1228668 Ground Penetrating Abilities of a LIDAR-like Imaging Spectrometer for Finding, Classifying and Monitoring Subsurface Hydrocarbons and Minerals

Gordon Stove 1 (1) Adrok, Edinburgh, United Kingdom.

1. Introduction

The development of Atomic Dielectric Resonance (ADR) by Dr G.Colin Stove was inspired by his experiences of working with Synthetic Aperture Radar (SAR) sensors, from both satellites (ERS1 and RADARSAT) and from the Space Shuttle SIR-B experiment in the early 1980s, as well as his work with conventional Ground Penetrating Radar (GPR) systems. ADR was developed as an improvement over SAR and GPR to achieve deeper penetration of the earth's subsurface, through the creation and use of a novel type of coherent beam. ADR is used as a geophysical technique to provide a precision instrument for the accurate geological recognition of rock layers and identification of rock types by transmission through the rock medium as well as reflection from each subsurface rock layer.

Although ground penetrating radars (GPRs) are now popular as non-destructive testing tools, their analytical capabilities are rather restricted and imaging is often crude. The relatively high transmitter power used in conventional GPRs gives only very shallow penetration in many soils and rocks. Conventional SAR systems which also use electromagnetic waves at high power to investigate the internal structure of non-conducting substances within the ground likewise provide relatively low resolution and ground penetration. The ADR methodology does not involve such high power transmission and achieves much deeper penetration than conventional GPRs.

In contrast from conventional GPRs, which transmit omni-directional electromagnetic signals, ADR technology uses directional electromagnetic radiation as resonating transmitting and receiving beams of energy.

An ADR beam transmitted through the ground is a pulsed, confocal beam (like a long, narrow inverted cone in shape) of coherent (in-phase) radiowaves and microwaves, producing minimal dispersion through its confocal and resonant mased nature.   The transmitted ADR beams have two components: a long wavefront standing wave to achieve deep penetration; and shorter resonance waves within the standing wave to enhance vertical resolution.

When Synthetic Aperture Radars (SAR) were first deployed from aircraft towards the end of the last century (Climino & Elachi,1982; Stove, 1981), 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 (Stove, 1981, 1983). 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 3m of sands as reported by McCauley et al (1982) from South-western Egypt. Laboratory studies by Elachi et al (1984) showed that for the SIR-A sensor at L-band frequency   field confirmation of the airborne and spaceborne data by Elachi and Schaber in Elachi et al (1982) 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. For the duration of this open test programme, Dr Stove was commissioned by the UK Ministry of Defence to under fly the Space Shuttle and acquire 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. Maser beams are well known. They are coherent beams of electromagnetic waves at microwave and radio frequencies. They are the longer wavelength equivalent of lasers. In this contribution we wish to report on a series of experiments in which rocks of different compositions and textures have been exposed to pulsed beams of wideband, maser 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 mased radio waves and microwaves which are good for illuminating target interfaces and materials.

2.   How Atomic Dielectric Resonance works

2.1   Description of the ADR System

Atomic Dielectric Resonance (ADR) is a patented investigative technique (Stove, 2005) 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.

Some aspects of the field and laboratory ADR equipment involve certain conditions being satisfied during the setup of the apparatus so as to obtain "standing wave oscillations" in ADR test sample chambers and / or in ADR remote sensing antenna system assemblies. In this respect, it is important to selectively control the group velocity of the radio wave and microwave radiation as it is emitted or "launched" by the transmitting antennas into the ground. In particular, for deep scanning it is important for the launch speed of the wave to be sufficiently slow to ensure that the wave can be accurately registered at a precise "zero time" location by the receiver antennas, after the pulse has been transmitted. The zero time position t(z) in remote sensing or t(0) in geophysics, is the start position for ADR range measurements and must be identified on the received ADR signal to determine the true time range (in two way travel time, usually TWT(ns)) represented by the received signal, returning from each resonant subsurface reflection layer.

Referring to the Figure 1 block diagram of subsurface beam pathways targeted by a vertical pulsed ADR beam, then the Wide Angle Reflection and Refraction (WARR) tracking method is able to (a) identify the upper and lower boundaries of each stratum, (b) determine the inter-layer beam velocity and mean dielectric constant of the material in each stratum and (c) identify the materials in the various strata from both the dielectric constants, known molecular or atomic spectral lines (after FFT Analysis of the received signals) and spectral ADR statistical parameters data-based for known rock types.

ADR accurately measures the dielectric permittivity of materials encountered and determines the Dielectric Constant (DC) of each layer of rock to an accuracy of at least 1:400. With deeper penetration and a narrower ADR beam, the accuracy of dielectric mapping improves and at 1km depth an accuracy of 1:4000 can be achieved for the mean dielectrics of narrow layers at this depth. The dielectric constant is basically the effect that a given material has on slowing down the ADR transmission signal. Determining the dielectric constant of each layer enables each rock layer to be mapped with a depth computation from ground level and can also determine physical properties of the rock layer, such as moisture content, porosity and density indices. In general, dielectric measurements for hydrocarbon layers in the earth tend to be between two (2) and five (5) for the author'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 DC of one, whilst water has a DC of approximately 80. Most geological materials lie within these boundaries.

