedule because it also benefited from the results obtained in WP4.

1.5 Coordination of Information between Partners and Communication Activities

Organised Meetings

Steering Committee Meetings

No	Location	Date
1	Brussels	18th February 2002
2	Stenmar, Fort William	1st August 2002
3	NUI, Bergen	24th March 2003
4	Stenmar, Fort William	17th December 2003

Scientific Meetings

No	Location	Date
1	Stenmar, Fort William	29th July to 2nd August 2002
2	NUI, Bergen	24th to 26th March 2003
3	NUI, Bergen	7th to 11th July 2003
4	Stenmar, Fort William	3rd to 7th November 2003
5	Stenmar, Fort William	15th to 19th December 2003

During the 24 month period NUI, FSA and UOL communicated mainly by email and telephone. Technical drawings and specifications were discussed and improved. In the case of the results of the simulation results using the FEKO package, a telephone conference was held between UOL and FSA.

Attendance at Conferences

Professor Lucas gave a review paper entitled "An Overview of Automated Sensor Systems for Marine Applications" at Sensors and their Applications XII, 2 – 4 September 2003 at Limerick, Eire.

1.6 Difficulties encountered at management and coordination level and proposed/applied solutions

The project has run smoothly during the full 24 month period. All the system components from workpackages WP1, WP2, WP3, WP4, WP6 are now completed and the final phase in vertical water (WP5) has been broadened to include a range of more experimentally friendly power amplifiers. Technical setbacks, as documented in this report, have now been solved.

2 SECTION 2: Executive publishable summary, related to reporting period (24 months)

Contract n°	EVK3-2001-0078	**Reporting period:**	12 to24 Months
Title	Underwater Communications using Electromagnetic Waves		

Objectives:

- To propagate electromagnetic waves through seawater.
- To undertake vertical water trials to a depth in excess of 10m.
- To undertake horizontal water trials to a distance in excess of 100m
- To transmit text and video signals

Scientific achievements:

Antenna and electronic systems have been designed and fabricated to a high standard to be able to withstand the pressure and corrosive aspects of seawater. The antenna operating frequency has been maintained at its optimum transmission value irrespective of water depth and its conductivity and temperature by using automatic frequency control. Without this feature, long distance propagation is not possible. Another important feature is the remote control of the amplifier power source consisting of multiple batteries. The mission duration depends on reducing unnecessary battery activation and only to use it during signal transmission. The propagation of CCD camera images has been added as a feature of the system.

Socio-economic relevance and policy implications:

The EM wave propagation system will compliment the present acoustic system to provide safe communications between ships, submersibles and divers. The EM wave can also be used for sensor systems in the oil/gas industry, sea pollution monitoring and fish detection. However, a special feature of EM wave propagation is the ability to use high frequencies beyond 1MHz and hence a large bandwidth will be used to propagate video camera images in real time. A completed EM wave system will create employment within the EC manufacturing and sub-sea activities.

Conclusions:

The first 24 months of the 36 month project has been completed. During the next 12 months, further system optimisation will be undertaken. Transmitter power will then be upgraded to allow longer horizontal water propagation distances in excess of 100m to be undertaken suitable for the transmission of video images with high integrity.

Keywords:

- Electro Magnetic Wave
- Propagation through Seawater at MHz Frequencies
- PCM Transmission of Video Images
- Sub-sea Antenna
- Marinisation of Electronic Systems

Publications (cumulative list)

A. Shaw, A. I Al-Shamma'a, S. Saman, J. Lucas	Oct. 2004	Theoretical Modelling and Simulations of EM Propagation in Seawater	Accepted for publication by the IEEE Antenna and Propagation
J. Lucas, A. Shaw, A. I Al-Shamma'a	Dec 2002	Is Propagation of MHz Electromagnetic Waves Through Seawater Possible	Submitted to Nature
A. Shaw, A. I Al-Shamma'a, S. Saman, J. Lucas	April 2003	Design and Construction a Standalone Transmitter and Receiver for Underwater Communications	Planning to submit to Journal of Measurements
Symeon Gerasimidis	Thesis submission September 2002	Optical Fibres, Electromagnetic Waves & Wireless Systems for Underwater Communications	MSc Degree Awarded
Saher Saman	Thesis submission April 2003	Electromagnetic Waves Propagation for Underwater Communications	MPhil Degree Awarded
A.I. Al-Shamma'a A. Shaw, S. Saman J. Lucas	September 2003	The Fourth Unmanned Underwater Vehicle 24-25 September 2003, Southampton Oceanography Centre UK	Oral Presentation on exploiting the use of EM wave propagation for underwater vehicles
J. Lucas	2003	An overview of automated sensor systems for marine applications	Sensors and Their Applications, IOP, pp177-185, ISBN 0750309784
A. Shaw, A. I Al-Shamma'a, R. Tanner, J. Lucas	2003	EM wave monitoring for the oil industry	Sensors and Their Applications, IOP, pp105-111, ISBN 0750309784

Patents:

1. J. Lucas, A.I. Al-Shamma'a and S. Takel (DERA)
   "Underwater Communications Systems Using Electromagnetic Signal Transmission",
   International Patent No. WO 01/95529, December 2001.
2. J. Lucas, A.I. Al-Shamma'a
   "Apparatus and method for Determining Dielectric Properties of Electrically Conductive Fluid",
   US Patent PCT/GB00/00168, 2003

3 Section 3: Detailed Report Organised by Workpackages Including Data On Individual Contributions From Each Partner, Related to the Reporting Period

3.1 Objectives

This report covers the period 12 to 24 months. The Gantt chart is given in figure 1.1 page 2, occurring earlier in this report.

There are, in total, nine workpackages to be undertaken (WP1 to WP9). The workpackages WP1, WP2, WP3 have been completed and reported in the 12 Month Report. During this reporting period three workpackages have been undertaken and fully completed. These are:-

- WP4. System Testing Vertical Water.
- WP5. Large Power Electronics.
- WP6. PCM Signal Electronics.

3.2 Methodology and scientific achievements related to workpackages including contribution from partners.

The achievements of these workpackages will now be described. Each workpackage has been started on a new page.

3.2.1 Work Package WP4 System Testing (Vertical Water)

Objectives

To undertake sea trials on the transmission and receiving of EM waves over a vertical distance of 30m. The integrity of transmission of both data and video signals in shallow water will be investigated.

Description of the Work

Task 4.1 Mounting of the transmitter on the barge

The marinised transmitter will be mounted on the deck of the barge with full electrical screening to prevent any signal loss into the atmosphere. All the power will be transmitted by the transmitter antenna, which has both motorised depth and direction control. Command and control links to the deck of the barge will be via fibre optic cable.

Task 4.2 Mounting of the receiver on the barge

The receiver electronics and antenna will both be mounted sub-sea to prevent any direct radiation pick-up. The depth and direction of the antenna will be motor controlled. The electronics will be battery operated.

Task 4.3 Investigation of transmitter signal strength at varying distances

The receiver will remain stationary and the transmitter will be lowered from the barge. The polar plots of the transmitter signal will be measured as a function of both depth and distance. The separation distance will be varied by approximately 0.2 intervals over a distance of 30m.

Task 4.4 Investigation of the carrier performance at varying frequencies

The carrier signal strength over a distance of 30m will be measured in the frequency range 1 to 5MHz. These measurements will be analysed to produce attenuation coefficients.

Task 4.5 Investigation of the effects of sea surface and sea bed reflections

The effect of sea surface reflections on the strength and fading of the received signal will be investigated. The reflection coefficient will be measured in a direct experiment for both surfaces. The techniques developed for analysing signals with a reflection component will be evaluated.

Achievements

The measurements on the Stenmar barge trials at the NUI test site very early on in this workpackage indicated that signal transmission through seawater was more complicated than expected. Firstly all the electronic containers have to be constructed from metal, either stainless steel or aluminium. Secondly, Jupiter electrical connectors have to be used to avoid seawater contact with the metal part of the antennae. The performance of the antennae was critically dependent on both the water temperature and conductivity. In coastal water the conductivity increased with water depth. The temperature, in addition to the seasonal variation (5^oC to 13^oC), also had a depth variation. These results are summarised in figure 6.

