LBNL FORGE Project Report for Milestone 2.1
Status Report on The VEMP tool

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Introduction

As part of LBNL FORGE project the EESA Geophysics division is tasked with making borehole EM measurements to image the induced fracture volume for the enhanced geothermal system at the Utah FORGE Site. For this project we will use the VEMP system recently acquired on loan from Japan.

The Vertical Electromagnetic Profiler (VEMP) system was a concept that was developed ahead of its time. At that time there were few imaging tools available or experience with downhole data sets other than minerals exploration or single well logging. The tool was last used in 1999 and some evaluation is required to determine if it can be used for FORGE and what step would l be required to make it field ready.

Below we provide a status report for the first part of this project.

VEMP Tool Characteristics

The Vertical Electromagnetic Profiling system (VEMP) was designed and built at Electromagnetic Instruments Incorporated (EMI) with Geothermal Energy Research and Development (GERD) in 1995. The tool was intended for high temperature borehole deployment and subsurface imaging especially in geothermal wells, but also for mining applications.

The tool was last used in 1999 but has been in storage since then. Under an agreement with GERD, LBNL has obtained the tool for evaluation and if possible for use in the field campaign at the FORGE site in southern Utah

The VEMP system features separate surface transmitter and downhole receiver sections for surface to borehole logging in a high temperature environment. The system operates with separate stations logging independently but linked by high accuracy system clocks.

The transmitter develops square wave signals in the range from 1 Hz to 128 Hz at the surface linked to a commercial transmitter/ motor generator and provides them to a surface electric (bipole) or magnetic coil antenna. The high current output is provided by a commercial field transmitter (ie a Zonge model GGT 40), which is coupled to the system clock. The VEMP surface station measures the current signal from a shunt resistor on the Zonge transmitter, synchronously with the receiver.

This signal as well as the signal from the receiver tool is logged with a field laptop connect to the surface station (see Figure 1).

At the receiver station, data is collected downhole with a 3 component inductive sensor, and a fluxgate magnetic orientation sensor both linked to a downhole digital data acquisition system (Figure 2). The inductive signals are sampled and stacked dowhhole and sent to the surface using short haul modem telemetry. The data are then collected, Fourier transformed and stored on a laptop computer.

