Metal Detectors for Humanitarian Demining: a Patent Search and Analysis

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Disclaimer

The following references to or inclusion of specific patents are not all-inclusive and do not represent endorsement of specific systems, techniques or manufacturers.

1. Introduction

Detection and clearance are still being very often carried out in Humanitarian Demining using manual methods as the primary procedure. When operating in this way the detection phase still relies heavily on metal detectors, whereby each alarm needs to be carefully checked until it has been fully understood and/or its source removed. This is normally done visually, and by prodding and/or excavating the ground. Metal detectors are still to the best of our knowledge, apart from dogs, the only detectors really being used in the field, and are probably going to remain in use for some time.

Metal detectors cannot unfortunately differentiate a mine or UXO (Unexploded Ordnance) from metallic debris. In most battlefields, but not only there, the soil is contaminated by large quantities of shrapnel, metal scraps, cartridge cases, etc., leading to between 100 and 1,000 false alarms for each real mine. Each alarm means a waste of time and induces a loss of concentration. Note that when manual methods follow other procedures, such as mechanical clearance, constraints on the need to check each alarm are often somewhat relaxed.

When looking at the actors dealing with metal detectors we are confronted on the one hand with a relatively small market in which mostly SMEs operate, on the other with a scientific community which is not always aware of the practical problems linked to the actual production of equipment and its operation under field conditions (e.g. the importance of ground signals). Manufacturers do not tend to participate to scientific conferences and workshops, and rely mostly on patents, of which the scientific community is not always aware, to protect their intellectual property.

This work, carried out within the framework of the European IST EUDEM2 survey activity (http://www.eudem.vub.ac.be/), does therefore aim at bridging the previously mentioned gap. It focuses on the metal detector technology and details a corresponding patent search and analysis. To increase cross-fertilization opportunities interesting patents in fields other than humanitarian demining (e.g. security applications or Non-Destructive Testing) have also been integrated whenever possible and appropriate.

2. A Brief Introduction to Metal Detectors

Electromagnetic induction devices, which are the ones often referred to when speaking of “metal detectors”, are active, low frequency inductive systems. They are usually composed of a search head, containing one or more coils carrying a time-varying electric current. The latter generates a corresponding time-varying magnetic field that “propagates” towards the metallic target (and in other directions as well). This primary (or incident) field reacts with the electric and/or magnetic properties of the target, usually the soil itself or a solid structure, and any metallic object contained in it. The target responds to it by modifying the primary field or, as a more accurate description, by generating a secondary (or scattered) magnetic field. This effect links back into the receiver coil(s) in the search head, where it induces an electrical voltage which is detected and converted, for example, into an audio signal.

The secondary field depends, both temporally and spatially, on a large number of parameters: the problem’s geometry (object distance and orientation), the object’s properties (shape, size, conductivity and permeability), the temporal and spatial distribution of the primary field and, last but absolutely not least, the presence of any background signal (in particular the ground itself in the case of buried objects!). Note that at the frequency range of interest we are basically insensitive to the target’s dielectric properties. Target characterization is very difficult in the general case, but there are a number of situations where some (limited) statements on its nature can be issued.

The secondary field is due to eddy currents, which are induced by the primary field in nearby conductive objects. Low conductivity metals, such as some alloys and stainless steel, are in general more difficult to detect, whereas the detector’s response is magnified for ferromagnetic objects due to the high value of their relative permeability μ_r (induced magnetization). Magnetic effects can play a substantial role, in particular for ferromagnetic objects at the lower frequency range.

Eddy currents are due to time-varying magnetic fields and are basically governed by the law of induction (Faraday’s Law). They circulate mostly on the surface of the metallic target (“skin effect”), which explains why metal detectors are mostly surface area detectors. As a rule of thumb, larger objects will generate more eddy currents, but an object with twice the surface will not be found twice as deep; indeed, the field decreases very rapidly with distance.

Metal detectors can be schematically subdivided in Frequency Domain (FD), or Continuous Wave (CW), and Time Domain (TD) systems.

Frequency Domain instruments make use of a discrete number of sinusoidal signals, very often just one. Single coil and separate transmit/receive circuits are possible. Information on the target's nature is contained in the amplitude and phase of the received signal, or equivalently in the real and imaginary part of the probe's complex impedance, as the detector approaches the target. Their measurement in background conditions can be used to reject part of the background signal itself, especially in areas in which the detector's performance would otherwise be seriously degraded[1], such as sea beaches (salt water is conductive) or strongly mineralized regions (containing for example bauxite, laterite, magnetite or magmatite), which can be conductive or iron rich, as found in parts of Cambodia, Mozambique and Angola. Generally speaking, background rejection is more difficult in non-homogeneous areas.

Frequency Domain systems have often been the choice for mine detection because the seem to work well especially for very small and close objects, except where ground conditions are severe and request the use of pulsed systems. The possibility of using an array of frequency domain detectors is somewhat complicated by interference effects between neighbouring systems.

Most modern Frequency Domain metal detectors do in fact use separate transmit/receive circuits and operate in the VLF region of the spectrum, typically between a few kHz and a few tens of kHz (say 1-50 kHz). For this type of detectors the coils are often arranged to have as low a mutual inductance as possible when no object is present (i.e. minimize direct coupling if we talk of transmitted and received field), in order to enhance the contrast between the situation with presence and with absence of signal. They are therefore usually referred to as *Induction Balance* systems. In such a setup the position of the coils can therefore be critical, for example in presence of large temperature gradients and/or of mechanical stress (coil flexing) which can influence the coil coupling.

Time Domain, or "**Pulse Induction**", instruments work by passing pulses of current through a coil (typical repetition rate of the order of 1 kHz), taking care to minimise the current switch-off time (a few µsec). Eddy currents are thus induced in nearby conductive objects; the exponential decay of the corresponding secondary magnetic field, which is slower than the primary one, is observed with time. A Time Domain metal detector measures in other words how quickly the momentarily generated magnetic field breaks down, which happens to be slower in presence of metal.

