Radiofrequency Sensor Network for Monitoring Containment Integrity[1]

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Abstract: Many waste legacy sites, even after remediation, will require long-term monitoring (100 to 1000 years) to ensure that no leftover contaminants are released to local environments (groundwater and air). Engineered surface covers are being built to contain waste within remediated sites. Rugged, low-cost sensors are needed to monitor the integrity of the engineered covers over both the short and long term. This paper describes a network of radio frequency (RF) sensors, coated with a corrosion protective layer, for monitoring the migration of contaminant plumes. Input impedance of the network will vary with frequency and the dielectric properties of the soil medium, including that of contaminant plumes leached out of capped sites. The network is much like a telephone cable buried around the containment boundary, and the sensors are interrogated from one end of the cable. The system is passive in that the line is not powered all of the time and provides measurements only on demand. As a result, it is a simple, inexpensive, and rugged network for monitoring the integrity of engineered covers over a long period. Preliminary tests at 100, 500, 1000 MHz of an open-ended coaxial probe buried in a sand box showed good sensitivity to chemical contaminants.

Description and Testing of the System: The types of RF sensors that can be embedded in a transmission line include a pair of electrodes (parallel plates or rods) or open-ended coaxial probes inserted into the vadose zone (see Fig. 1). Input impedance of the sensor will vary with frequency and the dielectric properties of the soil, including permeability, moisture, chemical infiltration, and other contaminants. In a complex plane representation, the variation of impedance with frequency will provide distinct response patterns, depending on the dielectric property of the material between the electrodes. An electromagnetic analysis (Smith chart type) can be used to determine from one end of the transmission line the impedance variations at various sensor locations. By periodically interrogating the transmission line, one can monitor the changes that occur over the years from the initial baseline parameters.

To prove the technical feasibility, we built an open-ended coaxial RF sensor and tested its response by immersing it in sand under various environmental conditions. Figure 2, for example, gives the input impedance of the probe for air, sand, and acetone-contaminated sand. The measurements were performed with a vector network analyzer at three frequencies: 100, 500, and 1000 MHz. At each frequency, the line plot of input impedance is shown on a Smith chart for the set of three materials. Clearly, the sensor is responsive to soil contaminants.

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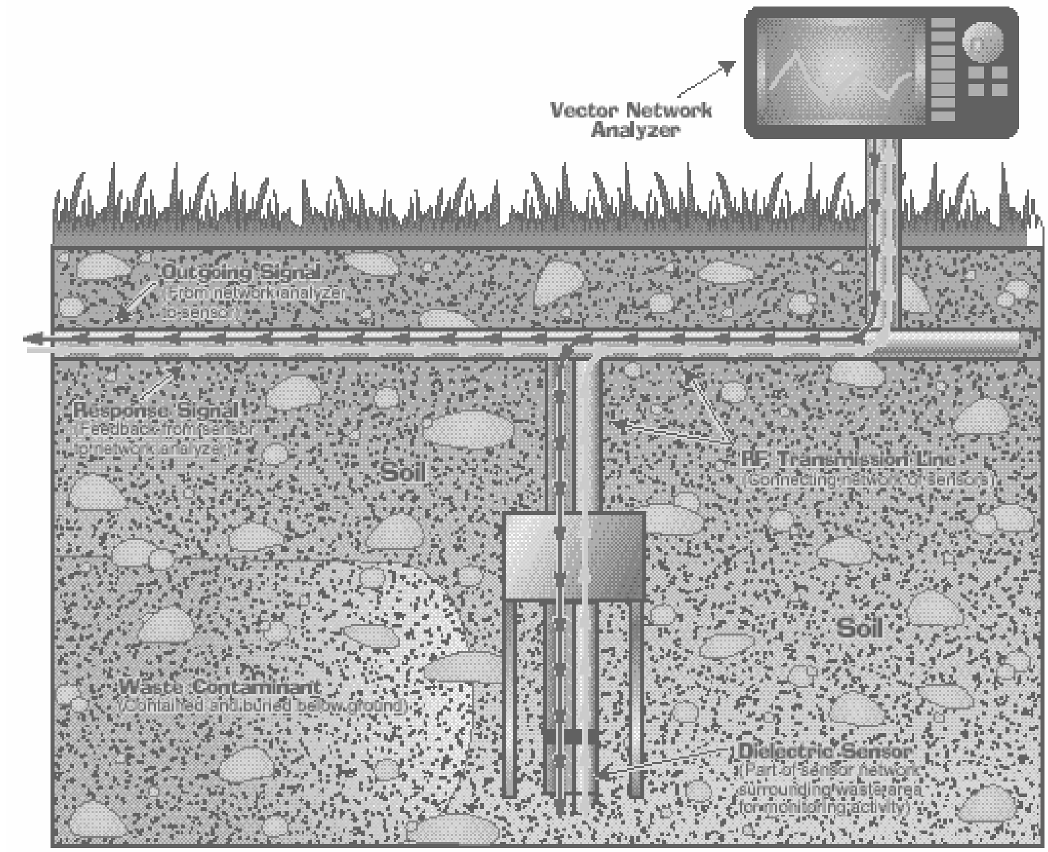

Figure 1 — Schematic representation of radiofrequency sensor.