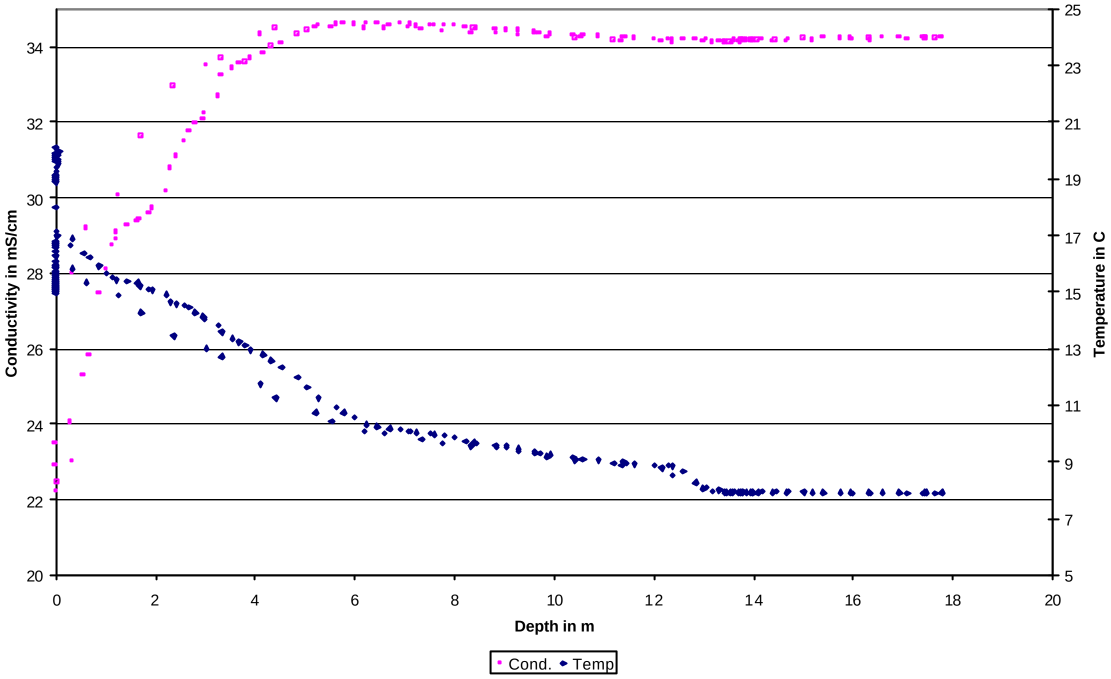

Figure 6 Water Temperature and Salinity at NUI (Reproduced again)

Using the network analyser, the impedance of the 32cm double loop antennae was measured in Loch Linnhe and the Liverpool Dock at both 5^{o}C to 13^{o}C. The results are shown in figures 8a and b, figure 39a and b and figure 10.

ALBERT DOCK TEST- 32cm Double Loop aerial WATER, measured with HP network analyzer set to +0dBm and 1MHZ to 10MHz. - Conductivity: 38.5mS/cm - water Temp: 5C

