GPRtech – Australian MALA GPR Distributor
4/105A Ben Boyd Road, Neutral Bay, NSW 2089, AUSTRALIA
Tel: +61 0438 278 902 | Fax: +61 02 9908 1484
Web: www.malagpr.com.au | Email: sales@malagpr.com.au

MALÅ MIRA System

MIRA - **M**alå **I**magine **R**adar **A**rray for fast and true 3D data aquisition

Technical Information

Scope/General

MIRA-systems are built up of several, essential, sub-systems with designs based on several critical conditions. This document aims at bringing the different parts into context as well as explaining the underlying theoretical conditions. It should be pointed out that the system described here comprises essentially new, patented, technology.

MALÅ delivers several standard MIRA-systems; however, many of our clients are dealing with research projects or work within organisations with very wide areas of applications. It is not possible to define a set of standard items fulfilling the needs of all these specialized applications. Therefore the following description and specifications focus on what we have chosen as a standard set-up, clients wanting to apply the array technology on specialized applications, falling outside the more common ones, should not feel that this document constitutes limits. Customized specifications, data acquisition schemes, antenna frequencies, positioning sub-systems, communication interfaces etc. can all be delivered on request. The specialized group, within MALÅ, handling the MIRA sales will guide clients to a suitable system.

3D-GPR arrays – the base line

The term ‘Array’ is widely used in the marketplace for almost any kind of multiple antenna configuration, and this is causing some confusion. There is a growing need for being able to distinguish between systems capable of real 3D data acquisition and systems merely suitable for multiple antenna operation and MALÅ therefore suggests the following definition of the term ‘Array’.

MALÅ suggests that a true Array system should fulfil the following 4 conditions. For anyone serious about true 3D data acquisition these conditions are of vital importance and should be followed as closely as practically possible:

1. The individual radar channel spacing should be less than one quarter of the centre wavelength in the media under investigation.

This condition defines what is necessary in terms of physical channel spacing to avoid spatial aliasing, i.e. loss of information due to spatial under-sampling. Avoiding spatial under-sampling is essential for real 3D data gathering, but nevertheless a condition almost never fulfilled when standard GPR systems are used. Some may argue that since the object searched for may be much larger in one dimension, this condition can be stretched widely and channel spacing of 0.5 - 1m would be sufficient. However, even if it may be true that this condition is not an absolute limit, i.e. 3D-data interpretation will certainly be possible outside this condition, but as the channel spacing increases above the limit, the quality of the end results deteriorate quickly. This is especially true for surveys for non-linear targets, which will be substantially harder to interpret if data is under-sampled. Assuming a geologically average dielectric constant of 9 (corresponding to a ground velocity close to 100m/µs) would advice a maximum channel spacing of 12.5, 6.3, and 2cm for the frequencies 200, 400 and 1300 MHz respectively. These numbers give the answer to why real 3D-data acquisition has been avoided in the past; gathering data with e.g. 6.3 cm channel spacing over thousands of square meters, is simply not feasible with standard systems.

2) Any combination of receiver and transmitter elements should be possible within the array, i.e. shooting from any transmitter to any receiver/s.

This condition effectively reduces the physical channel spacing by half by allowing any receiver within the array to receive signals from at least two transmitters. Practically this is of outmost importance since there are physical limitations to how small the antenna elements can be built. Besides being a practically necessary sub-condition for our first condition (above), this condition widens the use of the array by allowing gathering of multi offset data at each measurement point.

3) All included antennas in a 3D Array, need to produce a 'near-identical' response (signature).

In order to produce high quality images, it is absolutely necessary that each channel receives the same information from a given target. If this condition is not fulfilled, the resulting images will contain ghost lines and other imperfections. It could be argued that such defects could be processed away, but the effects of badly tuned antenna elements creates ambiguities in data that in most cases will be very hard to compensate for. Under optimal conditions, data from each receiver should produce identical frequency spectra, regardless of which transmitter it receives signals from. This would then require that all involved antennas are producing an identical centre frequency as well as using identical antenna orientation (polarization). Therefore, extremely careful attention has to be made to tuning and the control of Array antennas.

4) The array system should have a positioning device/sub-system providing an accuracy of at least half the channel spacing, over the whole area of investigation.

