A Device for Broad-band VLF Electromagnetic Geophysical Surveying

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Meeting a Need

The lack of clean drinking water is a serious world-wide problem. In 2006, Kevin Watkins of the UN Development Program said:

> "There are over 1 billion people in the world who do not have access to clean water. These are people who start their day walking to rivers to collect water. Sending young girls to collect water and so on. There are over 2.6 billion people in the world who do not have access to sanitation. These twin deficits, I think do speak to a global crisis."

The use of surface water and water from shallow dug wells can lead to many health problems. In many rural regions, obtaining clean potable water requires drilled wells. Simple inexpensive technologies that can help locate successful drilling sites are essential.

Rocks with high water content tend to have high electrical conductivity. Therefore, potential successful water well drilling sites can be located by subsurface electrical properties surveying methods.

Object of Invention

I have invented a new device for performing geophysical surveys based on the measurement of VLF radio signals. VLF is an abbreviation for Very Low Frequency, and includes electromagnetic waves within the 3–30 kHz frequency band. The principle of VLF geophysical surveying is the study of the interaction of these radio waves with geological elements in the ground. This interaction induces secondary electrical and magnetic fields which can be measured at and above the surface of the Earth. This, in turn enables the measurement of VLF waves and their interactions with earth materials to be used for exploration of subsurface geological structures, such as ore bodies, groundwater deposits, and buried objects.

VLF waves penetrate relatively deep into the ground (and the sea). For this reason, a series of military VLF transmitters have been set up around the world for submarine communication purposes. The range of these signals is global, allowing them to be also used for civilian purposes, including the geophysical prospecting for water and minerals. For geophysical prospecting purposes, at any locations or situations where the military transmitters are not emitting signals of sufficient strength, portable VLF transmitters are available commercially to provide a local source of radio waves.

The near-vertical VLF electromagnetic wave front from one of these military or auxiliary transmitters will be affected by subsurface geological features such as a conductive ore body or a water-filled fracture zone. The amount of this disturbance in the magnetic or electric fields over these geological anomalies can be measured, processed, and interpreted.

Current State of The Art

The most well-known instrument for VLF surveying is the "Wadi" by ABEM, Sweden. This device is specifically designed for rapid surveys using the VLF military transmitters as a source. The device works by measuring the vertical and horizontal components of the magnetic field at the transmitter frequency, calculating the tilt of this field from the background level (i.e. the tilt anomaly) at specified points along a straight-line traverse. This tilt anomaly is used in a well-documented filtering program to produce a 2-D depth profile of the subsurface electrical properties (specifically the electrical conductivity).

While straightforward, the use of this instrument is actually quite cumbersome in practice. In my personal experience with a Wadi field survey of the boundary between permafrost and unfrozen ground in Alaska the following measurement procedure is typical:

The user decides which compass direction to profile. It is helpful to consult a map to check for possible transmitter locations perpendicular to the traverse. The user faces in the profile direction, switches the instrument on and enters a mode to scan for strong transmitter signals. This takes several minutes. A graph of frequency versus signal strength is displayed on the LCD screen and the user moves a cursor along to select the best (strongest) transmitter currently broadcasting. At this point the instrument is ready to use. The user presses the sample button, waits perhaps 30-60 seconds, then after a beep is signaled to move. The user walks forward to a new sample location (by following a tape or counting paces), stops and presses the sample button again. After 30-60 seconds more the instrument beeps to indicate it has finished and is ready for the next data point. The user proceeds in this fashion, walking, stopping, sampling until the traverse is finished. At the end of the traverse, the user may choose to walk back along a parallel line without delay, or may walk another traverse, provided the scanning and setup procedure is again followed.