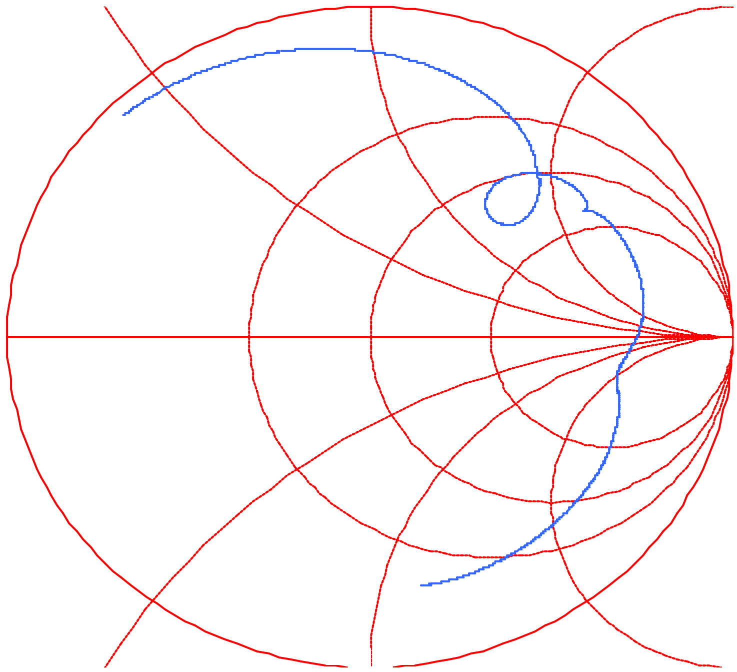

Figure 8a The Smith Chart

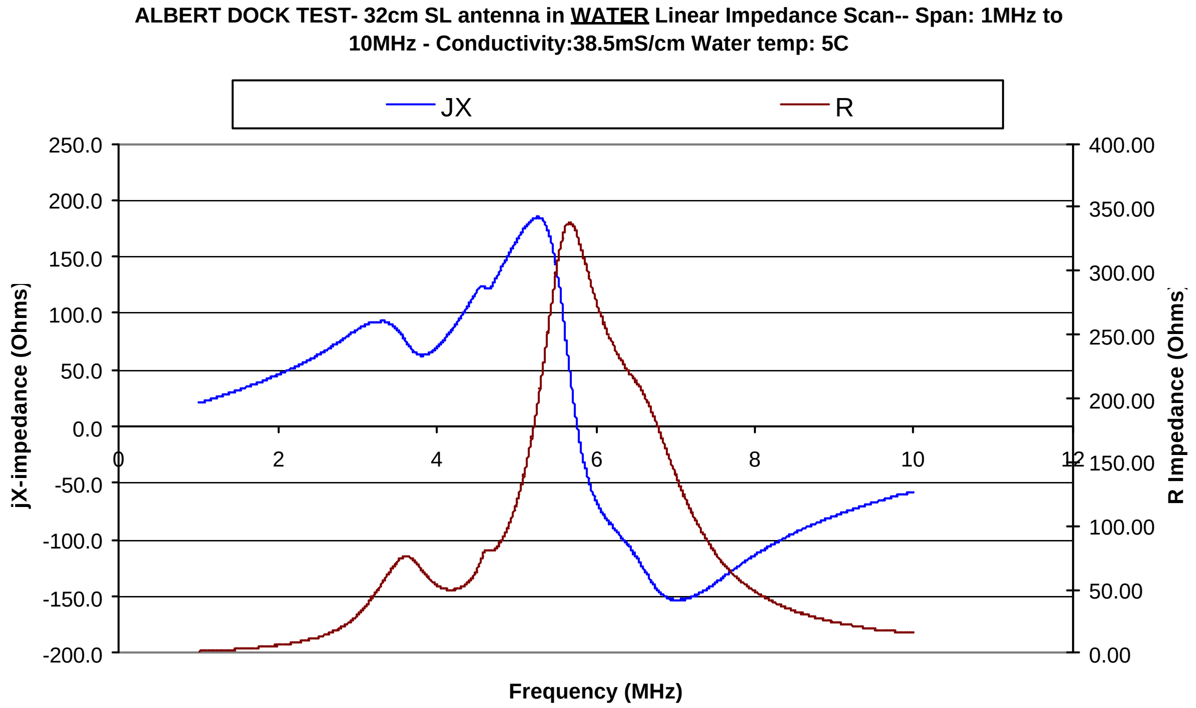

Figure 8b The Antenna Impedance

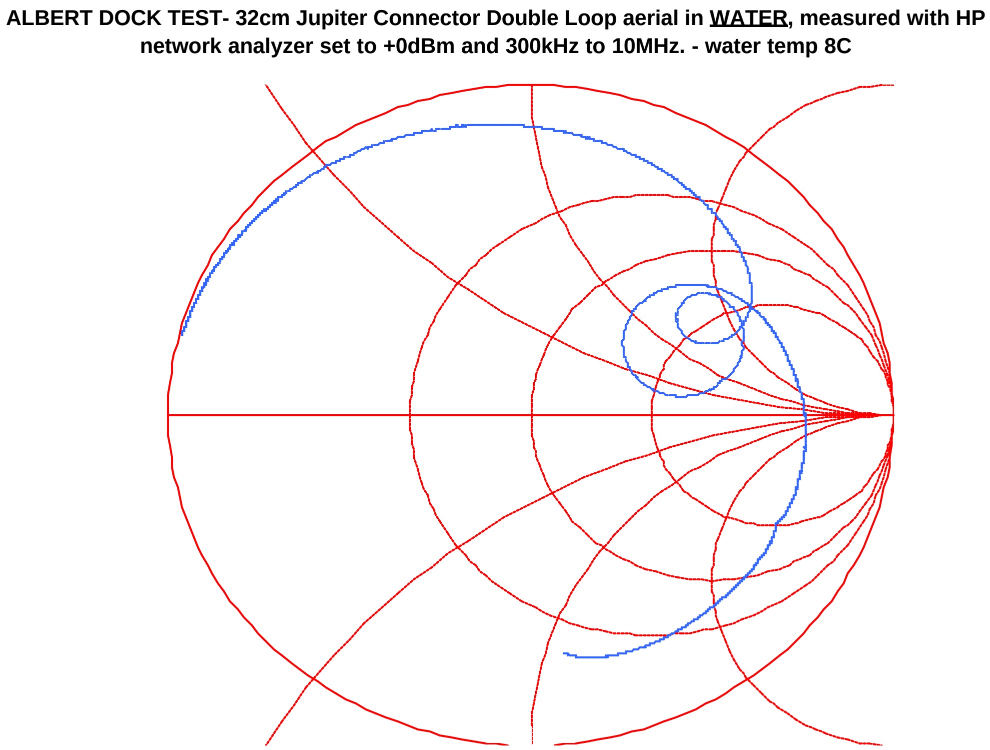

Figure 9a The Smith Chart

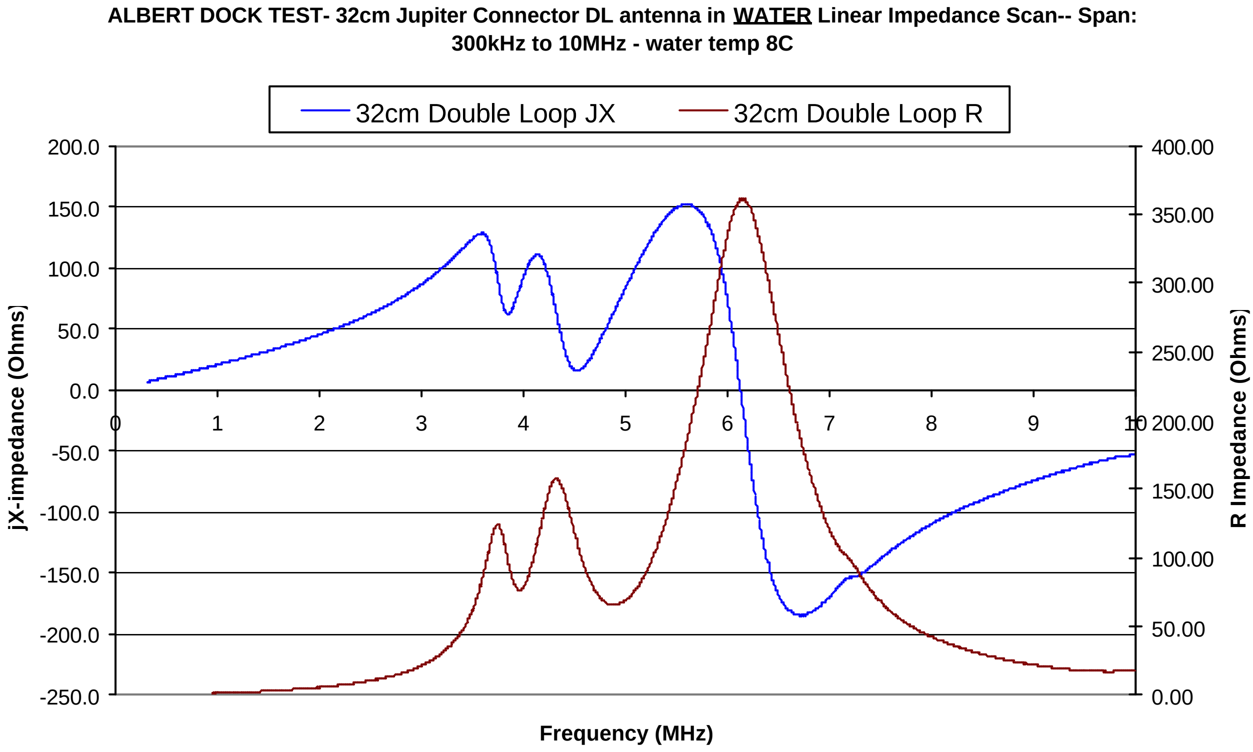

Figure 9b The Antenna Impedance

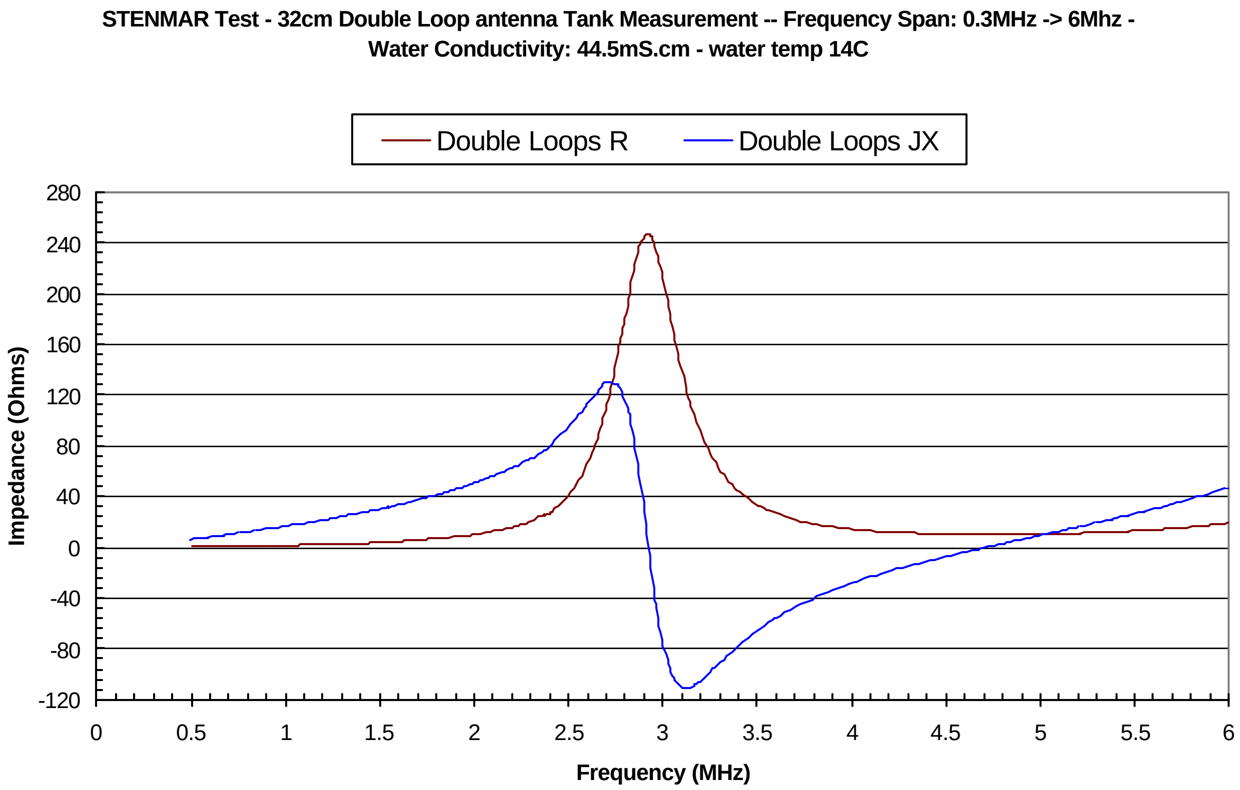

Figure 10 The Antenna Impedance

Hence it was necessary to have a fully variable frequency source to allow the resonance condition to be attained at all sea conditions. For maximum power transmitted from the antenna it is necessary to use matching circuits such that the antenna impedance becomes 50 Ohms. For transmission in the atmosphere where the gas parameters are constant this is the preferred mode of operation. However, because of the capricious nature of the seawater this has been shown to be difficult to attain. For propagation in seawater the antenna frequency has to be close to its resonant frequency. As can be seen in figure 11, as much as 40dBm of signal can be lost by poor mismatch between the transmitter operating frequency and the antenna resonance frequency because of the sharpness of the resonance.