The normal approach for 3D data processing and imaging is to divide the whole area of investigation into small volumes. Each volume is then "filled" with data received from this specific point in space, prior to processing and interpretation. This procedure is often referred to as "binning". The size of the cubes/bins is preferably selected close to the channel separation/point distance used and it follows that in order to position data correctly, the accuracy of the positioning needs to be half the channel spacing. The importance of correct positioning cannot be overestimated; data without correct positioning is useless.

Above conditions creates certain consequences for an Array system and brings clarity to most of the confusion around GPR-arrays. Whenever an Array system is to be evaluated, it is good practice to study the system specifications and then return to these conditions and evaluate how well they are fulfilled. Creating true 3D GPR images with arrays containing antennas with different centre frequency or polarizations is simply not possible today. Similarly, Arrays with channel spacing of one wavelength or more are highly questionable, the resulting image quality and consequently the interpretations will not be reliable.

Control unit- the array option

The control unit used in the MIRA systems is the ProEx controller together with the Array option, thus there's no dedicated Array control unit (further references to the control unit refers to the combined unit). This unit constitutes the core of the MIRA system. It creates the control signals for the individual antennas according to the selected acquisition scheme and manages the incoming data. The high performance has been reached by a novel (patent pending) design of the control signal generation as well as by an advanced data management design involving a multitude of individual computers. A common configuration for 16-channel operation will comprise 10 specially designed computers, working in parallel with data gathering, buffering and transfers.

The array option, expandable up to 16 individual receiver and transmitter antennas, is configured with a specific number of antenna interfaces at time of delivery from MALÅ. The control unit can be configured for any receiver-transmitter combinations at each point of measurement. During data acquisition, the unit will keep track of the position along the survey line and gather the selected sequence of receiver-transmitter combinations at each point of measurement.

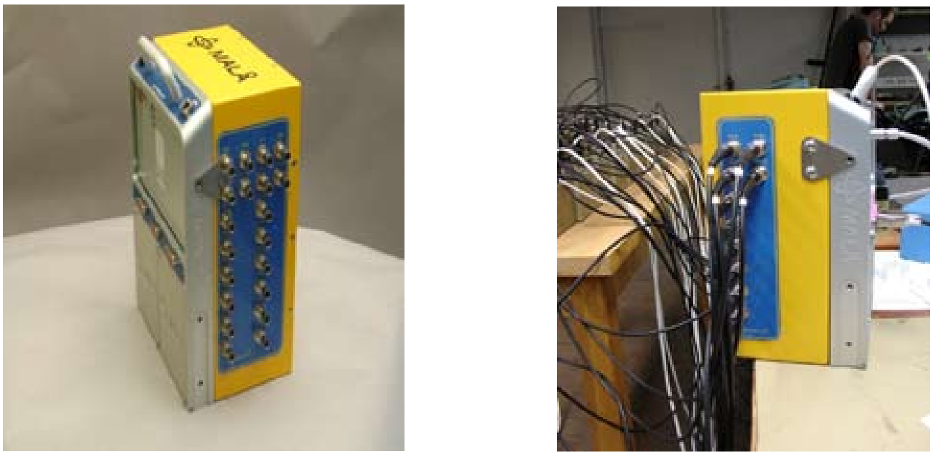

Figure 1. The ProEx control unit with array option attached, together comprising the MIRA control unit.

In Figure 1 above a control unit is shown. The unit is connected to the antennas by means of coaxial lines, carrying control signals and digitized data. It is powered from the ProEx main unit, 12V@3A, and is connected to the acquisition laptop via an Ethernet cable. Deployed for data acquisition, numerous cables will be connected to the unit and, therefore, it is recommended to be mounted as a fixed installation, whatever the carrying system may be. Care should also be taken for minimizing the environmental stress on the unit, such as rain, temperature variations etc. However, when a standardized package is purchased, these kinds of practical issues will be taken care of by Mala.

The most common scheme of data acquisition is shown in Figure 2 below. Each receiver is synchronized against two transmitters in order to make the physical channel spacing as small as possible.

