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Adapting magneto-telluric (MT) geophysics systems to measure high frequency ranges for environmental investigations

- ENVIRO-MT -

Technology Transfer Project
supported by the European Commission, Directorate General XIII

Contract No.: **IN10048I with the EC DGXIII**

Partners:

Metronix Meßgeräte und Electronik GmbH (MTX), Braunschweig, Germany (Project Co-ordinator)

Department of Geophysics, Uppsala University (UU), Uppsala, Sweden

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Instituto Tecnológico GeoMinero de España (ITGE), Madrid, Spain

Netherlands Institute of Applied Geoscience (TNO), Delft, The Netherlands

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PROYECTO ENVIRO-MT

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1. INTRODUCTION

Subsequent to a successful completion of the Definition Phase, the Demonstration Phase of the ENVIRO-MT Project commenced on 1 January 1997, and was scheduled to last 39 months until 30 September 1999.

This Final Report of the ENVIRO-MT Technology Transfer Project summarises the overall achievements of Demonstration Phase. The progress of the Project has been documented in the regular 6-monthly Project Progress Reports. In this Final Report reference is commonly made to the Project Progress Reports and their Appendices, which contain much of the technical data that has been compiled during the past 39 months.

All the Work Packages described in the Annex 1 (Project Programme) to the Contract were completed. Although there were some slight modifications to the scheduling of the Work Programme as compared the original plan, the overall technical and dissemination objectives of the Project have been achieved. Furthermore, as is demonstrated in the relevant sections of this Report, various improvements, additional to those that were originally anticipated, were made to the prototype systems.

Comments on the problems that arose during the Project are discussed in the relevant sections.

1.1 Project Partners in the Demonstration Phase

The partners participating in the Demonstration Phase of the ENVIRO-MT Project are listed in Table 1. Partners TNO and ITGE joined the project for the Demonstration Phase, while the remaining partners MTX, UU and JBA were the original members of the consortium in the Definition Phase.

1.2 Project Objectives, Targets and Goals

The project objectives were defined in the Report on the Definition Phase as:

- adaptation of established magneto-telluric technology to the requirements of the European environmental and geotechnical engineering industry.

The ENVIRO-MT system was to be practically tested at two end-user sites.

The quantitative targets were defined as:

- construction of two operational and economically viable ENVIRO-MT prototype systems
- demonstration and presentation of the system at two end-user sites
- compilation, editing and printing of an Operations Manual
- presentation of the project at 2 European conventions

As goals the results of the Project would make significant contributions towards:

- increasing efficiency and reliability of geoscientific data presented in planning applications for waste disposal sites, and
- detection and monitoring of the sub-surface migration of potentially harmful saline fluids.

This Final Report to the Demonstration Phase will demonstrate that these objectives, quantitative targets and goals have been successfully achieved.

NAME	Abbreviation	TYPE	ROLE	COUNTRY
Metronix Meßgeräte und Elektronik GmbH	MTX	Electromagnetic Geophysical Systems: Development and Manufacturing	Project Leader and Technology Provider	DE
Department of Geophysics, University of Uppsala	UU	Research and Development of Electromagnetic Systems	Technology Provider	SE
John Barnett & Associates Ltd	JBA	Environmental and Geotechnical Engineers	Know-how Provider & End-User	IR
TNO Institute of Applied Geophysics	TNO	Hydrological, environmental and geotechnical consultants	End-User	NL
Instituto Tecnológico GeoMinero de España	ITGE	Research and Consultants for environmental and geotechnical industry	End-User	SP

Table 1: ***Partners in the Demonstration Phase of the ENVIRO-MT Project***

2. PROJECT MANAGEMENT AND CO-ORDINATION (Work Package 1)

Work Package 1 (Project Management and Co-ordination) of the contractual Work Programme includes the various aspects of Project Management, and is discussed below on a task by task basis.

2.1 Project Progress Meetings (Tasks 1.1 and 1.2)

Progress Meetings were held regularly during the Project. The Meetings were called and chaired by the Project Co-ordinator. The Meetings were normally timed to last 4 – 8 hours on the 1st day, with a work-shop, demonstration or field test for all participants on the 2nd day.

Although efforts were made to ensure that the Meetings were held more or less every 6 months as was originally planned, it was considered important that they also be held at times at which important decisions regarding the progress of the Project had to be made. For example, particularly in initial 2 meetings, important decisions were made regarding the acceptance of the prototype systems and, ultimately, the viability of the Project.

In order to avoid unnecessary extra travel expenditures, the Meetings were usually scheduled to coincide with other Tasks in which the Partners were participating – for example, Project Meetings were schedule to coincide with field tests (Work Package 4) or dissemination events (Work Package 6). In this way, the maximum synergy between the Meetings and participation in other Tasks was achieved.

Meeting	Date	Location	Attendees	Comments
Kick-Off Meeting	16 – 17 January 1997	MTX, Braunschweig, DE	All partners + Project Officer	
Project Meeting #1	6 – 7 September 1997	Ebeltoft, DK	All partners	Meeting scheduled to coincide with the 3rd Annual Symposium on the Application of Geophysics to Environmental and Engineering Problems in Aarhus DK on 8 - 11 September 1997, where the project was presented.
Project Meeting #2	26-27 June 1998	Braunschweig DE	All partners except TNO	Meeting deferred due to delays in WP 2, and called to approve the final design of the prototype (demonstrated)
Project Meeting #3	12 November 1998	Hardenberg, NL	All partners	Meeting scheduled to coincide with 1st field tests in The Netherlands
Project Meeting #4	19 April 1999	Almuñecar, ES	All partners + Project Officer	Meeting scheduled to coincide with 2nd field tests in Spain
Project Meeting #5 (Final Meeting)	6 September 1999	Budapest, HU	All Partners	Meeting scheduled to coincide with the Project Dissemination at the EEGS Convention, Budapest.

***Table 2**: List of Project Meetings convened during the ENVIRO-MT Project*

The same considerations had to be taken into account for the location of the Meeting – normally each of the Partners were asked to host one meeting, and this effectively occurred with the exception of JBA/Dublin, Ireland.

Minutes were taken by the Project Co-ordinator of the proceedings of the Meetings, and these were distributed to all participants in draft form for comment and review prior to being sent to all partners and the Commission. Furthermore, a copy of the Minutes was attached as an Appendix to each of the Progress Reports.

2.2 General Co-ordination and provision of advice on administrative and financial matters to all partners (Task 1.3)

This item was deleted from the Work Programme during the final negotiations for the Demonstration Phase.

2.3 Maintaining regular communications with DGXIII/D/4 and Preparation of Consolidated Financial Statement and 6-monthly Technical Report (Tasks 1.4, 1.5 and 1.6)

Consolidated Financial Statements, which were compiled from the Cost Statements submitted by the partners, and regular 6-monthly Progress Reports were submitted to the Commission and all the partners for the following periods:

- 1 January to 30 June 1997
- 1 July to 31 December 1997
- 1 January to 30 June 1998
- 1 July to 31 December 1998
- 1 January to 30 June 1999

No problems were encountered other than a minor formal error that delayed the approval of one set of financial statements, and the predictable problems related to delays in the compilation of reports and cost statements due to vacations over the summer months of July and August.

Technical information was provided in the 6-monthly Progress Reports, both in the text as well as in Appendices, and these are referred to in this Final Report.

Communication with the Commission was maintained through the Project Officer. During the course of the Demonstration Phase, four different Project Officers and contact persons were appointed. There is no doubt that, although the Project Officers were normally very helpful and supportive, the lack of continuity may have caused some misunderstandings in the routine management and objectives of the programme.

2.4 Deliverables

The following deliverables have been prepared (See Table 3). These deliverables are either attached, have been prepared as separate reports appended to earlier Progress Reports, or are available for inspection at the offices noted.

No	Deliverable	Status
D11	Minutes of Kick-Off Meeting	Appendix 1 to Progress Report #1
D12	Minutes of Project Meeting #1 Minutes of Project Meeting #2 Minutes of Project Meeting #3 Minutes of Project Meeting #4	Appendix 1 to Progress Report #2 Appendix 1 to Progress Report #3 Appendix 1 to Progress Report #4 Appendix 1 to Progress Report #5

No	Deliverable	Status
D13	Six-monthly Report for 1 January - 30 June 1997 Six-monthly Report for 1 July - 31 December 1997 Six-monthly Report for 1 January - 30 June 1998 Six-monthly Report for 1 July - 31 December 1998 Six-monthly Report for 1 January - 30 June 1999	Progress Report #1 Progress Report #2 Progress Report #3 Progress Report #4 Progress Report #5
D14	Final Report	This Document
D21	Technical Specifications	Distributed to partners in April 97, with subsequent updates sent to all partners.
D22	Materials Order and Invoices	On file at MTX and UU
D23	Six-monthly Progress Reports to the Co-ordinator	UU and MTX submitted detailed 6-monthly reports for inclusion in the Progress Reports to the Commission.
D24	Report on Results of Laboratory Tests and Calibration - Acceptance of the System	Presented at the Project Meeting#2, and additional details on Software adaptation are included in Appendices 2 and 3 of Progress Report #3. Final calibration was completed in August.
D25	Contributions to the System Manual	Appendix I to this Report
D31	Evaluation of Geophysical Interpretation Software Packages and Recommendation of package most suitable for ENVIRO-MT	Appendix III to Progress Report #2
D32	Licensing Agreement with publisher of selected software	Correspondence with *Fortner Software* on file
D34a	Report on adaptation of software package for interpretation of ENVIRO-MT data	Presented at Project Meetings #3 and #4 and Progress Reports.
D34b	Contributions to the System Manual	Appendix I to this Report
D41	Report on selection of demonstration sites with geoscientific data package	Information on demonstration sites were presented, discussed and accepted at Project Meetings #1 and #2. Data package on Site #1: The Netherlands test sites submitted October 1998 (on file). Data package on Site #2: Almuñecar, Spain, test site submitted January 1999 (on file)
D44	Report on survey, data and interpretation from Demonstration Site #1	Results described in Appendix 2 of Progress Report #4, and Report on Mapping subsurface pollution in Collendoorn, TNO (on file)

No	Deliverable	Status
D45	Report on survey, data and interpretation from Demonstration Site #2	Report on the Interpretation of ENVIRO-MT data from Test Site of Almuñecar (Spain), 1999, ITGE (on file)
D46	Report on end-user training and recommendations to technology providers for incorporation into final hardware and software design.	Recommendations for Technology Providers (MTX & UU) – Final Hardware and software design: Appendix 6 in Progress Report #5.
D47	Field Operations Section for System Manual	ENVIRO-MT system manual – receiver setup and field operation: Appendix 4 in Progress Report #5
D51	Methodology for Technical Assessment of Project	PACE monitoring system presented at the Project Meeting #1.
D52/55	Base-line study of production costs at the Metronix Production Site.	Appendix 3 to Progress Report #5
D54	Draft version of the users manual for the ENVIRO-MT system	Appendix I of this Report
D61	Project Description Leaflet	Appendix 5 to Progress Report #2
D62	Project Mailing List	Appendix 5 to Progress Report #2 Appendix 8 to Progress Report #5
D63	Members of the Observer Group	Appendix 8 to Progress Report #5
D64	Dissemination Plan related to the launch of the ENVIRO-MT system at the EEGS Meeting	Appendix 5 to Progress Report #5
D65	Newsletter and Press Releases	Various items, including own mailing actions and regularly updated internet site (Section 7.2 of this Report)
D66	Presentation Materials / Computer presentation	Appendix II to this Report. The database and user interface was demonstrated at the EEGS-ES, September 1999

***Table 3**: List of Deliverables submitted during the ENVIRO-MT Project*

2.5 Modifications to the Project relevant to Project Management

During the final year of the project it became clear from the Cost Statements that some partners would overspend their allocated budgets, while other partners would underspend. The principal reasons for this were:

- JBA found itself unable to make the contribution to Work Package 3 as had originally been planned, and their contribution was taken on by UU. Furthermore, JBA had over estimated their planned travel costs (Project Meetings and other Tasks were scheduled on dates convenient for partners to use cheap APEX tickets as compared to the full-price air tickets).

- The work undertaken by TNO on the field demonstration sites in The Netherlands was less than originally anticipated, while that undertaken by ITGE on the field demonstration sites in Spain was more than originally anticipated.
- The MTX Project Leader, who was also expected to contribute to the System Manual, was seriously injured in an accident and could not complete the task as planned. This work was taken on by UU.

The Partners requested the Project Co-ordinator to submit a revised budget that conforms to the contractual requirements of §18.2 of the ANNEX II to the Contract. The revised budget (Table 4) was submitted to all partners with the Minutes for Progress Meeting #5.

The minor modifications relate to slight changes between expected and actual work undertaken by certain partners in specific Work Packages as noted above, as well as minor modifications in the estimated expenditures in certain cost categories. There are no changes to the Commission's estimated contribution to the Project or to the % contribution to each partner.

Hereby the following should be noted:

- the revised estimates do not exceed the contractual limits for the total contribution by the Commission (EURO 551.240), and the original %contribution to each partner of total costs has been retained,
- the total sum that is transferred between partners' budgeted total costs is 68,339 EURO, and that is still well below 10% of the planned budget of ca 1.1 million EURO,
- the scope of the Project has not been fundamentally affected by the changes,
- the changes permit the objectives of the Project to be achieved as originally planned

	MTX	UU	JBA	TNO	ITGE	TOTALS
Labour	181,355	143,422	84,409	55,000	52,121	516,307
Durable Equipment	2,947	5,536	9,813		3,849	22,145
Material	31,509	26,442	12,469			70,420
External Services	18,711		52,261			70,972
Travel and Related Costs	15,385	16,935	21,625	3,819	11,955	69,719
Other						
Labour Overheads	217,626		94,538		32,833	344,997
TOTAL	467,533	192,335	275,115	58,819	100,758	1,094,560
Contribution by EC %	39.78	100.00	39.78	39.78	39.78	
Contribution by EC EURO	185,985	192,335	109,441	23,398	40,082	551,240
Differences to Original Budget						
Disbursements	-17	5,212	-21,171	-16,942	24,997	-7,921
Contribution by EC (EURO)	0	5,212	-8,417	-6,739	9,945	0

Table 4*: *Revised Indicative Budget for the ENVIRO-MT Project

Due to the differences in the % contributions due to the partners and the fixed figure for the Commission's Contribution, if any modifications are made to the estimated costs incurred by each partner this will result in a slight change to the previous estimate for the Total Cost.

3. DESIGN, CONSTRUCTION AND LABORATORY TESTING OF PROTOTYPE ENVIRO-MT SYSTEM BASED ON ADAPTATION OF CSMT TECHNOLOGY (WORK PACKAGE 2)

This Work Package was planned to be the principal activity during the first 15 months of the Project, and a successful completion was essential to the continuation of the Project. In fact various delays resulted in the prototype transmitter and receivers being accepted in June 1998 (Project Month 18), and finally completed during August 1998 (Project Month 20).

The transmitter and the receiver were tested successfully during a field test held in Sweden during August 1998 prior to the 1st Field Test in The Netherlands in October – November 1998. Further adaptations were subsequently made to the ENVIRO-MT system on the basis of the experiences gained from the field tests in both The Netherlands and in Spain.

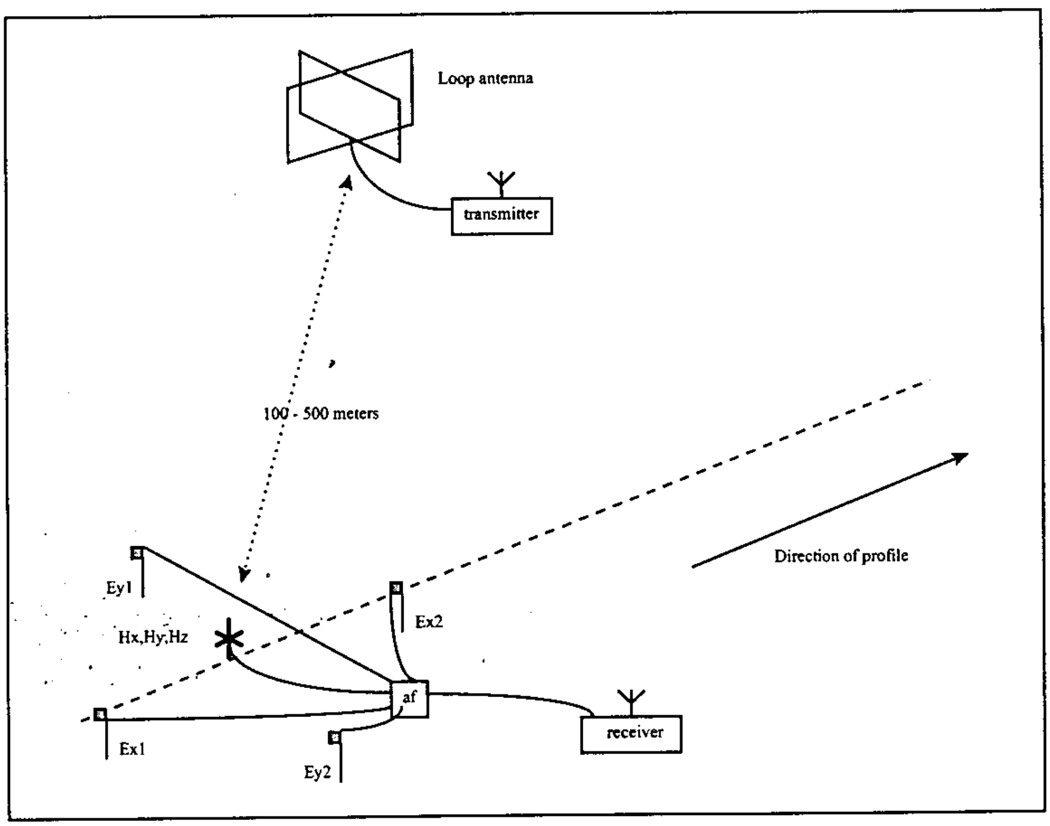


***Figure 1:* Overview and Field Set up of the ENVIRO-MT system**

The field layout for the transmitter with antenna, and the receiver with sensors, is shown in Figure 1. The transmitter can be operated remotely from the receiver site by means of radio modems. A distance over 1000 m between receiver and transmitter could be achieved without a break in communication between the modems, which is sufficient for ENVIRO-MT surveys.