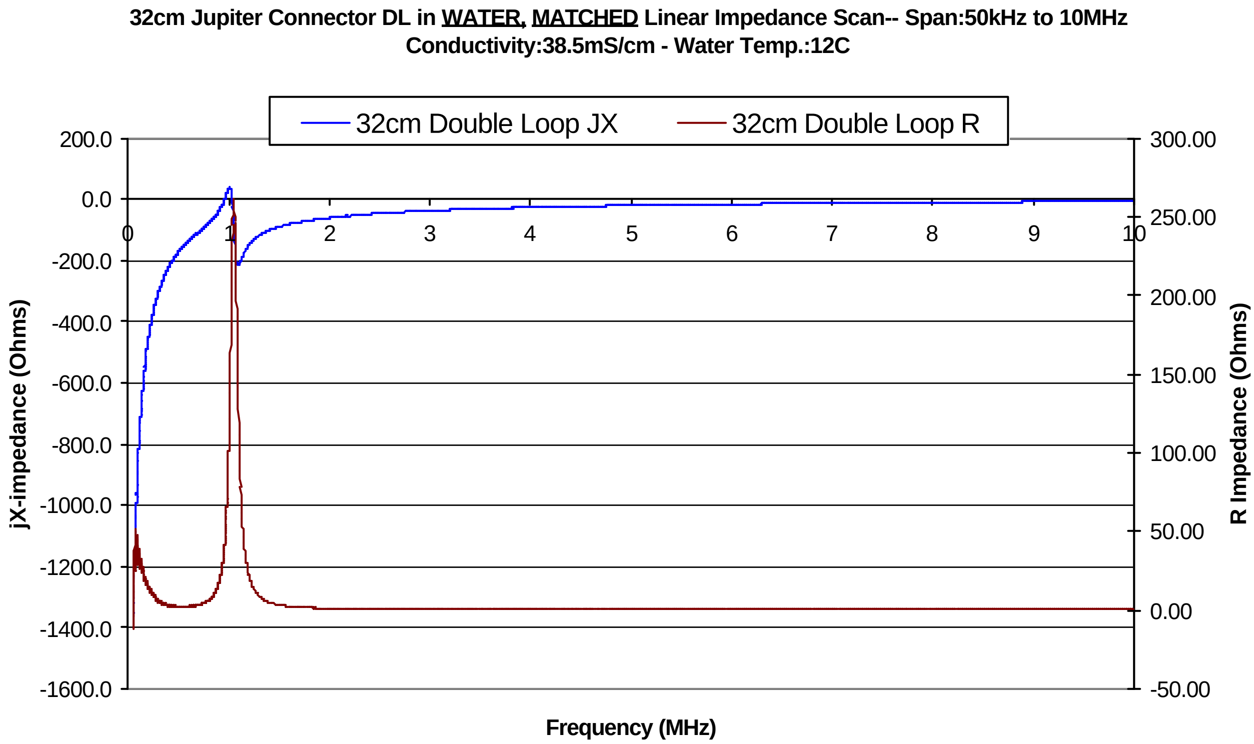

Figure 11 The Antenna Impedance with matching Circuit

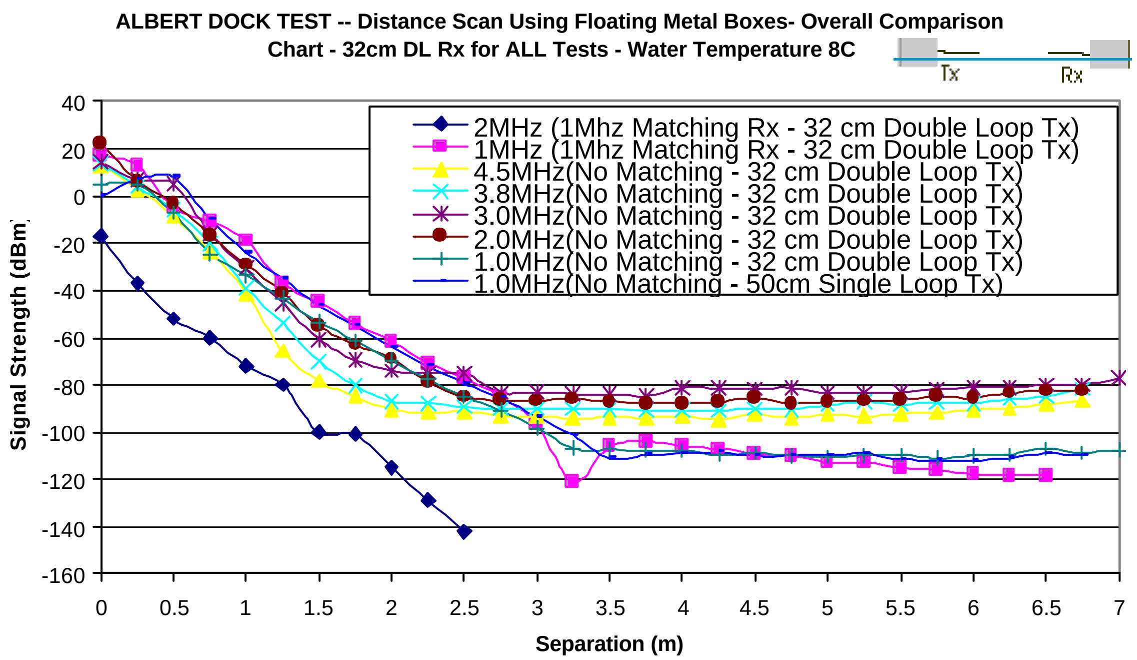

Figure 12a Propagation in seawater

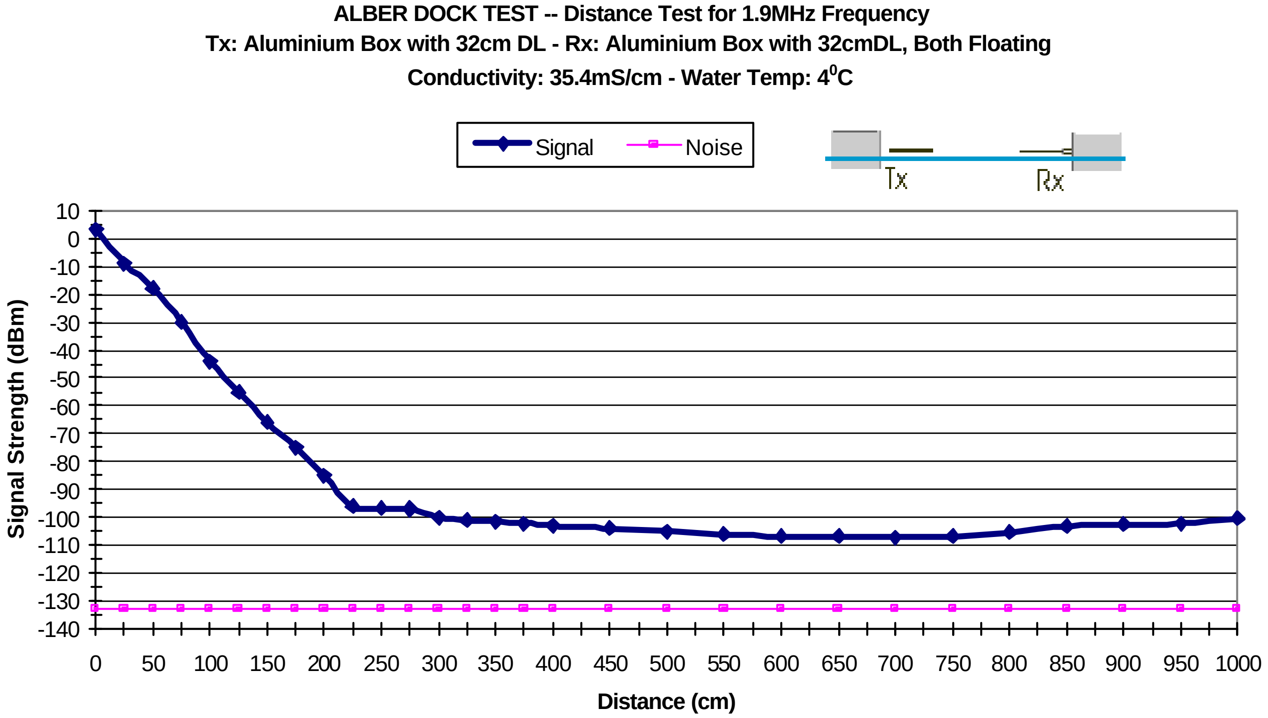

Figure 12b Propagation in seawater

The results given in figures 12 show that propagation is better at 3MHz rather than 1MHz. The electronic matching for the wrong water temperature, as can be seen from the 2MHz frequency results, which are 40dBm down on what can be attained by natural matching using the water resonance properties. Such a result also indicates that there is no far field available for transmission when poor matching is set up. Signal propagation for distances greater than 7m have been taken. The maximum depth at Liverpool dock is 10m, at Stenmar it is 12m and at NUI it is 15m. Results have been measured at these depths and show only a small attenuation in the far field between 3m and 17m.

