Probing earth's subsurface with low frequency pulse radar

Dr K. van den Doel (CSO, Adrok Ltd, Vancouver, Canada)

Dr G. C. Stove (Chairman & Science Director, Adrok Ltd, Edinburgh, Scotland)

M. Robinson (CTO, Adrok Ltd, Edinburgh, Scotland)

Dr A . P. Cracknell (Emeritus Professor, Dundee University, Edinburgh, Scotland)

Dr C. A. Varotsos (Athens University, Greece)

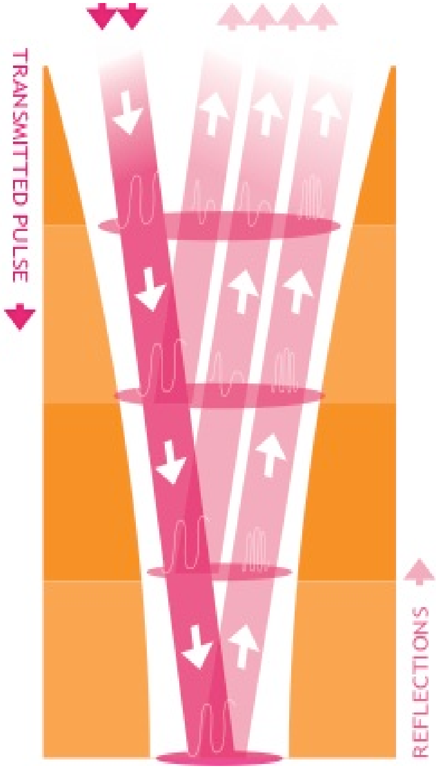
Outline

- Technology overview
- Current earth based applications
- Advantages of migrating to a space platform
- Technical challenges for orbital deployment
- Concluding remarks