3.1 Final Review of component specifications and suppliers, ordering of materials (Task 2.1)

The specifications for the prototypes were established during the Definition Phase of the Project, and are briefly reviewed in the relevant sections below. A review of the component specifications was carried out during the first months of the Demonstration Phase, and all the important materials with a long delivery time were ordered.

A special ferrite with excellent high frequency specifications was ordered for the core material for the magnetometers.

The design of the analogue box was specified in greater detail than in the Definition Phase, and the electronic components for the amplifiers and filters were identified during the first 6 months of the Project.

The amplifier modules for the transmitter were selected and ordered. The GPS clock GP167 from the company Meinberg in Germany was selected as being the most suitable for synchronisation between receiver and transmitter. The clock module is customised by the manufacturer to our needs which also reduces the price.

The Materials Orders and Invoices (Deliverable 22) are retained on file at the offices for MTX and UU.

3.2 Design, assembly and testing of the transmitter system with loop antennas (Task 2.2)

The general specifications for the ENVIRO-MT transmitter and antenna system are shown in Table 5, and the configuration in Figure 2.

Frequency range :	1 - 250 kHz.
Maximum antenna moment :	6000 Amp-m^2
Antenna size :	Two perpendicular square shaped antennas, each 27 m^2
Control :	Remote controlled by Radio modem communication from receiver.
Power Requirement :	4x12 V, 60 Ah battery.

Table 5: Prototype Specifications for the ENVIRO-MT Transmitter

The transmitter system was developed as specified in the technical annexe of the Enviro-MT Specifications (Report on the Definition Phase). In order to save costs it is mainly based on components which are commercially available.

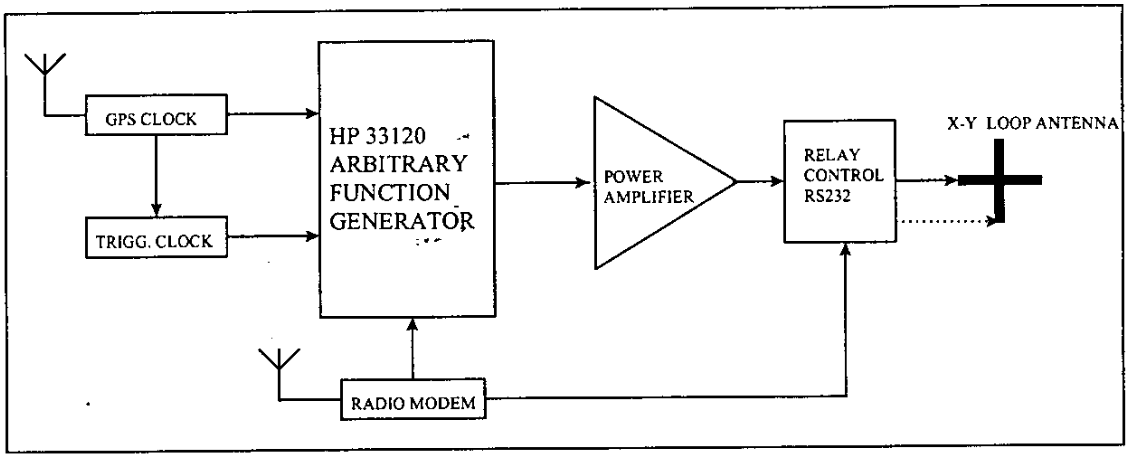


Figure 2: Transmitter Configuration

3.2.1 Transmitter Design and Construction

The nucleus of the transmitter was initially designed around the Punch 250 Monoblock car amplifier from Rockford Fosgate company, however subsequent field tests in August 1998 demonstrated that this amplifier did not the meet the specifications for the minimum permitted impedance. The result was that the power supply, or more precisely the last stage of the amplifier, failed when the transmitter was used under full load conditions. Once the amplifier was replaced by a second one, and additional precautions such as cooling with fans and transient suppressers at the output of the power amplifier had been implemented, the transmitter worked satisfactorily but only if the current was reduced to only 50%. Subsequently the second field test in the Netherlands demonstrated that it was necessary to use as much transmitter current as possible in order to obtain a reasonable data quality.

The transmitter frequency is generated by an „HP 33120A" programmable frequency generator which itself is controlled by a Meinberg GPS clock type „GPS 167". The 10 MHz signal from the GPS clock is fed into the frequency generator reference clock input and the generator is phase locked to the 10 MHz signal.

At the receiver, the sampling clock is derived from the same type of GPS clock, GPS 167. With a dedicated clock triggering, the acquisition of data segments at the receiver has a constant phase relationship for all the acquired data segments due to the GPS reference clocks at the receiver -transmitter.

A radio modem, manufactured by the Finnish company SATEL, receives all the necessary commands to control the transmitter system, such as change of frequency, selection of antenna dipole etc. The ENVIRO-MT receiver is equipped with the same type of modem. The control commands are generated automatically by software, for example when the frequency is changed.

The transmitter is powered either by a set of four 12 V car batteries or by a small 12V motor generator. The transmitter itself is mounted in a 19" rack system encapsulated by a waterproof case.

3.2.2 Antenna Design and Construction

The loop antenna consists of a 25m long rubber cable containing 5 wires each with 1.5 mm^2 cross section. The antenna loop is completed when the ends of the cable are plugged together. The wiring is such that a 5-turn loop is created. The effective loop area of the antenna therefore amounts to max. 9m x 3m x 5turns = 135 m^2. This is more than 30 times more than the originally assumed 4 m^2 in the technical specifications. In the field, the two antenna loops are mounted orthogonally as vertical loops of 3 x 9m using rods to maintain the loop curvature (Figure 3). Towards the end of the Project, the transmitter antenna loop was modified to enable operation with 1 loop for the 25 – 150 kHz band, and this was sent to UU for testing with the receiver unit.

***Figure 3:** Transmitter set up in the field during the field tests in The Netherlands.*

Laboratory tests with the transmitter have shown that in the low frequency range up to about 20 kHz, it is easily possible to feed in a current of 15 A. In the 100 kHz range the current drops to 4 to 7 A and even at 250 kHz a current of greater than 1 A can be achieved.

In order to feed in a reasonable current it is important to adjust the antenna system with a suitable capacitor, which is connected in series to the antenna circuit. The maximum current is achieved when the inductance of the antenna loop and its serial capacitor are adjusted to be in resonance at the selected transmitting frequency. However field tests in Sweden in August 1998 demonstrated a requirement for additional tuning of the resonant frequency at some of the frequencies to achieve maximum current flow in the loop antenna – this was undertaken by MTX.

In order to adjust the antenna circuit to the various frequencies required for the ENVIRO-MT data acquisition, a bank of 15 different capacitors can be selected by switching relays. Several capacitors can be switched in parallel in order to optimise the resonance frequency of the antenna circuit to the desired frequency.

The relays are also switched by remote control from the receiver via the radio modem that is mounted on the middle pole of the loop antenna about 3 meters above the ground (Figure 3).

The ENVIRO-MT transmitter system, consisting of the frequency generator and antenna, is shown in Figure 3 during test measurements in The Netherlands.

3.3 Design, assembly and testing of the E-field and H-field sensors and associated cabling (Task 3.3)

3.3.1 The E-Field Sensors

The prototype specifications for the E-Field sensors are shown in Table 6.

Frequency range:	1 kHz to 250 kHz
Electrode type:	stainless steel stick, buffer amplifier integrated in electrode cable
Gain of buffer amplifier:	5
Dipole length:	10 m

Table 6: Prototype specifications for the E-Field sensors

The E-field sensors will be steel sticks or a capacitive type (optional). The cable end contains the buffer electronics which drives the cable with a low output impedance. The electric field sensors were originally designed to be used with high speed LT 1028 operational amplifiers as a buffer, but these were subsequently replaced by OP27 amplifiers. The electronics are enclosed in a small waterproof case, on which the plug to the steel rod is directly mounted.

3.3.2 Magnetic Sensors

The prototype specifications for the H-Field sensors are shown in Table 7.

A new concept for the magnetic sensors was developed that uses a current amplifier instead of a voltage amplifier, and allows the direct measurement of the magnetic field instead of its time-derivative, as is normally done by a voltage amplifier that is driven by a coil with a large number of turns. In the case of the new concept, the current of a coil with a thick wire and a lower number of turns is measured. This principle avoids the disadvantages of a feedback coil with its capacitive feedback to the main coil.

A special ferrite with excellent high frequency specifications for the magnetometers was identified from a supplier in USA, and was included in the construction of the prototypes (see Table 7).

No. of channels:	3 orthogonal components
Type of sensor:	feedback induction coil with ferrite core
Frequency range:	1kHz to 250 kHz
Sensor self noise:	1.9 fT/√Hz @ 20 kHz
Preamplification:	variable
Sensitivity of coil without feedback and amplifier:	appr. 0.0125 μV/(nT*Hz)
No. of turns:	70
Sensor length:	30 cm
Core diameter:	7.5 mm
Core material:	ferrite

Table 7: Prototype specifications for the H-Field sensors

As foreseen in the Project technical specifications (Definition Report), the magnetometers have been mounted as triplet. The magnetometer sensor triplet is a new development and consists of 3 orthogonal induction coil sensors with integrated preamplifiers. Three sensors have been arranged as a triplet around a central support (sensor triplet). This central support also contains the common connector for the cable to the sensor box, which avoids additional wiring in the field. A level mounted on the support can be used to adjust the sensor horizontally. The support is fixed to a non-magnetic tripod (see Figure 4).

The magnetometers have a flat frequency response between about 700 Hz to 250 kHz, and it is intended to limit all errors to less than 1%. The noise characteristics of the magnetometers is shown in Table 8. The output sensitivity of the sensor is 0.6V/nT. Measurements of the cross-talk between the components have demonstrated that it is better than 60 dB for frequencies lower than 60 kHz. Capacitive coupling between the sensors for higher frequencies reduces the cross-talk to about 40 dB at 200 kHz. A screening foil made of copper has been added in order to prevent capacitive coupling.

Frequency (Hz)	Noise (fT/√Hz)
1	45
5	15
20	6
50 - 250	2.8

Table 8: Noise characteristics of the Magnetometers

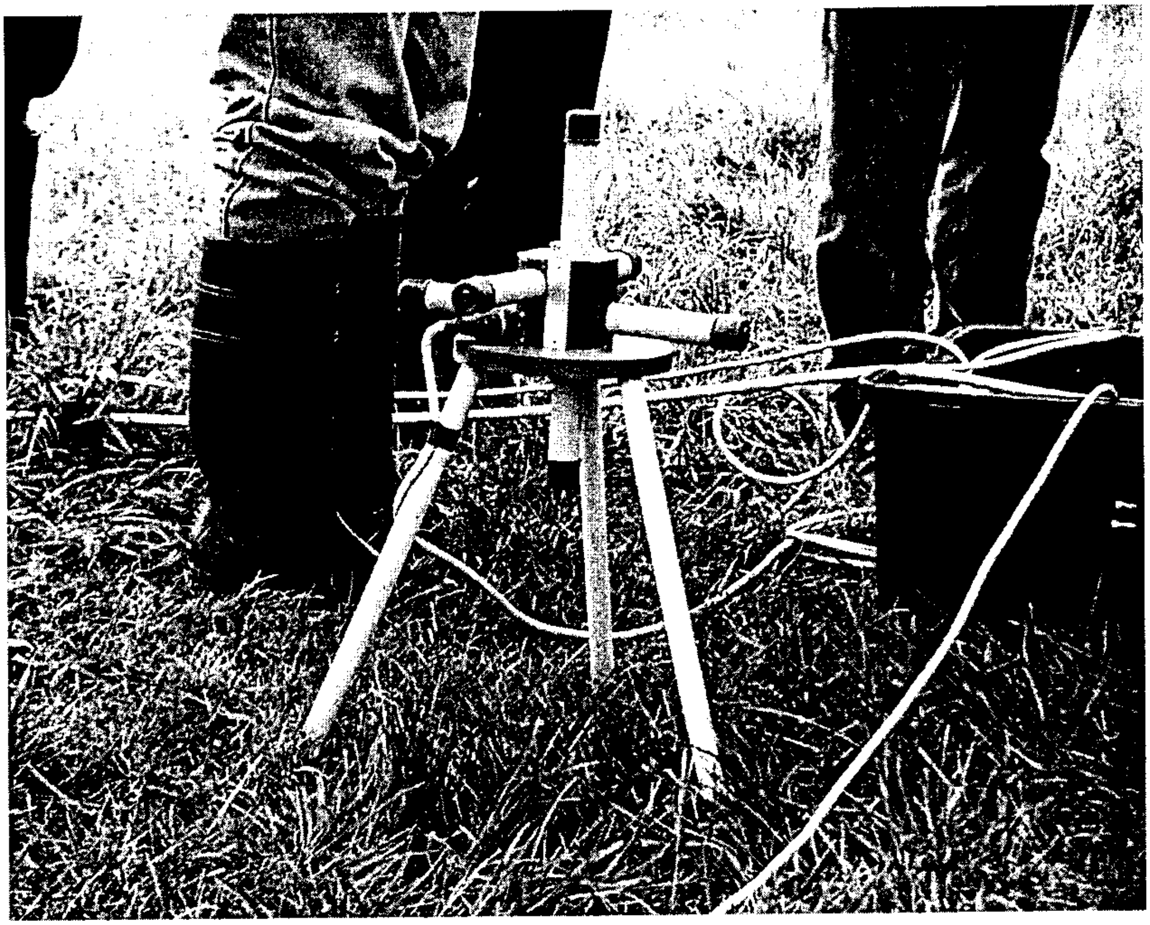


Figure 4: *Magnetometer Sensor Coil Triplet, Collendoorn, The Netherlands*

3.4 Laboratory calibration of the E-field and H-field sensors (Task 2.4)

The calibration of the E-field and H-field sensors had to be delayed until the sensor box had been constructed on the basis of the designed circuit diagrams (Appendix 2 in Project Progress Report 3). The sensor box is located between the sensors and the receiver unit, and can be controlled from the receiver unit, and is an essential part of the ENVIRO-MT system. Construction was completed and, with two minor exceptions listed below, successfully tested in Sweden in late August 1998.

The anti-aliasing low-pass filter in the analogue filter box was originally designed as a „switched capacitor filter" filter. However, the laboratory tests with the receiver hardware demonstrated that the noise created by this filter concept was too high in certain frequency ranges. The switched capacitor filter was therefore replaced by a regular 6-pole analogue filter circuitry, and the results with this filter were considered to be satisfactory.

In the strongly resistive ground such as occurs in Sweden, the buffer amplifiers showed a tendency to self-oscillation due to the use of very high speed operational amplifiers. The problem was solved during the first test in Uppsala by replacing the LT 1028 by an OP27.

The magnetic sensors worked well during the tests. After these modifications the whole system could be calibrated with satisfactory results.

The external hardware electronics (AF-filter box and sensors) connected to the receiver electronics are calibrated with the Ey channel connected through the buffer as the reference input. The calibration signal is delivered by the Hewlett Packard generator that is used for the transmitter system, working in a triggered sweep mode where the triggering is taken out from the receiver.

The electric sensors are calibrated by feeding the calibration signal directly to the input of the buffer amplifiers.

The magnetic sensors are calibrated with a 1 square meter loop antenna where the input reference (Ey) is taken across a serial resistance for the absolute field calculation.

3.5 Design and Assembly of the Receiver Hardware (Task 2.5)

This task was one of the most time-consuming components of the Project, and required a close co-operation between the technology-providing partners (UU and MTX).

The receiver specifications are shown in Table 9.

Bandwidth :	1 - 250 kHz.
Resolution :	14 bits.
No. of Channels :	5 (2E, 3H).
Processors :	DSP / TMS320C32, PC / 586/133
Hard disk :	>1 Gb, 2.5 inch
Display :	Colour LCD, SVGA, TFT with >200 mCd.
Power :	12 V, 6.5 Ah. (2 required for full days operation)

Table 9: Prototype Specifications for the ENVIRO-MT Receiver

As shown in Figure 5, the receiver consists of three sub-units:

- analog sub-unit (amplifiers, filters).
- dsp sub-unit (a/d converters, digital signal processor).
- pc sub-unit (computer, master control).

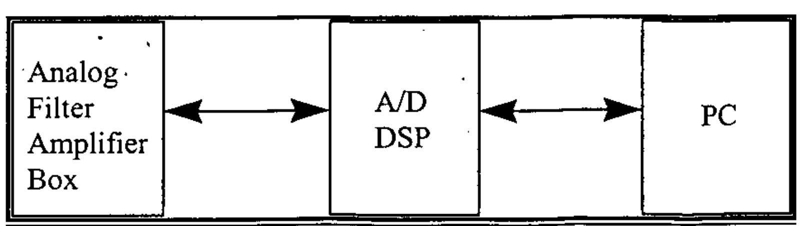


Figure 5: Receiver Configuration

3.5.1 Receiver design - hardware.

The following items were purchased for the acquisition unit (AU):

- Touch screen and *Sharp* TFT-LCD display module 12 inch, 250 mCd, 800x600 pixels.
- PC/104 system with a PC/104 to ISA bridge
- Low power 586 embedded PC with 24 MB RAM, 4 serial interfaces, parallel interface(*the System performance has been enhanced by using new low power Pentium 266 MHz ISA board).*
- SVGA controller on board .
- 2 GB hard disk.
- Signal processor board PC/C32 60 MHz, 256 kB memory.
- GPS-clock *Meinberg* GP167.
- Analogue power supply developed by Metronix.
- Digital power supply PC/104 board .
- Radio modem for transmitter control.
- I/O board with 2 additional serial interfaces and A/D converter to monitor the battery voltage.
- A/D converter board, see section 3.5.4 on A/D design.
- *Thermodyne* waterproof case for the receiver.