Therefore the electronics have been modified to include a DDS frequency synthesiser instead of individual fixed frequency crystals. The final circuit design is shown in figure 13.

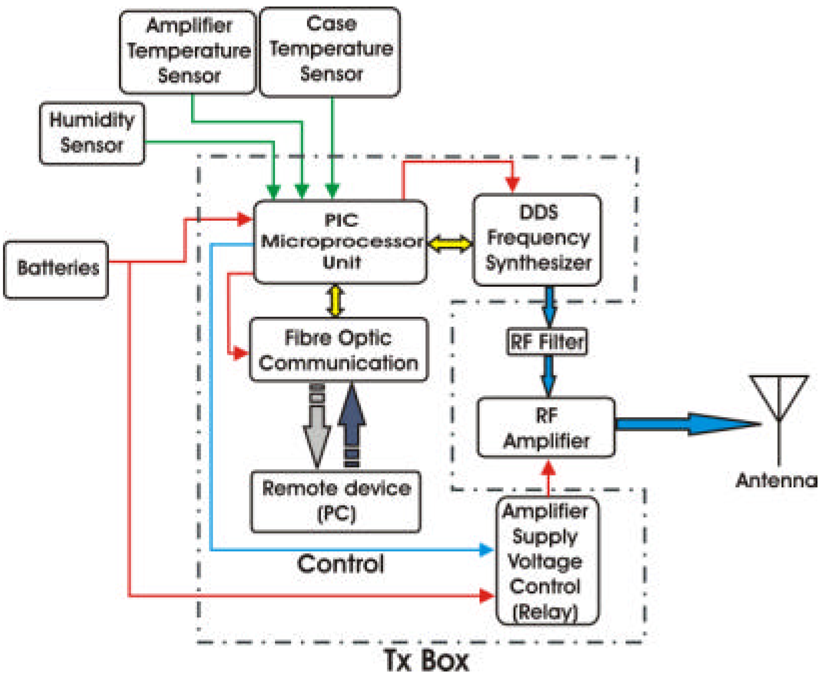

Figure 13 The Electronic Controller

Manpower Used

WP 4 System Testing (Vertical Water)		Person Months of Activity					
Task	**Activity**	**UOL**	**Bonn**	**NUI**	**Sten**	**FSA**	**Total**
4.1	Mounting of transmitter on the barge	2		1	1	1	5
4.2	Mounting of receiver on the barge	2		1	1		4
4.3	Investigate carrier signal system performance at distances varying by approximately 0.2m over a distance of 30m	2		1	1		4
4.4	Investigate the carrier performance with the frequency range 1 to 5MHz up to 30m distance. Examine the signal and attenuation coefficient.	2		1	1		4
4.5	Investigation of the effects of sea surface and sea bed reflections and ranging experiments	2		1	1		4
	Total Person Months	10		5	5	1	21

Project Status

This workpackage has been completed

3.2.2 Work Package WP5 Large Power Electronics

Objectives:

To interface the antennae to a 1000W power source so as to deliver the optimum power to the antenna in sea water.

Description of Work

Task 5.1 Impedance matching circuit between antenna and rf power source.

The impedance of the antennae, which is complex with a low resistance and reactive element, needs to be transferred into a resistive load of 50 Ohm in order to match the output impedance of the 1000W amplifier.

Task 5.2 Provision of a robust 10W signal amplifier.

The power stage has a gain of 63dB min and operates from 3 phase mains supply. It supplies 1000W of output power with a required input power of 500mW. It has a weight of 100kg. The amplifier is manufactured by the Bonn partner.

Task 5.3 Crystal oscillator and pre-amplifier.

The pre-amplifier will be designed using a crystal oscillator and a low gain pre-amplifier system to provide an output signal of 60dBm. It will be necessary to use two stages of pre-amplification based upon Mini Circuits components. The system will be powered low noise dc power sources and the use of matched tuned filters will ensure the elimination of harmonic signals.

Task 5.4 Dock testing with the antennae.

The full system will be tested at reduced power within a dock environment to ensure safe and efficient operation at the predetermined frequencies with nominal values of 1, 3 and 5MHz.

Task 5.5 Integration with PCM signal electronics

The pre-amplification stage will be operated under PCM conditions to examine the system response time to digital changes in the frequency of the carrier wave. The exact digital frequencies representing 0 and 1 will be allocated.

Task 5.6 Electrical screening framework for barge mounted system

It is essential that most of the signal power is transmitted from the antenna. The supply current and any associated cables must be fully screened to prevent direct transmission through the atmosphere between the two barges. Obviously the 1000W transmitter power only needs to be used when the barges are separated by 1000m and the power is reduced as the distance becomes shorter.

Achievements

The circuit shown in figure 13 has been designed and fabricated. Each module has been constructed on a single PCB and the final circuit is shown in figures 14 and 15.

Figure 14 Connectors between the antennae and the control electronics

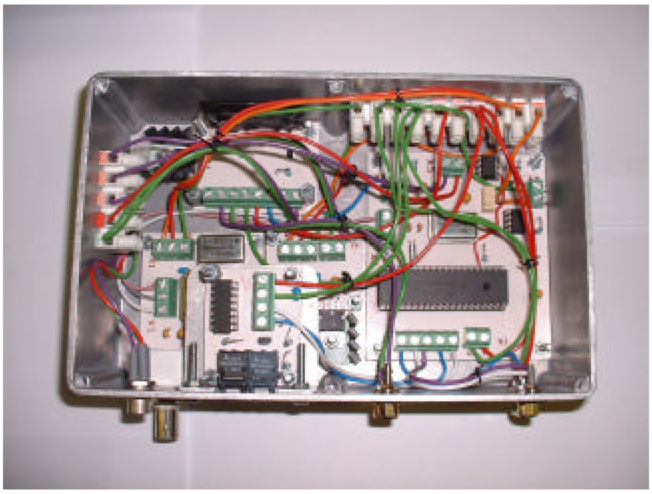

Figure 15 The Modular PCB

Rather than selecting a 1000W amplifier it was decided to only select the correct amplifier for the appropriate distance. It is anticipated that this will be less than 1W/m, but will be confirmed in the experiments scheduled under WP7 and WP8. The range of low cost battery operated amplifier modules are given in table 4.

EMPOWER RF SYSTEMS INC, http://www.empowerrf.com

SKU	Model	Freq. Lower (MHz)	Freq. Upper (MHz)	Power Out (W)	Gain (dB)	Vin (DC)	Iin (A)
3001	GCM0K1EFL	0.5	2	30	44	28	4
1081	BBM0A3ERR	0.01	175	500	56	28	85
1020	BBM0D3FK7	0.15	230	100	16	28	17
1038	BBM0D3FO7	0.15	230	250	16	28	3
1057	BBM1C3CKO	1	100	100	50	28	14
1058	BBM1C3CP8	1	100	300	18	28	25

Table 4 DC Power - Modules

The presence of a fibre optic communication link has allowed us to only switch on the amplifier for the duration of the transmission. This gave a large saving in battery power allowing longer missions to be run on smaller batteries. So far detailed experiments have been done with the 10W and 30W amplifiers within the dock and the present experiments are being carried out using the 100W amplifier. Finally the 500W amplifiers will be used if it is found to be necessary.

The DDS frequency synthesiser allows the full range of frequencies between 0.1 to 20MHz to be set with high Q factors comparable with the crystal oscillators. A useful feature is now the ability to avoid pick up from radio stations, whose frequencies seem to clash with those of the previous crystal oscillators.

The PCM circuit module of WP6 has been integrated into the amplifier module. The EM wave interference is still low with the higher power amplifiers because the electronics are within the antennae box shown in figure 16.