The eddy current decay time constant itself, some tens (short) to hundred µsec, depends (predominantly) on the target's conductivity, permeability and size. Low conductivity background and nuisance items, such as sea water and thin foils for example, have a very short decay time. A pulse detector, which is tuned to sample only a specific portion of the received signal, can therefore be "easily" made insensitive to them by an appropriate choice of the delay (some tens of µsec) between switch-off and sample. A similar argument applies to purely magnetic but non-conductive targets, which are magnetised by the transmit pulse but demagnetise just as promptly after switch-off. On the other hand it was true until a few years ago that overall sensitivity is probably reduced too in comparison with Frequency Domain detectors, and there can be problems in finding low conductivity metallic object such as those made of stainless steel.

Given that the transmit and receive phase are temporally separated – the received waveform is (usually!) sampled during the time in which the transmitter is off – pulse detectors can use one and the same coil for transmitting and receiving; the decoupling of the two phases also allows to work with high power, and therefore in practice to go deeper (increased sensitivity due to higher field strength). Power consumption might obviously become an issue, and the presence of a large inductance (due for example to a large number of turns and/or a large area of the transmitter coil) can cause switch-off problems.

Pulse systems are often the detector of choice when it comes to working in salt water or strongly mineralised soils; they are however increasingly challenging CW systems, and not only where conditions are severe.

Time Domain systems are inherently broadband and sample therefore a larger portion of the VLF electromagnetic spectrum. This information is however often not used directly, for example when the received signal is sampled only in a few points, or when its integral over a time window is used.

3. General Patent Information and Structure

A patent is a form of personal property that provides the owner with the exclusive right to make, use or sell the invention described in the claims of the patent, and is valid for a period of 20 years from the date of filing. Patents and published patent applications are public documents and not protected by copyright.

Patents can be very helpful as starting point for a new invention or a further development; this is particularly true when there is otherwise a lack of information, as in the case of metal detectors. The technical know-how is often explained in detail including diagrams, flowcharts and other useful graphical information; the description of the state of the art of the technology is also often quite useful. On the other hand patents are not scientific publications as commonly found in research papers for example; the reader has therefore to read quite often between the lines and cope with the typical jargon used in these documents.

The form of a patent looks similar in all states. The important parts like author names, dates, abstracts, etc. can easily be found in all kind of patents. Most of the patents listed in this report are of US origin and therefore we will focus on these to briefly describe their different parts.

3.1 The Front Page

On the front page of a US patent a lot of useful information is presented; it is particularly helpful when searching for other similar patents. On the left side of every line there is an index in brackets. The title is equivalent to [54] for example. The same indices can also be found in patents of most other states. Very useful may be the cited references [56] where the numbers of other patents dealing with a similar topic are listed. A search after the classification numbers [51], [52] and [58] can also lead to good results.

The classification number consists of two numbers separated by a slash: the first indicates the main class, the second the subclass. For our search only one main class was relevant: class 324 standing for ELECTRICITY: MEASURING AND TESTING. The most frequently used subclasses are:

233	MAGNETIC: With means to create magnetic field to test material; With phase sensitive element
225	MAGNETIC: With compensation for test variable
326	OF GEOPHYSICAL SURFACE OR SUBSURFACE IN SITU; For small object detection or location
327	OF GEOPHYSICAL SURFACE OR SUBSURFACE IN SITU; For small object detection or location; Using oscillator coupled search head
328	OF GEOPHYSICAL SURFACE OR SUBSURFACE IN SITU; For small object detection or location; Using oscillator coupled search head; Of the beat frequency type
329	OF GEOPHYSICAL SURFACE OR SUBSURFACE IN SITU; For small object detection or location; Using movable transmitter and receiver

The meaning of other US classification numbers and the international classification numbers [51] are detailed at, respectively:

http://www.uspto.gov/go/classification/

http://classifications.wipo.int/fulltext/new_ipc/ipc7/eindex.htm.

Where an application is performed on the basis of a foreign patent, this is marked by the index [30]. In general the number of the original patent and the date when it was accepted by the foreign state are reported.

3.2 The Main Parts of a Patent

The whole document can be divided in three main parts: the description, the image section and the claims. The description gives a detailed view of the invention. In the text explanatory images are described which can be seen in the image section, whereas the inventor's claims are defined and numbered in the claims section.

On many websites (see section 7) patents can be downloaded in PDF form for free but only one page at the time. On the websites of the patent offices the complete documents can usualy be ordered for a fee either in PDF or in paper form.

4. Classification of the Collected Patents

In order to offer the best possible overview of the existing patents and to help the reader in locating the most relevant ones we decided to classify them in several different classes according to their main topic, and to afterwards categorise them in order of importance.

