3. Ground Penetrating Radar Systems

3.1 Sensing principle

Operating principle

Ground Penetrating Radar (GPR) has come into use over the last 20 years in civil engineering, geology and archaeology, for the detection of buried objects and for soil study. The detection of buried landmines has also been a subject of considerable interest, in particular due to radar’s potential for the detection of plastic-cased mines which contain little or no metal. Today, a large number of organisations are working on different parts of GPR systems, and — among all the sensors proposed for humanitarian demining — GPR has had by far the greatest research funding and effort dedicated to it.

GPR works by emitting an electromagnetic wave into the ground, rather than into the air as in many radar applications, using an antenna which does not need direct ground contact. (In other domains direct contact is often required, e.g. non-destructive testing.) GPR systems usually operate in the microwave region, from several hundred MHz to several GHz. Buried objects, as well as the air-ground interface, cause reflections of the emitted energy, which are detected by a receiver antenna and associated circuitry. GPR can produce a fuzzy depth “image” by scanning the suspected area, and/or using an antenna array. The antenna is one of the most crucial parts of a GPR system.

What particularly matters for the detection of objects in a background medium, e.g. mines buried in soil, is the difference between the electromagnetic properties of the target (in particular its dielectric constant) and those of the background (the GPR works as a target-soil electrical contrast sensor). The amount of energy reflected, upon which reliable detection is based, also depends on the object’s size and form. Spatial resolution depends on the frequency used, and the resolution needed to cope with the smaller anti-personnel landmines requires the use of high frequency bands (up to a few GHz). These higher frequencies are, however, particularly limited in penetration depth.

GPR systems can be subdivided into four categories, depending on their operating principle. The first type is an impulse time domain GPR, where the emitted pulse has a carrier frequency, modulated by a nominally rectangular envelope. This type of device operates in a limited frequency range, and has in most cases a mono-cycle pulse. The

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2. The upper frequency band corresponds roughly to that of cellular phones/microwave ovens.
3. The capability to distinguish two closely spaced objects and/or to define the shape of an object. Increased spatial resolution leads to sharper “pictures”, whether real ones in the case of an imaging sensor, or “virtual” ones in the case where an operator interprets a sensor’s output — in demining, typically an acoustic signal — and builds a mental map of it.
second type of time domain GPR is the so-called Chirp Radar, which transmits a pulse-train waveform where the carrier frequency of each pulse is rapidly changed across the pulse width. Frequency domain GPR transmits a signal with a changing carrier frequency over a chosen frequency range. This carrier frequency is changed, either continuously, for example in a linear sweep (Frequency Modulated Continuous Wave Radar, or FMCW), or with a fixed step (stepped frequency radar).

The term Ultra Wide Band (UWB) GPR is generally used for systems operating over a very wide frequency range (in relation to their central operating frequency).

**Application type**

Close-in: hand-held, vehicle-based (arrays)

GPR systems for landmine detection are either designed to provide detection warnings when a mine-like object is located (e.g. an audio signal as is used in metal detectors), or to produce image data. As yet hand-held radar-only systems have not been brought to market, although the use of radar with metal-detectors in dual-sensor hand-held systems is becoming established with extensive trials of prototype equipment. Vehicle-mounted radar systems with a broad sweep have also been developed and field tested, mostly for military applications.

**Strengths**

- Capable of detecting entirely non-metallic objects (e.g. minimum-metal mines).
- Well established for a number of applications (see above).
- Can provide target depth information.
- Could be very useful in stand-alone mode for selected applications (e.g. deep minimum-metal anti-tank mines).
- Rather insensitive to small metallic debris therefore good potential to reduce false alarm rate (FAR) by discriminating clutter from mine-like objects.
- Most mine detection GPR systems use very low power and do not present any radiation hazard.

**Limitations**

- Microwaves are strongly attenuated by certain types of conductive soils such as clay, and attenuation increases with frequency and the water content of the medium. Wet clay in particular provides an extremely challenging environment (penetration is very poor).
- Soil inhomogeneities (roots, rocks, water pockets), very uneven ground surfaces, soil moisture profile fluctuations.
- Very dry soils have a reduced electrical contrast when looking for plastic objects and therefore plastic objects may not be detected.
- Small anti-personnel mines present a considerable challenge.
- Need to balance resolution (better at higher frequencies) with depth penetration (better at lower frequencies).
Potential for humanitarian demining

- Most mature of all alternative technologies, subject of extensive studies and trials.
- Preferred combination is with a metal detector.
- Advanced hand-held prototypes now available for extensive testing.
- Depending on the configuration, the GPR can be confirmatory after the MD, to reduce its false alarm rate.
- Vehicle-based systems mostly developed and tested for military applications (especially route clearance).

Estimated technology readiness:

Medium-High.