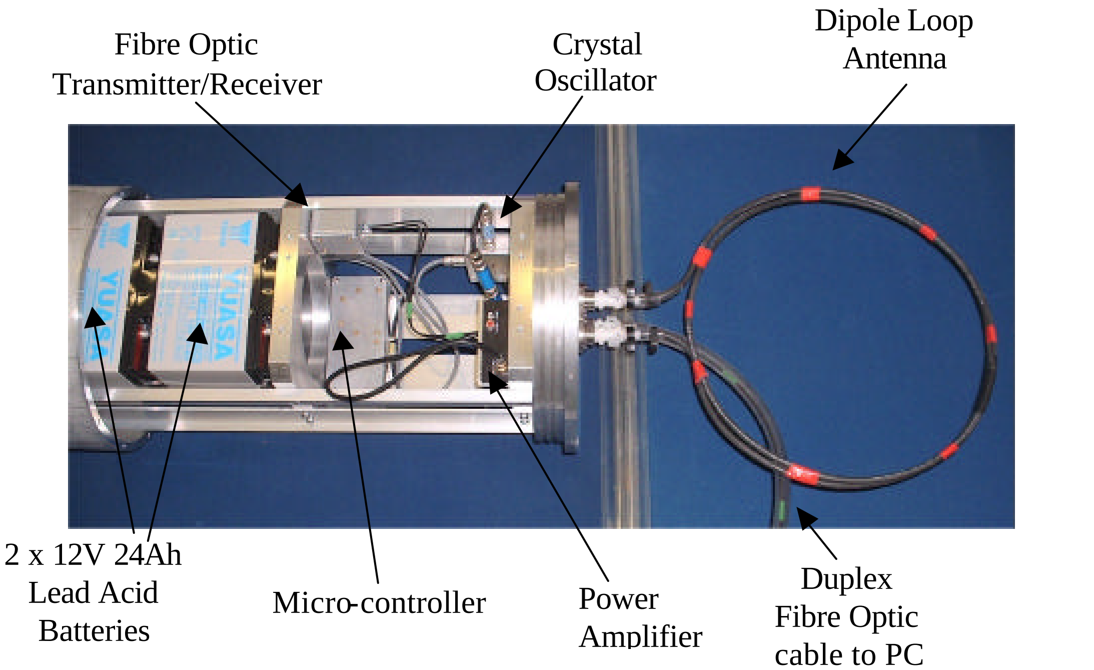

Figure 16 Transmitter Assembly

For higher power transmission FSA have designed a suitable antenna. This is shown in figure 17.

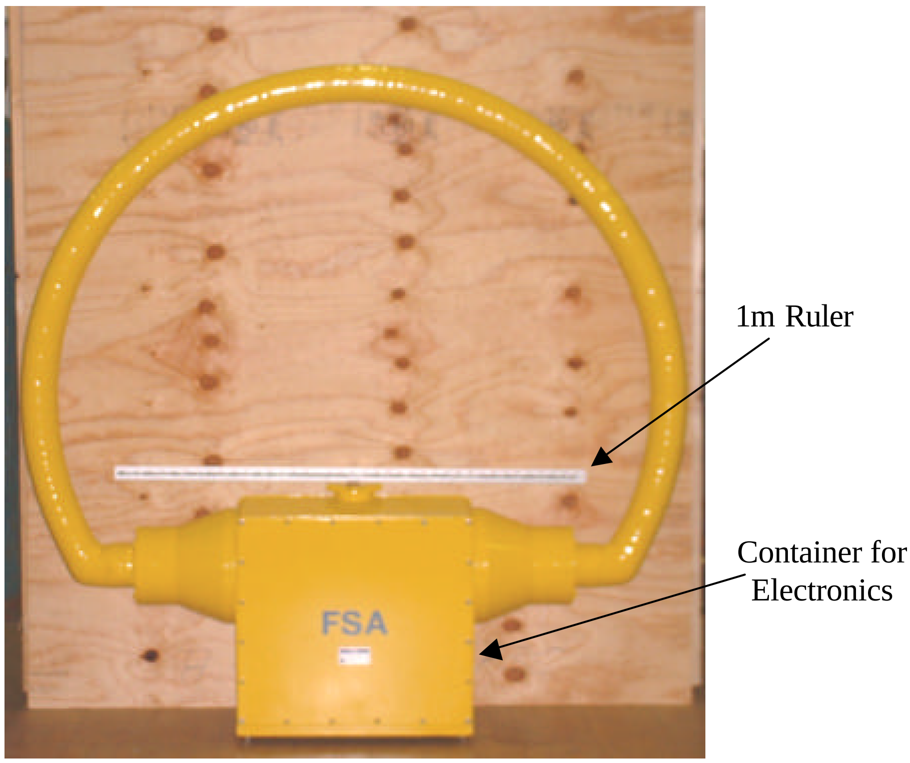

Figure 17 The FSA Antenna

The antenna had been calibrated by FSA in Munich at a temperature of 9^{0}C and salinity of 40mS/cm. They then calculated the 50 Ohm matching circuits and installed them into the electronic container. When the antenna were recalibrated at Stenmar, the temperature was 14.4^{0}C and the salinity was 44.5mS/cm. The resonance of the antenna had shifted. With our improved flexible operating system we are able to operate with this level of set up. Therefore the antenna can be approximately matched for the expected water conditions as shown in figures 18a, b, and c for 1MHz, 3MHz and 5MHz nominally. The DDS electronic tuning allows the antenna to be operated at the optimum conditions of 1.25MHz, 3.3MHz and 4MHz for T = 14.4^{0}C. Adjusting the DDS caters for any changes.