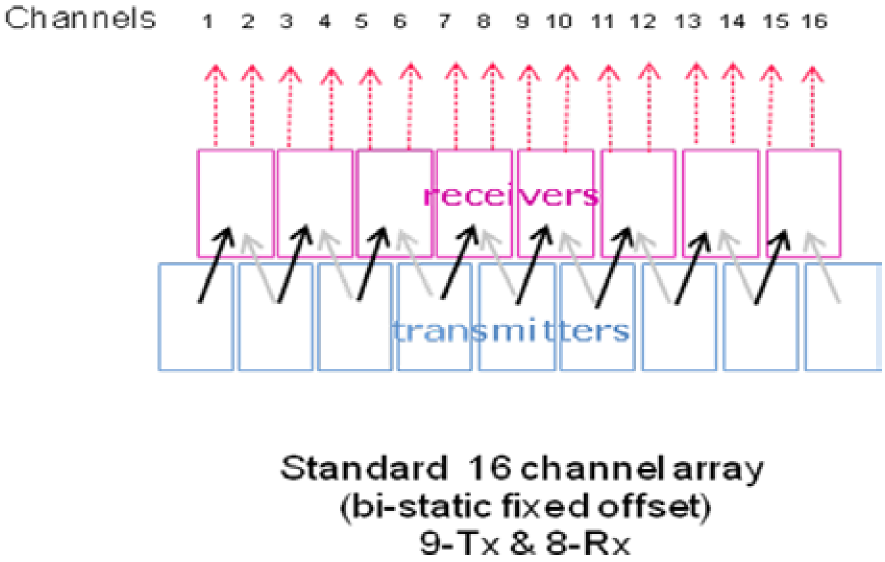

Figure 2. The most common channel configuration in which each receiver is synchronized against two transmitters in order to minimize the channel spacing.

Referring to Figure 2, data has to be sampled trace by trace, i.e. a receiver has to gather data from one transmitter at a time, and we cannot sample data synchronized to transmitter 1 and then, 5 μs later, sample data synchronized to transmitter 2. We have to wait until a complete trace is sampled in the first configuration, before switching to the second. This is to say that the black-indicated ray-paths are gathered completely, before the grayed paths are collected. Effectively this means that if the receivers' works on 200kHz the whole array will work on 100kHz since the control unit has collected two swats of samples in order to gather all the data channels. The acquisition software takes care of all the details and prevents the user from entering any prohibited sequence, such as firing the transmitters too frequently.

Whenever possible, it's always recommended to average data, something referred to as stacking. In spite of the high performance of the MIRA systems, this averaging and the selected point distance puts some limits on the maximum survey speed. Assuming 200KHz repetition rate and 8cm point distance and 350 samples, the maximal survey speeds are listed below, at different number of averaging.

Number of averages	Resulting maximum survey speed, km/h
1	75
2	37
4	19
8	9

It should be noted that if the higher speeds are used, the demands on the positioning system become higher as well. It must be able to reliably track the position of the gear, regardless of the survey speed.

Practically, the site conditions usually constitute the limit in survey speed. Surface roughness, obstacles preventing straight lines, crossing traffic and other details usually limit the speed to below 20km/h.

Antennas

The MIRA system is designed to handle shielded separable antennas (T and R) only. The T (Transmitter) antennas have one power connector and one trig connector, while the R (Receiver) antennas also have a connector for the digital data. The MALÅ separable antennas are designed to show as similar response (signature) as possible and each data channel in the array is tested individually with regard to this parameter. Both receiver and transmitter antennas have led-indicators for troubleshooting cable faults. The antennas are today available with centre frequencies of 200Mz, 400MHz and 1.3 GHz. In Figure 3 below 400 and 1300MHz antennas are shown.

Figure 3. 1300 and 400MHz antennas.

The antenna housing contains all electronics for generating the impulse, sampling the incoming signals and digitises it to 16 bit. The raw 16-bit data is transferred to the array-option where it's buffered for later transport to the PC for final storage and display.

Several separate transmitter and receiver antennas are combined into one single antenna array unit mounted in a box suitable for field surveys. 200 and 400MHz boxes are designed to include the control unit.

Positioning system

The use of any MIRA system requires a precision positioning system, capable of monitoring the array position with centimetre accuracy, over the whole site. This can be done with a robotic (self-tracking) total station or RTK GPS. A prism or a GPS antenna is attached to the array box, and a radio link is transferring the positioning data from the base station/total station back to the acquisition laptop.