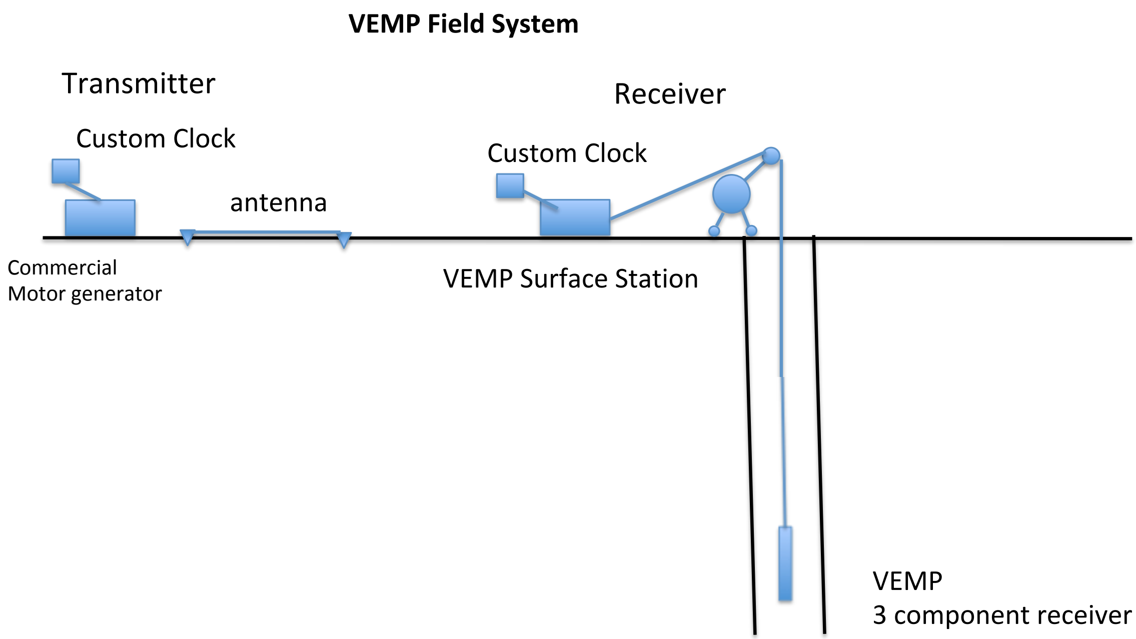

Figure 1 - VEMP surface to borehole field system.

The tools sensors were quite advanced for their time and are likely still state of the art. The axial sensor is 1.5m long with a 1 cm core of mu metal. It is wrapped with tens of thousands of turns of wire and connected to a down hole amplifier in a magnetic feedback configuration. It has excellent sensitivity from 1-300 Hz. The horizontal component is measured by a patented array of transverse orthogonal sensor coils connected in series with parallel feedback windings. These coils provide a temperature stable and high sensitivity for such a small package.

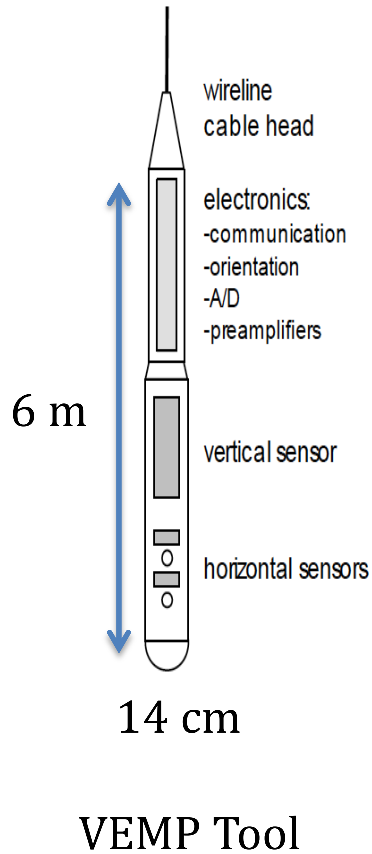

Figure 2 - Schematic of the VEMP borehole receiver.

The digital acquisition system characteristics are quite dated, and difficult to find replacements. The acquisition system is based on a 16 Bit A/D with analog electronics and data transmission via a short haul - low speed modem. Data are acquired and stacked downhole prior to sending data packets to the surface.

The system operates by initially synchronizing separated transmitter and receiver site clocks and then deploying the source and receiver stations separately. The file and logging characteristics are all recorded manually and data is collected at the receiver end using a depth encoder and manually moving the tool between recorded depths where the depths are input manually.

Although cumbersome to operate the tool was ahead of its time for sensitivity and temperature and pressure tolerance. Figrue 3 shows a sample plot from a successful high temperature logging test in Dixie Valley Nevada. In that test the tool logged 300m of open hole and 200m of cased hole at temperatures up to 250 C at depths to 2500m.