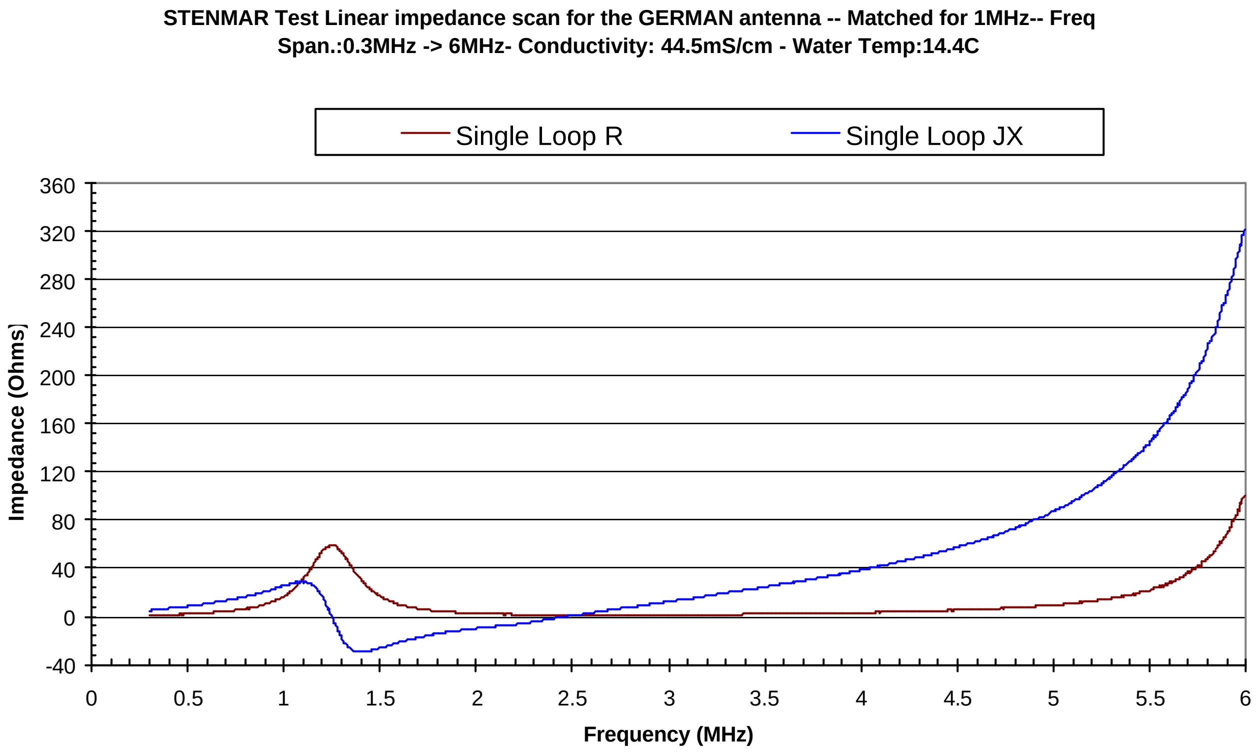

Figure 18a The Antenna Impedance

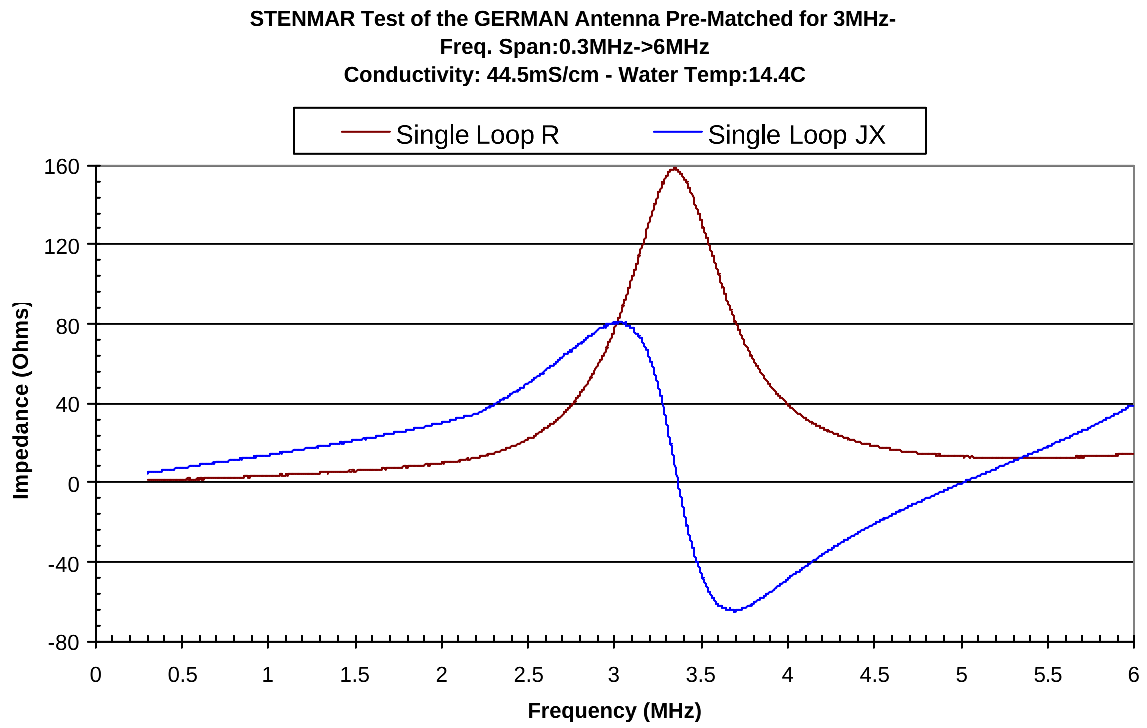

Figure 18b The Antenna Impedance

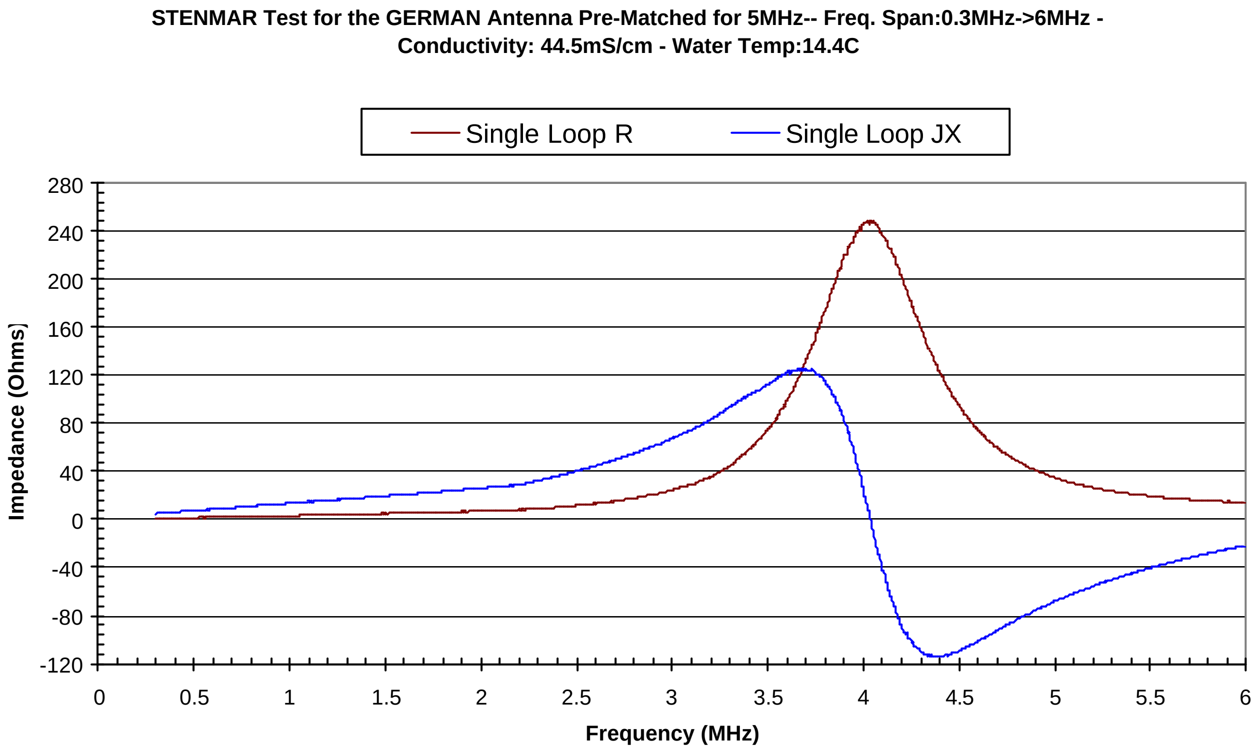

Figure 18c The Antenna Impedance

Manpower Used

WP 5 Large Power Electronics		Person Months of Activity					
Task	**Activity**	**UOL**	**Bon**	**NUI**	**Sten**	**FSA**	**Total**
5.1	Impedance matching circuit between antenna and rf power source.					2	2
5.2	Integration with the 1000W signal amplifier.		1			1	2
5.3	Crystal oscillator and pre-amplifier.	1	1				2
5.4	Dock testing with the antennae.	1					1
5.5	Integration with PCM signal electronics	1	2			1	4
5.6	Electrical screening framework for barge mounted system		0	0	0	0	0
	Total Person Months	3	4	0	0	4	11

Project Status

This workpackage has been completed.

3.2.3 Work Package WP6 PCM Signal Electronics

Objectives

To set up a pulse code modulation and demodulation system. To aid recovery of signals in the presence of noise

Description of the Work

Task 6.1 Establish pulse code modulation (PCM) with error correcting

The pre-amplifier circuit will be modified to allow one of two crystal oscillators to be presented to the pre-amplifier depending whether a digital or 1 or 0 is to be transmitted. The system time constant will be measured to allow the maximum bit rate to be operated.

Task 6.2 Selection of binary modulation frequencies

The objective is to use system filters which will allow the signal frequencies representing binary 0 and 1 to have a wide as possible difference but without introducing an excessive time constant for changing between frequencies.

Task 6.3 Detector system amplifier

The aim is to use high quality low noise signal amplifiers which are able to respond to –60dBm signal levels and provide an overall amplification of ±40dB. This will give an overall system amplification of ±160dB.

Task 6.4 Signal processing and signal recovery

At the maximum distance of 1000m it is anticipated that the signal to noise level will be high. It will be necessary to invoke signal averaging in order to ensure signal integrity. This will necessitate the reduction of the bit rate to a lower level but it is not anticipated that this will need to be reduced below 100kbits/s.

Task 6.5 Signal output using fibre optics

Fibre optics will be necessary if the signals from the transmitter and receiver need to be compared in real time. This will occur when the time of flight experiment is undertaken as the synchronisation of the transmitter and receiver have to be set up.

Achievements

The PCM system has been based upon frequency modulation. The module is directly connected to the amplifier module as is shown in figure 19.