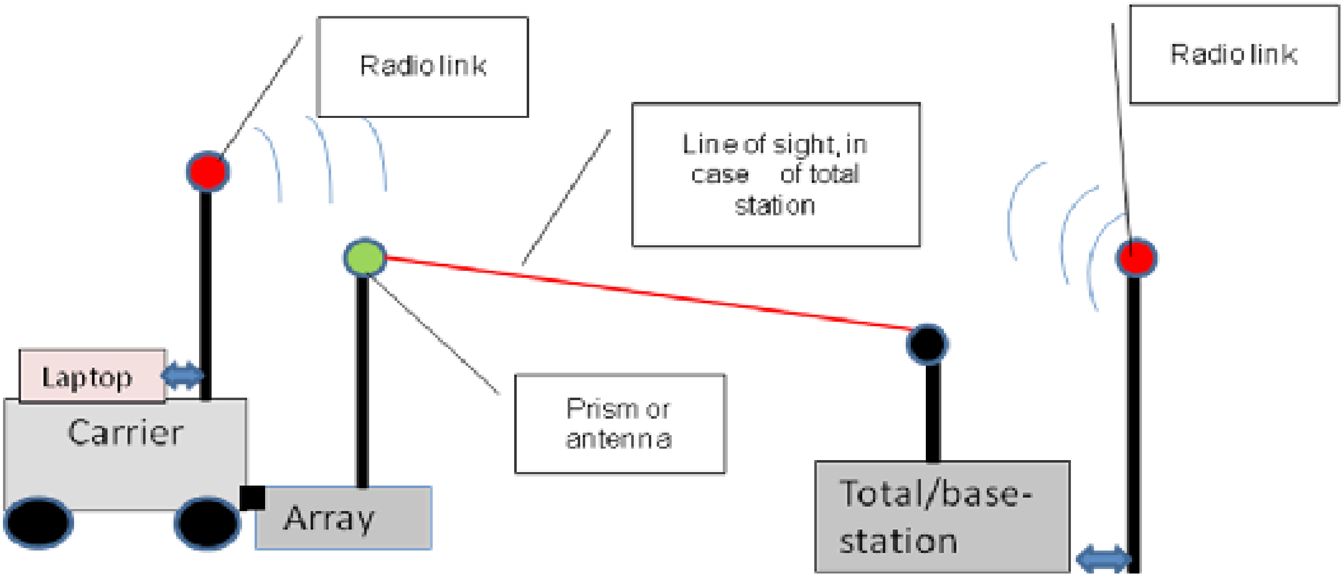

Figure 4. Principal layout of the positioning system

In Figure 4 above, a principal view of the positioning system and its set-up is shown. With this layout the operator of the carrier vehicle will be able to control/monitor both the operation of the radar system as well as the positioning system while steering the carrier vehicle.

For every swat, each channel will be precisely positioned and it is up to the operator to overlay the previous swat somewhat in order to completely cover the area. Excess overlap will be taken care of automatically by the processing software during the binning process but uncovered areas will produce artefacts in the resulting images. The processing software has been designed to minimize these effects but nevertheless, a careful data collection procedure is essential for the resulting image quality.

Both total stations and GPS systems have their pros and cons and it is outside the scope of this text to discuss these in detail. It should be mentioned though, that temporary loss of tracking will not cause the data to be useless, as long as start and end points are well defined.

Deployment – carrying system

The target applications for the MIRA systems are radar surveys over large areas and, practically, it’s not feasible to move the array manually over thousands of square meters. Some kind of motorized carrying system is usually necessary. It’s possible to ship the radar parts and accessories and attach the system to any carrier, but this requires a case by case handling and cannot be described precisely.

We have found the lawn-mower type vehicles very suitable for carrying the MIRA arrays and in Figure 5 below an action photo showing the carrier, including the array, is shown.

Figure 5. A suitable mounting of the array system on a lawn-mower type of vehicle.

Whatever vehicle chosen, some adaption for the radar system has to be done, these include:

- Fastening arrangement for the array box
- Power supply, typically the generator has to be exchanged to one with higher current specifications. Cables, fuses, and switches have to be installed.
- Attachment of marking system and laptop mounting.