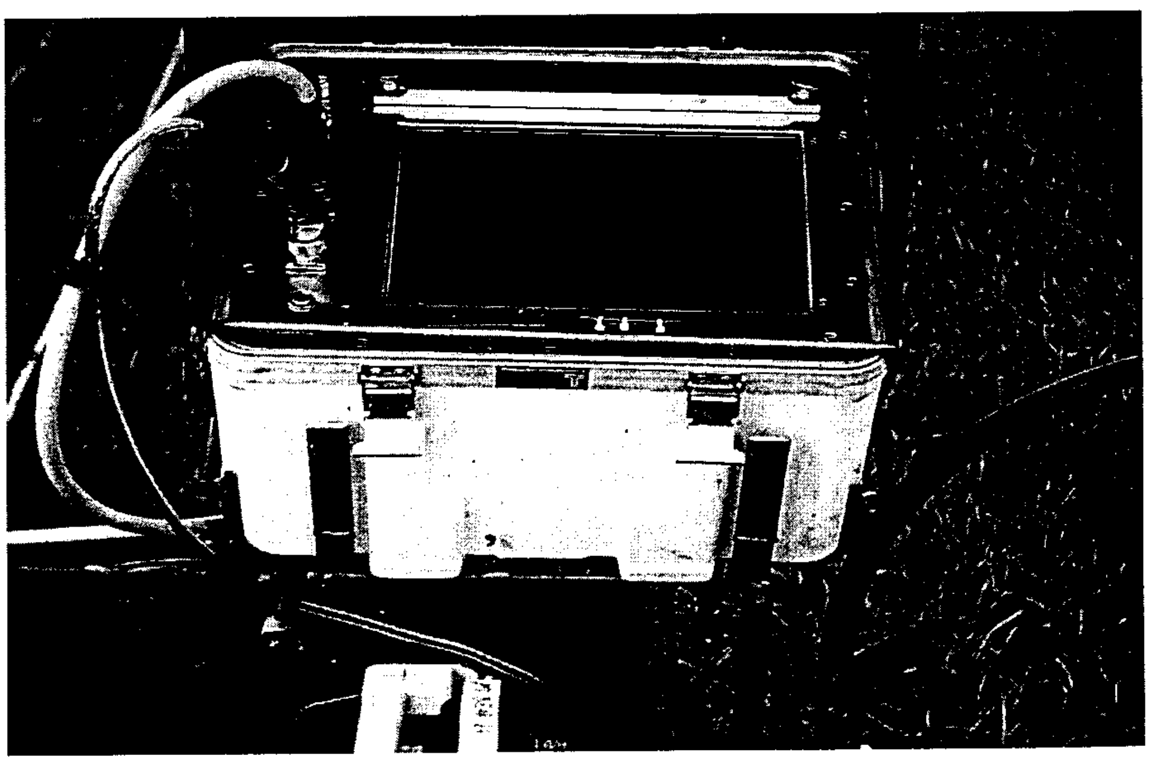


Figure 6: ***Receiver Box, Collendoorn, The Netherlands***

3.5.2 Receiver Mechanics and assembly.

The acquisition unit (Figure 6) is mounted in a waterproof case (Thermodyne) covered with a top lid. Inside the top of the case the touch screen is mounted on a panel with a good waterproof sealing. All the input and output connectors are waterproof MIL sockets and are located on the left side of the screen on the panel. The internal chassis was subsequently covered with thin iron plates (0.7 mm) for screening because of EM emission from the DC / DC converters in the receiver system (due to system noise).All the internal electronics are assembled on an internal aluminium chassis that is mounted on the front panel for easy access.

The batteries for the equipment are dry lead acid type and are located in a separate box. The receiver design was modified for work in the dense fruit plantations found in the Almuñecar area by using an aluminium carrying device that supports the receiver and battery on 4 legs, which was found to be an ideal way of transporting the system.

3.5.3 Design and assembly of the Analog amplifier and filter box

The analogue filters and amplifiers have been developed according to the technical specifications. Each channel is provided with a separate amplifier/filter module that is plugged into a motherboard. The analogue/filter box is enclosed in a waterproof aluminium box. The electric and magnetic sensors are connected to the input terminals. The output terminal is connected to the acquisition unit by a cable.

Laboratory tests demonstrated, however, that the noise level of the switched capacitor filters in the analogue filter box was not acceptable, the buffer amplifiers of the electric channels were not stable (ringing effects) and the power supply for the analogue electronics had some problems with regulation.

Additionally the power supply voltage to the analogue filter box had to be increased from + / - 6 V to + / - 12 V due to input level dependency of the transfer functions.

Functions to control the filter and gain setting were implemented in the software. The control of the analogue filter box is made through an RS232 interface driver. The control commands are ASCII strings and the different filter configurations are set according to the frequency band selected in both methods. The gain setting control of the post amplifiers are activated during acquisition and changed if necessary.

3.5.4 A/D converter design

The design of the analogue to digital (A/D) converter was undertaken by UU. The A/D board contains five identical sections with an input stage, 14 bit A/D converter and 16 kByte FIFO (First in - First out) memory buffer. A common section is the control electronics and the DSP link interface. The DSP has full control of the A/D board through the DSP link interface and a dedicated software driver that was developed in parallel with the hardware. With the software driver the following functions are implemented,

- sampling- and trigger frequency setting.
- internal or external (GPS clock) sampling clock.
- Transfer of FIFO memory buffer data to the DSP.

3.5.5. Testing of the A/D card and Implementation with signal processing software.

The final testing of the A/D card was completed in February 1998, and the new prototype functioned without any problems. The power supply for the A/D card, designed by MTX, was also tested and functioned successfully. The combined testing of the DSP processing algorithm and the A/D card was completed by the beginning of April 1998. The implementation was easy and fast, and the A/D card functioned very well together with the signal processing software.

Later a temperature problem was discovered on the A/D converter card. A clock signal was affected by the temperature and thus not stable, which caused a distortion on the digitised signal. The effect was removed by adding a small capacitor at the corresponding electronics.

After the modification a test was made with high positive- and negative- temperature gradients from normal room temperature that did demonstrate any abnormal operation of the A/D converter card under these conditions.

3.5.6 Testing and Modification of the Receiver Hardware

The phase stability was tested in the laboratory with the receiver- and transmitter GPS clock locked. Acquisition of different transmitted frequencies was made from the phase-locked *Hewlett Packard* generator with the GPS clock, which is used, as the signal source in the transmitter system. The test showed that the phase stability was excellent even for the highest frequency with a stacking level of 300 stacks.

The original system used a PC 104 card with an AMD 586 - 133 MHz processor equipped with 24 Mb RAM. Using Windows NT, the memory is limited and at least 32 Mbyte of RAM memory is required. As the memory expansion of the board cannot be increased, and the speed of the computer is considerably lower, the computer board was replaced with a new ISA Pentium 233 MHz board. The board has 32 Mbyte memory, and the memory expansion can be up to an additional 128 Mbyte. The board is equipped with a low power Pentium chip and the overall power consumption is increased with just a few watts.

The increase of the processing power dramatically improved the overall performance of the system, especially the database application with its application software.

The NT operating system did not work properly with the original PC 104 board, and problems were encountered with the serial board access from the NT operating system. This card was replaced with an ISA serial board without such controller electronics, and this was found to be stable with the NT operating system.

Introducing the ISA standard provided a uniform factor for all the computer boards in the receiver design, as well as simplifying the mechanics and assembly of the boards.

Further details on testing of the Receiver system are provided in section 3.7.

3.6 Receiver software - user interface and data display (Task 2.6)

The receiver software was developed in the laboratories of technology-provider partner UU.

3.6.1 Menu-oriented user-interface

A menu-oriented user-interface was developed by using the DELPHI programming environment from *Borland*. The principal element of the operating interface is a user-friendly screen-view with windows-like facilities that most users will be well acquainted with, and buttons to press in order to select methods and settings of project and system parameters.

The operating system (OS) used is NT 4.0 from *Microsoft*. This OS is expected to be the leading OS in the future, and was thus selected. It is a pure 32 bit environment and has many advantages compared to DOS and Win95.

Microsoft NT 4.0 was installed on the system with a special configuration for the ENVIRO-MT system. Since the system functions without a keyboard, the log-in is automatic. The system is also configured with different hardware profiles, one for field work and one for office work, with and without floppy and CD-ROM. A touch screen with driver is installed and the system can be operated with a pointing device. When using the system in the office a keyboard, mouse and screen can be connected to the system. An additional PC104 serial board is installed in the system and there are a total or four serial ports. The distribution of the ports is as follows,

- Com1 - touch screen.
- Com2 - radio modem.
- Com3 - Analogue filter box.
- Com4 - GPS clock.

The GPS clock has its own driver for setting the start up parameters of the clock, show satellite information, clock status etc. The driver can be invoked from the ENVIRO-MT software by double clicking the GPS panel in the CSMT exec menu. The driver works on the ISA bus directly and the serial port is used to communicate directly from the ENVIRO-MT software to check the status of the clock (locked or unlocked).

A full description of the ENVIRO-MT Signal Processing Software is attached as Appendix 2 to Progress Report #3.

3.6.1.1 Structure of the menu system

At start up of the system the *START* menu is activated. From this menu the operator can select the method, calibration, *help file system* and set up of system- and project parameters by pressing the corresponding button.

The software maintains the file management for the data files and a system log file facility with time stamping is created for each new project.

3.6.1.2 Serial driver and remote control

A serial driver was implemented in the software. The software was tested with the radio modem connected to the computer at one end and another radio modem connected to the HP signal generator at the other end. The generator is controlled by SCPI commands that are transmitted sequentially according to the defined frequency list by the CSMT software. The same serial driver is used for the control of the analogue filter box and the GPS clock.

3.6.1.3 Magneto-Telluric Methods

The system includes two magneto-telluric methods - Radio Magneto Tellurics (RMT) and Controlled Source Magneto Tellurics (CSMT). Each method has its own window with panels for display of the project- and system- set up and system status. Easy management for testing, data acquisition, editing and evaluation of the results is achieved by pressing buttons or by pointing and clicking on the charts. The results for Rhoa, Phase, Rho* Z* and tipper A and B are displayed in chart diagrams. After display of the results *in the CSMT mode*, the operator can judge if he wants to edit the data. In the edit mode the operator selects the bad frequencies to repeat by pointing on the screen. The display is spliced up in two parts one for each direction (XY or YX). The display is either scalar or tensor, where the operator can select between RHOA and PHASE. The selected frequencies (-ies) are marked in red colour and after editing they are marked in green. Switching of transmitting direction is automatic. When the editing is completed the data is accepted and stored, and the system is ready for the next station.

It is possible to add comments in every menu. A comment memo will appear on a comment request.

<u>Measurement mode set up.</u> The normal way of field measurement with the ENVIRO MT system with more than one profile is a parallel layout of the geometry, named grid. By keeping track of the azimuth the system can administrate the increment / decrement of station no. and station co-ordinate. If the geometry is different named other the station no. and station co-ordinate is incremented on each line.

<u>RMT test mode.</u> The test mode is accessed from the RMT Exec menu. In the test menu the operator can select band and number of stacks. After the requested number of stacks the number of detected transmitters are displayed in a table. The table has three fields, frequency, signal to noise ratio (dB) and the direction of the transmitter (degrees). It is also possible to display the time series with the Quick Look module.

<u>CSMT test mode.</u> The test mode is accessed from the CSMT Exec menu. In the test menu the operator can select band, number of stacks, transmitting frequency and antenna direction. After the requested number of stacks is completed, the stacked time series is displayed with the Quick Look module. The time series can also be stored from the test menu.

<u>Additional representation of data results.</u> In the RMT mode the data can be selected to be displayed in the charts as Scalar, half octave tensor and full octave tensor. The selection is made in the method set up. In the CSMT and RMT mode the data can be presented in a table by pressing a button.

<u>Implementation of C32 DSP DLL (Dynamic link library).</u> The deliverer of the signal processor card has a DLL module that makes it easy to interface the host PC and the signal processor. The DLL is a set of different functions for accessing the DSP like downloading the DSP program code, deliver data to and from the DSP, reset and halt the DSP etc. The communication between the PC and the DSP functions without any problems.

<u>DSP - PC Flag system.</u> In order to handle and distinguish between all the different results from the DSP and parameter delivery to the DSP, an advanced flag system was developed (see also signal processing software). There are two flags connect and decode flag and they are allocated in the DPRAM on the two last addresses. The connect flag indicates if the computer, PC or DSP requires attention. The decode flags informs what type of result or parameter will be downloaded. Each decode flag has an unique number, and when decoding the flag a specific procedure call is made where the necessary actions between the PC and DSP are executed. Most of the actions are function calls to the C32 dynamic link library. Each method has their own flags, but some of them are also common. The different numbers of flags are as follows:

- RMT / Test method - 18
- CSMT / Test method - 14
- Calibration – 8

Analogue filter box control. Functions to control the filter and gain setting have been implemented in the software. The control of the analogue filter box is made through an RS232 interface driver. The control commands are ASCII strings and the different filter configurations are set according to the frequency band selected in both methods. The gain setting control of the post amplifiers are activated during acquisition and changed if necessary.

CSMT transmitter control. All the necessary settings of the transmitter are made through a serial driver and the receiver radio modem. The radiomodem signal is received at the transmitter and connected to the Hewlett Packard generator and the relay switch box.

The Hewlett Packard signal generator is controlled by SCPI string commands where the voltage level and the frequency is set according to the actual frequency, from the frequency list in use that is selected by the operator. Furthermore information strings are delivered and displayed on the front panel of the signal generator that contains information about the transmission direction and the frequency.

The loop antenna configuration at the transmitter is changed for each frequency by switching a set of capacitors to achieve serial resonance. A serial relay switch at the transmitter makes this. This relay switch also switches between the two perpendicular loop antennas. The control commands are a set of numbers. They are listed frequency by frequency and by antenna direction in three sets of constants where they are selected for the corresponding transmitting frequency and antenna direction.

GPS driver implementation. The GPS clock is used for the CSMT method, and it is necessary to check that the clock is locked to maintain the stability of the clock.

The clock is checked by a control request command through a serial interface driver that is activated once per second in the CSMT mode. If the clock is locked the GPS status display in the CSMT menu shows 'Locked' with green background, and otherwise it shows 'Unlocked' with red background.

A software driver from the deliverer of the clock has also been implemented where the operator can have complete information of the clock - and satellite information. The driver software is activated from the method set up tab named 'GPS' or by double clicking the GPS status display in the CSMT menu.

Help Function. A help function that can be accessed in the different menus has been implemented. It contains information about all the functions in the system. It is organised in such a way that relevant parts will be accessed from the selected active menu with indexed searching.

3.6.1.4 System Calibration

The system is automatically calibrated at each measurement site according to the diagram shown in Figure 6.

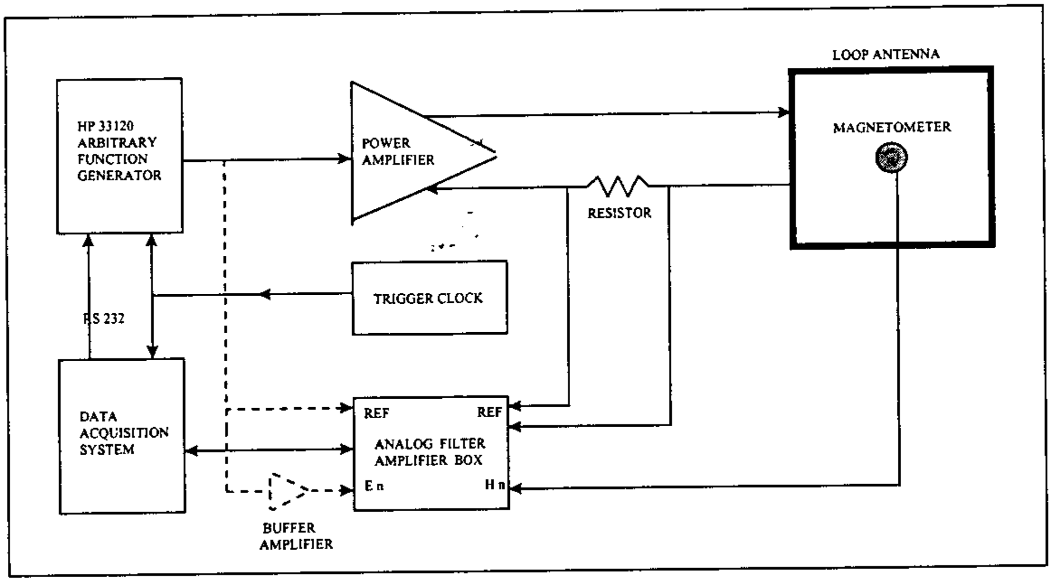


Figure 7: ***System Calibration***

Calibration menu. The calibration menu consists of two parts. One part is for the set up of the calibration parameters and the other is the menu for activating the calibration. When entering the calibration mode the set up menu is displayed. When the set up is ready the calibration can start. The calibration is made component by component and the function of the software is semi-automatic. A module from Metronix will display the calibration result and after confirmation and acceptance the next component is calibrated. If more stacks are required then the calibration can be continued with an additional number of stacks, or it can also be rejected and the calibration is restarted for the actual component. Both bands are calibrated and after the last calibration the operator is requested if he wants to save the calibration data. The data is saved to a file named project_ID + date.

Calibration. During the system calibration, due to the permanent presence of the radio transmitters, the calibration results were biased. In order to overcome this problem, we have implemented in the DSP code a median filter with a certain length to reject the effect of the transmitters. As the result, we decided to have both kinds of the median and non-median filtered calibration values available for evaluation. The median filtered calibration results are stored in a file.

The calibration menu software has been tested with the real calibration set up. When testing some additional features were added such as display of the time series and display of the median and non median filtered calibration data for quality control. The calibration file structure was modified. The present structure is a calibration header of 1024 bytes followed by the three vectors of 1967 real numbers, real part, imaginary part and relative error (percent), for each component and for each band.

3.6.2 Enviro-MT Signal Processing Software Development and Testing

3.6.2.1 RMT Software

The RMT processing code was designed and the principals of how this code works are described below:

Common processing Flow This flow is common for all the measuring loops.

- Reading the Raw Time Series (RTS) from the buffer.
- Gain check (just once for each station to detect overflows).
- Recording the RTS (in case it is confirmed by the operator in the parameter setting).
- Removing the probable spikes, tapering the RTS and doing FFT.
- Case check. There are two cases for SPM calculation. First case is for the whole band until the number of measurements attains a certain threshold.

Temporary Spectral Matrix Calculation (SPM) Flow (First Case)

- Calculation of the SPM elements for the whole band of interest and stacking.
- Using the median filter to pick the active transmitters and locking them.
- Cast the locked spectral components to a new SPM vector called the Main SPM
- Starting the next flow by changing the case to the second.

Main SPM calculation Flow (Second Case)

- Calculation of the SPM elements and stacking the picked spectral values.
- Checking the stack counter to do the transfer function computation.

Transfer functions, resistivity, phase and error calculation Flow

- Subband (half, one octave) definition and tipper components (**A**,**B**) computation.
- Robust checking of the Tipper using the Prediction Error Method.
- Impedance Tensor (**Z**)and Error estimation of the Transfer functions.
- Calculation of resistivity, phase, RHO* and Z* and their errors.