At any time in the process an interpreted depth profile of subsurface electrical conductivity structure may be displayed on the screen. At a later time, the profiles saved in memory can be downloaded into a computer for re-plotting. The Wadi measures both the vertical and horizontal (parallel to the traverse) components of the magnetic field at the selected VLF transmitter frequency. The vertical value is divided by the horizontal value to compute the "tilt angle." Since the two components are both time-varying signals and generally not in phase with one another, the tilt angle is expressed as a complex number. Internally, in the instrument memory, each sample station retains only the real and imaginary parts of the tilt angle. All interpretation is derived from the variation of these two numbers from sample station to sample station. The raw VLF time signals are not preserved, thus alternate interpretation methods are limited.

This instrument has the following limitations:

- measurements are time consuming, must stop at each sample station
- user must have a grid marked out on the ground to follow
- user must walk in straight lines perpendicular to the transmitter - very difficult in any rough terrain
- user must reset instrument for each profile direction
- the interpretation technique is built in - alternatives are extremely limited

These limitations stem from the following aspects of the design. The measurement of magnetic field is 2-D – requiring the 3rd dimension to be maintained but the linear traverse. The instrument works at single transmitter frequency – restricting the profiles to specific directions. The raw VLF data is not saved and the interpretation method is built in and fixed – limiting the ability to discern signal from noise and restricting the interpretation methods that can be employed. There are no internal direction or location sensors – requiring the placement of interpreted data on maps to rely on handwritten notes.

I have been told several times since 2015 that the Wadi VLF instruments are now no longer available from the manufacturer and now practicioners have limited options to make these types of measurements.

A New Device for VLF Geophysical Surveying

I have invented a new device for performing geophysical surveys based on the measurement of VLF radio signals. With this new invention I am addressing some problems and limitations encountered in using the portable or hand-carried VLF surveying devices such as the ABEM Wadi. The problems I address concern (1) the time it takes to complete a survey and therefore the extent of the survey possible, (2) the record keeping involved in performing the measurements, and (3) the versatility in interpretation of the measurements. My new device allows the user to walk freely over rough terrain at random and at any speed without stopping. Raw data is recorded continuously at a high rate and kept internally for later download into a computer for interpretation and plotting. There are built-in position and orientation sensors and there is simultaneous recording of all transmitter frequencies, so as to remove restrictions on the geographic location of the instrument and on the direction the user is facing at any given time. Receiving and recording a broad-band signal also provides for redundancy in the interpretation when more than one transmitter is operating. Broad-band recording also opens the possibility of using non-standard VLF transmitters and using other natural or man-made VLF signals. Location and orientation sensing provides for accurate placement of measurements on a map and for proper interpretation of the subsurface geologic structure.

All of this is possible in a lightweight packable instrument using a combination of a 3-D VLF receiver for the magnetic field, a vertical electric field receiver, an internal tilt meter, compass module, and a global positioning system (GPS) receiver. This device can be carried and operated by a single person. All signals will be encoded as broad-band time-domain wave forms and recorded using a multi-channel digital recording system. For example, currently-available professional digital audio recording technology can be used and is capable of recording directly onto a solid state memory device – allowing hours of continuous recording time.

How Invention is Used

Using this instrument, a geophysical survey proceeds by turning on the recording system and walking across the survey area. The survey need not follow specific traverses or a grid, although a plan is recommended for optimal coverage. The operator need not stop at any time, as data is recorded continuously for the entire survey.

The detailed interpretation of the data is performed once all data is collected. The multi-channel digital audio data is transferred to a computer and parsed to save the VLF waveforms as function of time and indexed to tilt, compass direction, and GPS coordinates.

One possible data interpretation scheme would be to select time segments of the data and separated into a grid based on GPS coordinates. The time series segment at each grid point can be Fourier-analyzed and filtered to extract separate the simultaneously-sampled transmitter signals. The vector components of the magnetic field these signals represent can be projected into a particular coordinate system using the tilt and compass data, and then interpreted for subsurface geologic structure using VLF filtering and analysis techniques presented in the literature to produce subsurface geophysical anomaly maps and cross-sections in three dimensions.