If the carrier is part of the purchase, these details will be taken care of by MALÅ. However, the client may find it more suitable to supply the vehicle locally, in which case he has to arrange the mounting details by himself.

Figure 6. A simpler, hand-pushed solution

For smaller scale projects and mapping over reasonable smooth areas, simpler solutions are available. In figure 6 below a hand pushed cart-solution is shown. In this case the system is powered by a car battery. This kind of deployment is possible with the 400 and 1.3GHz arrays but not with the 200 MHz, due to weight/handling considerations.

Data acquisition

Prior to radar data acquisition, some planning of the survey should be done. It's advisable to conduct the data acquisition in straight lines, whenever possible, the system does not require straight lines but the positioning errors will be less and the coverage of the area will be easier managed if the geometry is kept simple.

It's essential to ensure proper positioning over the whole area and this includes line of sight from the total station to the radar array, if a total station is used. Planning for how many different total station positions as well as mapping of reference points (buildings, man-holes, roads etc.) is preferably done prior to radar data acquisitions.

Figure 7. Data acquisition with a 400MHz array, the total station is seen in the background

To control the actual data acquisition, an odometer wheel is used to achieve a precise trace interval (point distance). The odometer is mounted on the carrying vehicle and directly connected to the ProEx control unit. The wheel controls the data acquisition along the survey line while the positioning system logs the position at predefined times/events. When selecting the point distance, one should use at least the channel spacing within the array. To get good data for the radar and the positioning a suitable speed for a survey is roughly 20 km/hour.

The array gathers data at every point interval specified in the MIRA Acquisition software and the operator should keep an eye on the incoming data and positioning during the survey. In Figure 8 below, the paths of the prism/GPS covered by the array are marked by coloured lines, and white areas can be seen between the array swats. These white areas are uncovered by the array and the operator should minimize their occurrence. Minor, uncovered, areas do not result in significantly deteriorated data, though.

Software/processing

Two kinds of software are used to create the final 3D-results from the MIRA systems, MIRAsoft for acquisition and rSlicer for processing and interpretation. The software is currently designed to work under windows 2000/XP. For acquisition it is recommended to use a field rugged laptop.

The acquisitions software is directly controlling the data collection process, including data from the positioning system, as well as performing “real-time” quality check of the gathered data-sets. The process of setting up the array system has been streamlined by default settings for the most common acquisition schemes as well as an easy to use interface. The quality checks are essential since substantial costs are connected with field time and mobilisations and include both single channel monitoring and positioning error analysis.

The rSlicer software is designed to process and interpret data from the 3D-GPR array systems produced by MALÅ. It allows pre-processing, interpolation and 3D migration of the radar data, followed by interactive interpretation of the features observed. The results can be printed out and exported as geo-referenced TIFF files or DXF-files. To our knowledge, rSlicer is the only software which seamlessly imports and enables 3D interpretations. That is; without extensive data manipulations and import procedures. The software is protected by a USB-dongle.

rSlicer is a, modern, project based software containing the processing algorithms commonly used for GPR data as well as the specific functions necessary for 3D data manipulation and interpretation. Among the specific 3D functions are:

- Geometry editing
- Coordinate system transformations
- Binning and interpolation
- 3D-migrations
- feature editing
- ribbon box enabling detailed analysis of sections

In Figure 8, 9, 10 and 11 screenshots from the software are shown.