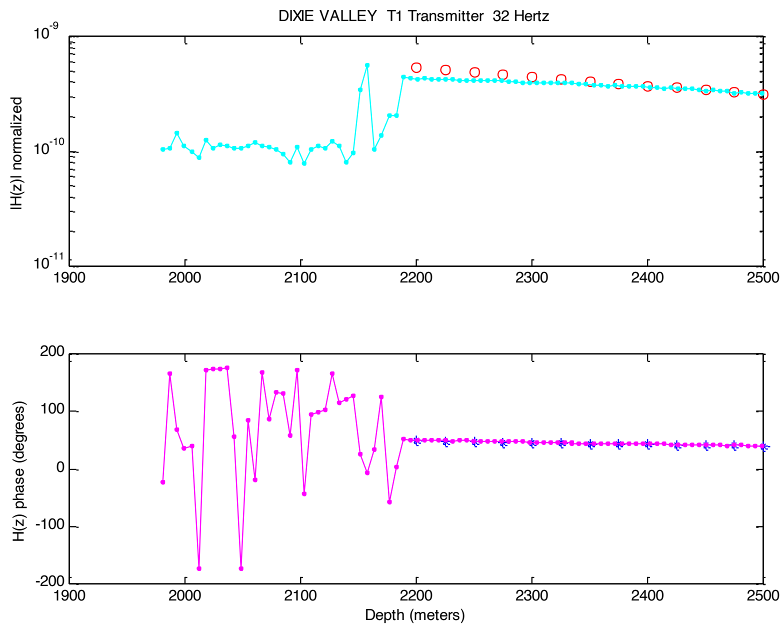

Figure 3 - VEMP vertical sensor tool response from a surface dipole transmitter that was 800m long.

Tool status

This tool has not been used in the US since 1999. It has been carefully stored at GERD facility in Japan and its mechanical and operational conditions are unknown at present.

The system was shipped to California in May 2022, and arrived at the field shop in mid May. The evaluation consisted of the following steps:

1. Unpacking, inventory and visual inspection
2. Evaluation of the analog sensors and amplifiers
3. Evaluation of the digital electronics
4. Evaluation of auxiliary and support systems such as power supply, orientation sensors, and modem for communication from downhole to surface station.
5. Recommendation for tool maintenance, upgrading and eventual operation at FORGE

VEMP Tool Inspection

After visual inspection we found that the major components, the borehole tool, dewar, surface station and centralizer were intact. What was missing was the surface control computer, the acquisition software, documentation, and some cables.

Tool Housing and Dewar

This polyimide epoxy housing contains the axial Hz sensor, and also the two orthogonal Hx and Hy patented transverse H sensor arrays. This section is oil filled and has an attached oil pressure compensation system. The original temperature rating of the polyimide was 260 C. However we do not have a rating for the 25 year old material.

Figure 4 - Sensor section for the VEMP tool

Status: This section appears in good condition. We checked resistance to the coils and also were able to pick up a voltage signal from the Hx, Hy and Hz sensor windings and have identified pin out for the corresponding coils. We also identified the feedback winding for each sensor and verified its integrity and also used these to send a signal to the main windings.

We did not disassemble the oil pressure compensation system. We recommend replacing the O-rings on the internal piston with new Viton O-rings. We think this section of the tool is serviceable. We will field test later this summer at our Richmond Field test site.

The Dewar also appears to be intact. There is no way of knowing how effective it is until we test. For this we will using an external heat source (heater tape) and measure the internal temperature using internal thermocouple, as heat is applied. The temperature rise is a function of the vacuum insulation and external temperature. We will determine the internal heating rate as a function of external temperature, and this will give us a measure of the integrity of the vacuum effectiveness of the dewar. We will attempt to contact dewar manufacturers to evaluate options if the dewar is performance is unsatisfactory. The operation time for the tool is determined by two factors, 1) the external heat load in the well and the effectiveness of the dewar, and 2) the internal self heating of the electronics, which is related to the power supplied to the tool.

VEMP Electronics:

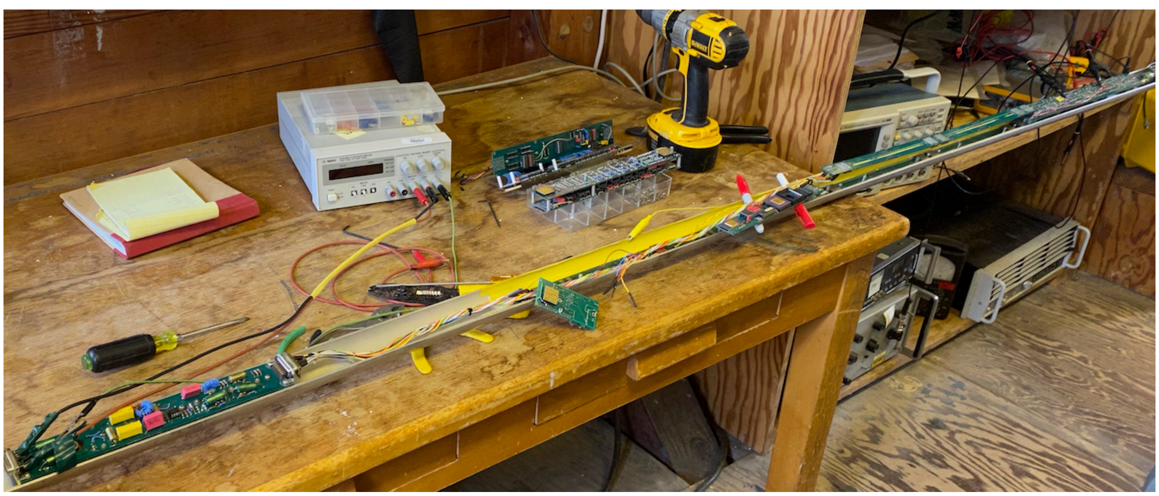

Figure 5 - Electronic Section of VEMP

This system also seems to be in good mechanical order, but we note the lack of a computer, any software, a development system, and the age of the electronics.

Power:

We identified the power supply board which takes a +/- DC voltage supplied from the surface and sends +/- 5V for digital electronics, and +/- 12V for analog section. This board pinout was identified and it appears working normally.

Preamplifier section:

We were able to connect the electronics cartridge to the receiver section and using the power supply board bring up the preamplifier board for the H sensors. We verified apparent normal operation of this board with the three-component H sensor receiver section. The next step will be to perform a frequency calibration of the H sensors and the associated preamplifier.

Digital electronic boards:

We are missing the surface control computer (obsolete OS-2 system), complete documentation for the data acquisition control program and downhole firmware, and missing the development system for the old Z80 microprocessor in the system. On power up – it appears there was excess power being used by the assembled electronics. We eliminated the digital electronics (microprocessor, A/D converters, timing) in further testing.

Downhole orientation system – APS 3-c fluxgate and 3-c accelerometer:

We did not test this device, however we have documentation and also there are modern replacements available for this function. Orientation functionality is needed for tool operation.

Short-haul modem:

The VEMP tool used a 4 wire used a pair of short haul modem boards to provide a 9600 baud full duplex link between the downhole electronics and surface station. The boards were identified and powered up and sent signals normally through short test cables. There are more modern chipsets such as RS485 protocol to perform this operation if needed.

However, for full tool capability it would be preferable to get these signals to the surface along with the orientation and status signals, so that we could monitor the internal temperature rise. There are several options we have to proceed as listed below.

Surface Station

The surface station consist of two power supplies, and an electronics module with the mating circuits for digital communication, winch depth control and a surface power supply. On powerup the surface power supply developed a short in at least one capacitor. because of this short and the of the electronics, we are unlikely to use this surface acquisition system.