4.1 Classification after the Topic

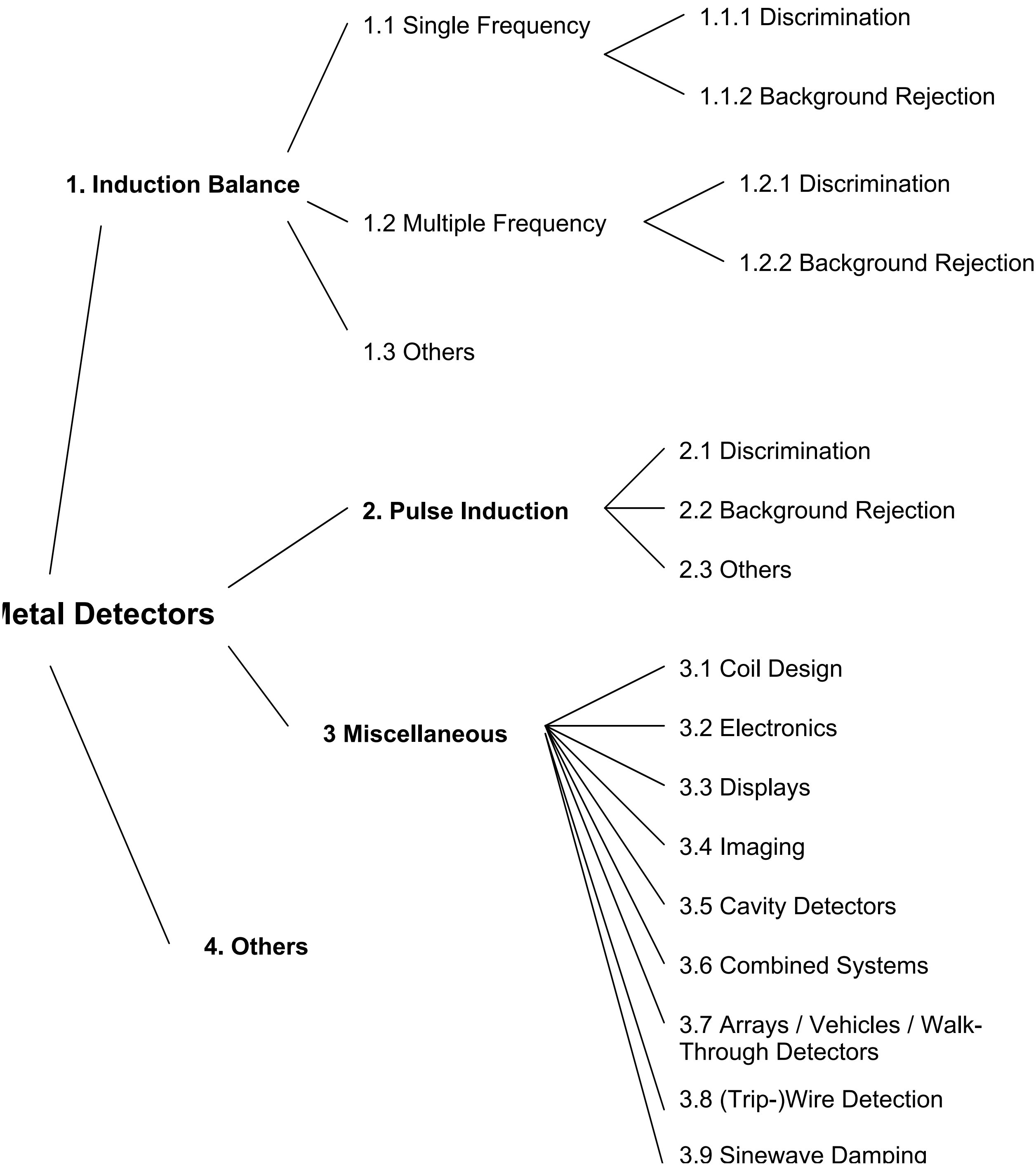
As discussed above the classification presented in this report is an internal one. The classification should help the user to find a searched patent of a special topic as fast as possible. A clear classification of every patent was sometimes not possible, because some patents fulfilled the criteria of more than one category. As an example in most of the patents focusing on the discrimination of objects various aspects related to the background rejection are also mentioned. In those cases the patent is classified after its main idea.

The patents are divided in four main classes, as shown in Figure 1. The *Induction Balance*[2] class contains all patents describing frequency domain sensors working according to the induction balance principle. The time domain sensors are in the *Pulse Induction* class. The *Miscellaneous* class contains all patents that concentrate on special hard- or software features. All other metal detector patents more loosely related to our main topic have been archived in the *Others* class. *Induction Balance* and *Pulse Induction* are mainly subdivided in a *Discrimination* class and a *Background Rejection* class. The *Discrimination* classes concentrate on systems able to distinguish between different types, sizes or shapes of targets, whereas the *Background Rejection* classes contain various techniques to subtract the unwanted ground signal, originating from the fact that the searched target is buried in the soil, from the total received signal.

4.2 Categorisation after the Importance

Furthermore the patents are divided in three categories according to their importance. Those that seem to represent the most important ones are marked bold with a star in front of the patent number. We call these patents *Reference Patents*. In this first category fall the patents with an absolutely new invention in the given field. The second category – the *Important Patents* – is also marked bold. These are also interesting patents because they include good explanatory text or illustrative drawings, etc. The third category includes all the other patents we found on a given topic and is not highlighted.

The patents in the first and second category, i.e. the most important ones, are summarized so as to help the reader focus on their new and/or most important parts.



Principle

Figure 1: Schematic view of the patent classes and subclasses used in this work

5. Overview of the Collected Patents

*** XY 1,234,567** Reference Patent
XY 1,234,567 Important Patent
XY 1,234,567 other Patent

"Date of Patent" indicates when the patent or pat
application with the corresponding number in the
column was published by the patent office.

1. Induction Balance

1.1 Single Frequency

1.1.1 Discrimination

Number	Inventor	Assignee	Date of Patent	Title / [Basic Idea]
US 5,786,696	**Weaver et al.**	**Garrett**	**Jul. 28, 1998**	**Metal Detector for Identifying Target Electrica Characteristics, Depth and Size [Fourier trans signal, energy of freq. band is used for identi Two RX coils to calculate object depth.]**
*** US 4,486,713**	**Gifford**		**Dec. 4, 1984**	**Metal Detector Apparatus Utilizing Controlled Response to Reject Ground Effects and to Discriminate between Different Types of Meta [variable rotation angle of sample axis, variab factor]**
US 6,172,504	Earle	White's	Jan. 9, 2001	Metal Detector Target Identification Using Flash Analysis [phase windows corresponding to the di targets]
US 4,507,612	Payne	Teknetics	Mar. 26, 1985	Metal Detector System for Identifying Targets in Mineralized Ground [motion detector to move fro detection to identification in mineralized ground]
US 4,024,468	Hirschi	White's	May 17, 1977	Induction Balance Metal Detector with Inverse Discrimination [Inverse discrimination: Signals be threshold are amplified]
US 4,016,486	Pecori	US Army	Apr. 5, 1977	Land Mine Detector with Pulse Slope, Width and Amplitude Determination Channels [slope, pulse and amplitude check. AND connected]

1.1.2 Background Rejection

Number	Inventor	Assignee	Date of Patent	Title / [Basic Idea]
US 4,783,630	**Shoemaker**	**White's**	**Nov. 8, 1988**	**Metal Detector With Circuits for Automatically Screening Out the Effects of Offset and Miner Ground [automatic ground exclusion balance**
US 4,628,265	Johnson et al.	FRL	Dec. 9, 1986	Metal Detector and Classifier with Automatic Compensation for Soil Magnetic Minerals and Se Misalignment [automatic compensation of minera and misalignment of coils]

US 4,514,692	Johnson et al.	FRL	Apr. 30, 1985	Metal Detector and Discriminator Using Different Background Signal Suppression [double differen employed to eliminate signals from the ground]

1.2 Multiple Frequency

US 3,686,564	**Mallick, Jr. et al.**	**Westinghouse**	**Aug. 22, 1972**	**Multiple Frequency Magnetic Field Technique Differentiating between Classes of Metal Obje and detection of more than one frequency]**

