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# Monitoring Moisture Content In Surface Barriers Using A Passive Sensor Platform

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# Monitoring Moisture Content In Surface Barriers Using A Passive Sensor Platform

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## Abstract

Work is being performed to develop a versatile micro-power sensor platform for the purpose of periodic, remote sensing of environmental variables such as subsurface moisture or radiation. The key characteristics of the platform architecture are that the components are passive, thereby requiring no internal power source and that it communicates with a "reader" via short range telemetry, i.e. no wires need penetrate barrier structure. Other significant attributes include the potential for a long service life and a compact size that makes it well suited for retrofitting existing barrier structures. Functionally, the sensor package is read by a short range induction coil that both activates/powers the sensor platform and detects the sensor output via a radio frequency signal generated by the onboard programmable interface controller microchip. To date, a prototype of the platform has been constructed and tested with a commercial moisture sensor. Work is now in progress to extend the capabilities of the existing platform to permit moisture sensing through landfill surface barriers (caps). Specifically, work is being performed to extend the telemetry range for transmission through a cap, select/develop low power sensor elements, and package the components to survive subsurface conditions. Considerations are being given to minimize package dimensions to permit retrofit applications.

## Background

Monitoring the performance of landfill caps will be important during the initial development and testing phases as well as during long term use. Little research has been conducted to establish viable strategies for long-term monitoring. Often, life-cycle monitoring costs at closed waste sites are estimated to 30 years without consideration of additional monitoring. At present, a water moisture monitoring strategy might involve multiple embedded sensors, each wired to a data logger or telemetry unit. The wires present obstacles to heavy equipment at the time of cap construction and subsequent cap maintenance, and use of wired sensors also implies cap penetrations. Any maintenance of sensors means additional penetrations. A means to mitigate such problems are to implement a sensor platform that is both wireless and passive. For this case, passive is defined as not having an onboard power source. Power is provided by a “reader” on the surface via magnetic induction.

The general configuration as it relates to a landfill cap can be understood from Figure 1. The basic approach is that one or more probes, in this case probes containing moisture sensors and telemetry, are mounted at points of interest that will allow determining the functionality and/or integrity of the landfill cap.