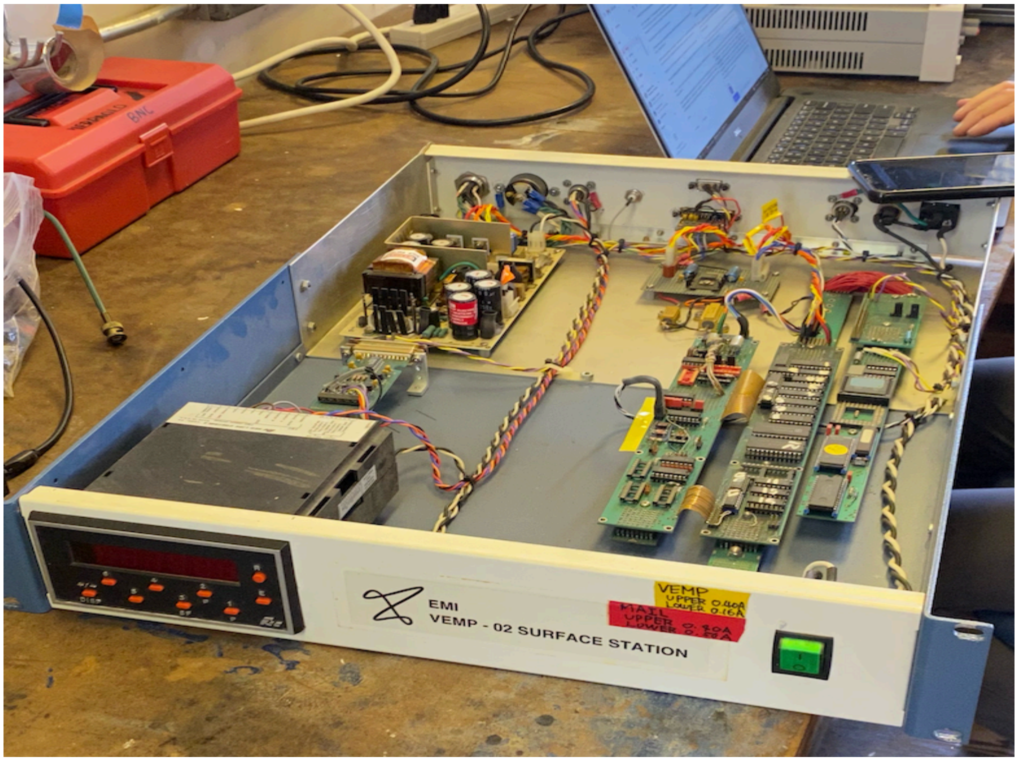

Figure 6 - VEMP surface station

Final Evaluation tasks

Prior to completing the evaluation the next steps are required.

1) Do a thermal assessment on the dewar - see also if we can get any information on the hold time, thermal load in the well and self heating timelines. We will see if we can identify a dewar supplier for technical assistance in evaluating the current vacuum housing.

2) On power-up of the APS 544 fluxgate magnetometer, it powered up and reported an internal firmware checksum error. We will follow up with the manufacturer Applied Physics System to determine whether we repair this one, or use a more modern sensor. There has been a lot of development in orientation since the development of this particular package, however there are not that many rated to operate at 125 C, which is the upper end of temperature expected for the tool electronics inside the dewar. We will need to evaluate upgrade options.

3) Perform a disassembly of the pressure compensation system to check for corrosion, replace O-rings and oil and verify normal operation.

After completion of these tasks the tool can be made ready for field testing (see below).

VEMP Options

From the analysis presented above we have determined that the VEMP tool is basically intact. The housing, sensors and analogue components are functional and the Dewar looks to be intact. We need to pressure test the system and heat test the Dewar so see if it can survive the downhole environment at FORGE.

The digital part of the system is not functional. There is no available computer with the operating software and no listing of the tool software and firmware to re-construct this. In addition there is no surviving system manual available.

To operate the tool as planned by FORGE one of the following options needs to be implemented:

1. debug existing system;
2. rebuild digital section with external contractor;
3. rebuild digital section with internal contractor;
4. provide a method for analogue acquisition only;
5. don't do anything.

Options 1 through 4 imply 'GO' decision to move from subtask 2.1 to 2.2 in the LBNL Project SOPO and Risk Register, while option 5 would represent a 'NO-GO' decision with respect to moving to subtask 2.2.

Option 1:Debug original system

The original system consisted of a series of digital and timing boards controlled by firmware and software developed in the mid-1990's. The computer that ran the software does not exist anymore and over the years a listing of the software and firmware is no longer available. Fortunately the software author and system developer Edward Nichols is currently on staff at LBNL so we can use his memory, expertise and qualifications if we wish to reconstruct the software and firmware.