Figure 2 shows the typical shape of an ADR transmit pulse into the earth and the received energy from the earth. Figure 3 displays photographs of the ADR equipment.

2.2 Producing the ADR beam for remote sensing

ADR transmitting antennas are optically designed using dielectric lenses and can be referred to as behaving like radio wave and microwave telescopes. In the ADR transmitting telescopes, the dielectric lens sequences amplify the pulsed waves, but the optical feedback provided by lasing in the telescope chamber converts the system into an oscillator and then into a coherent invisible light generator. (By invisible light, we mean frequencies within the radio wave and microwave spectrum.)

The conditioned ADR beam of photons (coming out of the transmitting antenna) enters the ground and penetrates through soil and rock. As the beam encounters the component materials it stimulates the electrons of 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.

2.3 ADR receiving system

The ADR transmitters must be oriented in the same direction as the receiving antennas. Mounted on a tripod, 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 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). Only when these two independent depthing methods give the same depth measurement does the ADR software accept that depth reading (this is what the authors call depth parallax). 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 exact rock volume illuminated between layer bounded beam limits. Different Pulse set-ups at the surface are possible and scanning a WARR line 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. This makes an ideal reference beam for checking the progress of drilling rods which do not always go straight into the ground through rocks of contrasting densities.

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. Repeated characterisation of the ADR signals received from known rocks at known depths in quarries or boreholes, it has made it possible to classify the principal rock types of Central Scotland and identify them with confidence in blind tests beside logged boreholes.

2.4   Processing and interpretation of the received ADR signals

The analysis of the returned ADR signals from the subsurface to the ADR receiving system is performed by FFT analysis of the received spectrum (which includes radio waves and microwaves). This results in mathematical and statistical analysis of the received spectrum and the recognition of energy, frequency and phase relationships.

More detailed spectrometric analysis is achieved through the quantum electrodynamic (QED) approach (Feynman, 1985) by quantising the entire ADR receive spectrum. In ADR quantum theory, this is similar to the equal temperament system of tuning musical instruments – in which each pair of adjacent musical notes has an identical frequency ratio. In this "tuning" methodology, an interval (usually an octave) is divided into a series of equal steps, with equal frequency ratios between successive notes. For example, a violin is tuned in perfect fifths. The notes are G – D – A – E for violins; where the fundamental G is 192 Hertz, D is 288 Hertz, A is 432 Hertz and E is 648 Hertz. Note that a perfect fifth is in a 3:2 relationship with its base tone. The octave frequency interval is covered in seven steps (A, B, C, D, E, F and G) and each tone is the ratio of the 7th root of 3/2, or in mathematical form [(3/2) ^ (1/7)]. For ADR, the quantised frequency spectrum includes 3 octaves of the radiowave spectrum and 33 octaves of the microwave spectrum. When ADR is applied to geological analysis, rocks can be genetically classified by notes and octaves using the above spectrometric approach – adding a new quantum dimension to recording "rock music".

2.5 Results output

For the oil industry and the mining industry, Adrok uses ADR to generate "Virtual Boreholes" - information equivalent to that derived from a drilled and logged well - remotely from the ground surface without piercing the ground.

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)

The outputs of the Dielectric Log and the Virtual Logs can be provided in ASCII format, to allow the client or end-user to input these measurements into their own software models of the survey site(s).

Adrok works with oil industry and mining industry technical staff to produce results in formats which will be familiar to petroleum geoscientists and mining geophysicists.

A number of third party witnessed and commercial surveys have been carried out by Adrok in North America, Europe, North Africa, the Middle East, and Australia; some of which from around the world and are reported on in more detail in this oral presentation.

References

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

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

Feynman, R.P., 1985 QED: The Strange Theory of Light and Matter, Princeton University Press, New York, USA.

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

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.

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

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.   USA Patent No: **6864826**. Edinburgh, GB

Figure 1. The ADR Scanner beam transmit and receive pathways through geological layers when one of the sensors is stationary and the other is moved progressively away at a regular speed

