Ground Penetrating abilities of a new LIDAR-like Imaging Spectrometer

The early use of SAR and LIDAR systems from aircraft and space shuttles revealed the ability of the signals to penetrate the ground surface. When pulsed electromagnetic radio-waves pass through a material they generate measurable responses in terms of energy, frequency and phase relationships. Following early applications of Atomic Dielectric Resonance (ADR) investigations in medical studies [1, 2] the technique has been extended to an exploration of the penetration of invisible laser light into minerals and suites of rocks, each of which show characteristic responses. A number of field surveys conducted by Adrok (for inhouse purposes and/or commissioned for third parties) have confirmed the ability of the method to distinguish the nature, thickness and depth of the rock units present. Recognition of subsurface limestones, sandstones, mudrocks, coals, gas and oil has been achieved.

When Synthetic Aperture Radars (SAR) were first deployed from aircraft towards the end of the last century [3, 4], it was anticipated that some, albeit limited, penetration of the ground surface might be achieved using X-Band (30mm) and C-Band (55mm) wavelengths. On 6th June 1981, a Canadian Convair 580 aircraft acquired X and C-Band dual-polarization SAR imagery of a European Space Agency Test Coastal Transect (GB1) which included beach and sand dunes at the Sands of Forvie Peninsula at the mouth of the Ythan Estuary in Scotland[4,5]. It was anticipated that ground penetrations of 1.5cm and 3cm, respectively (equivalent to half-wavelengths) would be obtained over the dry dunes and wet beach areas. However, the signals returned from the fixed look-angle sensor identified a distinct interface some 3m below the surface. Boreholes identified this interface as the top of the groundwater, confirming that the signals had penetrated to this depth from the surface over a lateral distance of more than 100m across the dune slack area. In 1981, this greatly enhanced depth of penetration was again recognised from NASA Space Shuttle (SIR-A) imagery which detected ancient river channel systems, beneath 10feet (3.05m) of sands as reported by McCauley et al[6] from South-western Egypt. Laboratory studies by Elachi et al[7] showed that for the SIR-A sensor at L-band frequency, the skin depth penetration could range from 1.5 to 6m (based on the complex dielectric constants of sand samples from the area in question. Field confirmation of the airborne and spaceborne data by Elachi and Schaber in Elachi et al[6] showed sand thicknesses between 0.8 and 2m in the Mojave Desert.

During 1984, the SIR-B (Synthetic Aperture Radar) sensor was operated onboard the Space Shuttle over an 8-day test programme which involved Dr Stove in under flying the Space Shuttle and acquiring, in real-time, simultaneous thermal infrared imagery over a shallow water test area in the North Sea. In this experiment the SIR-B used a variable look-angle sensor ranging between 15 degrees and 55 degrees. The ground penetrating capability of the narrower look-angle equipment was greater than that of the larger look-angle apparatus. This has stimulated the development of narrow coherent lased transmission beams for use in a new type of ground-surface-based imaging apparatus.

In recent years, the technology for the production of laser light has become widely available, and applications of this medium to the examination of materials are constantly expanding. Whereas the earlier applications concentrated on the use of visible laser light, the development of systems using invisible laser light are now being further explored. In this contribution we wish to report on a series of field surveys in which rocks of different compositions and textures have been exposed to pulsed beams of wideband, laser light conditioned dielectric resonance, to produce a range of differing atomic dielectric energy and frequency responses detectable by suitable receivers. Conditioning the beam by dielectric optics creates a synthetic lens effect so that the sensors appear to have much longer chambers with wider apertures than their actual physical size. This effect produces narrow coherent beams of pulsed and lased radiowaves which are good for illuminating target interfaces and materials.

Atomic Dielectric Resonance (ADR) [1, 2] is a recently patented investigative technique (US 6864826 B1 and EP 1 210587 B1) [8] which involves the measurement and interpretation of resonant energy responses of natural or synthetic materials to the interaction of pulsed electromagnetic radio-waves, micro-waves, millimetric or sub-millimetric radio-waves from materials which permit the applied energy to pass through the material. The resonant energy response can be measured in terms of energy, frequency and phase relationships. The precision with which the process can be measured helps define the unique interactive atomic or molecular response behaviour of any specific material, according to the energy bandwidth used. ADR is measurable on a very wide range of hierarchical scales both in time and space. Time scales may range from seconds to femtoseconds, and spatial scales from metres to nanometres.