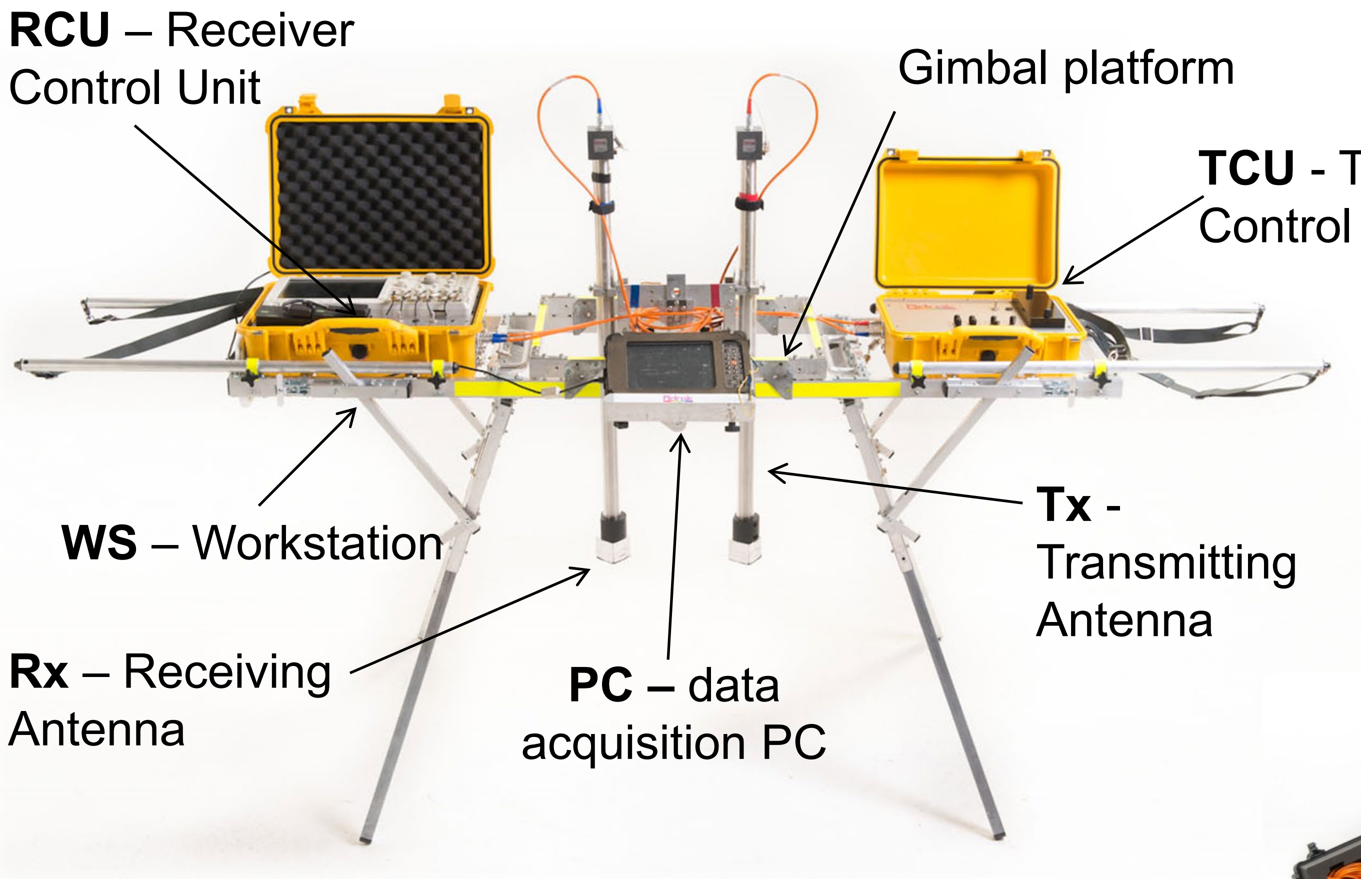
Technology overview

Atomic Dielectric Resonance (ADR)

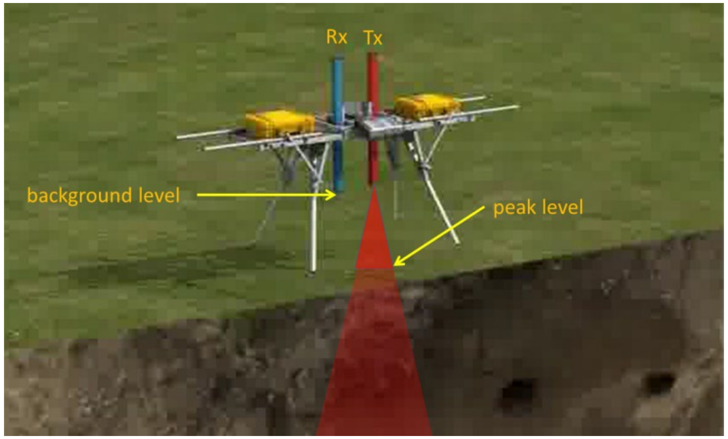
- **RA**dio **D**etection **A**nd **R**anging in visually opaque materials
- ADR sends broadband pulses of radiowaves into the ground and detects the modulated reflections returned from the subsurface structures
- Transmit broad band pulses at a precisely determined Pulse Repetition Frequency (PRF) with low power (of the order of a few milliwatts, Mean Power)
- For large depth geo exploration typically transmit between 1MHz to 100MHz
- ADR measures dielectric permittivity & conductivity of material
- ADR also uses spectral content of the returns to help classify materials (energy, frequency, phase)
- Temperature can be derived from ADR, which has applications in Enhanced Oil Recovery (EOR) using steam injections