Related publications

3. GPR International Conference series (biennial).
3.2 The AN/PSS-14 (HSTAMIDS)/AMD-14

<table>
<thead>
<tr>
<th>Project identification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project name</strong></td>
</tr>
<tr>
<td><strong>Acronym</strong></td>
</tr>
<tr>
<td><strong>Participation level</strong></td>
</tr>
<tr>
<td><strong>Financed by</strong></td>
</tr>
<tr>
<td><strong>Budget</strong></td>
</tr>
<tr>
<td><strong>Project type</strong></td>
</tr>
<tr>
<td><strong>Start date</strong></td>
</tr>
<tr>
<td><strong>End date</strong></td>
</tr>
<tr>
<td><strong>Technology type</strong></td>
</tr>
<tr>
<td><strong>Readiness level</strong></td>
</tr>
<tr>
<td><strong>Development status</strong></td>
</tr>
<tr>
<td><strong>Company/Institution</strong></td>
</tr>
</tbody>
</table>

**Project description**

CyTerra describes the AN/PSS-14 as revolutionizing landmine detection by combining ground penetrating radar (GPR), highly sensitive metal detector (MD) technology and advanced data fusion algorithms in a unique manner that enables the system to reliably and consistently detect low-metallic anti-personnel (AP) and anti-tank (AT) mines. The AN/PSS-14 is claimed further by the manufacturer to offer the highest probability of detection (PD) of any hand-held system along with an extremely low-level false alarm rate (FAR). This high level of performance is also claimed to be maintained across all soil types, including wet, dry, frozen, laterite (iron-rich), clay and sand.

The data fusion algorithms allow the operator to effectively discriminate between clutter and mines. CyTerra notes that the algorithms are based on terrain modelling using a real time novelty (RTN) methodology and that, as the operator advances, the terrain model is continuously updated, enabling the system to automatically adapt to varying soil conditions. Potential mine detection alerts are provided to the operator via audio alert signals.

**Detailed description**

The system combines a GPR and a highly sensitive MD. The AN/PSS-14 is shown in Figure 1.

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Two different audio signals are provided simultaneously to the operator. The MD signal is provided in the traditional format of a metal detector in which the signal varies in volume and pitch depending on the metal type, size and depth. The other audio signal is the output of the data fusion algorithms, also known as the Aided Target Recognition (ATR) algorithms, and is a sharp beep. This beep is generated only when the ATR processing determines that both the GPR and MD data indicates a “mine like” object. Because the MD and ATR sounds are distinctly different they can be present together without distracting the operator as two continuously varying audio signals might. Situation awareness is therefore maintained while allowing full operation of the GPR and MD sub-systems.

The operator cannot turn off (accidentally or deliberately) either the MD or GPR sub-systems. However, audio muting on a temporary basis to allow the operator to better focus on one of the audio signals is available. This feature is particularly helpful when investigating high metal anti-tank mines where the constant high volume of the MD can be distracting to the operator.

A variant of the AN/PSS-14 oriented to humanitarian demining, the AMD-14, is anticipated in 2006 with a significantly reduced list price. The new system will incorporate the same AN/PSS-14 electronics and sensor elements so detection performance will be unchanged (see Figures 2 to 4).
Test & evaluation

The US Army conducted extensive evaluations of the AN/PSS-14 as part of its type classification process prior to moving to full production. Tests ranged from basic environmental style testing to full operational evaluation including comparison with current industry metal detectors. System was deemed to meet or exceed the US Army Operational Requirements for all designated tests.

Operational tests were conducted by US Army Operational Test Command. They compared performance of AN/PSS-14, AN/PSS-12 (Schiebel AN-19 and the current US Army mine detector) and F1A4 (Minelab) using blind lane testing of new operators. Systems in the evaluation were assigned to a platoon of combat engineers with operators given the appropriate specified training course. The AN/PSS-14 standard training class is a 40-hour course and was provided by Contractor/US Army Engineer School.

Test environment comprised 106 mine lanes (1.5m x 25m) with a total of 514 missions (1,096 encounters) performed. Mine types included AT, AP and mixed (AT/AP) of both high metal (M) and low metal (LM) types. Developmental testing results are as follows:

<table>
<thead>
<tr>
<th>System</th>
<th>AP-LM</th>
<th>AP-M</th>
<th>AT-LM</th>
<th>AT-M</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN/PSS-14</td>
<td>98</td>
<td>99</td>
<td>94</td>
<td>99</td>
<td>97</td>
</tr>
<tr>
<td>F1A4</td>
<td>95</td>
<td>96</td>
<td>79</td>
<td>91</td>
<td>89</td>
</tr>
<tr>
<td>AN/PSS-12</td>
<td>80</td>
<td>99</td>
<td>64</td>
<td>99</td>
<td>81</td>
</tr>
</tbody>
</table>

Initial operational test results are described as follows:

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PD %</td>
<td>97</td>
<td>99</td>
<td>99</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAR</td>
<td>0.008</td>
<td>0.009</td>
<td>0.03</td>
<td>0.004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scan Rate</td>
<td>3.2</td>
<td>1.9</td>
<td>1.1</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Systems are available for individual country or organisation evaluation (subject to a suitable US Export License being obtained).

HSTAMIDS has also been undergoing the following operational field trials and demonstration under the ITEP banner, supported by local Mine Action Centres and/or NGOs:

- Thailand, September/December 2004, finalised,
- Namibia, March 2005, finalised,
- Afghanistan, late 2005, finalised.
The Thailand trials are fully detailed in [2] and can be summarised as follows. Participants included the US Humanitarian Demining Team of NVESD (Night Vision and Electronic Sensors Directorate), ITEP personnel, Thailand Mine Action Centre (TMAC), HALO Trust from Cambodia and CyTerra Corporation. The evaluation was conducted near the minefields at the TMAC Humanitarian Demining Action Unit (HMAU) #1.

The test target set was composed of mines that are found in the area of HMAU #1 and mines that are typically used for US Army testing. All mines, detonators, and fuzes were free from explosive. The main charges were replaced with RTV Silicone Rubber 3110. The metal components and characteristics of the mines remained intact. To get statistically significant results, the test was designed so that most mine types were encountered 36 times.