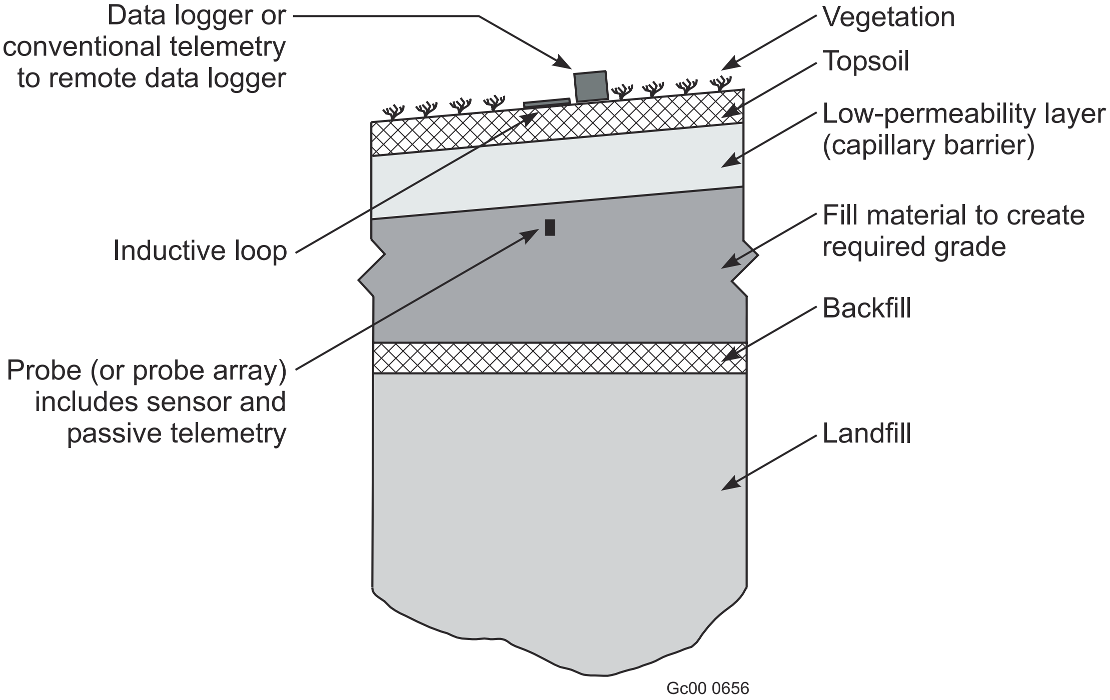

**Figure 1.** Cross-section showing a landfill barrier.

We recognize that the cap must retard the downward flow of moisture, e.g., by an actual barrier or by evapotranspiration from vegetation. At least one probe would be mounted below the cap's moisture barrier, while the inductive loop of the reader, which requires power, resides on top of the barrier. The moisture barrier within a landfill cap generally does not exceed two meters in depth, even for complex designs.[1] The data logger can be located at any convenient spot, and linked by conventional radio frequency telemetry to the reader. Use of multiple probes with a single reader is possible, allowing measurement of vertical moisture profiles and area monitoring. Moisture infiltration maps can be generated from such data.

This sensor architecture has several desirable attributes: (a) there are no wires to impede barrier construction activity; (b) there is no penetration of the barrier; (c) the probe can be robust and small, and thereby useful as an insertion-mounted retrofit to existing caps; (d) data acquisition can be remote and automated, as long as it is consistent with the approximate two-meter limitation between probe and reader; (e) the probe is low-cost and deployable in large numbers; (f) multiple sensors can be incorporated into a single probe; and (g) multiple probes can be interrogated by a single reader.

## Sensor Platform

To test the concept, a prototype was developed and tested. The platform was designed around a microcontroller produced by Microchip Technology.[2] It is essentially a single-chip computer programmable in a C-like language. It contains onboard nonvolatile memory, multiple analogue-to-digital (A/D) channels, and digital communication ports. The microcontroller can handle all the logic needed for power management, operation of a sensor, and communication with the reader.

The telemetry concept is for low-frequency magnetic fields to carry both energy and information. Low frequency has acceptable penetration in moist soil. Key parameters relating to penetration depth are the soil electrical conductivity and the frequency of the penetrating field. The attenuation of the magnetic field can be estimated using a conventional skin depth calculation. Conductivities in arid soils have been measured at the INEEL[3] with typical maximum (saturated soil) direct current values of order 0.1 Siemen/meter. Using this value, we expect that attenuation is not important if we stay with low frequencies and distances of about two meters or less. For reference, the electromagnetic skin depth at 100 kHz and the above conductivity value is 5 m. Von Hippel[4] has measured conductivity values at 100 kHz, but for lower moisture levels, which is consistent with this 5-m estimate. A working frequency of 125 kHz was used for the prototype.

For the reader to acquire a reading from the probe, the basic sequence is as follows. The reader first sends out energy in the form of a pulsating magnetic field, which is captured and stored in a capacitor within the probe. The captured energy then powers the microcontroller, which instructs the sensor to perform a measurement. This value (e.g., moisture content) is then digitized. At that point, the microcontroller powers the probe transmitter and also controls frequency-shift keying to impress the digital reading on the transmitted waveform, with subsequent decoding by the reader. A variation would be that the reader supplies instructions to the probe, as well as energy. For example, the probe might be instructed to report the value of a particular onboard sensor or to adjust the operating range of a sensor.

Figure 2 shows a simplified block diagram of the probe. The antenna, actually a resonant circuit, is used both for capturing energy from the reader and transmitting data back to the reader. As energy builds in the storage capacitor, the microcontroller begins to operate and polls the energy detector circuit to determine if the capacitor is fully charged, in which case about 5 volts are available. When that condition is achieved, the RF detection circuit is polled to determine if the reader (not shown) is still transmitting the energizing pulse. If not, the reader has stopped to listen. If so, the microcontroller interrogates the sensor, which requires applying power to it and digitizing its analog output.