Subsurface Pathways

Tx ▮ Rx ▮ ▮ ▮ → Rx scan direction

Tx

Transmit beam

Rx

Received energy from subsurface earth
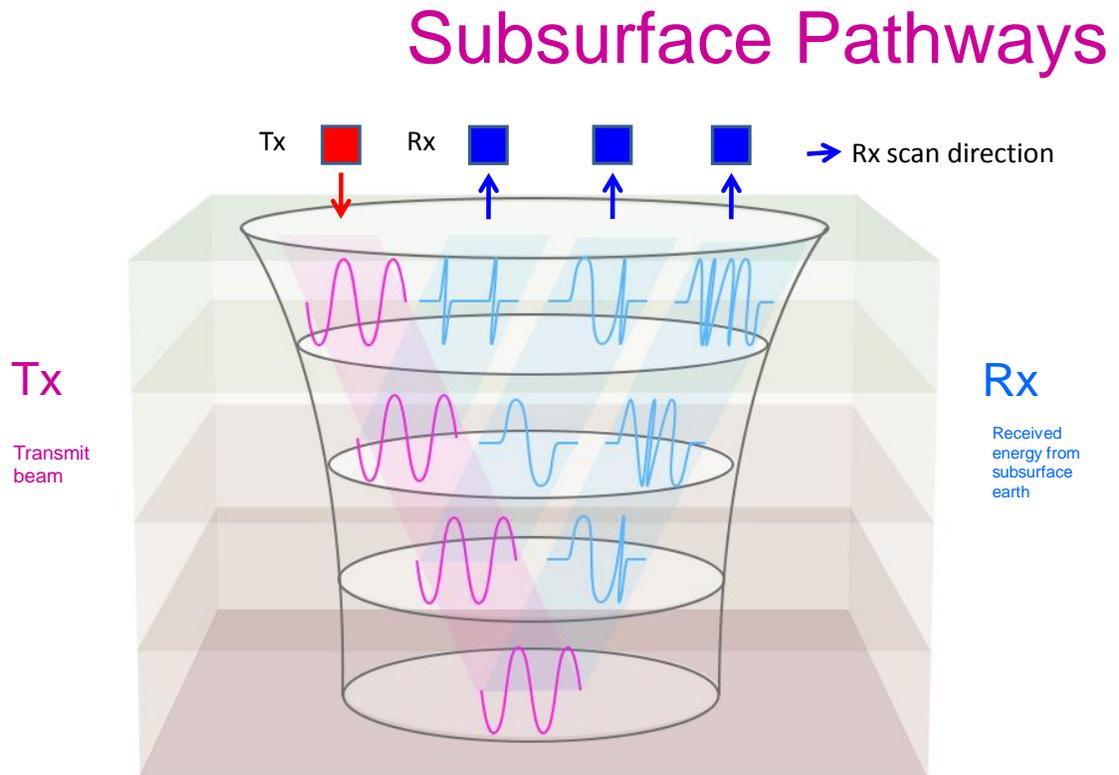
Figure 2. Examples of a typical ADR Transmit Pulse and Receive Signal

Ground Level

Time

Transmit Pulse

Amplitude

Ground Level

Time

Receive Signals

Amplitude
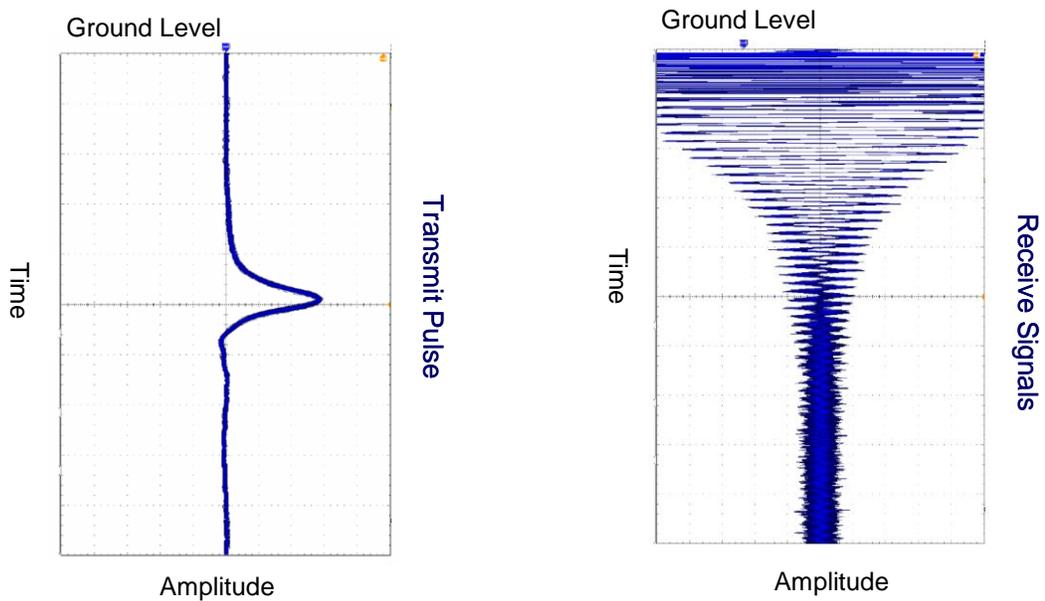
Figure 3. The ADR Scanner equipment

1 ADR Transmit Antenna
1 ADR Receive Antenna

ADR Data logging computer

Antennas Gimbal Platform

ADR Receiving Control Unit

ADR signal generator