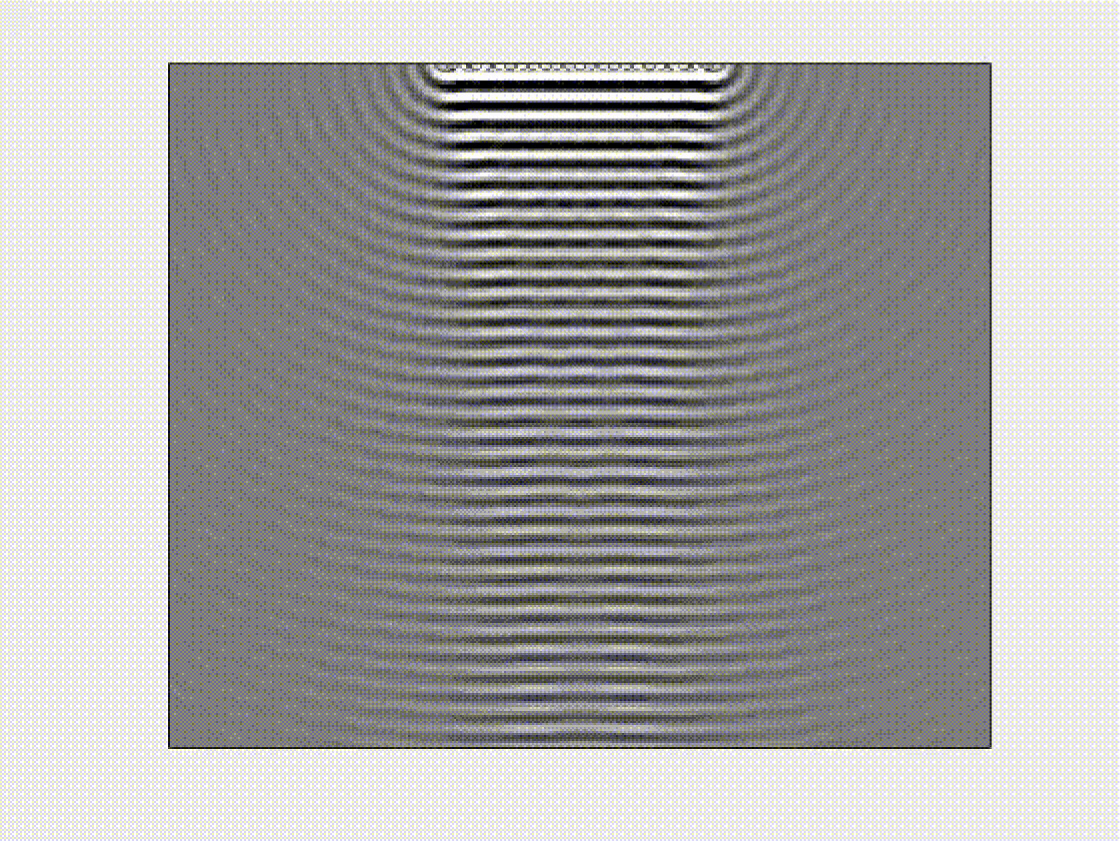


Earth based ADR Scanner



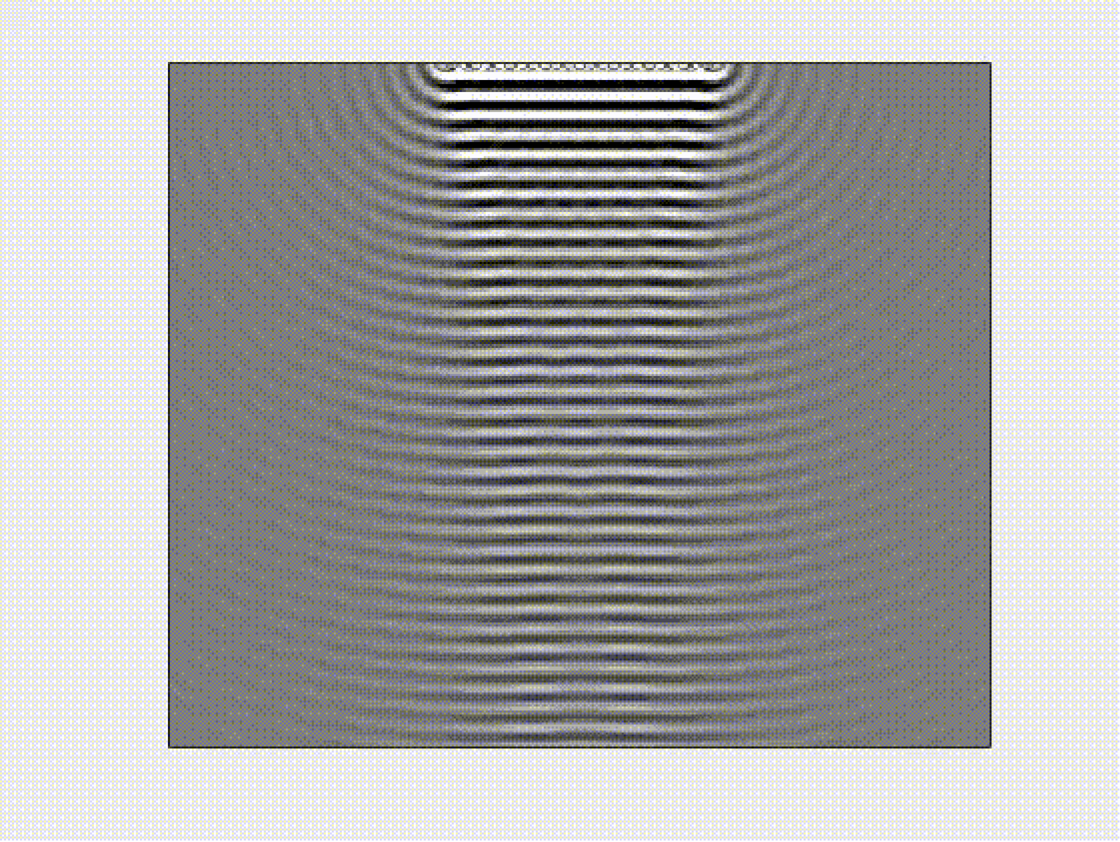
Wave propagation





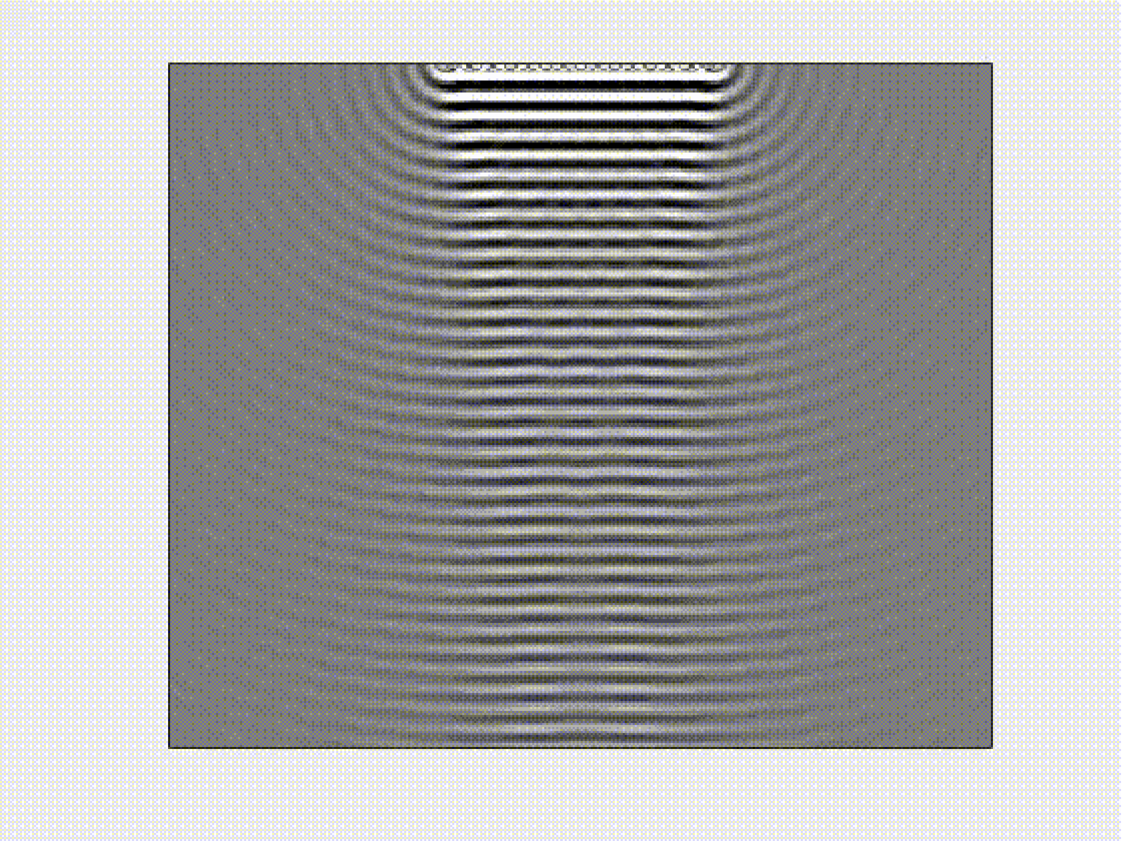
- Line of transmitters in Wide Angled Reflection & Refraction (WARR) mode creates beam (Synthetic Aperture Radar, SAR based phased array)

Wave propagation



- Beam can be virtually focused to various depths to illuminate Region of Interest (ROI)