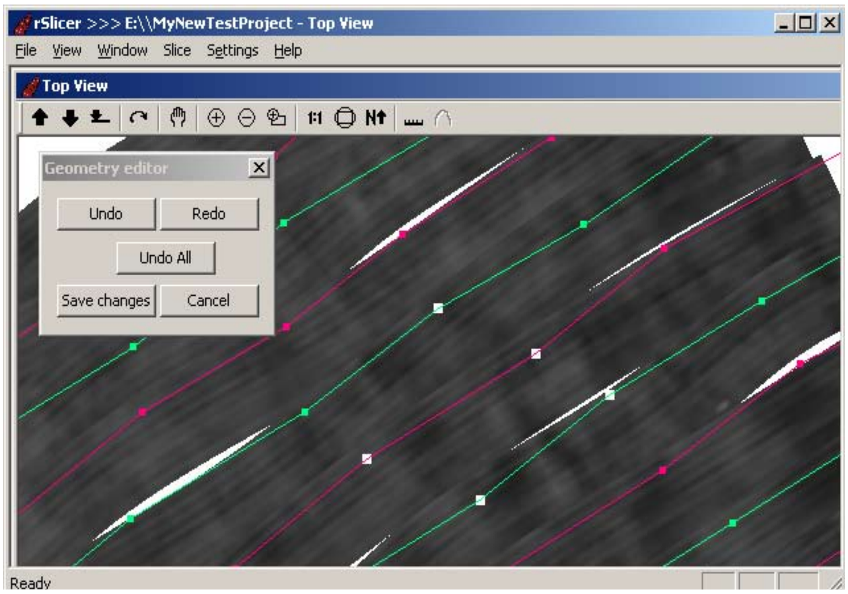

Figure 8. Screen shot from the processing software showing the array paths marked by colored lines and missed areas as white space between the swats.

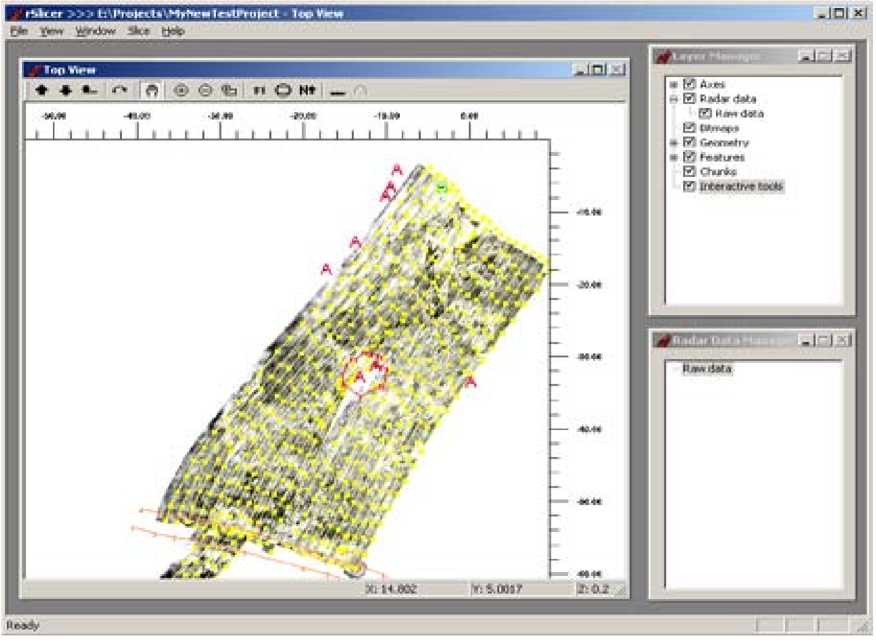

Figure 9. Raw Data displayed on the Top View together with geometry and surface features.

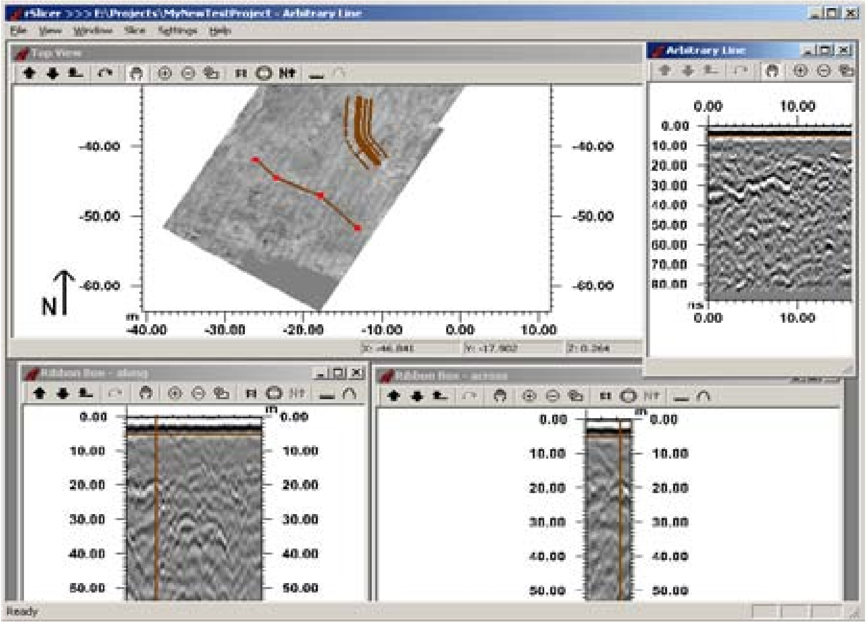

Figure 10. A ribbon box and an arbitrary line (highlighted by red nodes).