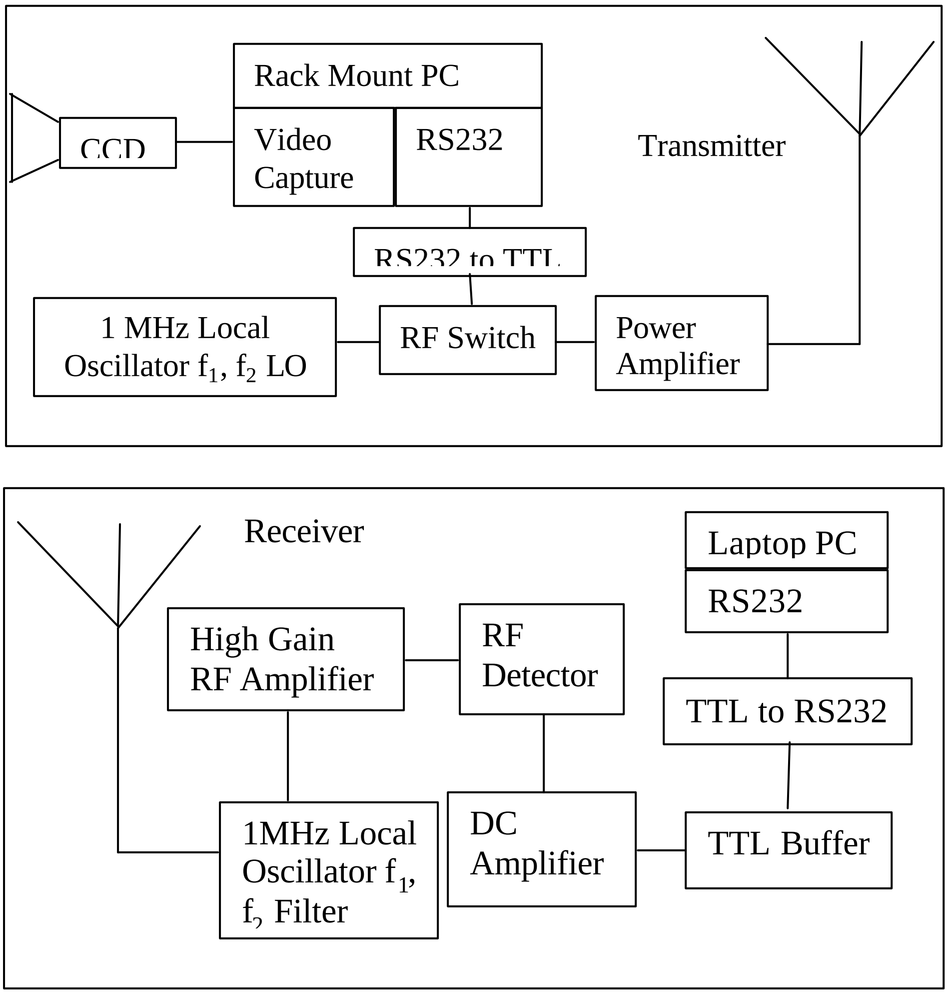

Figure 19 The PCM System

Since only a single system, namely a CCD camera, is being operated then frequencies of 2MHz (logic 0) and 3MHz (logic 1) are readily available for transmission. The CCD camera (Pulnix) image processing board (Hauppauge Win/TV) are shown in figures 20a and b.

Figure 20a Pulnix Camera

Figure 20b Hauppauge Win/TV Board

Trials in the Liverpool tank have shown that using a commercial streaming media encoding system to digitise and encode the live video fron the CCD camera it is possible to transmit the video similar in principle used on the internet at modem transfer rates.

Error correcting features based upon a number of techniques are currently being investigated. These are:

(1) Digitise image filtering

(2) Multi-channel techniques

(3) Hamming correction coding

The fibre optics system has been incorporated into the system under WP4 in order to only switch on the battery power for the amplifier system only when required. The same communications hardware and software has been installed under this workpackage.

Manpower Used

WP 6 PCM Signal Electronics		Person Months of Activity					
Task	**Activity**	**UOL**	**Bonn**	**NUI**	**Sten**	**FSA**	**Total**
6.1	Establish pulse code modulation (PCM) with error correcting	1					1
6.2	Selection of binary modulation frequencies	1					1
6.3	Detector system amplifier	1	1				2
6.4	Signal processing and signal recovery	1					1
6.5	Signal output using fibre optics	2		1	1		4
	Total Person Months	6	1	1	1	0	9

Project Status

This workpackage has been completed

3.3 Socio-ecomonomic relevance and policy implication

The EMCOMMS project has an important outcome which is to develop both economic growth and competitiveness in the production of a new system which is capable of transmitting both data and video images for a range >100m with a bit rate 1>Mbits/s. These systems will provide an alternative technology to the use of acoustics. A summary of the expected results and exploitation are given in table 5.

Table 5 Expected Results and Exploitation

Project Output Results	Range of Applications	Expected Impact	Time to Exploit	Partner Responsible for Exploitation
Community Added Value • Expertise in sub-sea propagation of EM waves. • Job creation in production of communications systems and remote monitoring systems	- Establishment of an EC sub-sea EM wave community - Development of an rf communications device - Development of remote monitoring systems	- High data rate transmission including video image transmission - Safer working conditions for divers - Job creation and consolidation	3 years	Stenmar Bonn Elektronik FSA NUI UOL
Social Environmental Impact • Ability to monitor for pollution 24hrs each day • Safe navigation of vessels • Increased education and training facilities	- Monitored information including video can be relayed to a land based site - Navigation channels can be electronically indicated - Specialist rf electromagnetic wave technology programmes	- Additional navigational aids under stormy or poor weather conditions - Better trained and highly skilled offshore engineers	3 years 3 years	NUI UOL Stenmar NUI UOL
Technical Economic Impact • Creation of a EM wave sub-sea communications industry which will also develop a wide range of associated sensors	- An EM wave system capable of operating over a distance of 1000m with propagation frequency of 1 to 10MHz and bit rate transmission of 1MHz - Development of new sensor systems e.g. sea bed surveying for oil	- Will compete against existing ultrasonic systems being developed - Will complement existing seismic systems	5 years 5 years	Stenmar Bonn Elektronik FSA UOL
• R & D on new activity areas	- Sub-sea vehicle collision avoidance and docking systems	- Ability to undertake deep sea exploration	6 years	UOL NUI

3.4 Discussion and Conclusions

The project is on schedule and Workpackages WP1 to WP6 have been satisfactorily completed and as a consequence Deliverables D1 to D5 and Milestones M1 to M6 have been attained. During the past 6 months an important aspect of this project has bee constructed and tested. This is the automatic selection and tuning of frequency to allow the antennae to operate at its resonance condition for all seawater conditions. Detailed experimentation has shown that the antenna impedance and hence emitted radiation drastically changes with water depth, temperature and salinity. Coastal water often has a layer of pure water (low conductivity) floating on the surface of the seawater. Hence it was impossible to set up the antenna to operate with a single crystal frequency and to transmit satisfactorily for such conditions. This was especially true of the vertical water tests but less so for the horizontal water tests.

The electronic system with PCM modules and a range of amplifiers (up to 500W output power) have now been encased in a single metal unit.

The FSA antenna is capable of operating at 1000W output power and 100m depth and will be used for the longer distance communications but have the added complications of requiring AC mains power.

3.5 Plan and Objectives for the next Period

The work plan for the next 6 months is to undertake Workpackage WP7 System Integration (Vertical Water). The requirements to be undertaken are as specified in the DOW.

Starting Date Month 24 Duration 6 Months Total Effort 16pm

Partners Involved WP7	R&D Task/Activity of Partner	Effort (pm)
NUI LEAD	Construction of marinisation system and barge mounted systems	6
UOL	Control and data logging system and sensor system electronics	5
Sten	Barge capabilities and mechanical fixtures	3
Bonn	Power transmitter and receiver electronics	1
FSA	Antennae interface electronics	1

Objectives:

To mount the transmitter and receiver systems onto the two barges to enable underwater EM wave trials to be undertaken.

Description of the Work

Task 7.1 To design and construct marinisation system for transmitter and receiver system.

The transmitter and receiver electronics need to be fully protected from seawater. The transmitter electronics will be deck mounted but the receiver electronics will be submerged in the sea. The transmitter and receiver also requires full electrical screening to prevent any direct signal propagation through the atmosphere between the barges.

Task 7.2 To construct sub-sea transmitter antenna mounting on first barge.

The antenna will be mounted onto a mechanical structure which will provide both depth and angular positioning within the sea vertically beneath the first barge. The depth will be up to 30m and the angular position is a single turn of 360^o with end stops.

Task 7.3 To construct sub-sea transmitter antenna mounting on second barge.

The electronic receiver amplifier will be battery operated and hence can be fully immersed in the seawater at the end of a similar mechanical structure used for task 4.2. Fibre optic links will be used to relay information from the receiver to the deck of the barge..

Task 7.4 To provide sensor systems.

Sensor systems will be provided for each barge to give the exact position using GPS. The depth and orientation, both angular and tilt of the antennae will be directly measured. Additional sensors to measure the water flow speed will also be mounted.

Task 7.5 Sensor testing and validation

A computer system will be used to continually monitor the sensor signals. This information will be displayed using Agilent VEE Graphical Programming Environment.

Deliverables.

- D7 Onboard barge mounted transmitter (or receiver) system with motor driven movements and position instrumentation.

Milestones.

M7 Transmission between barge mounted transmitter and receiver. A mechanical structure on each barge will allow the antenna to be placed opposite each other at a water depth of up to 30m.