1.2.1 Discrimination

***DE 196 48 834**	**Patzwaldt**	**Förster**	**May 28, 1998**	**Method for the Operation and for the Evaluati Signals from an Eddy Current Probe and Devi Performing the Method [combination of differ signals to realise a better discrimination. Sim target model (loop), ferromagnetic objects als considered.]**
*** US 5,642,050**	**Shoemaker**	**White's**	**Jun. 24, 1997**	**Plural Frequency Method and System for Ider Metal Objects in a Background Environment I Target Model [discrimination by the ratio of L skin factor]**
US 4,263,551	**Gregory et al.**	**Georgetown University**	**Apr. 21, 1981**	**Method and Apparatus for Identifying Conduc Objects by Monitoring the True Resistive Con of Impedance Change in a Coil System Cause Object [characteristic diagram when plotting component / frequency against frequency. Al signatures from complex objects.]**
US 5,654,638	Shoemaker	White's	Aug. 5, 1997	Plural Frequency Method and System for Identify Metal Objects in a Background Environment
DE 44 36 078	Eschner et al.	Dornier	Apr. 11 1996	Sensor System for Detecting, Locating and Ident Metal Objects [use of the gradient technology. Sy was known as ODIS (Ordnance Detection and Identification System). 2D probe data converted "image" of the objects (object map).]

1.2.2 Background Rejection

US 4,942,360	**Candy**		**Jul. 17, 1990**	**A Method and Apparatus of Discrimination De Using Multiple Frequencies to Determine a Recognisable Profile of an Undesirable Subst 3 frequencies, use of difference signals]**
US 4,868,504	Johnson	FRL	Sep. 19, 1989	Apparatus and Method for Locating Metal Object Minerals in the Ground with Return of Energy fro Transmitter Coil to Power Supply [power return to power consumption]
WO 87/04801	Candy	Minelab	Aug. 13, 1987	Metal Detection in Conducting Media Using a two Frequency Signal
GB 2 004 069	Poole	Plessey Comp.	Mar. 21, 1979	Improvements in or relating to metal detectors

2. Pulse Induction

US 3,315,155	Colani		Apr. 18, 1967	Method and Apparatus for Investigating a Genera Homogeneous Medium as to Regions of Anomal Electrical Conductivity

2.1 Discrimination

DE 197 31 560	**Laukemper et al.**	**TZN**	**Feb. 18, 1999**	**Localisation and identification method of buri mine, bomb, etc. [integral of the received puls is used to discriminate objects]**

US 5,537,041	**Candy**	**BHC Consulting**	**Jul. 16, 1996**	**Discriminating Time Domain Conducting Met Detector Utilizing Multi-Period Rectangular Transmitted Pulses [combining received sign different periods]**
DE 43 39 419	**Keller**	**Vallon**	**May 24, 1995**	**Arrangement and method for detecting metal [pulsed system with two oval coils, with very mutual inductance (can work like independen detectors).]**
US 5,414,411	Lahr	White's	May 9, 1995	Pulse Induction Metal Detector [better stability of pulsed system, less noise]
US 5,047,718	Aittoniemi et al.	Outokumpu	Sep. 10, 1991	Improving the Discrimination of an Impulse Tech Metal Detector by Correlating Responses Inside Outside of a Cut-Off Peak Area [correlation of the responses is compared, more reliability in discrin

2.2 Background Rejection

US 6,326,791	**Bosnar**	**Geonics Lim.**	**Dec. 4, 2001**	**Discrimination of Metallic Targets in Magnetic Susceptible Soil [ground has a linear (log-log response]**
AT 404 408	Eder	Schiebel	Nov. 25, 1998	Process and Device for Testing a Medium
US 5,654,637	McNeill	Geonics	Aug. 5,1997	Method for Detecting Buried High Conductivity O Including Scaling of Voltages for Eliminating Nois Particular Depth [Receivers at two horizontal coa planes; response ratio used to est. object depth, responses scaled and summed to eliminate the r from a particular depth (layer).]
US 5,576,624	Candy	BHC Consulting	Nov. 19, 1996	Pulse Induction Time Domain Metal Detector [us combination of the signal detected during non-transmission to eliminate signal from the ground]
DE 195 06 339	Ebinger et al.	Ebinger	Aug. 29, 1996	Method and arrangement for electromagnetic obj detection
GB 2 071 327	Corbyn		Sep. 16, 1981	Improvements in Electromagnetic Induction Syst Geophysical Exploration and Conductor Locatior

2.3 Others

US 6,326,790	Ott et al.		Dec. 4, 2001	Ground Piercing Metal Detector Having Range, E and Metal-Type Discrimination
US 4,894,619	Leinonen et al.	Outokumpu Oy	Jan. 16, 1990	Impulse Induced Eddy Current Type Detector Us Plural Measuring Sequences in Detecting Metal
US 4,605,898	Aittoniemi et al.	Outokumpu Oy	Auf. 12, 1986	Pulse Field Metal Detector with Spaced, Dual Cc Transmitter and Receiver System

3 Miscellaneous

3.1 Coil Design

US 5,969,528	Weaver	Garrett	Oct. 19, 1999	Dual Field Metal Detector [generation of a narrov wide detection field by coil arrangement]
DE 44 17 931	Rohrbeck	IUT	Aug. 17, 1995	Metal detector for indicating buried object presen direction
US 4,890,064	Candy	Minelab	Dec. 26, 1989	Metal Detector Sensing Head with Reduced Edd Coils
DE 37 07 210	Auslaender et al.	Förster	Sep. 15, 1988	Phase Shift Compensation for Metal Detection A [Means to suppress an unwanted phase shift of t transmitter frequency]
DE 37 05 308	Auslaender et al.	Förster	Sep. 1, 1988	Apparatus for the Detection of Metal Objects Loc within a Poor Electrically Conductive Environmer of determining exactly the difference between ref and received signal]
DE 36 19 308	Ebinger	Ebinger	Dec. 3, 1987	Sensor for a metal detector

3.2 Electronics

US 5,691,640	King	Ramsey	Nov. 25, 1997	Forced Balance Metal Detector [microprocessor electrical balance of the head and determine the characteristics of a product (food check)]
US 4,334,192	Podhrasky	Garrett	Jun. 8, 1982	Metal Detector Circuit Having Automatic Tuning Multiple Rates [plurality of operation modes, sele the user]