Site setup: brush and vegetation were removed and the ground was levelled to facilitate water drainage. A vehicle-borne magnet was used to remove significant amounts of surface metallic clutter. The test area consisted of ten 1mx25m blind lanes and one 1mx30m calibration lane. All anti-personnel mines were buried 5cm deep, and all anti-tank mines were buried 10cm deep.

Metal detectors were used to locate all indigenous metallic clutter in the lanes. The test targets were then arranged throughout the lane so that they had sufficient separation between them and the clutter. No indigenous clutter was removed from the lanes after being located by the metal detectors. Operators were credited with a detection if they marked a detection within 15cm of the edge of a target, as in all US Army testing of the HSTAMIDS.

According to the authors, the resulting overall detection probability (PD) and False Alarm Rate (FAR) show a reduction in FAR by a factor of five, with increased detection probability with respect to the locally used metal detector. Up to 77 per cent of false alarms have been rejected, with up to an estimated improvement of five times in clearance time.

<table>
<thead>
<tr>
<th>Table 3. Potential reduction of effort</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metal detector (Vallon)</strong> operators</td>
</tr>
<tr>
<td><strong>PD (%)</strong></td>
</tr>
<tr>
<td><strong>FAR (m^-2)</strong></td>
</tr>
<tr>
<td><strong>Total clutter marked</strong></td>
</tr>
<tr>
<td><strong>Clutter called mine</strong></td>
</tr>
<tr>
<td><strong>Clutter rejected</strong></td>
</tr>
<tr>
<td><strong>Time scanning</strong></td>
</tr>
<tr>
<td><strong>Time digging clutter called mine (hours)</strong></td>
</tr>
<tr>
<td><strong>Time saved</strong></td>
</tr>
</tbody>
</table>

*a* Average time saved based on 20 minutes per investigation, using TMAC data for operations in the same area.

**Other applications (non-demining)**

Civil engineering, security, weapons cache searches, in wall searches, through wall detection of people (option fielded to US Military but disclosure requires US Export License).
### Related publications


2. Doheny R.C., S. Burke, R. Cresci, P. Ngan, R. Walls (2005),  
   “Handheld Standoff Mine Detection System (HSTAMIDS) Field Evaluation in Thailand”,  

### Technical specifications

#### CyTerra HSTAMIDS / AMD-14

<table>
<thead>
<tr>
<th><strong>Detector</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Brand:</td>
<td>CyTerra</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Development status</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Status:</td>
<td>Continuous improvement process</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Dimensional data</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Working length:</td>
<td>AN/PSS-14: 96cm, AMD-14: 93cm. AN/PSS-14: 147cm, AMD-14: 166cm.</td>
</tr>
<tr>
<td>12. Search head:</td>
<td>AN/PSS-14: Width: 21cm, AMD-14: Width: 21cm, Height: 10cm</td>
</tr>
<tr>
<td>13. Transport case:</td>
<td>AN/PSS-14: 20kg, AMD-14: 20kg AN/PSS-14: Hardcase 64x53x36cm, AMD-14: Hardcase 95x45x25cm</td>
</tr>
<tr>
<td>14. Weight, hand-held</td>
<td>AN/PSS-14: 4.9 kg (excluding battery), AMD-14: 4.3 kg (excluding battery)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Environmental influence</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Humidity (limitations):</td>
<td>AN/PSS-14: meets and exceeds all US Army Requirements⁰ overall -32°C to +49°C, 0 – 100% humidity. AMD-14: STANAG 2895 A1 (dry desert), B1 (tropical), C1 (cold) and B3 (hot and humid) overall -32°C to +49°C, 0 – 100% humidity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Detection and detection performance specifications</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25. Control of working depth:</td>
<td></td>
</tr>
</tbody>
</table>

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³ MD: similar to Minelab F3.
⁰ AN/PSS-14: meets and exceeds all US Army Requirements overall -32°C to +49°C, 0 – 100% humidity. AMD-14: STANAG 2895 A1 (dry desert), B1 (tropical), C1 (cold) and B3 (hot and humid) overall -32°C to +49°C, 0 – 100% humidity.
27. Detection sensitivity: —  
28. Claimed detection performance:  
   ➢ low-metal-content mines: AN/PSS-14 & AMD-14: Will detect mines presenting an operational threat (PD, PFA).  
   ➢ anti-vehicle mines: AN/PSS-14 & AMD-14: Will detect mines presenting an operational threat (PD, PFA).  
   ➢ UXO: —  
29. Measuring time per position (dwell time): —  
30. Optimal sweep speed: 0.3 to 0.75m/s  
31. Output indicator: AN/PSS-14 & AMD-14: Audio, external speaker or headphones.  
32. Pinpointing feature: Combination of MD and ATR signals  
33. Search head/antenna type: —  
34. Soil compensation capability: All soils  
35. Soil limitations: None  
36. Interference with other detectors as well as from the environment: 5m separation  
37. Other limitations: Power line suppression: Not available.  
38. Other specifications: Test piece: 50mm plastic RTV filled, similar to small AP mines with 10 insert representing metal content of low-metal mines.  