The conditioned ADR beam of photons penetrates the rock and as it encounters the component materials it stimulates the atoms to release energy according to their compositions. The conditioned pulse of photons passes through the structure of the atom and emerges to encounter more atoms further along its path. Electrons from each individual atom release energy in all directions, and by timing the first arrival of this burst of low energy from a time-zero position beside the transmitting source to different delta-X separation distances between the transmitting sensor's (Tx) cylindrical chamber and the receiving sensor's (Rx) cylindrical chamber, the isometric move-outs or dispersion of the beam can be computed in the Y-direction at right angles to the Scanning X-direction path for increasing separations of Tx and Rx.

The receiving antenna (Rx) is kept vertical pointing into the ground at 90 degrees look angle and the transmitting antenna (Tx) is thus moved away from Rx on a Parallel path along the X-direction looking at 90 degrees into the ground. The increasing beam dispersion through ray path move-outs can be computed and the increasing cylindrical beam widths computed and plotted as the X separation distance increases. By simple triangulation, the changing beam velocities through rock layers of differing dielectric constant can be computed by Normal Move-Out (NMO) mathematics and Ray Tracing Theory (after Snell's Law). Since the Transmitting beam set up is lased in the cylindrical chamber of the transmitting telescope and the speed of the lased beam is slowed down by special dielectric optics in the chamber, the resulting beam dispersion going down through the ground becomes slightly narrower with depth. This arrangement is called confocal focusing (akin to that of a confocal microscope but in this case used at the macro-scale rather than the micro-scale with a microscope) at rock layers and is ideal for mapping geological layers of varying dielectric constants, in each case plotting the computed rock volume illuminated between layer bounded beam limits. Different Pulse set-ups at the surface are possible and scanning a WARR line (called Wide Angle Reflection and Refraction Sounding in Geophysics) is carried out by moving the Tx sensor away from Rx at a uniform speed, over scan lengths of 50m or 100m for example. Moving from a Tx to Rx separation of 50m increases the beam width and Y-dispersion from 0.5m to 25m. The important point is that the centre of the confocal beam is always looking straight into the ground at 90 degrees (if the antennas are parallel and pointed accurately using a scanning gimballed platform) and the light path direction obeys Fermat's principal of Least Time.

The nature of the return signal, its frequency, energy levels and phase changes (if any) are determined by the minerals encountered. In a rock mass the component minerals may vary, but in general, sandy rocks are composed principally of quartz (SiO_2), limestones mainly of calcite ($CaCO_3$), coals largely of Carbon (C), and clays or shales mainly of assemblages of iron- or magnesium-alumino-silicates. Cascading harmonic analysis of the emerging electromagnetic radiation enables the energies and frequencies of the signals released by the materials to differ sufficiently for the rock compositions to be recognised by computer processing. Adrok have found that by repeated characterisation of the ADR signals received from known rocks at known depths in quarries or boreholes, it has been possible to classify the principal rock types of the area under investigation and identify them with confidence in blind tests beside logged boreholes.

Adrok's Measurements

(1) Dielectric permittivity measurement

Conventional radar can locate objects in a less dense medium (e.g. a plane in the sky or a shallow buried object in the ground) because those objects reflect back some of the signal. Radar can also detect the dielectric contents of materials penetrated. Ground penetrating radar can therefore detect boundaries with different dielectric constants (rather as seismic detects changes in acoustic impedance). ADR is not depth constrained whereas conventional ground penetrating radar is limited to very shallow depths.

ADR accurately measures the dielectric permittivity of materials encountered and determines the dielectric constant of each layer of rock. The dielectric constant is basically the effect that a given material has on slowing down the ADR signal. Determining the dielectric constant of each layer enables each rock layer to be mapped as with seismic but much more accurately, as ADR transmits and receives its signals based on the speed of light (which is an order of magnitude faster than the speed of sound, used for seismic imaging).

Dielectrics also allows preliminary identification of the composition of each layer e.g. shale or sandstone.

In general, dielectric measurements for hydrocarbon layers tend to be between two (2) and five (5) for Adrok's ADR Scanner, if water is absent. In geological terms, the main effect on the signals velocity as it propagates through the material is the water content. For example, air has a dielectric constant of 1, whilst water has a dielectric constant of 80. Most geological materials lie within these boundaries. Water should be easily mapped by Adrok's ADR Scanner as it gives a very high dielectric reading.