Presentation of Final Flow

- Display of the RHO, Phase, RHO*, Z*,(**A**,**B**), for the final quality control.
- Confirmation of the Data quality and continuation of the measurements.

  There are three options:

  Save option: Acceptable results and the SPM are recorded (Just one version).

  Continue option: If the operator wants to continue without saving, all the specifications of the station are preserved and another measuring procedure will start. The new measurements will be stacked on the previous one and obviously the second flow is not executed.

Cancel option : The results are not acceptable and the measurements are repeated. In this case and the SPM will be over written.

The RMT processing code was tested with synthetic data and implemented on the DSP. The RMT_TEST Software was also tested with synthetic data and implemented on the DSP.

3.6.2.2 CSMT Software

The code was designed and tested with synthetic data, and is now implemented on the DSP. A brief description of procedures in the CSMT processing software follows (points 1 - 5), and is illustrated in Figure 8.

Flow No. 1: All the global parameters are adjusted in this flow. The PC delivers the frequency and the direction of transmission selected by operator.

Flow No. 2 : According to the selected frequency, some parameters related to spectral calculations and band specifications are computed. The A/D card is then set for the special configuration, and the spike removal filter and tapering filter are performed once for each band. The procedure of gain checking is done in this flow and parameters related to split the time series into a certain number of sub-segments are also adjusted in this Flow.

Flow No. 3 : In this part of the software, depending on the adjusted parameters (Sampling, Transmitting and Fundamental frequency, ...), sine and cosine tables are selected to perform a Discrete Fourier Transform (DFT) for the current frequency (F(IM)). Each time-series is checked for spikes, and any spikes identified will then be removed. Then the time series is split into sub-segments and DFT is performed for each sub-segment. When the number of sub-segments reaches a certain threshold, a robust technique is employed to reject the probable outlying values. Finally the processed sub-segments are stacked. These parts continue until the number of stacking reaches a certain threshold known as the Stacking Level.

Flow No. 4 : In this flow the final stacking is completed and NST No. of stacked spectra are stacked to obtain the expected value of each field component (Hx,Hy,Hz,Ex,Ey). These values are calibrated and their standard deviations for further error estimations are calculated.

Then scalar transfer functions (Z_{xy},Z_{yx}) are estimated and using scalar values ρ_{xy} , ρ_{yx} ,φ_{xy} and φ_{yx} are computed. If a second direction is being transmitted Tensor Transfer Functions are also estimated as well as their error and ρ_{xy} , ρ_{yx} ,φ_{xy} and φ_{yx} . In the next step ρ^* and Z^* for each direction are estimated. Finally all the results are delivered to the PC to be displayed.

Flow No. 5 : This is the final part of the software. After the operator decides about the quality of the results, a flag is delivered (repeat flag) by the PC which shows the decision of the operator. If the operator intends to repeat some frequencies the procedure starts from Flow No. 1 and the frequency (-ies) are repeated according the direction and the band.

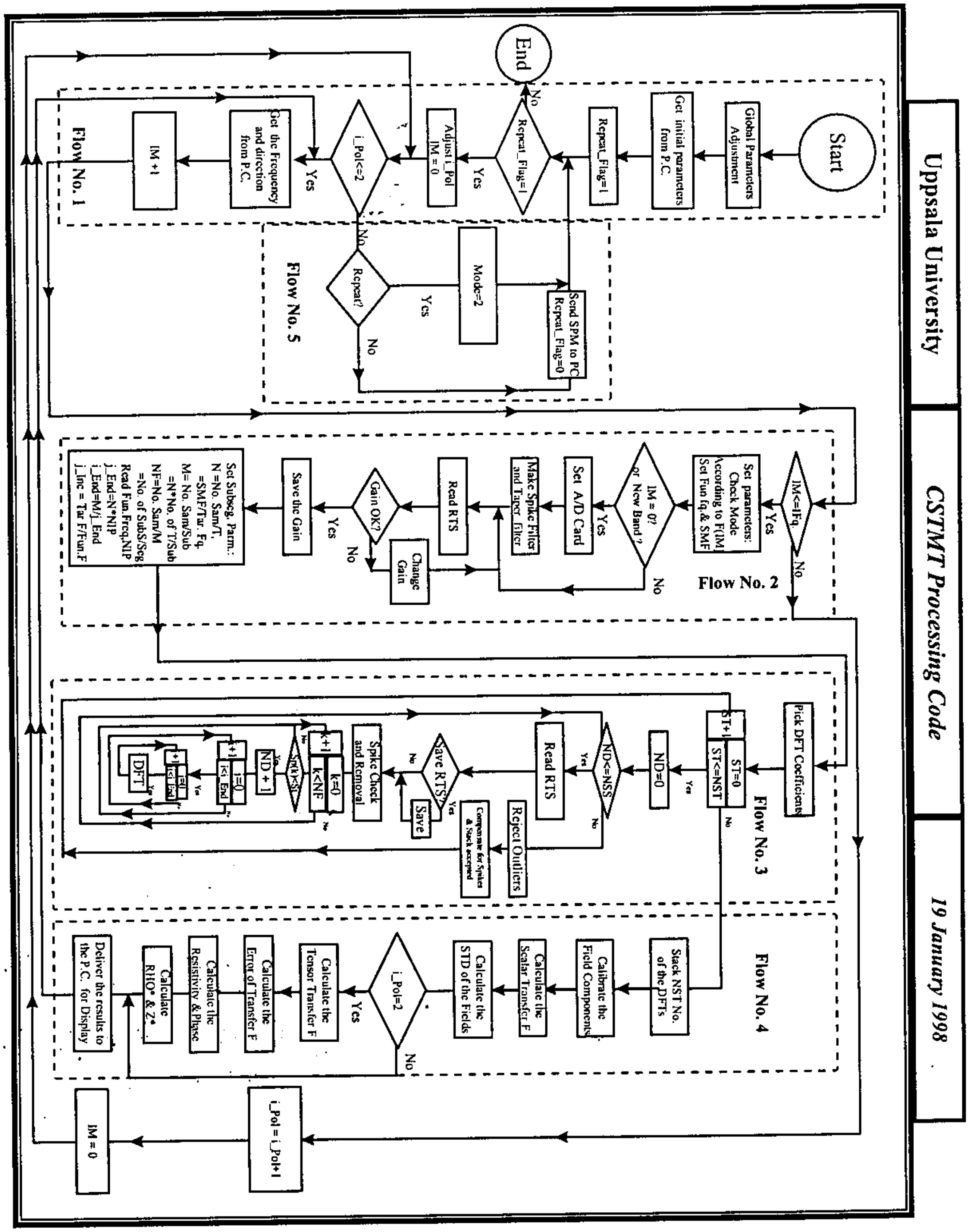


Figure 8: ***CSMT processing code***

3.6.2.3 Implementation of the RMT and **CSMT** algorithm on the DSP.

The RMT and CSMT program were implemented on the DSP. This also involves the interface between the PC and the DSP with exchange of parameters and data / result.

DSP-PC data exchange. Functions for exchange of data and results between the DSP and PC and vice versa were implemented in the RMT and **CSMT** software

3.7 Laboratory and Field Testing of the Complete System at Sites local to MTX and UU production centres (Tasks 2.7 and 2.8)

3.7.1 Testing of transmitter

During the initial tests in Sweden (August and October 1998), the loop antenna configuration together with the switching of antenna direction and capacitor switching worked well without any problem. However the test showed that there is need for additional tuning of the resonant frequency at some of the frequencies to achieve maximum current flow in the loop antenna. MTX undertook the necessary modifications.

The transmitter was tested together with the receiver during a field test held in Sweden during August 1998. The tests indicated that the amplifier manufactured by *Rockford Fosgate* that was installed in the transmitter did not meet the specifications for the minimum permitted impedance. The result was that the power supply, or more precisely the last stage of the amplifier, failed when the transmitter was used under full load conditions. Once the amplifier was replaced by a second one and the current was reduced to only 50% only, the transmitter worked satisfactorily.

However, as the second field test in the Netherlands showed, it is necessary to use as much transmitter current as possible in order to obtain a reasonable data quality. It was therefore decided to replace the amplifier with another type.

The tuning of the resonance frequencies was also improved in order to get a maximum current into the antenna loop.

The antenna of the transmitter radio modem was exchanged with a larger one that is mounted on the middle pole of the loop antenna 3 meters above the ground. The receiver antenna was replaced by a longer half wave antenna. With these modifications a distance of 1 km between receiver and transmitter could be achieved without a break in communication.

3.7.2 Testing of the receiver

The analogue filter box with sensors were constructed at MTX and delivered to UU by the middle of August 1998. Laboratory tests demonstrated that the noise level of the switched capacitor filters in the analogue filter box was not acceptable, the buffer amplifiers of the electric channels were not stable (ringing effects) and the power supply for the analogue electronics had some problems with regulation.

Additionally the power supply voltage to the analogue filter box had to be increased from + / - 6 V to + / - 12 V due to input level dependency of the transfer functions.

These problems were attended to by MTX.

A temperature problem was discovered on the A/D converter card. A clock signal was affected by the temperature and thus not stable. This caused a distortion on the digitised signal. The effect was removed by adding a small capacitor at the corresponding electronics. After the modification a test was made with high positive - and negative temperature gradients from normal room temperature. The test did not show any abnormal operation of the A/D converter card.

The RMT method was tested and some minor errors in the processing and calibration data delivery section were corrected. Some real test measurements along profiles were carried out in early October 1998 at one site in the Stockholm and one site in Uppsala. Electrical DC-sounding data was available from both sites from previous measurements. The measurements showed good correlation with the DC measurements. However it was evident that the measurements were affected by the receiver system noise with sensor - receiver distance dependency (see below – system noise).

The transmitter electronics and antenna system for the CSMT method was tested together with Metronix in Uppsala at the beginning of October. The power amplifier in the transmitter system failed and thus a complete test of the CSMT method could not be performed. However the following components of the system were tested:

- Radio - modem communication between the receiver - transmitter.
- Transmitting loop antenna configuration part.
- Phase stability of the GPS clocks.

The outdoor test demonstrated that the communication with the radio modems was limited to a few hundred meters due to the small size of the radio modem antennas. In the subsequent test the antennas were replaced at the transmitter radio modem by a dipole antenna mounted on one of the loop antenna sticks 3 meters above the ground, and a longer half wave antenna on the receiver radio modem. This test demonstrated that the communications worked perfectly with a transmitter - receiver separation of more than 1000 meters, which is sufficient for the ENVMT applications.

The loop antenna configuration with the switching of antenna direction and capacitor switching worked well without any problem. However the test showed that there is need for additional tuning of the resonant frequency at some of the frequencies to achieve maximum current flow in the loop antenna (see Section 3.7.1).

The phase stability was tested in the laboratory with the receiver- and transmitter GPS clock locked. Acquisition of different transmitted frequencies was made from the phase-locked Hewlett Packard generator with the GPS clock, which is used as the signal source in the transmitter system. The test showed that the phase stability was excellent even for the highest frequency with a stacking level of 300 stacks.

Calibration. The external hardware electronics (AF-filter box and sensors) connected to the receiver electronics was calibrated with the Ey channel connected through the buffer as the reference input. The calibration signal was delivered by the Hewlett Packard generator that is used for the transmitter system, working in a triggered sweep mode where the triggering is taken out from the receiver.

The electric sensors were calibrated by feeding the calibration signal directly to the input of the buffer amplifiers.

The magnetic sensors were calibrated with a 1 square meter loop antenna where the input reference (Ey) is taken across a serial resistance for the absolute field calculation.

System noise. The RMT test showed that the result was dependent on the sensor - receiver distance. The data was a lot smoother when the separation was maximised (approx. 10 m). The noise comes from the internal switching of the three different DC / DC converters in the receiver, all with different switching frequencies.

Screening is the best way of handling these kind of problems. As the first precaution the internal chassis was covered with .0.7 mm thick iron plates. This reduced the noise considerably. As a check, during December 1998, the system noise level was mapped by measuring with the magnetic sensor and the receiver in a screened room. In this environment only the noise peaks are visible in the frequency spectrum.

As expected almost all of the noise peaks of the fundamental switching frequencies and their harmonics was on an acceptable low level above the noise floor except for a noise peak at 46 kHz where the noise level could be significant for places where the noise floor is low.

At the test site at Collendoorn in the Netherlands the noise floor was considerably lower, and this noise peak was identified as a radio transmitter. Fortunately this did not harm the result of the measurement but it shows that this particular noise level has to be further reduced.

Subsequently the DC /DC converters were screened individually with My- metal plates, which provide excellent screening effects of lower frequencies. After the modification a new noise mapping of the system was made. The modifications attenuated the noise levels to an acceptable level.

3.7.3 Tests of ENVIRO-MT digital processing software in Sweden.

Some preliminary tests were carried out in Uppsala in order to test the RMT software. The results demonstrated some strong variations that were caused by the instrument. These effects were reduced dramatically when the magnetic sensors were placed far enough from the instrument.

The results of field tests in Sweden showed a good correlation between the DC and RMT measurements (resistivity range and depth estimation).

The first real test measurements with the system started early in the October 1998 at Hällby, which is an area close to Uppsala. At the first step, in order to have an overview and estimation of the resistivity of the ground, a set of DC measurements was carried out. Then a profile of 10 stations by a separation of 10 meters was measured using the ENVIRO-MT system. The results showed a good correlation between the DC and RMT measurements (resistivity range and depth estimation).

The second test site was in an area located in the Stockholm National Park were a set of DC measurements were done by the Geological Survey of Sweden (SGU) along two perpendicular profiles. The results showed that the value of the estimated resistivity is in the same range for both methods. There was also a resistive anomaly at the middle of one profile that was resolved with both methods.

3.8 Critical Decision Points and Deliverables, Work Package 2

The final specifications and ordering of materials were approved at the Kick-Off Meeting. The prototype equipment of the ENVIRO-MT system was accepted by all the partners at the Project Meeting #2 in June 1998. This was 6 months behind the original schedule (Project Month 12), and was due to delays described above related to design improvements and modifications during Work Package 2. None the less, the Partners considered that the Project, in particular Work Package 4, should proceed as planned, with the schedule for the field tests modified accordingly.

All the Deliverables have been submitted as listed in Table 3.

The menu-oriented receiver software is the principal interface for the end-user with the system. It is therefore an important component of the System Manual for the end-user operator (Deliverable D25).

4. EVALUATION OF SELECTED GEOPHYSICAL INTERPRETATION SOFTWARE PACKAGES, AND ADAPTING TO ENVIRO-MT (WORK PACKAGE 3)

At the Project Meeting #1 it was decided that, in view of the very large data sets that will be acquired during a typical ENVIRO-MT survey, the user-friendly software for the ENVIRO-MT system should contain a well designed database and data management system. UU agreed to develop and design a new software module in order to ensure that the data obtained from the field measurements would be stored in a structured database that can be directly linked to the data visualisation software and other interpretation packages.

In the event the design of the database and data management system was considerably more time-consuming than had been originally planned. However, the Partners consider that it is an essential part of the Project and the impressive results demonstrate that the work was well worth while.

4.1 Evaluation and selection of geophysical interpretation software package (Tasks 3.1 and 3.2)

The evaluation of selected geophysical presentation and interpretation packages was initially carried out by JBA and UU. Following a discussion at the Progress Meeting #1 it was agreed to assess the commercially available SURFER, NOESYS, and GEOSOFT packages for data visualisation.

A Report „Preliminary Evaluation of Software" (on file, Appendix III – Progress Report No.2) was presented to the partners by JBA for review and discussion in June 1997. In this report, the ENVIRO-MT system is compared with possible competitors. The important parameters for the geophysical interpretation software package that will be required and expected by the end-user are defined. These include:

- data handling on a desk-top PC
- capability for mapping resistivity distribution (colour-filled contour plan) over the small site of 1 – 20 Ha
- capability for making depth estimates and
- identification of cultural and instrumental effects

UU provided a number of dummy 'data' files to JBA for use in the assessment of potentially useful software packages. JBA also included data from an earlier controlled source electromagnetic survey in southern Spain. In the report, the results of using these data to produce the required output are assessed for the SURFER (*Golden Software*), OASIS Montaj – also now known as NOESYS, EMIX-MT and EMIX-MT2D (*Interpex*) and *GeoTools* packages. It was concluded that the NOESYS package was the most flexible and could provide the outputs required for the end-user.

The NOESYS package was finally selected as the most suitable data visualisation and presentation software for the ENVIRO MT system. Following final approval, negotiations with the software producer (*Fortner Software*) regarding licensing agreements and pricing were initiated with respect to the cost of incorporating the software into the ENVIRO-MT system. The correspondence is on file, including the pricing – USD 495.00 for the Visualisation Pro Software and USD 395.00 for the Transform package only.

4.2 Design of the data management software

A radical new concept for the management of the data acquired by the ENVIRO-MT system has been implemented by using database technology in the software. The use of a database structure simplifies the data management for post-processing as well as the evaluation of the data. A new database is created for every new project and contains the results as tables, spectral matrix and time series.

A detailed description of the database management in ENVIRO-MT system is attached as Appendix 3 to Progress Report #3. Figure 9 is the title page of the power-point presentation (only for the digital copy of this Report, otherwise see Appendix IV).

The database is accessed from a database manager with a user-friendly interface that is a free-running software on the instrument or another PC platform. The main concept for the database manager is the ability to select individual (station) or a group (line) of data and have direct access to plot- and data processing software. The following features were implemented:

- selection of project, type of data, line- or station data (results, spectral matrix, time series)
- display of Rhoa, Phase, Rhoa*Z*, tipperA, tipperB with Noesys software for an individual station
- display as above for a line or group of stations (cross section) with Noesys software
- inversion of a line or a group of stations and display as cross section
- display of time series with Quicklook software module from MTX
- presenting of results in a table (quick table) and possibility to print out the table or store to a separate file
- creation of EDI files for selected data with Metronix module for further processing with software such as *GeoTools*

All results are stored on specific tables in a database that is identifiable for the project. As the development of the database system was carried out it was decided that as much information as possible should be stored into the database. Therefore the database now also contains project information, system set up, system log, comments, calibration data, radio transmitter information. All this information can easily be accessed from the ENVIRO-MT database selector. All the specific database calls have been implemented in the ENVIRO-MT application by an addition of a database unit.