3.3 Displays

US 5,596,277	Rowan	White's	Jan. 21, 1997	Method and Apparatus for Displaying Signal Info from a Detector [phase angle and counts exceed threshold or amplitude are displayed]
US 5,148,151	Podhrasky	Garrett	Sep. 15, 1992	Metal Detector Having Target Characterization a Search Classification [VDI display to identify a ta

3.4 Imaging

US 6,124,712	Chaiken	University of California	Sep. 26, 2000	Apparatus and Method for Imaging Metallic Obje an Array of Giant Magnetoresistive Sensors
US 6,084,412	Guo et al.	Johns Hopkins University	Jul. 4, 2000	Imaging Objects in a Dissipative Medium by Nea Electromagnetic Holography
US 5,557,277	Tricoles et al.	GDE Systems	Sep. 17, 1996	Method for Locating Leakage of Substances fron Subterranean Structures
DE 41 03 216	Kousek et al.	Hilti	Aug. 6, 1992	Apparatus for Determining Location of an Elemen Magnetizable Material in a Construction Structur monitor shows the location of a hidden metallic o typicallly rebars in concrete]
US 4,476,434	Collins et al.	US Energy Dep.	Oct. 9, 1984	Non-Destructive Testing Method and Apparatus Phase Multiplication Holography

3.5 Cavity Detectors

*** DE 196 48 833**	**Förster**	**Förster**	**May 28, 1998**	**Method and Device for Locating and Identifyi Search Objects Concealed in the Ground, Par Plastic Mines [detection of metallic part follov searching ground for cavity, using one and th multifrequency system]**

3.6 Combined Systems

WO98/30921A2	**Goldfine et al.**	**Jentek**	**Jul. 16, 1998**	**Magnetometer and Dielectrometer Detection Subsurface Objects ["Meandering Winding Magnetometer" and dielectric sensor]**
US 5,680,048	Wollny	Net Results	Oct. 21, 1997	Mine Detecting Device Having a Housing Contai Metal Detector Coils and an Antenna [Portable m detector combined with ground penetrating radar
US 5,307,272	Butler et al.	US Energy Dep.	Apr. 26, 1994	Minefield Reconnaissance and Detector System combines metal detector with ground penetrating

3.7 Arrays / Vehicles / Walk-Through Detectors

US 6,133,829	Johnstone et al.	FRL	Oct. 17, 2000	Walk-through Metal Detector System and Metho [disturbance in earth's magnetic field are measur
DE 195 18 342	Ebinger	Ebinger	Nov. 21, 1996	Method and Probe Arrangement for the Electrom Detection of Metal Objects
DE 44 23 661	Ausländer	Förster	Nov. 1, 1996	Coil system for inductive object detector [Array o coils for a fast search with a high local resolution
DE 44 23 623	Eschner et al.	Förster	Nov. 1, 1996	Process for Detecting Metallic Items Including a Path Defined by a Linear Movement with a Supe Rotational Movement along a Curved Closed Pat [System was known as ODIS (Ordnance Detecti Identification System). 2D probe data converted "image" of the objects (object map).]

DE 42 42 541	Aulenbacher et al.	TZN	Jun. 30, 1994	Arrangement for Locating Below-Ground Ammur [remote control vehicle for ground search]
US 4,912,414	Lesky et al.		Mar. 27, 1990	Induction-Type Metal Detector with Increased Sc Area Capability [Array of receiver coils, also for underwater use]

3.8 (Trip-)Wire Detection

DE 196 42 748	Ebinger	Ebinger	Apr. 23, 1998	Method and apparatus for detection of metallic o

3.9 Sinewave Damping Principle

DE 198 58 713	Ebinger	Ebinger	Jun. 21, 2000	Buried metal object detection method uses lower operating frequencies for suppressing detection o metal objects and compensation of operating fre for suppressing ground interference
DE 196 26 363	Günnewig et al.	Ebinger	Jan. 8, 1998	Metal detector and process for operating a metal
DE 42 12 363	Ebinger	Ebinger	Oct. 14, 1993	Metal Detector

6. Description of Reference and Important Patents

Number: US 5,786,696
Title: Metal Detector for Identifying Target Electrical Characteristics, Depth and Size
Date: July 28, 1998
Author: Weaver et al.
Assignee: Garrett
Abstract: FD system (single frequency). A threshold (triggering) processing operation is performed to determine whether a valid target signal is present in the data. The in-phase and quadrature components are processed using Fourier transforms to select a frequency band which includes the energy for the target signal (basically a bandpass operation). The energy in this frequency band is then utilized for target identification, basically taking the ratio of quadrature to in-phase components in this frequency band (similarly to what usually done for the phase calculation).
Target depth: determined using 2 receive coils and comparing their quadrature components.
Target size: determined using a look-up table which takes into account the target depth, signal amplitude and target ID.
[Note: the in-phase and quadrature components are interchanged with respect to other patents and articles.]

Number: US 4,486,713
Title: Metal Detector Apparatus Utilizing Controlled Phase Response to Reject Ground Effects and to Discriminate between Different Types of Metals
Date: Dec. 4, 1984
Author: Gifford
Assignee:
Abstract: Metal detector with a variable sampling axis and a variable scale factor allowing an operation with reduced ground effects while discriminating between various types of metal. The resistive axis R and the reactive axis X (see figure 2) can be rotated with a variable

angle. Every signal of a metallic object can then be expressed as relation of the two new axis A and B according to its phase angle. With a simple condition of the form: IBI>Ix*AI where x is the variable scale factor, the signals can be divided in desirable and undesirable signals according to their phase angle.