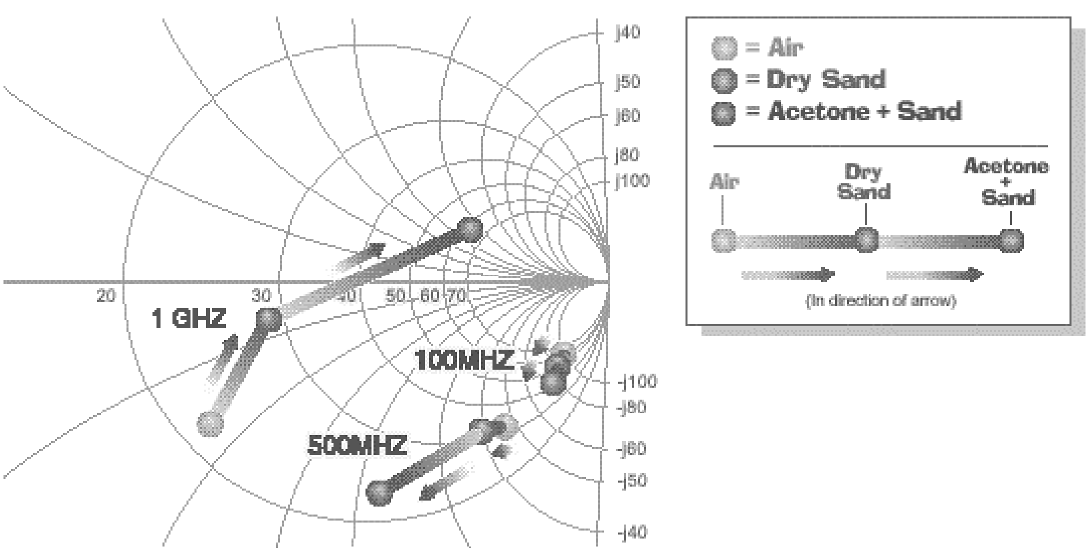

Figure 2 — Impedance changes of coaxial RF probe in air, sand, and acetone contaminated sand at three frequencies, shown on a Smith chart.

We also conducted an electromagnetic analysis of a transmission line by simulating three RF sensors in the form of shunt loads, located 0.1 wavelength apart. Figure 3 presents the changes to input impedance at the source end when we imposed a unit perturbation to either a real or imaginary part of each sensor impedance. The response curves are linearly independent, so a set of multifrequency measurements at one end of the cable can solve for the individual sensor impedances.

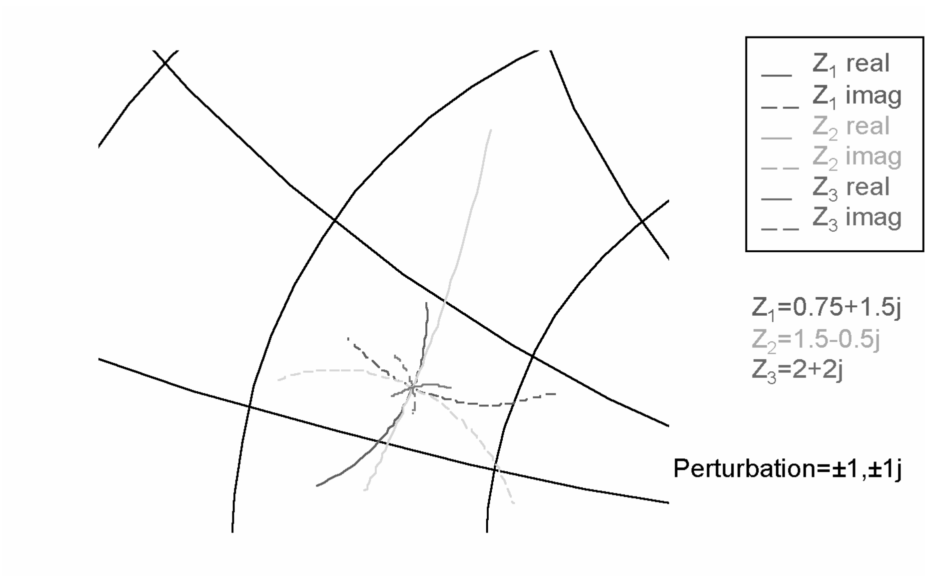

Figure 3 — Input impedance change of three-sensor transmission line; change in real or imaginary part of each sensor impedance produces differing trajectories for net input impedance at source end.

The buried sensor electrodes require inert protective coatings for long-term survivability. Work is underway to use the Argonne-developed near-frictionless carbon coatings on the sensor electrodes. Besides corrosion protection, the low frictional property of the coating allows easy insertion of the electrodes deep into the ground, obviating the need for expensive special digging.

In summary, the RF multisensor approach, with corrosion protective coating, appears responsive to contaminant plumes and feasible for monitoring containment integrity.

References

1 Bussey, HE (1967) "Measurement of RF Properties of Materials: A Survey," Proc. of the IEEE, 55(6): 1046-1053.

2 Elmer, TW and Gopalsami, N (2000) "Microwave dielectric Spectroscopy of Gases," Proc. 16th Intl. Conf. on Advanced Science and Technology 2000, FNAL, Batavia, IL, p55.