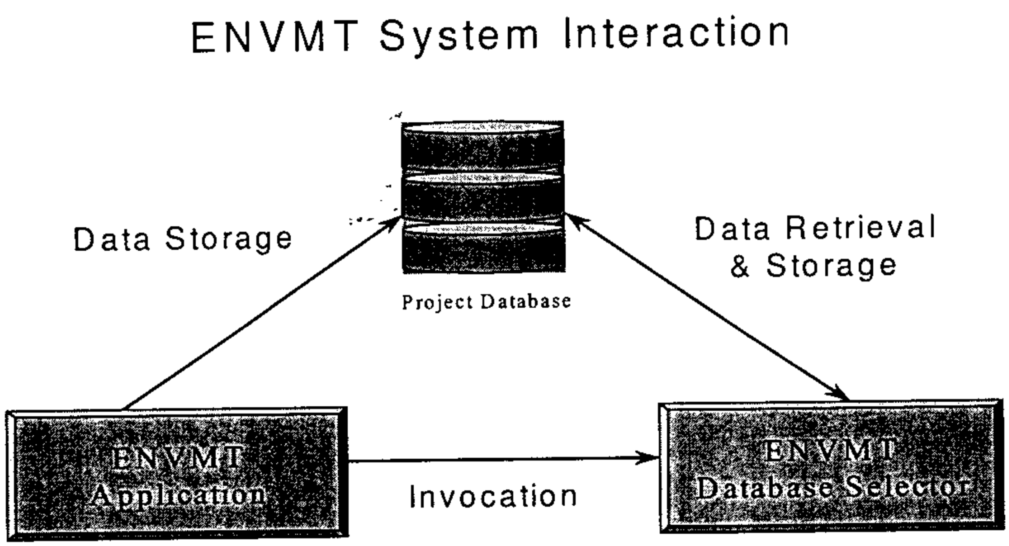


Figure 9: ***ENVIRO-MT database – Power Point Presentation (see Appendix IV)***

4.2.1 Testing and completion of the database software facility with real data.

The database facility was tested with real data in October - November 1998 while acquiring data at the test sites in Sweden and in The Netherlands. Some debugging and additional code was required for the external inversion software as well as the plot and transform software. Furthermore the macros for the plot- and transform software required some tuning to ensure a proper output of the results.

The overall impression of the database facility is excellent. The experienced geophysicist will have a very powerful tool to interpret the data and, because of the organisation of the software and database, very fast access to all the data and information within a specific project.

4.2.2 Additional developments

The overall bandwidth of the system is from 1 kHz to 250 kHz, however because the measurements are normally carried out with the CSMT method from 1 kHz up to 50 kHz and with the RMT method from 10 kHz up to 250 kHz, it would be preferable to integrate data obtained from both methods. An additional function in the database user-interface has therefore been implemented in order to be able to select and mix data from both methods. This new facility provides a complete output of the plot / transform software/data with or without inversion for the whole frequency range of the measurements.

The tensor estimates using the current RMT software are not stable in the band between 20 - and 50 kHz, but due to the overlap the CSMT data could replace these poor estimates. The start- and stop- frequencies will be defined for both methods before the data is extracted from the database. Figure 10 is an example of the combined results from the RMT and CSMT methods from line 1 at Collendoorn, The Netherlands.

It was planned from the beginning that the database management software should be able to produce output files for data exchange with other computer platforms. The EDI (Electrical Data Interchange) file format was chosen as it is a standard for the interchange of MT, EMAP or similar geophysical data. The intention is that the output data is extracted from a group or a line and then formatted into an EDI file. It will be possible to input SPM data as well as parameter data. In the EDI format mode the data is selected from a selection window as in the other modes. However, because some of the parameters do not exist in the tables they have to be calculated from the SPM data that is stored in a dedicated table in the database. The data is stored in ASCII column data files and then external EDI file format application software (originally written in Fortran) is invoked and the EDI file will be created. The column data file can also be used as it is as an input file for EXCEL or other column data oriented software.

The EDI format function was implemented in the database management software. The type of data that can be selected and formatted is as follows,

- Impedances
- Rhoa / Phase
- Tippers

The program needs real geographical co-ordinates (latitude, longitude) for each station. When the EDI format function is activated the geographical co-ordinates are calculated from the UTM co-ordinates automatically in a stand-alone Fortran routine. The geographical co-ordinates are stored in the database and also put in one of the input files for the EDI conversion routine.

The EDI files has also been tested by reading them into the Geo Tools software package.

Truncated Singular Value Decomposition processing (TSVD) was implemented in the database management software. For this function additional tensor tables are created in the database. Pressing a radio button named TSVD in the action panel accesses the function. Note only tensor data is valid for this processing. Data from both methods separately or combined can be processed. Input parameters for the processing are selected in a separate panel and the corresponding spectral matrixes are put into separate files, one per station. If the RMT method is selected the signal to noise ratios for all the stations and frequencies are put into a separate file. If processed data already exists the operator is warned and confirms if the data should be overwritten or not. When TSVD data exists the data type panel is updated with a select button for TSVD tensor data. In the combined data set up tab, the data can be combined from original data with a frequency list from each method, or from combined TSVD data with only one frequency list. The TSVD data can be displayed, inverted or EDI formatted as the original data

The new inversion Least Singular Value Inversion (LSVI) algorithm was implemented in the database management software. The input / output file structure is identical to the previous least layer inversion (LLI) algorithm. This made the modification simple and only an additional panel with two radio buttons for selection of inversion method was added.

4.3 Critical Decision Points and Deliverables, Work Package 3

The geophysical software packages that should be reviewed were selected and discussed by all the partners at the Project Meeting #1 in September 1997.

At the same meeting it was decided to proceed with the development of the ENVIRO-MT database software. A prototype of this software was presented to all the partners at the Project Meetings #2 and #3 in June and November 1998, and the full version was demonstrated at the Project Meeting #4 in April 1999.

All the Deliverables have been submitted as listed in Table 3.

The database software is a vital element of the user interface, and therefore is an important component of the System Manual (Deliverable 34b).

5. FIELD TESTING OF ENVIRO-MT AT END-USER DEMONSTRATION SITES; AND END-USER TRAINING (WORK PACKAGE 4)

The field tests planned in Work Package 4 were an important part of the Project, not only to test the ENVIRO-MT prototypes at relevant sites with appropriate environmental, geotechnical and hydrogeological problems, but also to obtain comments from experienced end-users regarding possible modifications and improvements to the system. The field tests were used as an ideal opportunity for providing training to potential end-users (tasks 4.2.4 and 4.3.4), and the onsite feed-back was important to all partners.

The field tests were planned and managed by the end-user partners in the Project (TNO, ITGE and JBA). The technology providers (UU and MTX) were present on site during the tests to provide the end-users with the necessary technical assistance and guidance, as well as to identify weaknesses in the hardware and bugs in the software that could be improved during the Project.

The field testing programme was delayed due to the additional modifications and improvements to the ENVIRO-MT prototypes that were being designed and assembled in Work Package 2 (see section 3). However, thanks to the diligence of the end-user partners, it proved possible to complete the full test programme before the end of the Project and within the shorter time that was available for Work Package 4.

5.1 Selection of Test Sites

Two possible field test sites in the Netherlands were presented by Sjef Meekes, TNO, and discussed by all partners at the Project Meeting #1 in September 1997. A site relating to water contamination near a waste disposal site at Collendoorn had been tested by other techniques, and was considered to be suitable as the first ENVIRO-MT test site. Possibilities for applications and testing ENVIRO-MT near dykes were also discussed.

Three possible field test sites addressing hydrogeological problems in Spain were presented and discussed by ITGE at the Project Meeting #1 in September 1997. The results of other geophysical studies at the proposed site at Almuñecar near Malaga, Spain, were presented in detail by Dr. Juan Plata (ITGE) and discussed by all partners at the Project Meeting #2 in June 1998. It was considered that the Almuñecar site fulfilled all the criteria for a useful test site.

5.2 Field Tests at Collendoorn and Montferland, The Netherlands (Tasks 4.1.1, 4.2.1 and 4.2.3)

The first official field test site for the ENVIRO-MT, was in Collendoorn, a small town in NE Holland. Former research had been undertaken on this test site by TNO in 1995. The objective was to determine a percolation plume of polluted water expanding at the east of a former waste disposal site with the help of CSMT and RMT measurements. The percolation water is contaminated by the chloride and iron ions, which should make the pollution plume very conductive. Furthermore the RMT and CSMT results were to be integrated with the results from other measurements using NanoTEM and PEC (Permanent Electrode Cables).

A detailed report about the test site was compiled by TNO by analysing earlier work and other relevant information (on file – Deliverable 41). The report contains information about the geohydrology of the area, the geophysical (resistivity) structure of the area and a proposal for the location of the measurements (survey grid).

Furthermore, all logistical aspects, such as contacting the organisation managing the waste disposal, contacting the landowners for permitting and organisation of lodging for the full field crew were carried out by TNO (on file – Deliverable D42).

The fieldwork took place from 7-15 November 1998.

The original plan was to measure three profiles in E-W direction at the eastern side of the former waste disposal, for testing by both the CSMT and the RMT method. The RMT method was completed fairly easily within two days, and a 4th N-S oriented profile was also measured.

Due to problems with the controlled source for the deeper penetration, another test-site for more RMT measurements was selected at Montferland near Zeddam, located 100 km south of Collendoorn. This site was considered to be ideally suited to test the ability of the ENVIRO-MT system to locate small lateral variations caused by sub-vertical clay beds.

The 4 ENVIRO-MT profiles were surveyed at Collendoorn by JBA along exactly the same profiles covered by TNO with an EM34 survey (Loop-Loop measurements and the details can be found in TNO report). Table 10 presents the specification of the ENVIRO-MT test profiles at Collendoorn.

Access to the test sites is good, and normal road vehicles were rented to transport personnel and the equipment in the field. The field measurements were undertaken with the assistance of personnel from TNO, JBA and UU.

Profile No.	Length(m)	No. of Stations	Profile Direction
1	410	42	E-W
2	350	36	E-W
3	200	21	E-W
4	350	36	S-N

__Table 10:__ Profiles measured at Collendoorn, The Netherlands

RMT measurements were undertaken at an average of 3 minutes per measurement, and the CSMT at about 7 minutes per measurement.

After the field work some additional information was provided to Uppsala University (UU) about both sites in The Netherlands relevant to processing the ENVIRO-MT data. The RMT and CSMT data was processed using the newly developed Truncated Singular Value Decomposition (TSVD) technique, and subsequently inverted using the Least Squares Value Inversion, both of which were developed and refined at Uppsala University.

5.2.1 Results from Collendoorn

TNO proposed 4 profiles at Collendoorn, 3 E-W and 1 N-S direction. There are also 3 observation wells in the area and the log information belongs to the year 1994, when TNO had carried out the measurements. According to the log files the conductive layer starts at a depth about 20 meters and ends at 35 meters in wells WP5, WP6. These wells are situated along the profiles 1 and 2. According to TNO's report this layer is very conductive and the resistivity ranges between 2-20 Ω.m . The report also shows that the overburden layer is composed of two zones - a thin resistive zone with a resistivity between 100 to 200 Ω.m and a more conductive zone with a resistivity ranging from 40 to 100 Ω.m.

Results of inversions for all three lines are shown on Figures 10, 11 and 12. The results are displayed in two perpendicular directions of measurement, for every line.

The most important results are:

- The resistivity increases from the west to the east along the profiles 1,2 and 3, which compares favourably with the results from the earlier measurements done in 1995
- Along the profile 3 resistivity is higher than the other profiles.
- Combined results of CSMT and RMT measurements of line 1 show that there is a resistive overburden varying between 40-200 Ωm. At the western part of the profile a very conductive layer (pollution plume) with a resistivity less than 10 Ωm is resolved. This layer gets thinner from the west to the east. The bottom of this very conductive layer could not be resolved even with the lowest frequency (1 kHz), the reason is the high conductivity of the layer. The top of this layer is located at an average depth of 22 meters along the profile.

RMT and CSMT Interpretation

Line 1: The results are shown on Figure 10. The top of the pollution plume is at a depth of 20-23 m and can be seen in great detail. The plume has expanded up to station 131. A shallow clay bed can be seen at approximately 8 m beneath the surface.

Line 2: The results are shown on Figure 11. The top of the pollution plume is at a depth of 20-22 meters, with a slight trough between station 212 and 215. A shallow clay bed can be seen at approximately 8 m beneath the surface.

Line 3: The results are shown on Figure 12. According to the results of the measurements in the YX direction the plume has expanded eastwards up to station 310.
The shallow clay at a depth of 8 m, can be interpreted as the Eem Formation.

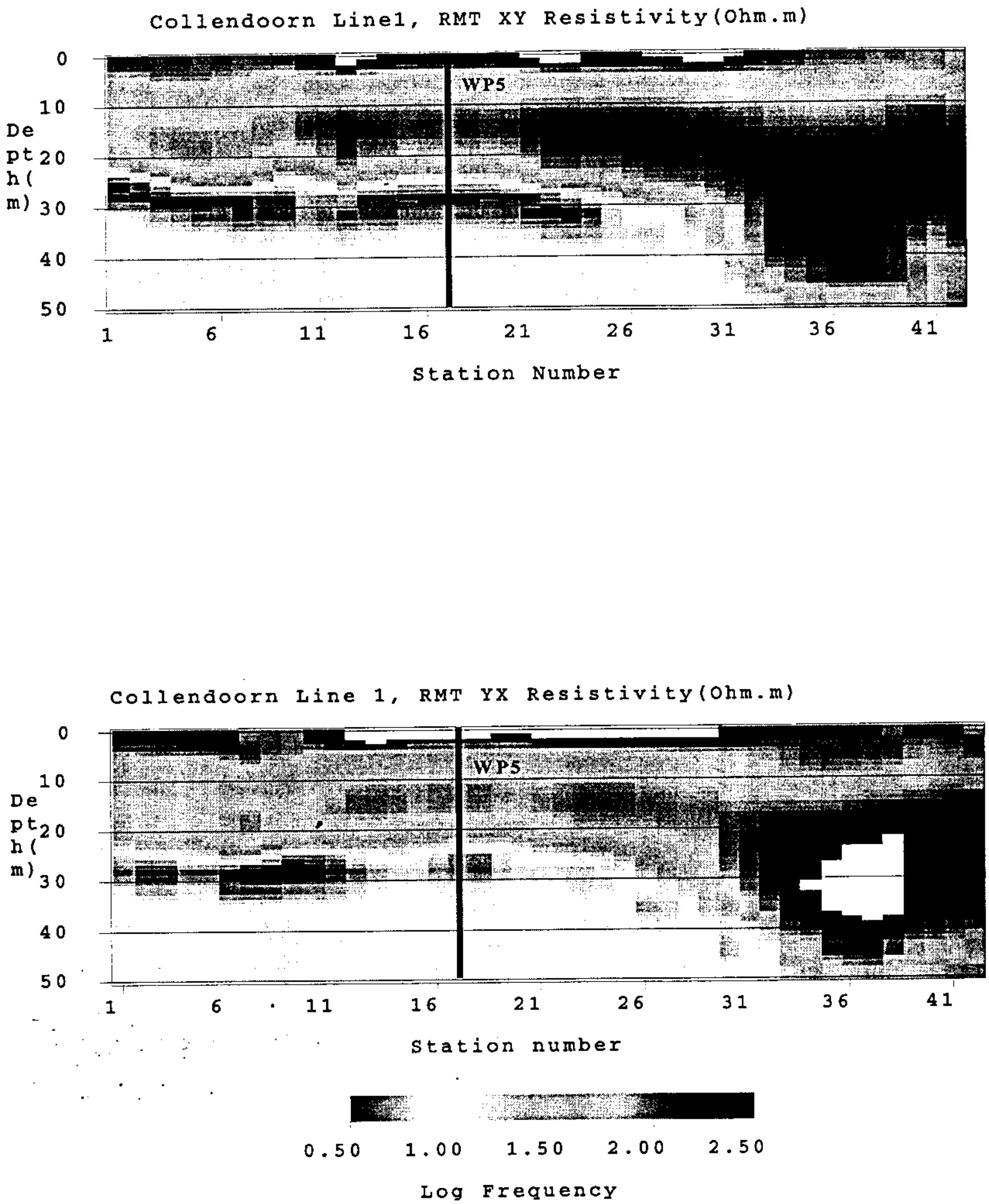
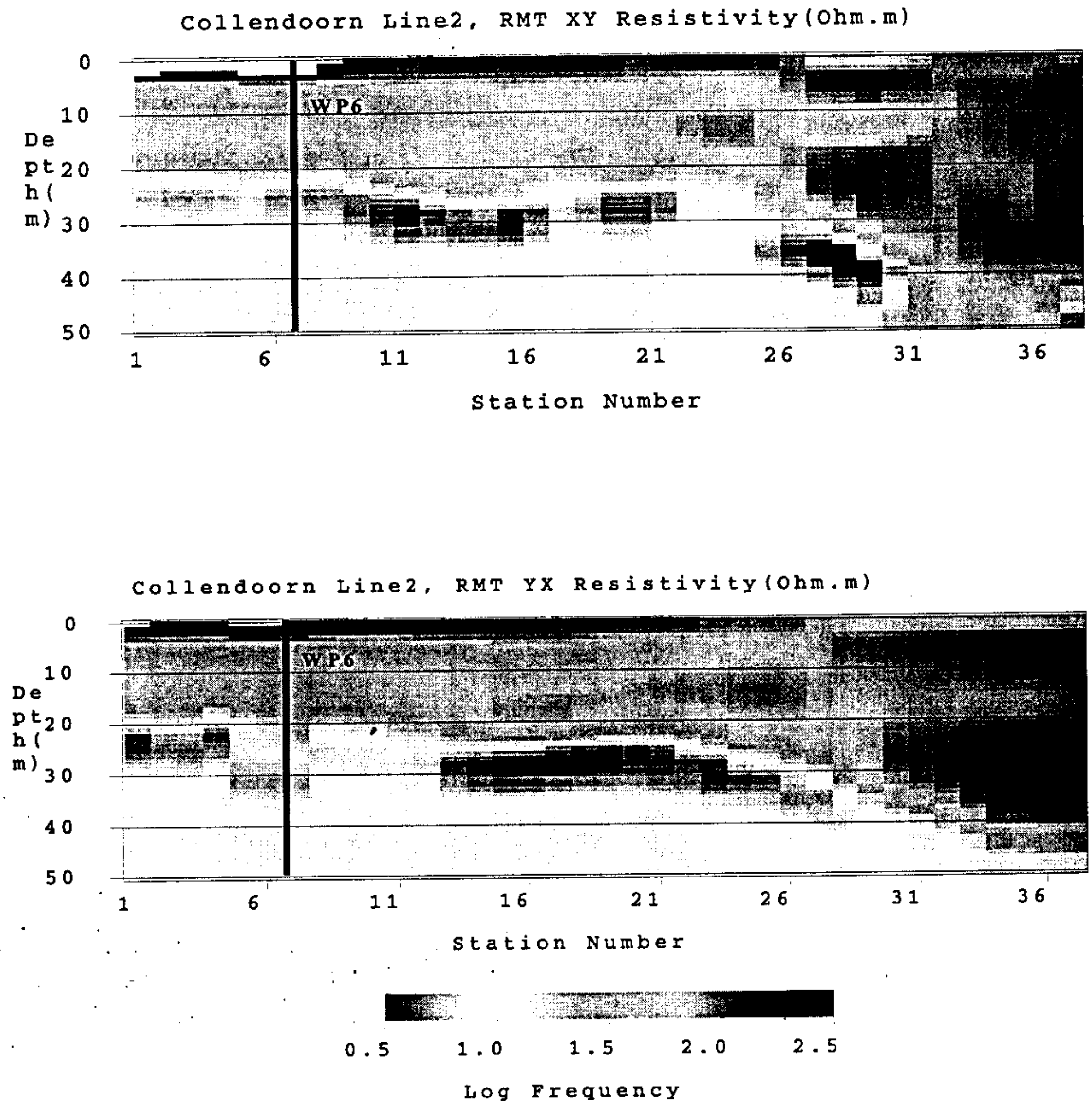