### Power  
39. Power consumption: 30W  
40. Power supply/source: 12V, Battery  
41. Operating time: AN/PSS-14: 4h (Nickel Metal Hydride); AMD-14: 4h (NP-Fx70 series Li-ion)  
42. Power supply:  
   ➢ weight: AMD-14: 0.6kg (Li-ion pair) rechargeable  
   ➢ no. of batteries/size/type: AN/PSS-14: NiMH rechargeable battery.  
   ➢ rechargeable: AN/PSS-14 Battery is mounted externally on operators’ hip belt, therefore system can be adapted to use other batteries, provided basic V/Ahr ratings are met. AMD-14: battery pack mounted on handheld system or on belt with optional cable.  

### Price and availability  
43. Price:  
   ➢ for low volume: AN/PSS-14: 23,500 USD; AMD-14: 12,000 USD (estimate)  
   ➢ operating costs: —  
44. Availability for hire: None  

### Sensor specifications  
45. Active/Passive: Active  
46. Transmitter characteristics: GPR: Stepped frequency, 1-3GHz.  
47. Receiver characteristics: —  
48. Transmitted power: +7 dBm (typical)  
49. Spatial resolution: —  
50. Signal to Noise ratio: —  
51. Detection algorithm: Aided Target Recognition (ATR) employing Principal Component Analysis (PCA) to automatically generate terrain model.  
52. Feature extraction: Background/terrain rather than target modelling, with the GPR looking for objects against a clutter background.  
53. Safety issues: None  
54. Other: Detection algorithms: preset, with no user selectable inputs except for system sensitivity level. GPR: three antennae mounted in a triangular configuration inside the MD coil.  

*Detailed disclosure requires US Export License.*  

**Remarks**  
Metal detector specifications are similar to those of the commercially available Minelab F3.
### Project identification

<table>
<thead>
<tr>
<th>Project name</th>
<th>Handheld Multi-Sensor Mine Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acronym</td>
<td>VMR1-MINEHOUND</td>
</tr>
<tr>
<td>Participation level</td>
<td>National</td>
</tr>
<tr>
<td>Financed/co-financed by</td>
<td>National, UK, Vallon GmbH</td>
</tr>
<tr>
<td>Budget</td>
<td>DFID contract</td>
</tr>
<tr>
<td>Technology type</td>
<td>Metal detector, ground penetrating radar</td>
</tr>
<tr>
<td>Readiness level</td>
<td>Completed</td>
</tr>
<tr>
<td>Development status</td>
<td>Completed</td>
</tr>
<tr>
<td>Company/institution</td>
<td>ERA Technology Ltd; Vallon GmbH</td>
</tr>
</tbody>
</table>

### Project description

The MINEHOUND dual sensor detector combines ground penetrating radar (GPR) and a pulsed metal detector to reduce the false alarm rate normally encountered by metal detectors. This results in improved productivity of mine clearing operations. MINEHOUND was developed for the detection of anti-personnel landmines and hand-held humanitarian operations. It is based on a custom-designed GPR from ERA (UK) and the pulse induction MD-Type VMH3 from Vallon (Germany). The original development (called MINETECT) was developed under the sponsorship of the UK Department for International Development (DFID) and MINEHOUND was additionally supported by the German Foreign Ministry.

### Detailed description

MINEHOUND is a combined metal detector (MD) and GPR system designed specifically for use in humanitarian and military demining operations using advanced technology. The output to the operator from both the metal detector and GPR is by means of audio signals. The metal detector audio provides accurate information on position and mass of metal indication. The GPR provides accurate position information, depth information and radar cross-section of target information. Both detectors can be used together or independently. The manufacturer reports that trials show that the GPR responds to even the smallest of flush buried mines but not to small metal fragments. This results in a large amount of metallic clutter — such as bullet casings, small arms rounds and shrapnel, which cause false alarms — to be rejected by the system. Production systems

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5. The radar cross-section describes how well an object reflects the radar’s incoming electromagnetic waves, and therefore how much “visible” the object is to the radar.
will offer a combined mode to further reduce the time taken to scan the ground and autocalibration for the GPR soil conditions and mineralised soil for the MD.

According to the manufacturer, trials in live minefields show that the FAR can be reduced by a factor of between two and seven times with respect to a standalone MD, and the GPR also detects zero or minimum metal mines that are difficult for the MD. Following initial encouraging results, mine classification is also being further investigated.

The manufacturer also notes that experienced deminers soon gain full performance level with MINEHOUND. Effective training is an important requirement, although this does not require more than one day for experienced deminers.

MINEHOUND uses a state-of-the-art metal detector from Vallon and a custom-designed 1GHz ground penetrating radar designed by ERA Technology Ltd. The GPR is a time domain radar operating at a centre frequency of 1GHz and compliant with international licensing requirements. The GPR transmitter-receiver and associated control and signal processing is mounted on a compact, purpose-designed printed circuit board. A dedicated state-of-the-art digital signal processor (DSP) is used to provide all control and signal processing functions. The operator can select MD or GPR or MD and GPR functions. The GPR will operate in standby mode when not being handled to increase battery lifetime.

**Test & evaluation**

A number of trials have been completed, in particular in the UK (ERA) in July-August 2002, in country trials in Bosnia (NPA) in August 2002, at a US Army site in September-October 2002, real trials in Lebanon (BACTEC) in November-December 2002, again at the same US Army site in September-October 2003, and in the UK (Hurn) in December 2004-February 2005. Further trials were carried out in live minefields in Cambodia, Bosnia and Angola during 2005 (see below).