Figure 11. Final interpretation results overlaid on local map/site drawing

Accessories

The main parts of the system have been briefly covered in the previous text. In order to perform effective surveys some other, less complicated, tools are necessary, i.e.:

- Marking system for plotting the array paths on ground. This is necessary in order for the operator to ensure proper coverage of the area. It's simply a spray-bottle with remote control, attached to the array and aligned with the centre line of the outmost channel.
- Measuring wheel for control of the data acquisition. Usually this is mounted on one of the wheels of the carrying vehicle, but other designs are possible.
- Power supply. Preferably a connection to the generator of the carrying vehicle is used, if this is not an option, arrangements with portable power sources may be considered. Operation from batteries is possible but will require exchanges during a working day.

Other accessories may be necessary in the specific case/application but it is not possible to outline all options within the scope of this document.

Technical specifications

Control unit- ProEx with array option
Dimension: 222x160x285[mm]
Weight: 5.5 Kg
Power: 3 A@12V, 10-14V operation and possible to supply from car battery
PRF: 2 versions 100 and 200kHz
Time window: 130ns, minimum
Data input: Serial 16-bit
Max no.of channels: 31 channels, handling max 16 receiver antennas and 16 transmitters
Number of samples: up to 1024
Communication: Point to point Ethernet, 100Mbit/s
Positioning input: Compatible with all MALÅ measuring wheels
Environmental: IP65

1.3 GHz antennas
Dimension: 90 x 114 x 85 [mm], (L x W x H)
Weight: 1.5kg/antenna, max
Power: 0.9A@12V/antenna, max, 1.2A/pair
Centre frequency: 1.3GHz, within 10%, measured on reflection off a target in dry sand
Bandwidth: >100%
Cable lengths (coaxial) >10m
Cable connectors: BNC
Power connectors: Tsaye, mick jack line/mic plug chassis, 4 pol
ADC 16-bit.
Data output: 16bit serial
Compliance: EN 302 066-1
Environment: IP65

400 MHz antennas
Dimension: 230 x 165 x 160 [mm], (L x W x H)
Weight: 2.1kg/antenna, max
Power: 0.9A@12V/antenna, max, 1.2A/pair
Centre frequency: 400 MHz, within 10% (measured reflection from target in dry sand)
Bandwidth: >100%
Cable lengths (coaxial) >10m
Cable connectors: BNC
Power connectors: Tsaye, mick jack line/mic plug chassis, 4 pol
ADC 16-bit
Data output: 16bit serial
Compliance: EN 302 066-1
Environment: IP65

200 MHz antennas
Dimension: 455 x 255 x 25 [mm], (L x W x H)
Weight: 4.2 kg/antenna, max
Power: 0.9A@12V/antenna, max, 1.2A/pair
Centre frequency: 200 MHz, within 10% (measured reflection from target in dry sand)
Bandwidth: >100%
Cable lengths (coaxial) >10m
Cable connectors: BNC
Power connectors: Tsaye, mick jack line/mic plug chassis, 4 pol
ADC 16-bit
Data output: 16bit serial
Compliance: EN 302 066-1
Environment: IP65

MALÅ
www.malags.com

Head Office

MALÅ GeoScience AB
Skolgatan 11, SE-930 70
Malå, Sweden
Phone: +46 953 345 50
Fax: +46 953 345 67
E-mail: sales@malags.com

Your Distributor

GPRtech – Australian MALA GPR Distributor
4/105A Ben Boyd Road, Neutral Bay, NSW 2089, AUSTRALIA
Tel: +61 0438 278 902 | Fax: +61 02 9908 1484
Web: www.malagpr.com.au | Email: sales@malagpr.com.au