Figure 10 *Results from the combined RMT and CSMT measurements of line 1 in Collendoorn. Processing is done using a Truncated Singular Value Decomposition (TSVD). Data are inverted with a Least Squares Values Inversion, developed by L.Pedersen (Uppsala).*



<u>*Figure 11*</u> *Results of inversion of the RMT data of line 2 in Collendoorn. Processing is done using a Truncated Singular Value Decomposition (TSVD). Data are inverted with a Least Squares Values Inversion, developed by L.Pedersen (Uppsala).*

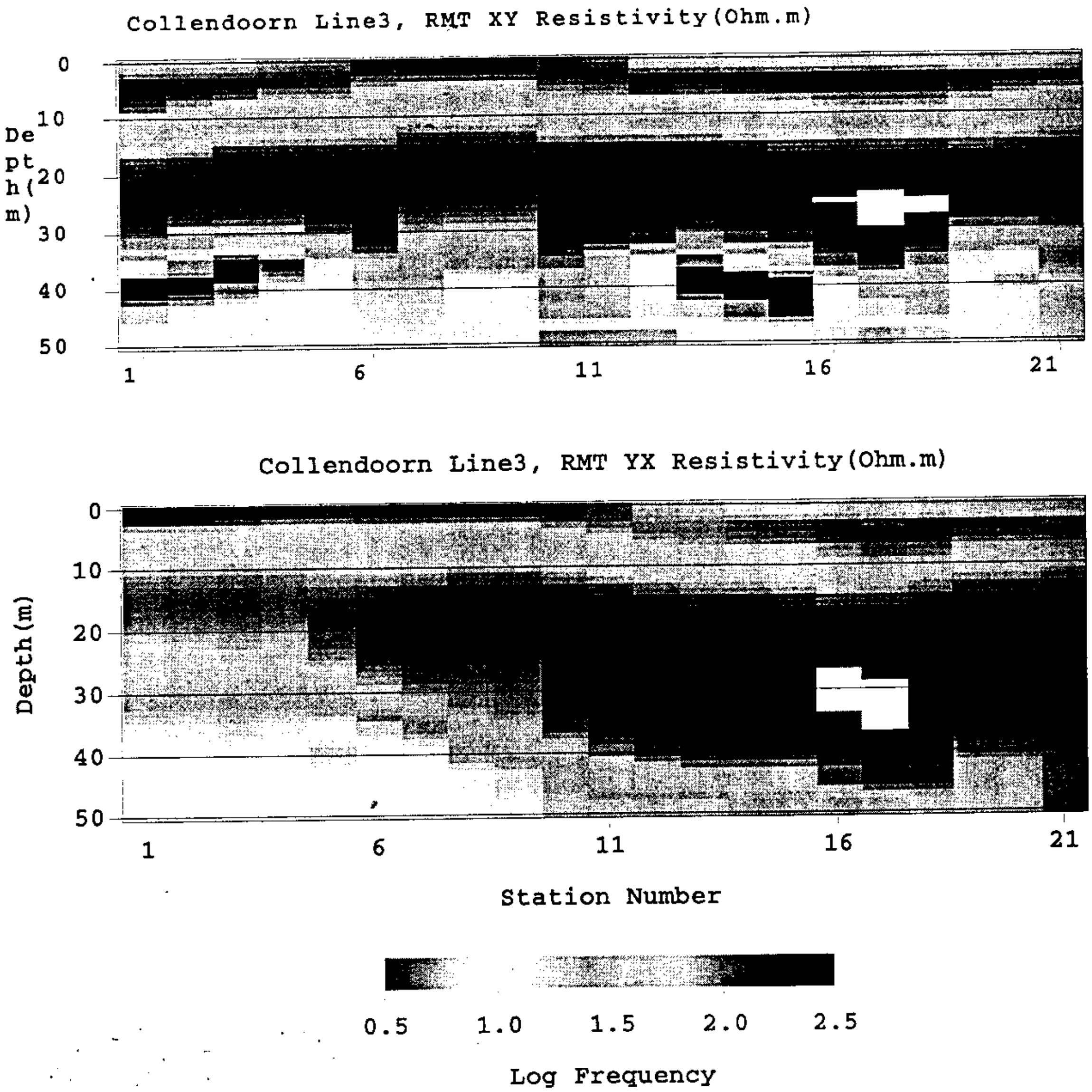


Figure 12 *Results of inversion of the RMT data of line 3 in Collendoorn. Processing is done using a Truncated Singular Value Decomposition (TSVD). Data are inverted with a Least Squares Values Inversion, developed by L.Pedersen (Uppsala).*

Comparison of RMT and CSMT with other techniques

The RMT and CSMT measurements are the most reliable of the mapping measurements up to 40 m beneath the surface. This can be concluded after comparison with the permanent electrode cables. For deeper targets, the NanoTEM measurements are used.

The measurements of the PEC give the exact resistivities. However, these resistivities are only from one location. When a thin conductive is just in between two electrodes, this layer can not be seen by the PEC.

The EnviroMT data as well as the NanoTEM data provide a continuous resistivity display. Assuming the PEC data are correct, the quality of these continuous data can be checked at the locations of the observation wells. A comparison of the data (see Deliverable D44) demonstrates that the EnviroMT system detected a conductive layer, clay, at 6-8 m at observation well 5, in both Line 1 and Line 2. In Line 1, this conductivity is not found in the PEC and hardly found in the NanoTEM data. In line 2, this layer is not found by the NanoTEM measurements, the PEC do not indicate the conductive layer clear. The NanoTEM data do not locate the shallow clay, is caused by the mentioned unknown effect.

The quality and the resolution of the data from EnviroMT is better than NanoTEM. However, the exploration depth is not very deep when using only RMT (in this case about 30-35m). When comparing the data with the measurements of the Permanent Electrode cables, a high degree of comparability can be concluded.

Conclusions for the Collendoorn Test Site in The Netherlands

From the results of all measurements done in Collendoorn it can be concluded that the pollution plume in the subsurface has been mapped with three methods, which give similar results. The plume has expanded eastwards in time, compared to the results of the researches done in 1994-1995.

The pollution can be divided in two depth intervals:

1. 20-38m, at which the horizontal expansion rate has been 40-50 m a year between 1994 and 1999
2. 38-60m, where the pollution has only arrived after 1994 by penetrating (inhomogeneous) claybeds at 35-38m

From the permanent electrode cables, we have reliable measurements of the subsurface at the exact locations near the observation wells 5, 6 and 8 from 1995-1999. At greater depths, lower resistivities are found in comparison to 1995, which means that the pollution has increased.

The NanoTEM data are of reasonable quality up to 60 m depth. Due to a still unknown effect the first measuring windows (depth interval 0-10 m) are of poor quality.

The EnviroMT data are of very good quality in the shallow subsurface (0-40 m). The latest inversion method gives very good results, the shallowest claybeds and the pollution plume can both be seen. The EnviroMT results are most consistent with the data of the Permanent Electrode Cables.

5.2.2 Results from Montferland

The main purpose of this test measurement was to find a steeply dipping clay layer in sands. According to TNO this impermeable layer that is more conductive than the surrounding, divides the water table into two parts such that the water level is different in both sides of this layer.

At this site, because of the higher resistivity and the shallower target depth, only the RMT method was applied. The results of a very preliminary 1-D inversion of the RMT data along the profile number 2, with 16 stations and a total length of 150 meters in Montferland demonstrate that:

- there are two distinct layers resolved along this profile.
- the first layer which is probably sandy is resistive with a resistivity ranging from 700 Ω.m to a few thousands Ω.m.
- the second layer that is probably the water saturated sandy layer, is more conductive and has a resistivity less than 200 Ω.m. This shows a very sharp contrast that might suggest the effect of the water on the apparent resistivity. The depth of this layer varies between 15 to 30 meters.
- the most important feature along this profile is the sudden change of the resistivity at the station number 7. At this station the resistivity of the second layer drops to the 30 Ω.m which can represent a very steeply dipping layer.
- another interesting point is the different depth of the second layer at the sides of this station. This means that, as a rough guess, if we suppose that the start of the second layer is the water table level, we can see that there is a sharp and sudden change of the water level at the both sides of the station number 7. This can be assumed as the location of the thin clay layer.

More information from this site is required in order to do further detailed interpretation.

5.3 Field Tests at Almuñecar, Spain (Tasks 4.1.1, 4.3.1 and 4.3.2)

ITGE delivered a comprehensive Pre-demonstration Data Package for the Almuñecar field test site (Task 4.1.1) that was the basis for the selection of the survey profiles (Deliverable D41 on file, "Predemonstration Data Package for the Field Test Site Almuñecar (Granada, Spain) 1999").

As part of Task 4.3.1, an initial visit to the site was made by ITGE and JBA in March 1999 in order to clarify the situation regarding access to the sites (the land is privately owned and used for fruit plantations).

At Almuñecar the environmental problem is caused by intrusion of saline sea water into the fresh water aquifer that supplies the village with water for agricultural and domestic use. The objective of these tests was to:

- determine the morphology of the aquifer under the proposed area
- detect the sea water intrusion zone

- evaluate the practical application of ENVIRO-MT system and methodology
- demonstrate ENVIRO-MT to end-users

The measurements were made during the period 10 – 24 April 1999.

The geology at Almuñecar consists of Quaternary alluvial deposits (interlayered silts, clays, coarse sands and gravels, medium sands and silty fine sands) that fill a valley and overlie resistive Palaeozoic basement. The alluvial lithologies vary due to the presence of palaeochannels that are characterised by the highest hydraulic permeability.

Three profiles were measured (Table 11: maps and survey points are on file in Metronix office): P1 was longitudinal to the valley and P5 and P77 were transverse and intersecting P1 (Figure 13). The profiles measured are close to drill holes where the geology is known as well as close to resistivity surveys previously undertaken by ITGE. Both CSMT and RMT measurements at 129 sites were made, with a total of about 160 readings including repeated control measurements. Readings were also taken using different transmitter antenna locations (transmitter position dependence test) and different measurement spacing along the profiles (horizontal resolution test).

Profile Name	Length (m)	Station Interval m	No. of Stations	Measure -ment interval	No of measure-ments	TX location	Approx. Profile Direction	Measuring method
1	1050	15	72	30	36	Tx4, Tx5	S→N	RMT & CSMT
5	550	10	57	10	56		E→W	RMT
51				20	28	Tx1	E→W	CSMT
52				50	11	Tx2	W→E	RMT & CSMT
77	500	10	52	20	26	Tx3, Tx4	E→W	RMT & CSMT

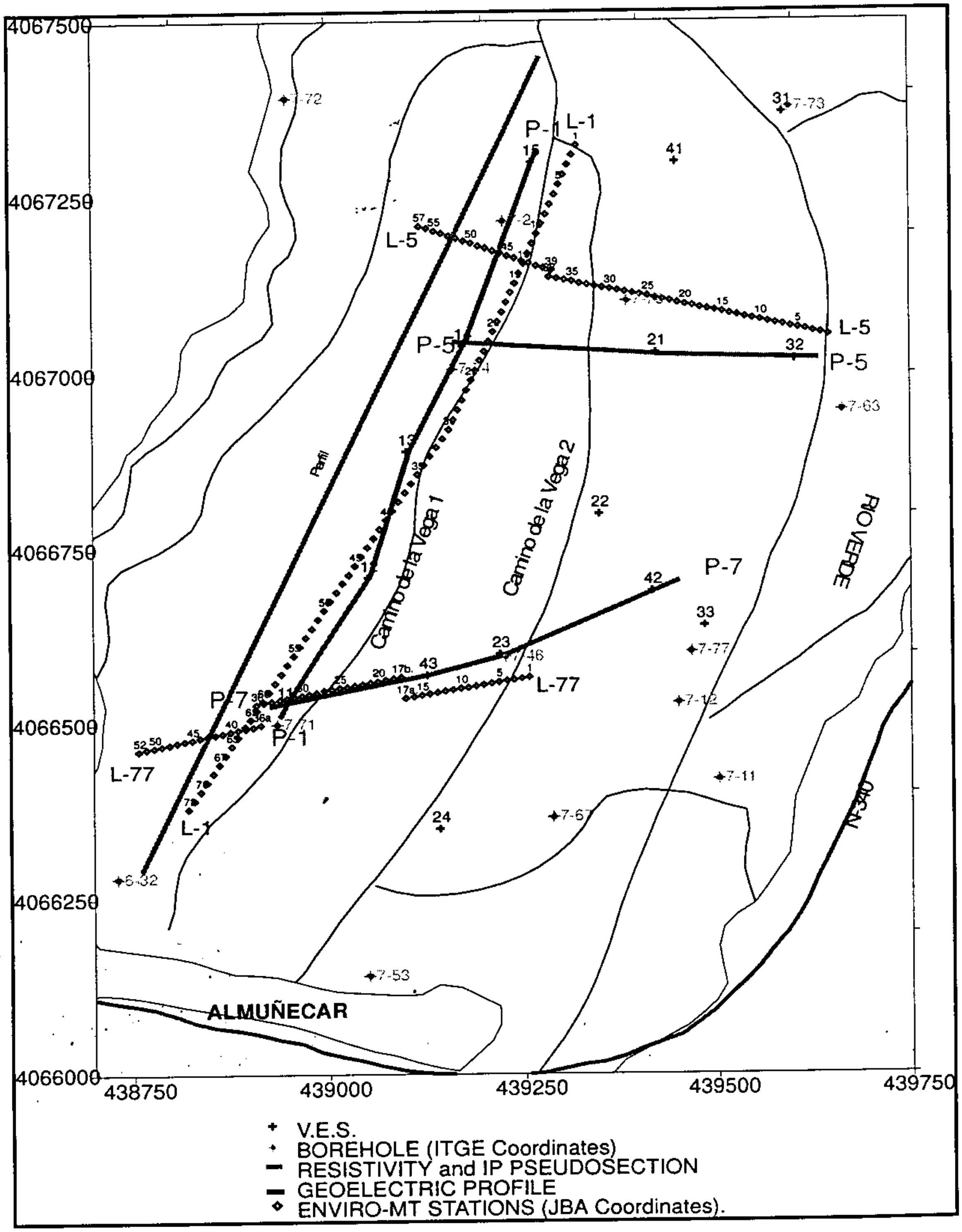
Table 11: ***Profiles measured at Almuñecar, Spain***

Profiles 5, 51 and 52 are the same with different station spacings and different transmitter locations.

A total of 73 combined CSMT & RMT readings, 56 RMT and 28 CSMT readings were taken.

The different tasks were divided among three crews:

- surveying UTM coordinates of the marker posts with station number
- operation and monitoring of the antenna and transmitter
- operation of the receiver and quality control of data



<u>Figure 13</u>: Location of measurement profiles, vertical electric soundings (VES), boreholes, and interpretation pseudosections, Almuñecar

Transmitter locations are shown on Figure 14.