We view this option as a long shot with dubious rewards. With no software available we would need to find old computer hardware and older version of software compilers to write code that the older chips can understand. In addition all of the chips are over 20 years old and if they are not functional no replacements are available.

This option although possible has been ruled out as the tool failed power consumption tests at powerup so it is not considered feasible. Indeed, if we are successful in restoring the tool function no maintenance is possible because many parts are already obsolete. So this option is rejected.

Option 2: Replace Digital Electronics using External Contractor

A number of geophysical contractors have expressed an interest in moving their existing digital data acquisition technology downhole to field a new set of tools. The rebuild of the VEMP digital section allow for that possibility with a tool that is otherwise operational. If a joint development agreement can be worked out with one of these companies then the technology could be obtained at a reasonable cost

Candidate companies include Sercel, which has a series of downhole seismic systems already built, Zonge International who has an advanced EM surface based technology and has expressed interest in a downhole version, and the more local company Geometrics whom have also expressed some interest.

The next step here is to make a series of calls to determine interest and conditions. These conversations are underway.

Option 3: Replace Digital Electronics using Internal Resources

LBNL has the personnel and experience to complete this task internally. Engineer Todd Wood has considerable experience is system and software development and is certainly capable of providing a digital acquisition system under direction from Ed Nichols.

The advantage of this approach is that the development remains in house and can be customized and applied to different tools. The disadvantage is that with limited capable personnel available and limited time it may be difficult to complete the tasks in a short time.

Option 4: Analogue Version

With some fairly simple changes it is possible operate the system in analogue mode only. That is the 3 component sensors would be brought to the surface on analogue wireline cable and the digital part of the system could be bypassed.

Some changes in wiring would be required and the system would need to be operated on an internal battery so that six of the wireline conductors would be available for the downhole signals. We would also like to add a microcontroller to record orientation, temperature and power data so that we could independently measure tool orientation as well as electronics power consumption and temperature information.

Option 5: do nothing

Our initial assessment of the system has found an intact analogue sensor compartment, analogue electronic and power supply. Based upon this we feel that the tool can be operated either with a digital upgrade or as an analogue device. This option is therefore rejected.

Next Step

We feel the most logical next step is to bring the VEMP tool to operation condition using the analog operation only. Under this plan the tool can be ready for FORGE and tested in a relatively short time and within the limitations of the available budget. Ideally it would be best if the tools digital operations could be also restored. This we view as a longer term plan where we proceed with the analogue option in parallel with the digital upgrade. This will proceed at lower priority.

GO/NO-GO DECISION: GO with an emphasis on Option 4.

For Analog Operation

The following steps are required prior to analog operation:

- add differential signal drivers to send the signal up the wireline;
- add downhole batteries to reduce the number of required conductors, and improve signal quality;
- add a small microcontroller to record orientation and housekeeping data. This would help track orientation for later processing. Note these data could be transmitted to the surface using available wires.

Below we show the system configuration for analog operation (Figure 7). The system uses a combination of existing instrumentation form our crosswell seismic and EM systems in combination with the VEMP sensors.

The transmitter side uses the same source and clock as the crosswell system and would provide adequate power for surface operation. The source provides a current of up to 20 amps at a voltage of up to 2 kVolts. This is adequate for a surface grounded source, an inductive loop source, and/or a source that makes use of steel casing(s) drilled into the reservoir such as 16A and/or 16B. The GPS clock is used as a signal source and a phase reference.

The receiver system uses a Geometrics Geode seismic data acquisition system to record the three channel analog signals. The Geode also does signal averaging and can calculate a Fourier transform from the collected time series. The standard Geometrics acquisition as used in our crosswell seismic application would work as is for acquisition and the surface-to-borehole data would be recovered using MATLAB programs on a laptop computer.