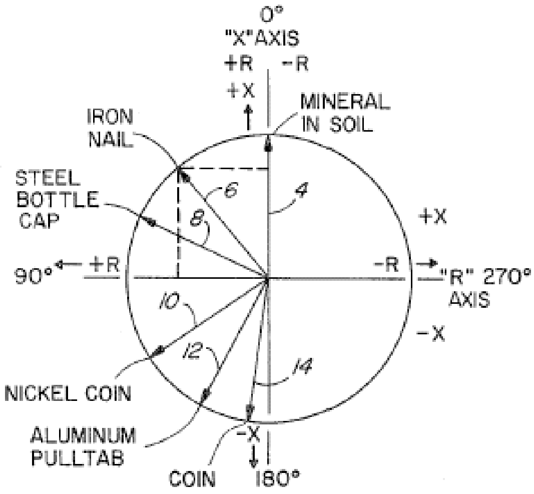


FIG. 2

Number: US 6,172,504
Title: Metal Detector Target Identification Using Flash Phase Analysis
Date: Jan. 9, 2001
Author: Earle
Assignee: White's
Abstract: The phase of a received signal is analysed simultaneously in several phase windows. A parallel output is provided which indicates whether the signal of the target falls in one of the phase windows. A signal falling in a special phase window is characteristic for a certain type of material. A faster discrimination is guaranteed than with a conventional serial phase check.

Number: US 4,783,630
Title: Metal Detector With Circuits for Automatically Screening Out the Effects of Offset and Mineralized Ground
Date: Nov. 8, 1988
Author: Shoemaker
Assignee: White's
Abstract: The system provides an automatic ground exclusion balance (GEB). It can be used in a static or in a continuous mode. In the static mode the influence of the ground is measured and excluded before the sensor is used whereas in the continuous mode the ground exclusion is readjusted during the use. The instrument's control logic circuit automatically makes the necessary changes in the loop circuit parameters to accomplish ground effect elimination.

Number: US 3,686,564
Title: Multiple Frequency Magnetic Field Technique for Differentiating Between Classes of Metal Objects
Date: Aug. 22, 1972
Author: Mallick, Jr. et al.
Assignee: Westinghouse
Abstract: Security applications. Uses the response at two well separated frequencies (their in-phase and quadrature components) for object classification. Some emphasis is put on permeable objects (e.g. guns).
Of particular interest: suggests the use of a magnetization direction having components of the primary field along the object's principal axes (fixed geometry or rotating magnetic field) and one discrimination system for each axis!

Number: DE 196 48 834 (equal to US 6,005,392)
Title: Method for the Operation and for the Evaluation of Signals from an Eddy Current Probe and Device for Performing the Method
Date: May 28, 1998
Author: Patzwaldt
Assignee: Förster
Abstract: Multifrequency; background reduction, metal identification. A better object discrimination is guaranteed by a combination of differential signals.
At least two different frequencies are used. The received a.c. voltage is broken down into corresponding frequency components and the real and imaginary parts of every component are formed. Then a differential signal is formed out of the real/imaginary parts of the different frequency components. This leads to a background free signal. At least two differential signals are combined in a non-linear way (e.g. via quotients) to a combination signal offering more information for object discrimination based on a simple target model (loop).
Ferromagnetic objects can also be taken into account by adding another (two) low frequency component(s) and adapting the model.
Constant target L,R and background signal (at least the imaginary component) are assumed. The eddy current probe can be used as a ground probe, i.e. to deliver only the signal from the ground itself.

Number: US 5,642,050
Title: Plural Frequency Method and System for Identifying Metal Objects in a Background Environment Using a Target Model
Date: Jun. 27, 1997
Author: Shoemaker
Assignee: White's
Abstract: At least two frequencies are used. The metal detector generates background excluded components from the signal components measured in phase detectors. A signal processor then computes the ratio between resistance and inductance and the skin constant of a given target; this amounts to an extension of a simple target model (loop), actually a hybrid model looking like a combination of a sphere and a loop (simple circuit) model. The background is excluded by subtracting signal components measured at two different frequencies or by the use of filters. A background which changes with frequency can apparently also be coped with.

Number: US 4,263,551
Title: Method and Apparatus for Identifying Conductive Objects by Monitoring the True Resistive Component of Impedance Change in a Coil System Caused by the Object
Date: Apr. 21, 1981
Author: Gregory et al.
Assignee: Georgetown University
Abstract: Security applications. The resistive component of the received signal is measured for different frequencies (stepped frequency like, ~30 frequencies in the 0.1-10 kHz band). The measurement points are plotted in a diagram with the resistive component divided by the frequency against the frequency (see figure 4). The diagram is characteristic for a kind of metal and an approximate cross section. Furthermore for a given cross section and metal type there exists a frequency at which the resistive component reaches a maximum. Different cross sections lead to different maximum frequencies. This peak frequency is proportional to the sample's resistivity divided by its cross-sectional area.
Actual signals for complex objects (e.g. revolvers, see figure 10) are also discussed, as well as phase accuracy and system stability issues. Object orientation effects do however not seem to be addressed.