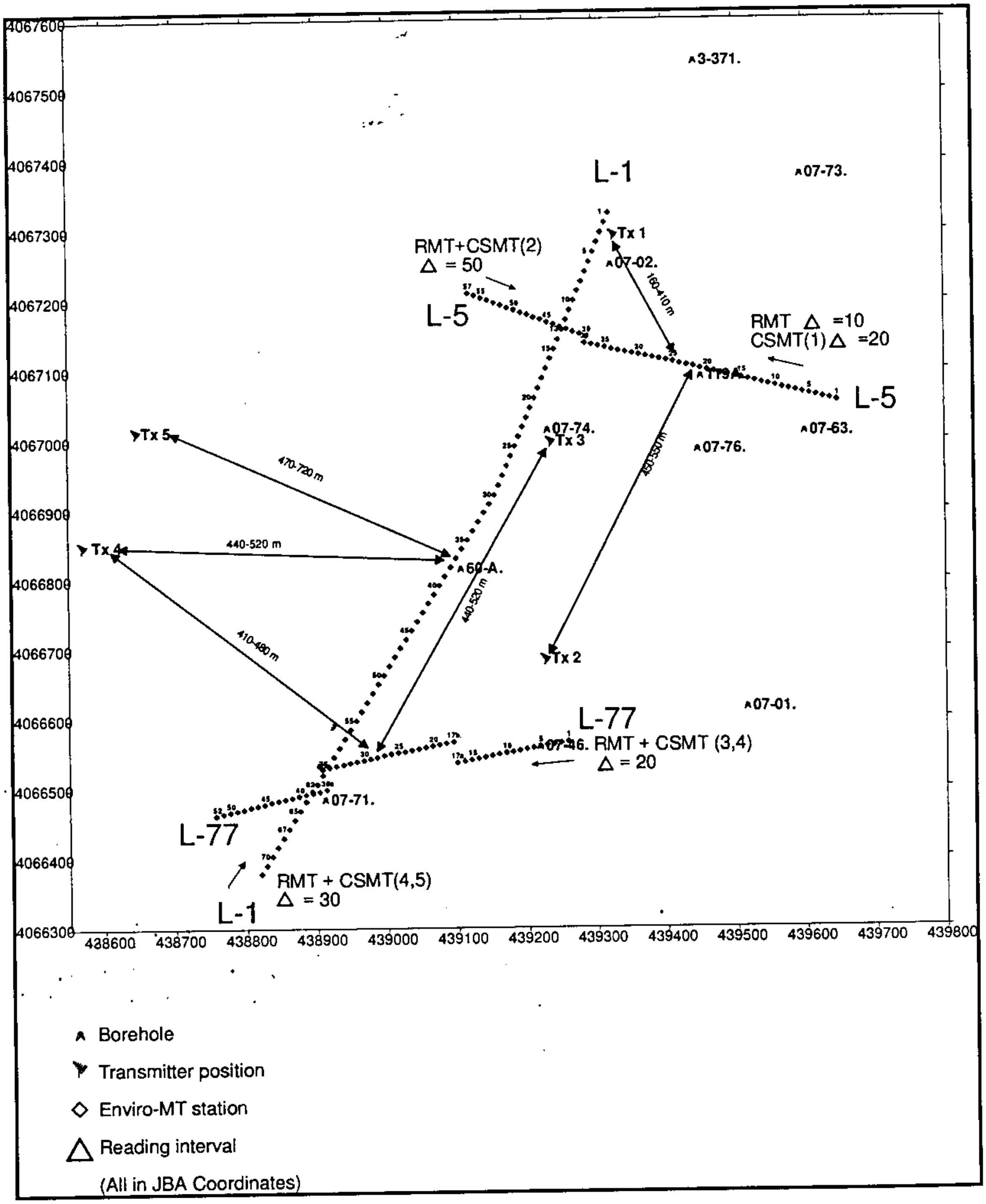


Figure 14: *Location of transmitter sites and profiles, Almuñecar*

Two field vehicles were provided by ITGE, and additional vehicles were hired to transport personnel and the equipment in the field. ITGE also provided marker posts and a generator for the transmitter. JBA personnel who were mostly engaged in surveying the measurement sites in thick plantation vegetation, but were also trained as end-users on the ENVIRO-MT system.

The main problems encountered during the field work were related to noise from cultural interference (in particular power lines), and therefore some repeat measurements were required. Additional problems arose from discrepancies between the location of the measurement sites as surveyed as compared to their location from the published topographic maps and the location of the previous VES geophysical survey sites (ITGE has made the best possible estimate), and complications arising from possible confusion in the station and measurement numbering protocols (these have now been addressed in the database). The design of the „legged" carry-frame for the receiver station was ideal for moving the receiver between measurement sites in the thick *Chirimoya* plantations, and ITGE concludes that the ENVIRO-MT system proved to be very suitable for use in difficult terrain conditions, where other methods requiring longer electrode arrays and large antennas are more difficult to use.

5.3.1 Results from Almuñecar.

UU processed data (Progress Report #5, Appendix 2, sections 2.4.2, 2.4.3 and 2.5 with illustrations), and the results were forwarded to ITGE for interpretation.

ITGE presented a detailed interpretation of the processed data, and compared the results to the geology known from drill holes as well as earlier vertical electrical sounding (VES) measurements (Report on the Interpretation of ENVIRO-MT data from Test Site of Almuñecar (Spain), 1999 – Deliverable D45 on file).

It became apparent that the high background noise level, the presence of cultural interference (pumps, pipes, etc) and fewer available radio transmitters with a low signal to noise ratio resulted in less satisfactory results for the processing, and as a result UU developed a new TSVD (Truncated Singular Value Decomposition) data processing algorithm that provides improved results and enhanced resolution for both the RMT and CSMT data. The results are presented as resistivity-frequency and phase-frequency sections for both RMT and CSMT. Inversion was performed only on the TSVD data for RMT and CSMT. These results are presented in the ITGE Report, and examples are illustrated in Appendix 2 of Progress Report #5.

As expected, shallow resolution is better with the RMT data but penetration is limited, and CSMT must also be used in order to define the depth to basement.

The interpretation by ITGE for Line 1 (Figure 15) demonstrates that the ENVIRO-MT data is compatible with the geological information, and provides important guide for the accurate extrapolation of the geological information and correlation of the different stratigraphic layers in the aquifer between the drill-holes and VES sites. It can be seen that the YX sections fit better than the XY sections, with the exception of the thickness and continuity of the second conductive layer (d). The absolute values for the apparent resistivity measured by the VES and ENVIRO-MT methods are of the same order of magnitude.

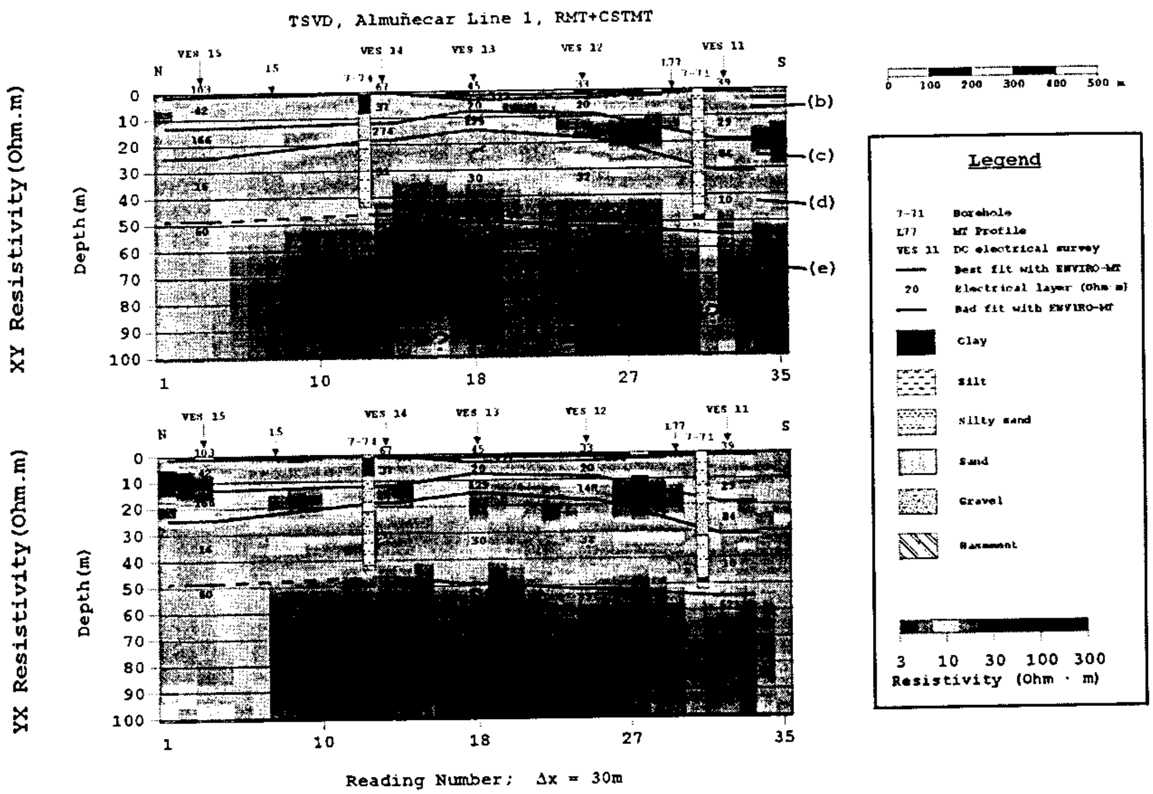


Figure 15: Interpretation of inverted RMT and CSMT data, Line 1, Almuñecar

In detail the ENVIRO-MT data provides a good indication of depth to basement, and the higher conductivity recorded in the north of the profile is compatible with the higher proportion of graphite known to be in the basement in that area. The conductive layer "d" is the main aquifer, but the upper and lower boundaries are best defined by the XY and YX profiles respectively. The variation in resistivity within this layer is recognised by both the ENVIRO-MT and VES data, and may be due to variations in clay and/or water contents. The resistive "c" layer (gravel and coarse sand) is well defined by the ENVIRO-MT data. The upper conductive "b" and resistive "a" layers are well defined by the ENVIRO-MT data, in spite of their shallow depths and low thicknesses.

Although the general trend and sequence of the electrical properties of the alluvial layers in Line 77 are generally compatible with the known situation (Figure 16), the ENVIRO-MT results for Line 77 are not so easy to correlate with the known geology as in Line 1. The reason for this may be due to the more heterogeneous geology that can be expected in the E-W sections across the valley. However, ITGE conclude that the ENVIRO-MT data permits correlation between the VES sections and provides a better geological interpretation.

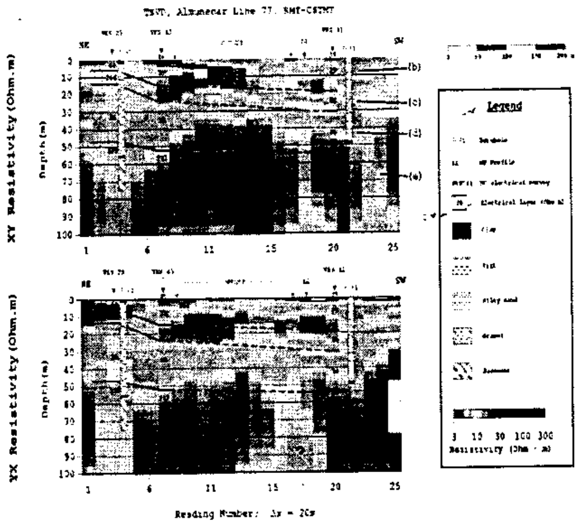


Figure 16: ***Interpretation of inverted RMT and CSMT data, Line 77, Almuñecar***

The data from Line 5 are more difficult to interpret (Figure 17), although the general trend of the resistivity distribution is in agreement with the known values, but there is poor correlation of the spot data.

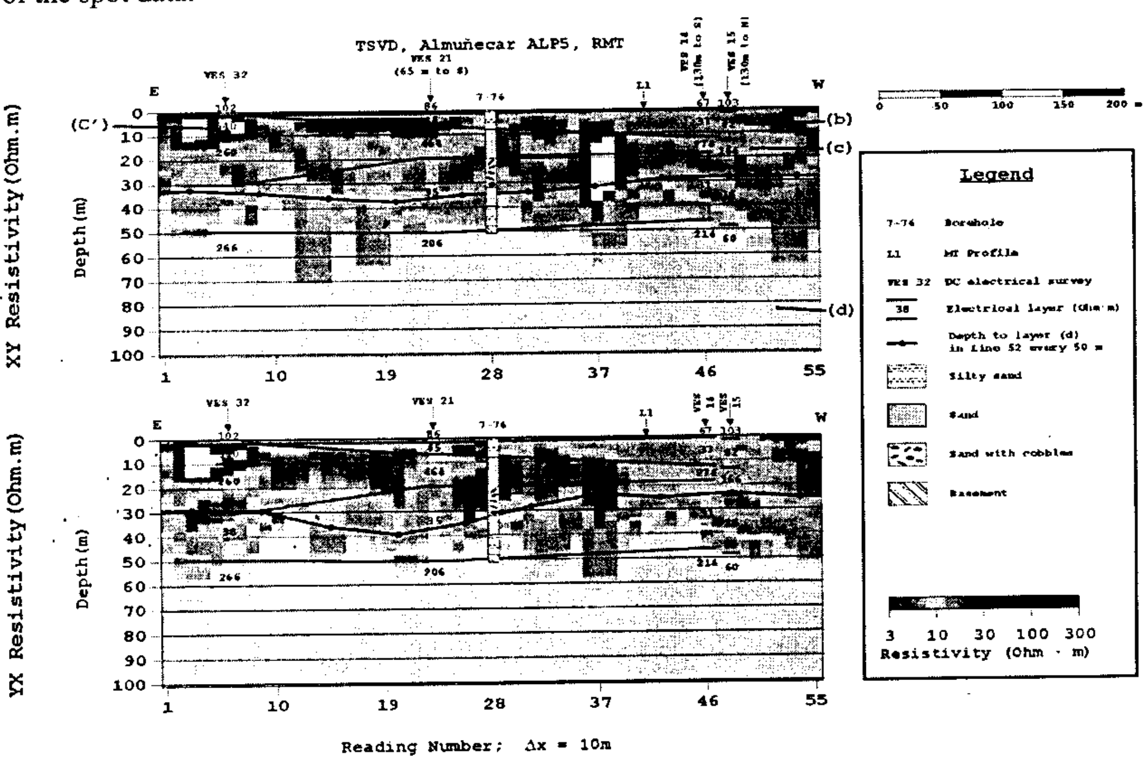


Figure 17: ***Interpretation of inverted RMT data, Line 5, Almuñecar***

5.4 Training of End-User Personnel (Task 4.3.4, 4.5) and preparation of Field Operations Section in the System Manual (Task 4.5)

End-users were introduced to the ENVIRO-MT system during the field testing in The Netherlands and Spain.

During the field test in Almuñecar, Spain (April 1999), UU delivered a workshop for the end-users in order to explain the theoretical background of RMT and CSMT, and how this is applied to ENVIRO-MT. The possible applications for ENVIRO-MT in the field, as well as the limitations of the technique, were also discussed in detail.

All end-users received practical training at the transmitter and receiver stations, and the operation of the system as well as the initial quality control of the data displayed on the screen at the receiver unit.

JBA compiled a report (Recommendations for Technology Providers (MTX & UU) – Final Hardware and software design -- Progress Report #5, Appendix 6) on the practical aspects of the field operations of ENVIRO-MT from the point of view of an end-user. This report includes recommendations for technology providers (MTX & UU) on the final hardware and software design from the point of view of the end-user.

JBA have compiled a draft contribution for the Operations Section of the System Manual (Deliverable D47, and appended as Appendix 4)

5.5 Technical Modifications and adaptation of the system as necessary (Tasks 4.2.3 and 4.3.3)

Modifications to improve the system were undertaken after each of the field tests. These improvements were often made at the suggestion of the end-users. Details on the modifications to the hardware and software of the system have been included in the description of the development and adaptations described in Section 3 of this Report.

5.6 Critical Decision Points and Deliverables, Work Package 4

The tests sites proposed by TNO and ITGE were reviewed and discussed by all the partners at the Project Meetings #2 and #3 before being finally approved.

The technical modifications made to the system after each of the tests were discussed in detail with the Partners, and were introduced for evaluation before the subsequent field test.

All the Deliverables have been submitted as listed in Table 3.

6. TECHNOLOGY CO-ORDINATION AND EXCHANGE

6.1 Establish procedures for monitoring the technological aspects of the Project (Tasks 5.1 and 5.5)

The PACE system for technological project monitoring of the Project (Table 12) was presented (Deliverable D51) and discussed at the Project Meeting #1 in September 1997. The Partners accepted this as a basis for monitoring the technological aspects of the Project.

The Design Review after Phase 1 took place at the Project Meeting #1 in September 1997.

The ENVIRO-MT prototype system (Phase 2) was accepted by the Partners after detailed review of the results of tests undertaken by UU and MTX, and further discussions at the Project Meeting #2 in Braunschweig, Germany, in June 1998.

The technological modifications to the ENVIRO-MT system that were made after the field tests were accepted at the Project Meeting #6 in Budapest 5, September 1999.

Overview of the "PACE" Project Control System

Project Phases

Phase 0	Develop Initial Concept
Phase 1	Project Planning / Preparation
Phase 2	Project Development / Design
Phase 3	Implementation and validation
Phase 4	Preparation for Production
Phase 5	Production of the "zero" series

Design Reviews

Design Reviews are carried out at the completion of each Phase, and include:

- Presentation of the tasks accomplished and future plans
- Address final questions regarding technology
- Definition and documentation of problems, changes and improvements to be included in the next Phase,
- Approval to commence the next Phase
  It is anticipated that these Design Reviews will coincide with the regular ENVIRO-MT Project Meetings

Phase 0	Completed with the presentation of the Definition Phase Report
Phase 1	Presentation of Specifications and Design of the ENVIRO-MT System (This Meeting)
Phase 2	Acceptance of the ENVIRO-MT Prototype, equipment tested and accepted
Phase 3	Acceptance of the technological modifications to the ENVIRO-MT after field tests

Table 12: ***Outline of the Project Monitoring Procedures based on the PACE system***

6.2 Trade-Mark and Patent Searches (Task 5.3)

A Trade Mark search for ENVIRO-MT (Task 5.23) was co-ordinated by JBA. This search was undertaken by Tomkins & Co, Dublin, Ireland, who are registered as European and Community Trade Mark Attorneys. The Trade Mark search was carried out in the Classes 7 (machines, machine tools), 9 (scientific and electronic apparatus and instruments), 40 (treatment of materials and related services) and 42 (consultancy and design services and related services, miscellaneous services). The results of this search did not disclose any prior registrations or pending applications for the name ENVIRO-MT in Europe. Communications related to this search are on file and the attorney's report is attached to Progress Report #5 (Appendix 7). At the time of writing this report, the technology provider partners (UU and MTX) do not intend to proceed with applying for a patent, but are considering registering the name "ENVIRO-MT" as a trade mark.

The Project is registered at the IPR-Helpdesk (Directorate DG XIII-D), and useful information and advice continues to be obtained regarding registration of patents and trade-marks as well as on possible licensing agreements.

6.3 Base-line study of production costs and optimisation of final design for MTX production facilities (Tasks 5.2 and 5.6)

A base-line study and detailed assessment of production costs of the receiver unit at the MTX production site was appended to Progress Report #5, Appendix 3. The production costs are estimated at EURO 23,160, but this figure does not include additional software, license fees, contingencies or profit.

The transmitter will be offered as an optional extra for those customers wishing to apply the CSMT method in addition to RMT.

A final sales price will be decided after close consultation between the technology providers, but is expected to be in the range of EURO 50,000.