**MINETECT tests**

**US tests:**
The manufacturer believes that the prototype system has demonstrated that the combined sensor approach is a valid method of achieving the goal of a significant
reduction in false alarms. The results from a US calibration lane for the original development MINETECT-B system were, for all mines, blanks, non-metallic clutter and the following categories of metallic clutter [4]:

- PD=100 per cent at PFA of 0.03 for small metallic clutter;
- PD=100 per cent at PFA of 0.28 for all clutter.

The GPR function was well able to discriminate against small pieces of metal and in some cases was more effective than the MD in detecting minimum-metal anti-tank mines.

**Bosnia 2002:**
Three test sites were used, with the results summarised in full in [6].

**Lebanon 2002:**
Typical FAR rates for an MD and the MINETECT GPR at Lebanese sites, as well as the corresponding false alarm rate reduction, were reported as follows [7]:

<table>
<thead>
<tr>
<th>Site location</th>
<th>MD FAR (m⁻²)</th>
<th>GPR FAR (m⁻²)</th>
<th>Reduction in FAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baraachit 1</td>
<td>2</td>
<td>0.375</td>
<td>5.3:1</td>
</tr>
<tr>
<td>Baraachit 2</td>
<td>1.75</td>
<td>0.5</td>
<td>3.5:1</td>
</tr>
<tr>
<td>Training 1 (BLU)</td>
<td>0.875</td>
<td>0.125</td>
<td>7:1</td>
</tr>
<tr>
<td>Training 1 (BLU)</td>
<td>0.94</td>
<td>0.125</td>
<td>7:1</td>
</tr>
</tbody>
</table>

The typical depth range performance for the GPR in Southern Lebanese soil was also assessed [8] at three different test sites:

<table>
<thead>
<tr>
<th>Mine type</th>
<th>Israeli AP No. 4 (fuze)</th>
<th>Israeli AP No. 4 (no fuze)</th>
<th>VS50</th>
<th>French AP Model 1951</th>
<th>French AT Model 1947</th>
<th>PMA3</th>
<th>BLU15</th>
<th>TM46</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP No. 4</td>
<td>20/–/15</td>
<td>10/–/5b)</td>
<td>15/5/-</td>
<td>13/5/10</td>
<td>20/–/–</td>
<td>–/–/10</td>
<td>15/–/10</td>
<td>30/–/–</td>
</tr>
</tbody>
</table>

a) Training site, Baraachit site and Naquora site, respectively.
b) Not tested deeper because of ground conditions.
– Not available.

**MINEHOUND tests**

**Recent field trials:**
A pre-production version has undergone field trials in real minefields, alongside the currently used MD and under ITEP invigilation. These trials were conducted in Cambodia (September 2005), in Angola with the assistance of Mines Advisory Group (MAG) [1], and in Bosnia (September 2005) with Norwegian People’s Aid (NPA). The Bosnia and Cambodia results should be available in 2006. Additional trials are planned in Angola in 2006.

During these trials the detector was used to follow up an indication from the existing metal detector. MINEHOUND was then used to investigate that alarm and the results
recorded. The alarm was then investigated according to the standing operating procedures (SOPs) of the demining organisation. Approximately 1,000 data records (mine or fragment encounters) were collected for each country and for Cambodia and Bosnia the potential reduction in false alarms ranged from 5:1 to 7.5:1 with 100 per cent detection of mines. In Angola, tests are continuing at additional locations where mines are expected.

**Other applications (non-demining)**

Civil applications such as pipe detection, and other security applications, such as through wall radar.

### Related publications

   *MINEHOUND* tests underway in Cambodia and Bosnia, September, www.itep.ws.

2. Daniels D.J. (2005)  


### Technical specifications

**Vallon/ERA VMR1-MINEHOUND®**

#### Detector

1. **Brand:** Vallon / ERA  
2. **Model:** VMR1-MINEHOUND®  
3. **Version:** —  
4. **Detection technology:** MD, GPR  
5. **Mobility:** Hand-held  
6. **Mine property the detector responds to:** Dielectric characteristics (see GPR Operating Principles) and metal content.

#### Development status

7. **Status:** Production ready late 2006  
8. **Detectors/systems in use/tested to date:** —  
9. **Location of use/test:** Angola, Bosnia, Cambodia, Lebanon  
10. **Other types of detectors/systems:** —

#### Dimensional data

11. **Working length:**  
    - min. length: 66cm from handgrip nominal  
    - max. length: 106cm from handgrip nominal  
12. **Search head:**  
    - size: Width: 17cm (x axis), 30.5cm (y axis)  
    - weight: 1.5kg  
    - shape: Oval  
13. **Transport case:**  
    - weight: 3.5kg  
    - with equipment (full): 8.75kg  
    - dimensions: 103cm x 34cm x 25cm  
    - hard/soft case (material): Case with foam insert  
14. **Weight, hand-held unit:** 4.1kg  
15. **Weight, vehicle-based sensor unit:** —  
16. **Weight, additional equipment:** —  
17. **Weight distribution/balance:** Batteries are housed in a compartment opposite the search head to provide a counterbalance, but can be removed and the detector connected to a belt battery (weight reduction by nearly 1kg).