Upon completion of the above listed modifications the full system will be tested at our field site in Richmond California.

LBNL Surface to Borehole Field System

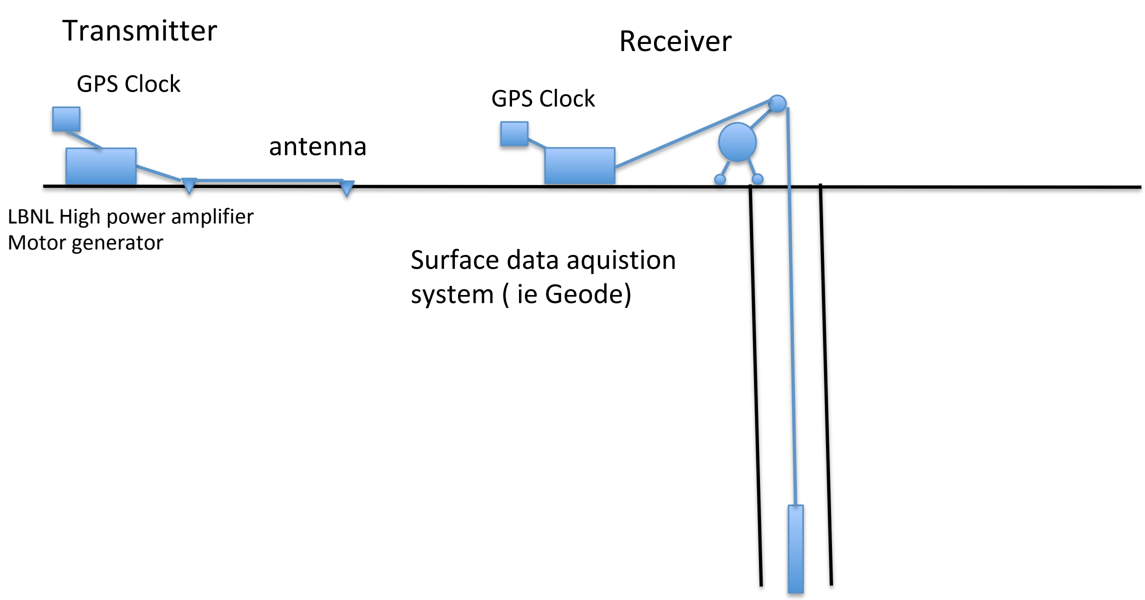

Figure 7 - LBNL Surface to Borehole EM system

APPENDIX 1 - Budget estimates for VEMP reconditioning via Analogue Upgrade

ANALOGUE UPGRADE OF TOOL:	Fully burdened costs
A1 Design new differential driver boards to send signals to surface	
Todd Wood – 2 days	3,731
Supplies – $1500 (boards + parts)	2,079
A2 Adapt microcontroller board to acquire and store orientation data, temperature data and internal housekeeping voltage	
Todd Wood – 10 days	18,655
Ed NIchols - 2 days	1,799
Parts and Supplies -$2500	3,465
A3 Design battery power pack and wiring and mounting	
Todd Wood 1 day	1,866
Ed Nichols 1day	899
Alejandro Morales 2 days	2,127
Parts and Supplies - $1000	1,386
VACUUM DEWAR TESTING	
Ed Nichols 3 Days	2,698
Alejandro Morales 2 days	2,127
Mike Wilt 3 Days	2,748
Parts and Supplies (heater tape, insulation, temp monitors) – $1000	1,386
OIL COMPENSATOR REPORTS	
Paul Cook 2 days,	3,715
Supplies and Parts - $500	693
TOOL CALIBRATION	
Ed Nichols 3 days	2,698
Mike Wilt 3 days	2,749
RICHMOND FIELD STATION WELL TESTING	
Ed Nichols 3 days	2,698
Mike Wilt 3 days	2,749
Total	**60,268**