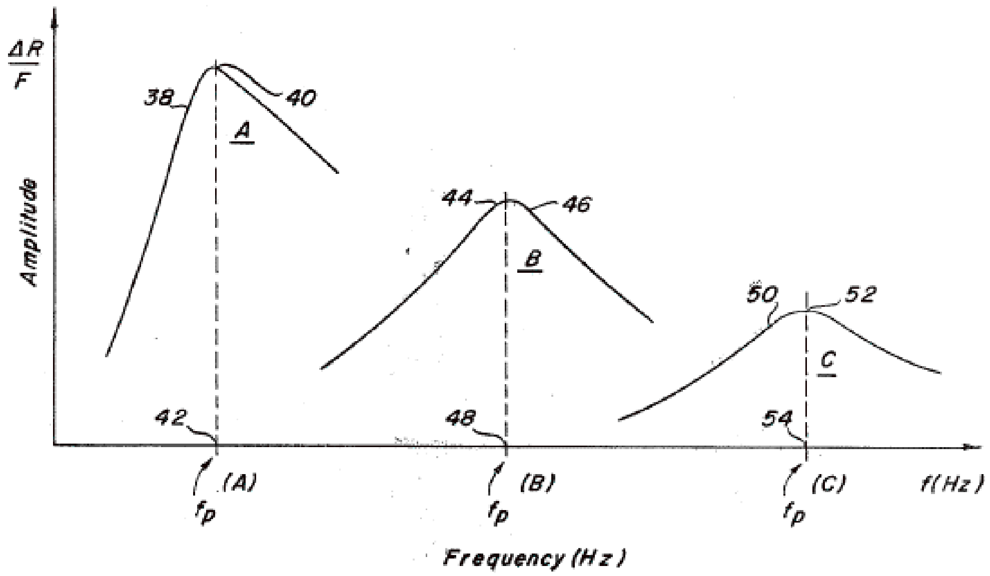


Fig. 4

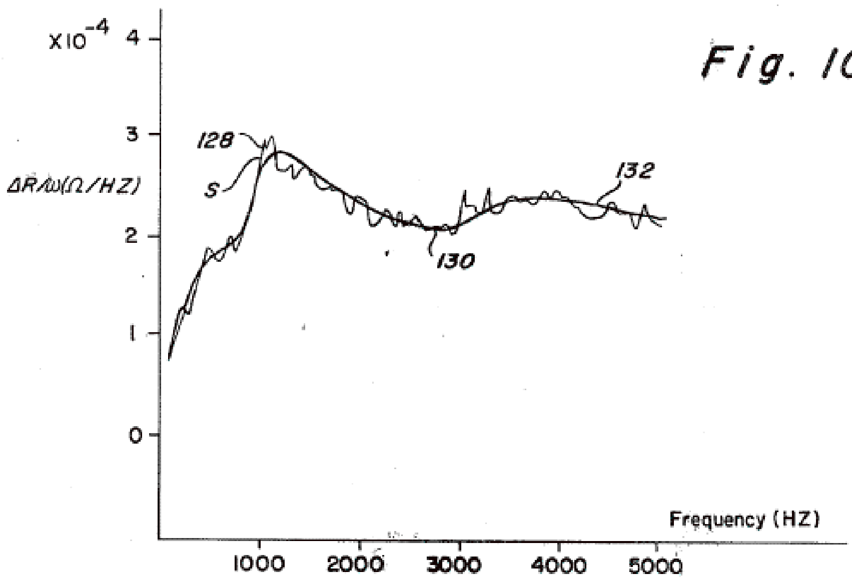


Fig. 10

Number: US 4,942,360
Title: A Method and Apparatus of Discrimination Detection Using Multiple Frequencies to Determine a Recognizable Profile of an Undesirable Substance
Date: Jul 17, 1990
Author: Candy
Assignee:
Abstract: At least two or in preference three frequencies are used to interrogate a target. Resistive and reactive components of the received signals are distinguished. Then a difference signal is build in such a way as to exclude the background effect. “Magnetic viscosity” effects (“superparamagnetic” ground) are probably also addressed.

Number: DE 197 31 560
Title: Localisation and identification method of buried mine, bomb, etc.
Date: Feb. 18, 1999
Author: Laukemper et al.
Assignee: TZN

Abstract: The discrimination of the received signal is based on its fade out. The received signal (see figure 3) is integrated over a given time interval (T3-T2). The integral value S2, normalised by the peak value S1 (S3 = S2/S1), results in a value which is characteristic for the material and the shape of a buried object.

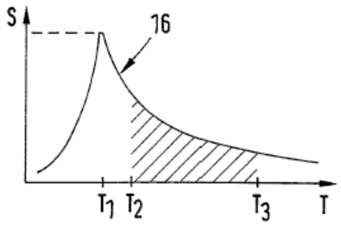
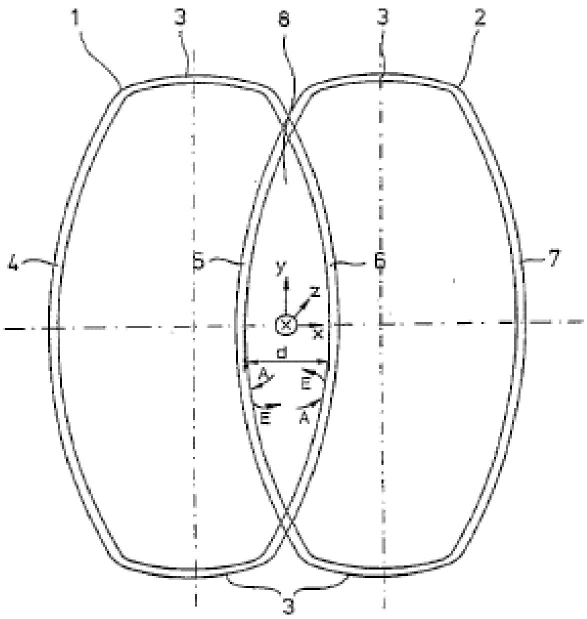


FIG.3

Number: US 5,537,041
Title: Discriminating Time Domain Conducting Metal Detector Utilizing Multi-Period Rectangular Transmitted Pulses
Date: July 16, 1996
Author: Candy
Assignee: BHC Consulting
Abstract: Uses a multi-period rectangular transmit waveform (different pulse periods) and combines the components received during different periods, using a ground model to eliminate the ground signal (in particular for magnetic soils).
Magnetic soils: describes their response in terms of an instantaneous and a historical component, the latter due to “magnetic viscosity” effects (“superparamagnetic” ground). Their ratio is apparently constant up to 100 kHz.

Number: DE 43 39 419
Title: Arrangement and method for detecting metal objects
Date: May 24, 1995
Author: Keller
Assignee: Vallon
Abstract: (Pulse) System with two oval, coplanar partially overlapping coils with very low mutual inductance; it can therefore be used to measure short time constants as well. The two coils can work like two independent detectors, whose received signals allow absolute as well as differential measurements.



Number: US 6,326,791
Title: Discrimination of Metallic Targets in Magnetically Susceptible Soil
Date: Dec. 4, 2001
Author: Bosnar
Assignee: Geonics Lim.
Abstract: Pulse systems. The received signal is plotted in a double logarithmic diagram (see figure 2). In such a diagram the background signal (due to magnetically susceptible soil, V= kt^{-x}, with x~1.3 usually?!) is linear. Thus the received signal is tested at three different times (t1, t2, t3) and the corresponding amplitude values are compared. If they do not lie on a single line then an alarm signal is produced.
Alternatively, the response is measured at a late or very late time, when the ground signal is much larger than the target signal; the soil response is then subtracted from the total response to obtain the target signal alone.
[Note: the reason for the x=1.3 value is unclear.]