(2) Accurate Depth measurements (by two independent methods)

Adrok's ADR Scanner measures depths to each subsurface horizon that gives a reflectance and change of beam velocity. Adrok uses two independent methods to calculate depths to each horizon: (a) Normal Move Out (NMO), and (b) Ray Tracing. Only when both methods give the same depth measurement will Adrok's software accept that depth reading. Adrok's depth measurements can be used to help tie-in or improve depth measurements made by seismic tools.

(3) Spectrometric measurement

The most important result of ADR's ability to penetrate materials is that all the current imaging techniques of spectrometry become available to identify all materials encountered subsurface. Identification of these materials is based upon:

- absorption and reflection and emission of different wavelengths of electromagnetic radiation
- many different spectral harmonic relationships of components in the returned signals

After the subsurface has been divided into its geological horizons by determining its dielectric constant, spectrometry is used. The principle is as follows. The ADR system analyses many components of the return signal from a location where the geology is known and learns what return signals each material emits (i.e. the material is "typecast"). When ADR encounters an unknown material in the subsurface it compares the return signals from that material with its data base of known typecast materials until it finds a perfect, or nearest, match. The material encountered is then identified. For example, oil bearing sands, water bearing sands and shales encountered in previous wells are typecast in an area. Then the ADR response from a target formation in an undrilled prospect is compared to those typecast formations until a match is achieved. This identifies the undrilled target formation. Adrok is building a database of many different rocks containing different combinations of oil, gas, water, etc. Ultimately ADR will be able to classify geological formations encountered by comparing it with this database.

Output

For the oil industry Adrok uses ADR to generate a virtual well log i.e. information equivalent to that derived from a drilled and logged well.

Presently the output takes the form of:

1. Spectrometric material classification of subsurface layers (Virtual log providing material classification)
2. Dielectric Log - showing dielectric permittivity curves
3. Image of the subsurface (two-dimensional Cross-Section)

Adrok can provide the outputs of its Dielectric Log and the Virtual Logs to the client in ASCII format, to allow the client to input these measurements into their own software models of the survey site(s).

Adrok is presently working with oil industry technical staff to produce results in formats which will be familiar to petroleum geoscientists.

A number of third party witnessed and Commercial surveys have been carried out by Adrok; some of which from onshore Morocco, USA and UK and are reported on in more detail in this oral presentation.

1 Fagge, T.J., Barclay, G.R., Stove, G.C., Stove, G., Robinson, M.J., Head, M.W., Ironside, J.W. and Turner, M.L. 2007 J. Translational Medicine, 5:41

2 Valentine, H., Fraser, J., Stove, G.C., Barclay, G.R. and Farquhar, 2002 C.F. Atomic dielectric resonance spectroscopy: a novel technique for the identification of TSE infected tissues. Proc. Int.Conf. on Transmissible Spongiform Encephalopathies, Edinburgh 9.

3 Cimino, J.B. and Elachi, C. (Eds.) 1982 Shuttle Imaging Radar-A (SIR-A) Experiment. JPL Publication 82-77 NASA Jet Propulsion Laboratory, 230pp.

4 Stove, G.C. 1981 The European SAR580 Experiment 1981 Report on Ground Data Collection Programme for Block GB1, Macaulay Institute for Soil Research Experiment 21GB, In: Sorensen, B.M. and Gatelli, E. (Eds.). The European SAR-580 Experiment 1981 – In-Situ Data Collection Reports “Ground / Sea Truth”, Joint Research Centre, Ispra.

5 Stove, G.C. 1983 The current use of remote-sensing data in peat, soil, land-cover and crop inventories in Scotland. Phil. Trans. R. Soc. Lond. A 309, 271-281

6 McCauley, J.F., Schaber, G.G., Breed, C.S., Grolier, M.J., Haynes, C.V., Issawi, B., Elachi, C. And Blom, R. 1982 Subsurface valleys and geoarchaeology of Eastern Sahara revealed by shuttle radar. Science 218, 1004-1019

7 Elachi, C., Roth, L.E. and Schaber, G.G. 1984 IEEE Transactions on Geoscience and Remote Sensing, GE-22, 4, 383-388

8 Stove, G.C., 2005 Radar apparatus for imaging and / or spectrometric analysis and methods of performing imaging and / or spectrometric analysis of a substance for dimensional measurement, identification and precision radar mapping. International Patent No: 10/ 070,768: 1-37. Edinburgh, GB