18. **Other dimensional specifications:** —

#### Environmental influence

19. **Humidity (limitations):** —  
20. **Temperature (limitations):**  
    - storage: MD: -55°C to +75°C  
    - operational: -10°C to +45°C. MD: -32°C to +65°C.  
21. **Water resistant:** Up to 1.5m  
22. **Shock/vibration resistant:** MD: according to MIL STD 810 F 514.5 C1  
23. **Environmental compensation:** MD: all soil conditions  
24. **Operational hours/operating endurance:** 5 hours

#### Detection and detection performance specifications

25. **Control of working depth:** Audio  
26. **Calibration/set-up:**  
    - auto/manual: MD: auto; GPR: auto  
    - duration: A few seconds  
27. **Detection sensitivity:** —
28. Claimed detection performance:
   - low-metal-content mines: Max depth range: 20cm, PD>0.98, PFA<0.25 for all clutter and PFA<0.08 for small metal fragments.
   - anti-vehicle mines: Max depth range: 40cm, PD>0.98, PFA<0.25 for all clutter and PFA<0.08 for small metal fragments.
   - UXO: —

29. Measuring time per position (dwell time): —
   Optimal sweep speed: <1.5m/s

30. Output indicator: Audio (min/max output frequency: 150/1500Hz) and visual (LED bar showing MD detected signal level).

31. Pinpointing feature: Maximum signal over centre of target

32. Search head/antenna type: Oval MD head containing one transmit and one receive GPR antenna.

33. Adjustment of search head angle: Freely adjustable

34. Soil compensation capability: MD: normal/conductive soil.
   GPR: salt water and heavy clay.

35. Soil limitations: MD: min distance 2m
   as well as from the environment: No problem

36. Interference with other detectors: None

37. Other limitations: Demining environmental conditions: all world. Supervisor can control additional settings (target type, sensitivity mode, time/depth range control).

Power

39. Power consumption: —

40. Power supply/source: Batteries

41. Operating time: >4hrs continuous, >4hrs at 20min on and 20min off. MD: up to 25 hrs.

42. Power supply:
   - weight: 650 g
   - no. of batteries/size/type: 4x1.5 V rechargeable 8 Ahrs D cells
   - rechargeable: Yes
   - other: Alkaline D-Cells

Price and availability

43. Price:
   - for one detector: —
   - operating costs: —

44. Availability for hire: Yes

Sensor specifications

45. Active/Passive: Active

46. Transmitter characteristics: GPR: centre frequency: 1GHz

47. Receiver characteristics: Automatic gain set-up.

48. Transmitted power: —

49. Spatial resolution: —

50. Signal to Noise ratio: —

51. Detection algorithm: —

52. Feature Extraction: —

53. Safety issues: None

54. Other: MD operating programmes: Normal/Conductive soil. MD: power line suppression: Yes. GPR: type selectable (AP/AT), sets the value of average removal.

Remarks

Supervisor can set up and optimise the GPR settings for a specific operational scenario.

a) Excluding salt water and heavy clay for GPR.
b) For anti-personnel mines of diameter >5cm with up to 10cm cover, anti-tank mines of diameter >15cm with up to 20cm cover.
### Project identification

<table>
<thead>
<tr>
<th>Project name</th>
<th>Mine Stalker</th>
<th>Technology type</th>
<th>Ultra-wideband ground penetrating radar (WGPR)</th>
</tr>
</thead>
</table>
| Acronym                 | —                     | Readiness level | ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ⬤ ......
Detailed description

System
- Remote controlled.
- Very low ground pressure in the configuration shown in Figure 1 (anti-tank overpass, not anti-personnel overpass).
- Visible marking system.
- Flashing light, horn and auto-halt for detections.

Radar
- Ultra-wideband ground penetrating radar developed specifically for vehicle-mounted mine detection.
- Can be mounted on various platforms.
- Remote subsurface visualisation.

Algorithm
- Automatic target recognition algorithms.
- Detects all anti-tank mines including hard to detect plastic mines such as the South African #8, VS1.6, and VS2.2.
- Detects large AP mines such as PMN and PPM-2.

Test & evaluation

During US Army testing from 2002 to 2005, the NIITEK GPR performance far exceeded expectations. It demonstrated a higher probability of detection and lower false alarm rate against metal and plastic cased anti-tank mines than any other vehicle-based GPR evaluated to date.

Recently, in October 2005, the Mine Stalker was tested at a US built test site in Namibia and then completed a field evaluation in Angola. A real-time, non-discriminating, pre-screener algorithm processed the GPR data to automatically detect targets. At the Namibia test site, 42 individual AT mines were buried in 10 test lanes. Nineteen per cent of the targets were metal AT mines and eighty-one per cent were low-metal AT mines. The Mine Stalker encountered a total of 252 AT mines and covered 1,800m². The pre-screener algorithm achieved a probability of detection of 0.996 with a false alarm rate of 0.079 per square metre.

Figures 3 and 4. Mine Stalker GPR imagery taken during Namibia testing (a) metal AT mine and (b) plastic-cased, low-metal AT mine.
The field evaluation in Angola was conducted in cooperation with the German NGO Menschen gegen Minen (MgM). MgM deminers operated the Mine Stalker throughout the evaluation. Four previously cleared areas were selected for the field evaluation. The primary objective of the evaluation was to evaluate the effectiveness and reliability of the Mine Stalker under field conditions. Data collection in realistic minefield conditions was the second objective. The Mine Stalker was extremely reliable during the evaluation with no significant maintenance issues. All AT mines used to verify GPR performance were detected, even when buried to depths as deep as 25-33cm.

Other applications (non-demining)

Subsurface visualisation, non-intrusive inspection, buried object detection and counterdrug.