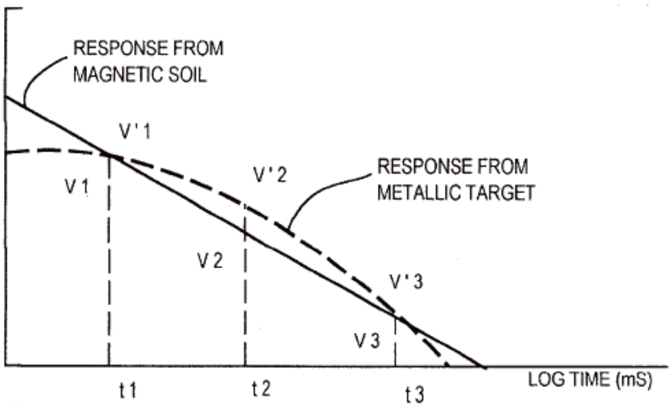
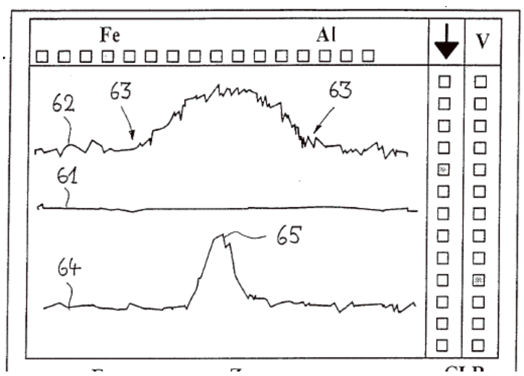
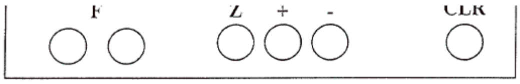


FIG. 2

Number: DE 196 48 833 (equal to US 6,097,190)
Title: Method and Device for Locating and Identifying Search Objects Concealed in the Ground, Particularly Plastic Mines
Date: May 28, 1998
Author: Förster
Assignee: Förster
Abstract: Multifrequency system; MD and ground probe (uses the ground signal normally suppressed) are identical.
Metal detector designed to detect minimum metal and plastic mines. First the position of the metallic part is located. Then a search area around this part is investigated for the presence of ground material. For this purpose an eddy current probe with at least three frequencies is used. The ground conductivity or permeability can be increased by impregnating it with a liquid. Thus it can be searched for metallic parts in combination with a “cavity”, a lack of ground material. The results can be combined in a display (see figure below) where (64) represents the signal from the metal detector and (62) the detected absence of ground material, which is wider than (65) in this example.





7. Conclusions

We can briefly summarize the most important aspects of this work as well as what we learned as follows:

- The described and listed patents, although not exhaustive, represent a good information source on the working principles of most modern metal detectors for humanitarian demining and similar applications.
- The importance of the ground signal has been confirmed; a large number of techniques employed to counteract its effects are indeed reported.
- As already hinted at in section 3, one has often to read between the lines and cope with the technical and legal jargon. The intimate principles on which some patents are based on can indeed be quite hard to understand, and reading them quite time consuming. It therefore helps quite a lot to have a good prior knowledge of the topics discussed.
- Nearly all the references are to other patents
- Internet based patent servers have become quite powerful, accessible and useful tools.

Finally, one should always keep in mind that patents are not synonymous with products (and vice versa, a product or system has not necessarily been patented), and that they do obviously not represent a guarantee that the corresponding system or idea will really be useful in practice.

8. References

8.1 Documents

[1] **Bruschini, C.:** *A Multidisciplinary Analysis of Frequency Domain Metal Detectors for Humanitarian Demining*, PhD thesis (in preparation), Vrije Universiteit Brussel (VUB) (2002)

[2] **Bruschini, C.; Sahli H.:** *Phase angle based EMI object discrimination and analysis of data from a commercial differential two frequency system*, Proc. SPIE proceedings, Vol. 4038, paper [4038-156] (2000) Available from http://www.epfl.ch/lami/detec/

[3] **Bruschini, C.:** *Metal Detectors in Civil Engineering and Humanitarian De-mining: Overview and Tests of a Commercial Visualising System*, INSIGHT, Non-Destructive Testing and Condition Monitoring, Vol. 42, pp. 89-97 (2000) Available from http://www.epfl.ch/lami/detec/

[4] **Carin, L.:** *Special Issue on Landmine and UXO Detection*, IEEE Transactions on Geoscience and Remote Sensing, Vol. 39 No 6 (June 2001)

[5] **Daniels, D.; Cespedes E.:** *Special Issue UXO and Mine Detection,* Subsurface Sensing Technologies and Applications (SSTA), Vol. 2 Issue 3 (July 2001)

[6] **Rocker, G.:** *Systeme zur Detektion und Ortung von Gegenständen und Personen (Systems for Detecting and Locating Objects and Persons)*, (in German), Erfinderaktivitäten, Deutsches Patent- und Markenamt (German Patent Office), 10 pp (1999) http://www.dpma.de/veroeffentlichungen/jahresbericht98/ea/seite2.html

[7] **Rowan, M.; Lahr W.:** *How Metal Detectors Work*, White's Electronics, (19??) Available from http://www.treasurenet.com/misc/howmetaldetectorswork.html

[8] **Szyngiera, P.:** *A Method of Metal Object Identification by Electromagnetic Means*, in Proc. MINE'99 (Mine Identification Novelties Euroconference), Florence, Italy, pp. 155-160 (1999). Available from http://demining.jrc.it/aris/events/mine99/index.htm

8.2 Websites

Patent Offices

Federal Institute for Intellectual Property (Swiss Patent Office): http://www.ige.ch/

European Patent Office: http://www.european-patent-office.org/

US Patent Office: http://www.uspto.gov

Patent Servers

Espacenet: Patents of all countries can be found. Various criteria can be used for the search: http://ep.espacenet.com/

The Swiss version of the Espacenet: http://ch.espacenet.com/espacenet/ch/de/e_net.htm

Search site of the US Patent Office: Only US patents can be found; all mentioned reference patents are linked: http://www.uspto.gov/patft/index.html

The Delphion intellectual property homepage: Free search is only possible to a limited extend. All mentioned reference patents are linked: http://www.delphion.com/

Others

Geotech: The homepage for all treasure hunters: http://www.thunting.com/geotech/index.shtml

Geotech's excellent patent list on metal detectors: http://www.thunting.com/geotech/misc/patents/index.html

9. Acknowledgements

First of all we would like to thank Carl Moreland from the Geotech homepage. His list of patents has been an excellent starting point for our search.

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[1] We are talking here about buried objects.

[2] Induction Balance is usually synonymous with Very Low Frequency (frequency domain) transmit/receive systems, a convention we decided to follow.