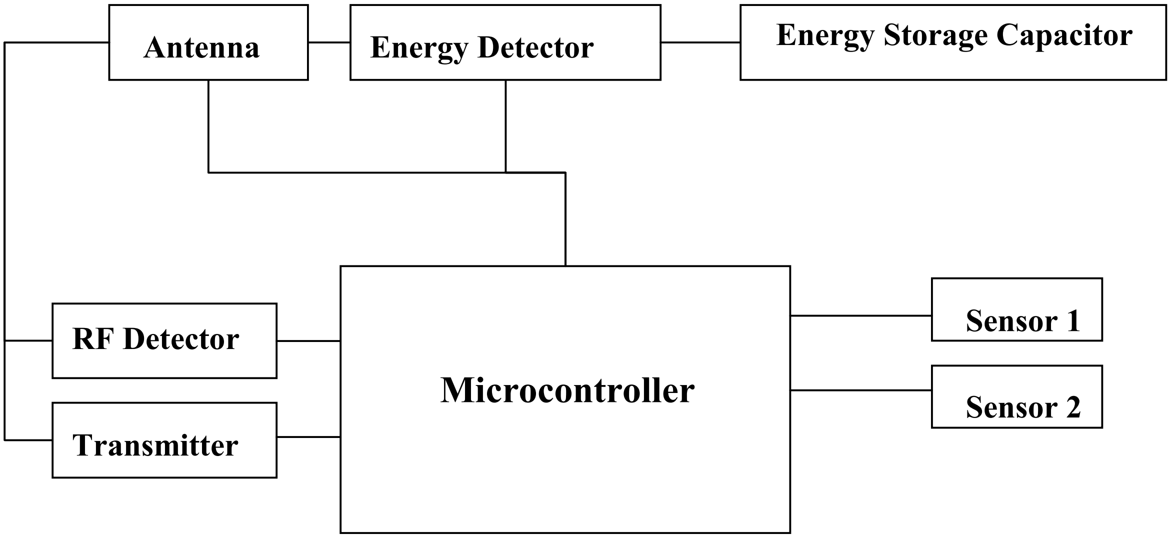

**Figure 2.** Simplified block diagram of the sensor platform.

At this point, the measurement result is stored in the microcontroller's memory. Power is then applied to the transmitter, which in turn drives the antenna. Frequency-shift keying is accomplished by switching a small capacitance in and out of the resonant circuit of the antenna; the switching is controlled by the communications port on the microcontroller. The receiving process is straightforward. An FM receiver is tuned such that its passband is centered on one of the frequency components of the modulated wave. This produces analogue output from the receiver that is level shifted to become a proper RS-232 signal. That signal is captured by the serial port of a computer, which serves as the data logger.

Critical to operation is the method of power management within the platform, i.e. the platform and sensor(s) must operate on the low power available from the induced currents. The microcontroller has a low power sleep mode that is used during the charging period. During sleep, the chip periodically awakens at predetermined intervals to execute the instructions outlined above. The maximum separation of the platform from the reader is determined by the point at which the charging current is less than the sleep current. Figure 3 is picture of the prototype platform and moisture probe[5] used to demonstrate feasibility.