Related publications


### Technical specifications

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Used detection technology:</strong></td>
<td>WGPR, ultra-wideband GPR</td>
</tr>
<tr>
<td><strong>2. Mobility:</strong></td>
<td>Vehicle-based</td>
</tr>
<tr>
<td><strong>3. Mine property the detector responds to:</strong></td>
<td>Shape, size, and internal structure</td>
</tr>
<tr>
<td><strong>4. Detectors/systems in use/tested to date:</strong></td>
<td>Many in US Army field tests and one in Africa.</td>
</tr>
<tr>
<td><strong>5. Working length:</strong></td>
<td>Not applicable</td>
</tr>
<tr>
<td><strong>6. Search head:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size: 1.2m x 1.5m x 0.25m, as shown in Fig. 1</td>
</tr>
<tr>
<td></td>
<td>Weight: 45kg (100lbs) for detection and marking subsystem</td>
</tr>
<tr>
<td></td>
<td>See Fig. 1</td>
</tr>
<tr>
<td><strong>7. Weight, hand-held unit, carrying (operational detection set):</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>Total weight, vehicle-based unit:</strong></td>
<td>295kg (650lbs) as shown in Fig. 1</td>
</tr>
<tr>
<td><strong>8. Environmental limitations (temperature, humidity, shock/vibration, etc.):</strong></td>
<td>NIITEK GPR has temperature compensation features. No other environmental limitations have been identified to date.</td>
</tr>
<tr>
<td><strong>9. Detection sensitivity:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>10. Claimed detection performance:</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low-metal-content mines: Performance depends more on size</td>
</tr>
<tr>
<td></td>
<td>Anti-vehicle mines: Nearly 100% in all tests to date</td>
</tr>
<tr>
<td></td>
<td>UXO: 100% in limited test to date</td>
</tr>
<tr>
<td><strong>11. Measuring time per position (dwell time):</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>Optimal sweep speed:</strong></td>
<td>1-15 km per hour (depending on application)</td>
</tr>
<tr>
<td><strong>12. Output indicator:</strong></td>
<td>LED lights, audible tones/voice, visible mark on ground</td>
</tr>
<tr>
<td><strong>13. Soil limitations and soil compensation capability:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>14. Other limitations:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>15. Power consumption:</strong></td>
<td>Fully functional from vehicle power</td>
</tr>
<tr>
<td><strong>16. Power supply/source:</strong></td>
<td>Onboard vehicle power</td>
</tr>
<tr>
<td><strong>17. Projected price:</strong></td>
<td>Undetermined</td>
</tr>
<tr>
<td><strong>18. Active/Passive:</strong></td>
<td>Active</td>
</tr>
<tr>
<td><strong>19. Transmitter characteristics:</strong></td>
<td>Ultra-wideband GPR</td>
</tr>
<tr>
<td><strong>20. Receiver characteristics:</strong></td>
<td>Ultra-wideband GPR</td>
</tr>
<tr>
<td><strong>21. Safety issues:</strong></td>
<td>—</td>
</tr>
<tr>
<td><strong>22. Other sensor specifications:</strong></td>
<td>—</td>
</tr>
</tbody>
</table>
3.5 Advanced Landmine Imaging System (ALIS)

**Project description**

ALIS, the Advanced Landmine Detection System, is a hand-held dual sensor for anti-personnel landmine detection, which can visualize the metal detector (MD) and ground penetrating radar (GPR) signals for the benefit of deminers. The visualized metal detector signal image provides a direct information about the location of metallic objects, and then the GPR gives the radar image of the buried objects, which can be used to detect landmines. According to the developer, the visualisation system increases the reliability of operation. The locus (position in space) of the sensor head scanned by the deminer can also be recorded in real time. This record can be used for the quality control of the operation, and also for the training of operators.

**Detailed description**

ALIS combines a MD and a GPR. The sensor signals from the metal detector and GPR are stored in a PC, which provides both detection and sensor position information. The entire system is controlled by a PC which is carried inside a backpack worn by the deminer. The deminer monitors the metal detector signal displayed on a handheld display or PDA and scans the ALIS sensor as shown in Figure 1. The same image which the deminer is looking at is transmitted by wireless LAN to a handheld PC display, allowing several operators to also monitor the operation. For the normal operation of ALIS, one operator scans the sensor and another operator controls and monitors the sensor signals.

![Figure 1. ALIS and details of the search head.](image)
The scanning by ALIS follows a procedure that is similar to the normal hand-held metal detector. A deminer stands at the front of the boundary of a safe zone, and scans an area of about 1m x 1m. Continuous scanning is recommended, even if the deminer detects an anomalous signal from the metal detector. One set of data acquisition by ALIS takes several minutes, which is almost equivalent to the time required for normal scanning operation of a conventional MD.

After scanning the area, the acquired data sets are processed using the PC. First, all acquired data sets are transformed to a regular grid of points. An interpolation algorithm is used for this process. The full processing usually requires one to a few minutes until all the data sets are displayed. Subsequently, ALIS provides a horizontal (plan) visual image of the metal detector signal (Fig. 2a) and 3-D GPR information. The 3-D GPR information is, however, usually too detailed and cluttered for interpretation on site, so the displays of horizontal time slices (C-scans) of the GPR signal (Fig. 2b) are preferred instead. In the developer’s experience, the detection of buried landmines with the horizontal time slice image is the most reliable.