6.4 Pre-commercialisation marketing studies

In order to determine the economic viability of the ENVIRO-MT system it was necessary to compare with other geophysical measuring systems for shallow (0-50 m) investigations that are normally carried out for hydro-geological and environmental surveys These include:

- DC and low frequency AC resistivity meters (several systems) for electrical soundings with multi-spaced electrode arrays
- Inductive electromagnetic two-coil systems operating in the low induction regime that provide a direct read-out of apparent conductivity without the need for ground contact (Geonics EM-38, EM-31, EM-34 and similar systems)
- Inductive electromagnetic systems multi-coil and multi-frequency systems (Apex "MaxMin" and similar systems)
- Transient electromagnetic systems for deep soundings (Geonics "Protem", SIROTEM and EG&G "Nano-TEM" systems)
- Scalar magnetotelluric systems that use distant VLF transmitters and measure one electric and one magnetic field component (Geonics "EM-16R", BRGM "T-VLF", Scintrex "OMNI").
- Stratagem System (EMI-Geometrics), fixed frequencies and scalar MT system

The ENVIRO-MT system is technologically the most advanced electro-magnetic system for environmental and geotechnical studies. Enquiries by JBA on behalf of the Project partners showed that the price for the nearest competitor system (EMI Geometrics Stratagem System) is estimated to be USD 50,000, and a rental price USD 284/day plus a USD 568 mobilisation fee.

6.5 Licensing agreements between Partners

At the Kick-Off Meeting on January 16-17 1997 it was decided and minuted that the Contract document covers all the important aspects of the management of the Project and the responsibilities of each Partner and the Co-ordinator.

As a result there was no requirement for an additional Consortium Agreement to cover the duration of the Contract. None the less, this does not cover the relationships between the Partners subsequent to the Project regarding the exploitation of the results of the Project. In this respect, the following points were agreed and minuted at the Kick-Off Meeting:

1. MTX and UU (the owners) will jointly own the ENVIRO-MT system, and the details will be covered by an agreement between these two partners
2. all partners will have access (purchase, rental or leasing from the owners) to the ENVIRO-MT system for their own use at favourable rates under conditions to be agreed.
3. a commission (to be agreed) will be paid by the owners to other partners who complete sale of the ENVIRO-MT system(s) to non-consortium customers

With respect to Point 1, the ENVIRO-MT system will be manufactured by MTX. At the time of writing this Report, a licensing agreement between MTX and UU to cover the recompense of UU and definition of the responsibilities of UU for further software development and guarantee considerations is in an advanced stage of negotiation. Relevant correspondence is on file.

With respect to Points 2 and 3, more work needs to be done before the system can be fully commercialised. The figure for renting and leasing will depend on the list price that is finally determined – standard industry charges are based on about 10% of the list price per month for renting/leasing. The partners will be offered a rate that is significantly less than this, and this will be established in writing with all the partners.

6.6 Users Manual

A Users Manual has been completed and is attached to this Report as Appendix I.

6.7 Critical Decision Points and Deliverables, Work Package 5

The PACE system for technological project monitoring of the Project was accepted by the Partners at the Project Meeting #1 in September 1997.

Due to the delay in preparation of the Users Manual, at the time of writing the partners had not had time to accept this document.

As noted above, all the Deliverables with the exception of the draft versions of the Users Manual, have been submitted and are listed in Table 3.

7. PROJECT DISSEMINATION ACTIVITIES (WORK PACKAGE 6)

For all of the partners, dissemination of the results of the Project was a very important aspect of the ENVIRO-MT Technology Transfer Project. The dissemination activities were managed and undertaken by end-user partner JBA.

It is estimated that 300 different potential client companies and organisations have been informed directly (mailings) or indirectly (web-site, distribution of brochures at conventions), which would represent a high proportion (ca 75%) of all potential clients for the system.

7.1 Dissemination Methods and Database

The dissemination procedures were presented to the partners and reviewed at the Project Meeting #1 in September 1997. The principal activities were identified as mailings, newsletter, demonstrations and presentations at relevant workshops, conventions and conferences. Subsequently it was decided that it would be more beneficial to maintain information about the project on a web-site rather than printing and mailing newsletters (see description of Task 6.1)

A poster describing the project was prepared for the EEGS Meeting in Aarhus, Denmark, in 1998. This document was used as a draft for the Project Description Leaflet, and was submitted to all partners for review and comment. The final version of the Project Description Leaflet is attached as Appendix II to this Report (Task 6.2).

JBA established a database of end-user organisations relevant to the ENVIRO MT system. The TRACKER database system was used to monitor communications and marketing with each end-user organisation. A draft listing of the End-User organisations was circulated to the Project Partners in September 1997 for their review and recommendation of additional end-users in their respective countries (Task 6.3).

7.2 Mailing Actions

A draft mailing list was compiled using the End-User database in September 1997. This was finalised and was the basis for the circulation list of the first newsletter circulated in the first quarter of 1998. A copy of the final mailing list (107 addresses of relevant companies and organisations, derived from 18 European countries as well as USA, Canada, Japan and Australia) was attached as Appendix 8 to Project Progress Report #5 (Task 6.4).

In addition to the end-user database, an Observer Group, consisting of five companies and organisations that had expressed a special interest in the ENVIRO-MT system, was established (Appendix 8 to Project Progress Report #5). The members of the Observer Group are located in Austria, Belgium, France and U.K., and they were invited to attend the presentation and demonstration of ENVIRO-MT at the EEGS Convention in Budapest in September 1999 (Task 6.6).

The initial version of the Project Description Leaflet was mailed to relevant companies and organisations on the mailing list in 1997. An additional brochure describing the system and applications – ENVIRO-MT a high resolution EM system for environmental and geotechnical investigation (Appendix II to this Report) – was prepared by MTX for a mailing action.

MTX and ITGE included a description of the ENVIRO-MT Project in their regular newsletters that are distributed throughout the world. The preliminary results of the field tests in Almuñecar were reported by ITGE in the Boletin Informativo, No 7; September 1999.

An internet web-site was considered to be accessible to a broader spread of potentially interested companies and organisations, and is therefore more suitable than a regular newsletter as a means of Project Dissemination. It was therefore decided to include a reference to the ENVIRO-MT Project on the Metronix internet web-site (www.metronix.de), with details of the system in the pages "EM Systems – ENVIRO-MT" (Appendix II of this Report), and a brief description in the pages Projects / Current Research in the geophysical section. This web-site site will be updated with the case histories from the Field Tests in Collendoorn, The Netherlands, and Almuñecar, Spain.

7.3 Presentation Materials on Project Results (Task 6.8)

An initial poster describing the basis of the ENVIRO MT Project, the system and the project partners was prepared for presentation at the 3rd Meeting on Environmental and Engineering Geophysics held in Aarhus, Denmark, 8th to 11th September 1997 (Appendix 5 to the Project Progress Report #2).

MTX prepared a brochure (two-page A4 format) brochure describing the system, brief technical specifications, and applications of the ENVIRO-MT system (ENVIRO-MT a high resolution EM system for environmental and geotechnical investigation - Appendix II to this Report)

JBA prepared a brochure (two-page A4 format), case-study information sheets (two-page A4 format) and posters (A1 format) for the Collendoorn and Almuñecar Demonstration Sites. Draft examples were sent to partners for review and comment. Great care was given to including all the relevant information about the advantages of the new technology as well as details on the results obtained from each of the test sites. 1000 full colour copies of each of the brochures and case-study information sheets were printed. Copies of the brochures and case-study information sheets are included in Appendix II of this Report.

The brochures and case-study information sheets have been distributed to all companies and organisations on the mailing list, and were provided to interested participants at trade fairs and conventions.

The Project is described on the Metronix web-site as mentioned in section 7.2.

7.4 Conferences, conventions, seminars and trade fairs (Tasks 6.7 & 6.9)

The participation in trade fairs and conventions is an important component of Work Package 6 and of Technology Transfer Projects. Dissemination was a very important aspect of the ENVIRO-MT Technology Transfer Project, and events such as workshops, seminars, participation in fairs, exhibitions were considered to be very useful as an ideal pre-marketing action in which you have the opportunity to identify potential new users and future customers of the innovative technology.

The EEGS-ES (Environmental and Engineering Geophysics Society – European Section) Annual Convention is the only European forum that is specifically devoted to the application of geophysics to the environmental engineering industry, which is the target for the technology developed in this project. The EEGS-ES holds an annual convention at different

European cities – Aarhus (1997), Barcelona (1998), Budapest (1999) and Bochum (2000). There are no alternative events in Europe that attract the target industry, and at which the industrial competitors from North America and Japan are also present.

The initial project poster was exhibited at the 3rd Meeting on Environmental and Engineering Geophysics Society (EEGS) held in Aarhus, Denmark, 8th to 11th September 1997. This event was used to present the Project as an idea and concept to the industry and related organisations. The feed-back was positive, and was the basis for the compilation of some of the addresses in the Mailing List as well as for identifying the Members of the Observer Group.

It was agreed at the Project Meeting #4 that the main Project dissemination event would be the launch of the ENVIRO-MT system at the Environmental & Engineering Geophysical Society (European Section) in Budapest during September 1999. A draft dissemination plan was forwarded to the Project Partners (Deliverable 64, Appendix 5 to Project Progress Report #5). The following measures were undertaken to maximise the impact of the innovative technological developments and results of the ENVIRO-MT Project:

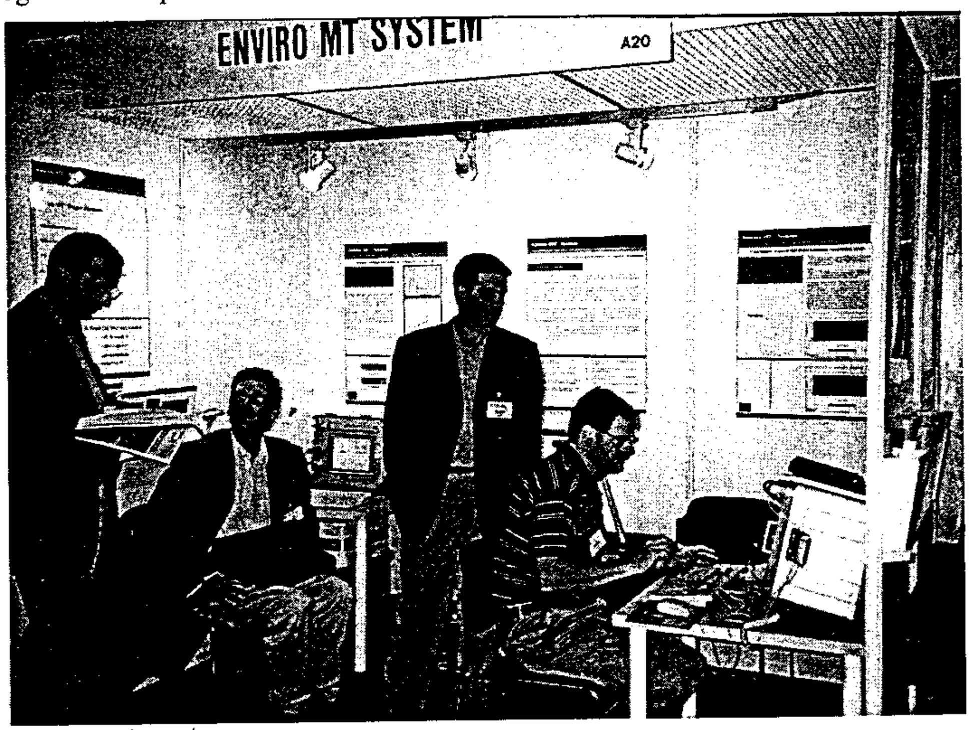


Figure 18: ***ENVIROMT stand at the EEGS Meeting, Budapest, September 1999***

- the Project maintained a stand with the prototype system on display, posters, brochures, as well as an ongoing demonstration of the operating software and database,
- the technology developed during the Project was demonstrated at a site next to the Convention Centre, and
- an oral presentation about the results of the Project was made by the Project Partners UU and MTX (the text of the presentation entitled "ENVIROMT. A NEW RADIO/CONTROLLED SOURCE SYSTEM" is included as Appendix III to this Report).

The ENVIROMT stand (Figure 18) was one of 25 commercial stands at the Convention, and it was manned throughout the day. Two complete ENVIROMT systems were on display and the software and setup was demonstrated to interested delegates. It s estimated that over 250 delegates visited the stand, of which 10% were considered to be genuine potential clients. The demonstration was well attended (Figure 19) by 50 to 60 people.

Figure 19: Field demonstration of the ENVIROMT system, EEGS, Budapest.

Other dissemination activities, included the presentation of technical papers by Professor Pedersen (UU) at the EAGE Meeting in Helsinki in June 1999 (Abstract is attached as Appendix 2 to Progress Report 4).

7.5 Critical Decision Points and Deliverables, Work Package 6

The dissemination methods were reviewed and approved by all partners at the Project Meeting #1 in September 1997.

The dissemination plan, which was based on the launching of the ENVIRO-MT system at the EEGS-ES convention in Budapest in September 1999, was presented by JBA and approved by the partners in June 1999.

The deliverables for the Work Package 6 have been completed and are itemised in Table 3.

8. SUMMARY AND CONCLUSIONS

8.1 Summary of Achievements

It is concluded that the objectives and quantitative targets of the Project have been fulfilled. Table 13 summarises the achievements of the Project.

Goal/Target	Achievements
adaptation of established magneto-telluric technology to the requirements of the European environmental and geotechnical engineering industry	the ENVIRO-MT instrumentation has been successfully adapted from deep-penetrating technology used in the exploration for natural resources to the shallow environment for the geotechnical industry – ENVIRO-MT applies a technology that is superior to competitor systems manufactured in North America.
construction of two operational and economically viable ENVIRO-MT prototype systems	prototype systems are located at MTX and UU, both proved to be operational at the test sites, and probable retail price is comparable to that for inferior American competitor technology
demonstration and presentation of the system at two end-user sites	the ENVIRO-MT system was successfully demonstrated at sites selected by the end-user partners in The Netherlands and Spain.
compilation, editing and printing of an Operations Manual	an end-user operations manual is attached to this Report as Appendix I
presentation of the project at 2 European conventions	the ENVIRO-MT Project was successfully presented to the geotechnical industry at the Environmental and Engineering Geophysics Society (EEGS) conventions 1997 and 1999

Table 13: Achievements of the ENVIRO-MT Project

All the project deliverables have been completed, and the project has been finished within the contractual 33 months.

The overall planned schedule for the project was not effectively changed during the 33 month duration.

8.2 New Technological Developments

The original prototype specifications were improved by further modifications during the project, and these are itemised in Section 3. The acceptance date of the prototypes was delayed due to the extra time required to make the necessary modifications. Further delays were also experienced in the delivery of components from outside suppliers. However, these matters did not materially affect the overall scheduling of the project since the subsequent field tests were undertaken at shorter intervals than had originally been planned.

The EnviroMT system contains a number of novel features including (communication from Professor Pedersen):

- Broad band radio-signal reception

  In standard MT the natural source EM fields are used to estimate transfer functions connecting the horizontal magnetic field with the horizontal electric field and the vertical magnetic field, the impedance tensor and the tipper vector, respectively. Due to variations in the source field strength and interference with man-made sources it is well-known that in the *band 1 kHz to 500 kHz it is notoriously difficult* to get stable estimates of transfer functions using standard approaches. In the new approach we identify distant man-made sources in the form of *VLF and Radio transmitters in the LW and MW band*. And for the estimation of transfer functions we only make use of the signal from those *transmitters*, in contrast to standard MT where the whole frequency band is considered as plane wave sources perhaps mixed with non-planar events and man-made noise. The technique is therefore similar to the Tensor VLF technique. In fact in Northern Europe there are generally more than two independent transmitters available in each half-octave/octave band that transfer functions can be estimated starting at 14 kHz. The advantage of the new approach is that the signal to noise ratio of the radio signals is generally very large, whereby high quality of estimates can be guaranteed at all stations. Individual radio stations are stored separately whereby the standard scalar RMT method can be simulated. Also more advanced ways of estimating transfer functions can be carried out off-line.

- Controlled source with synchronous detection

  By using *GPS* clocks combined with stable oven controlled oscillators at both *transmitter* and *receiver* the signal to noise ratio can in principle be made as large as required. With white noise the signal to noise ratio increases linearly with integration time. Thus with a small 200 W transmitter fed by a single car-battery it is quite fast to measure up to distances of 500 meters. By putting 4 car batteries in series a maximum distance of 1000 meters can be achieved. The transmitter is controlled entirely from the receiver via a *radio link. A future development is the automatic tuning of the transmitter to resonance without man-made interaction*. Thus the transmitter can be turned off to reduce power consumption and a selection can be made between the two transmitter coils, but most importantly transmitting frequencies can be changed together with series capacitors in order to secure that the transmitter coils are always driven in resonance.

  Whereas the standard estimation of transfer functions in the RMT mode is based upon the assumption that they are constant in each sub-band no such assumption is necessary in the controlled source mode. Here, unique transfer functions can be found right at the transmitter frequencies chosen because the transmitter consists of two independent horizontal dipole coils. Even though these transfer functions are most easily interpreted in the plane wave (or far field) case they can still be uniquely defined in the intermediate and near field range.

- Built in database handling

  Taking into account that the speed of data acquisition is very high it means that large amounts of results must be stored. Consider for example that there are 4 complex impedance and 2 complex tipper elements per frequency and that there are 16 frequencies per site. This means a total of 192 real numbers per site. With 100 sites per day this amounts to about 20000 real numbers that need to stored and manipulated to various pseudo-sections of apparent resistivity, phase, tipper elements, etc.

In addition to the *pseudo-sections* the system also provides a facility for *automatic 1D* inversion of selected impedance combinations (off-diagonal elements, determinant, etc.) along selected profiles. In the future even a fast 2-D inversion code will be added to the system to make it more flexible and self-contained.

All the above mentioned manipulations can be done in-field. The built-in colour display unit is of excellent quality and with the fast built-in computer, in a few minutes the user can get a complete overview of the data collected along various profiles.

8.3 Project Dissemination

Patent and trade mark searches have been undertaken. However, it is unlikely that IPR acquired during the project will be legally protected due to the rapid advances in the basic technology as well as the difficulties and costs of policing a patent. The technology provider partners are considering applying for a Trade Mark registration of the "ENVIRO-MT" name. A basis for an agreement whereby all partners will have access (purchase, rental or leasing from the owners) to the ENVIRO-MT system for their own use at favourable rates has been established. Discussions regarding an agreement between the technology provider partners for the manufacture of the system are well advanced.

The ENVIRO-MT Project and system have been actively promoted to the industry at relevant conventions and meetings. Judging by the number of follow-up inquiries about the system, it can be shown that the ENVIRO-MT Project and system has attracted very considerable interest within the environmental and geotechnical engineering industries. It is estimated that 300 different potential client companies and organisations have been informed directly (mailings) or indirectly (web-site, distribution of brochures at conventions), which would represent a high proportion (ca 75%) of all potential clients for the system.

Duncan Large

Project Co-ordinator

26 November 1999