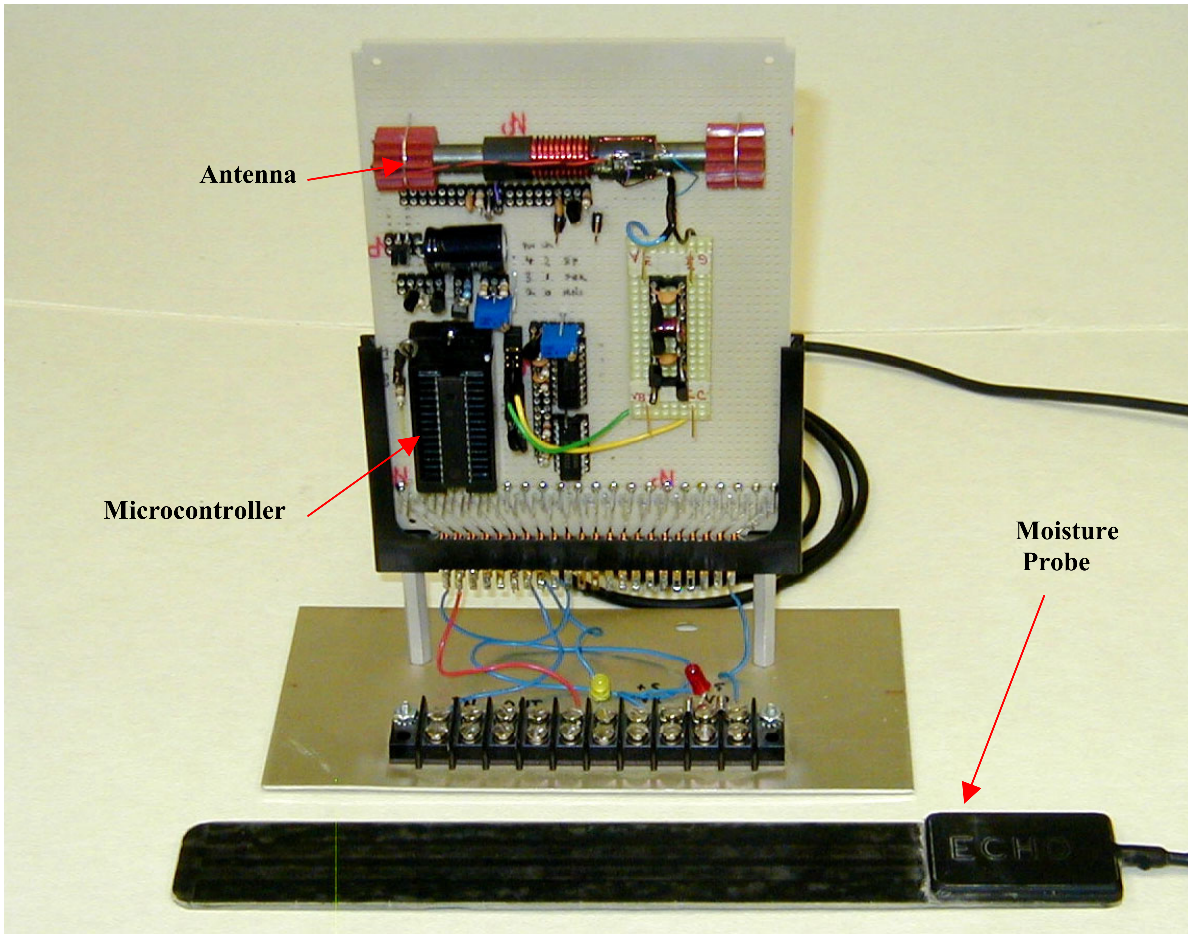

**Figure 3.** Prototype sensor platform

## Current Status

Efforts are now underway to develop and test a field deployable moisture sensor. To accomplish this task work needs to be performed to 1) extend the telemetry range, 2) develop programming to handle two way communications, and 3) package the components for subsurface use.

*Extended Telemetry Range* - Although functional, the original prototype had a very limited telemetry range, approximately 0.6 meter in air. To increase the range, improved antenna designs are being developed and tested. Presently, a 3.0 meter range in air has been achieved. Further improvements will be necessary to address magnetic field losses due to the electrical conductivity of the soil.

*Two Way Communications* – The effort to develop two way communications will allow multiple/separate sensor packages to be addressed and read. Included will be the ability to implement multiple sensor types in a single package, e.g. moisture, temperature, or other sensor types that meet the current speed and low power consumption requirements.

*Packaging* – The current goal is to achieve a cylindrical package size of 5 cm in diameter by 30 cm in length. This size will permit implementation using conventional drilling/boring techniques and/or insertion into existing wells. Note that antenna orientation, i.e. the package, will need to be consistent with the orientation of the antenna used with the reader. Internal to the package will be the microcontroller, antenna, and power storage capacitor bank. The moisture sensor intended to be implemented has short range detection capabilities and will require it's sensing components to be attached to and/or integrated with the external surface of the package.

Field testing of the completed moisture sensor package will be performed at facilities located at Hanford and/or the Nevada test Site. Both locations have instrumented test beds that will allow a direct comparison of the sensor package to current moisture sensing technologies.

## References

1. G. W. Lee and A. L. Ward, "Still in Quest of the Prefect Cap," conference proceedings of "Landfill Capping in the Semi-Arid West: Problems, Perspectives, and Solutions," edited by T. D. Reynolds and R. C. Morris for the Environmental Science and Research Foundation, ESRF-019, Idaho Falls, ID, 1997.

2. Microchip Technology, Inc. Programmable Interface Controller PIC16F876-04/SP.

3. W. M. Roggenthen and D. K. Parrish, South Dakota School of Mines, "Factors Affecting Ground Probing Radar at the Radioactive Waste Management Complex Idaho National Engineering Laboratory," prepared for EG&G Idaho, Contract No. C92-17099 (1994).

4. A. R. Von Hippel, editor, "Dielectric Materials and Applications," *The Technology Press of MIT*, John Wiley and Sons, New York.

5. Decagon, Pictured is a prototype of commercially available Echo Probe.