After processing and generating the signal images, one can locate/designate the suspect position on the display. Currently, the data is interpreted manually. First, anomalies appearing in the metal detector image are detected. Normally this is quite easy, but it includes many signals due to metal fragments and other objects (i.e. false alarms). After marking the location of these anomalous points on the GPR horizontal slice image, the operator can move the depth of the horizontal slice images trying to find a continuous image that can correspond to a GPR image of buried landmines. A semi-automatic detection algorithm can be used to get advice during the manual interpretation procedure.

Another unique feature of ALIS is its compatibility with conventional landmine detection operations, as it requires, according to the developer, minimum modification of the operational procedures. The ALIS is an add-on system that can be attached to an existing commercial metal detector (e.g., CEIA MIL-D1). The performance of the metal detector is not altered by adding the ALIS system: the operator still hears the audio tone signal from the metal detector, and can detect anomalies using its own experience.

**Test & evaluation**

ALIS was evaluated at several locations, including tests in Kabul City, Afghanistan, in December 2004. The field tests were conducted at two locations: the first site (CDS: Central Demolition Site) was a controlled flat test site, prepared for the evaluation of

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7. Note: *a priori* this does not apply to all metal detectors.
landmine sensors; the second site (Bibi Mahro Hill) is a small hill inside Kabul City, which is a real minefield where a demining operation was being carried out.

At the CDS site, the operation of the ALIS for known targets could be validated under various conditions. The soil in the CDS site was relatively homogeneous, although much clutter was found in the raw GPR profile. Metal fragments had basically been removed from the soil before the evaluation was carried out. After migration processing\(^8\) of the GPR data, in most cases clear images of buried landmines could be found. The climatic conditions during the field tests were partly rainy, and water content of the soil at the CDS site was about 10 per cent, corresponding to a dielectric constant of 5.3. Real PMN-2 and Type 72 landmines without boosters were buried at the CDS site at different depths between 0 and 20 cm. The metal detector could only detect landmines buried shallower than 15 cm, whereas GPR could show clear images of landmines which were buried up to a depth of 20 cm. Metal fragments do not show clearly on the GPR images, and could therefore be discriminated from landmines using ALIS. Figure 2 shows an example of the ALIS output for an inert PMN-2 mine, which was buried at 10 cm. Both MD and GPR images are clear in this case.

Bibi Mahro Hill is a small hill near the Kabul airport. The soil in this site is very non-homogeneous, and contains many small objects such as gravel, pieces of wood and metal fragments. At the calibration site in Bibi Mahro Hill, a PMN-2 plastic shell model filled with TNT explosive was buried; it also contained a small metal pin imitating the metallic part of a booster in a real landmine. In addition, a small metal fragment was added at about 15 cm from the landmine model. Figure 5 shows the corresponding ALIS visualisation output. Figure 5(a) is the MD image, which features two separated metal objects.\(^9\) Figure 5(b) shows the GPR image, in which only one clear image could be found that corresponds to the landmine model. (The images in Figure 2 and Figure 5 have a 20cm offset between MD and GPR.)

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8. Software refocusing of the GPR data after data acquisition.
9. The CEIA MIL-D1 has a differential signal output. A single metal object shows therefore a symmetric response with a null point at the centre, right above the object.
Other applications (non-demining)

The ALIS stepped-frequency GPR is capable of operating in the 100MHz-4GHz frequency range. The operational frequency range can be adaptively selected as a function of the soil conditions, mainly its moisture. This unique feature is useful not only for landmine detection, but also for other applications. Especially, its capability in the lower frequency range allows using ALIS for environmental studies including ground water monitoring and detection of buried utilities, e.g. pipes.

The sensor head of the ALIS is small, and is also suitable also as a sensor unit for a robot arm mounted on a vehicle as shown in Figure 6. In this case the scanning speed can be increased due to higher accuracy of the sensor positioning.

![Figure 6. ALIS mounted on a vehicle during field tests in Croatia.](image)

### Related publications


   “Pre-stack migration applied to GPR for landmine detection”, *Inverse Problems*, 20, pp. 1-17.


Technical specifications | Tohoku University ALIS
---|---
1. Used detection technology: | Metal Detector and GPR Visualisation
2. Mobility: | Hand-held (vehicle-based possible)
3. Mine property the detector responds to: | Dielectric characteristics (see GPR Operating Principles) and metal content.
4. Detectors/systems in use/tested to date: | Two prototypes
5. Working length: | —
6. Search head: | —
   - size: | 30cm diameter, 20cm height
   - weight: | ca. 2kg
   - shape: | Round (CEIA MIL-D1)
7. Weight, hand-held unit, carrying (operational detection set): | ca. 6kg
   - Total weight, vehicle-based unit: | —
8. Environmental limitations (temperature, humidity, shock/vibration, etc.): | —
9. Detection sensitivity: | —
10. Claimed detection performance: | —
   - low-metal-content mines: | Max 20cm depth (PMN-2)
   - anti-vehicle mines: | Not applicable
   - UXO: | Not applicable
11. Measuring time per position (dwell time): | 2-3 min/m²
   - Optimal sweep speed: | 30cm/s
12. Output indicator: | PDA Display
13. Soil limitations and soil compensation capability: | Equivalent to CEIA MIL-D1
14. Other limitations: | —
15. Power consumption: | —
16. Power supply/source: | DC12V car battery
17. Projected price: | —
18. Active/Passive: | Active
19. Transmitter characteristics: | 100MHz-4GHz Stepped Frequency
20. Receiver characteristics: | Synchronized to Transmitter
21. Safety issues: | —
22. Other sensor specifications: | —