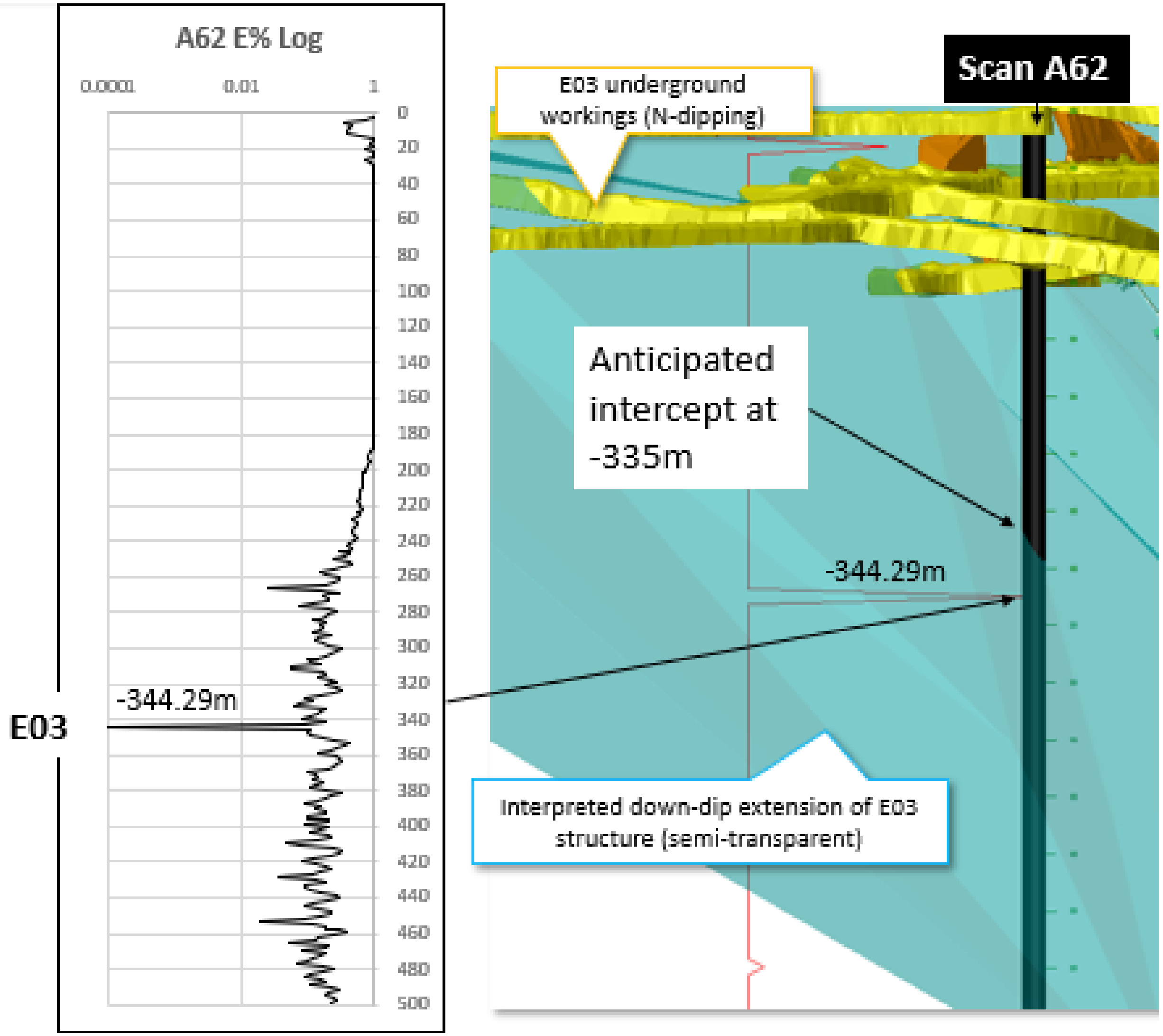
Wave propagation



- Beam can be virtually aimed to illuminate ROI

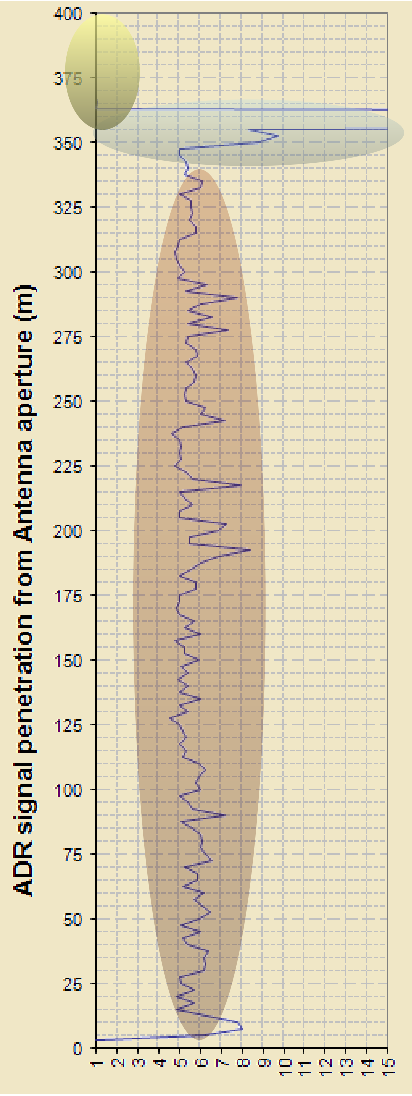
Current earth based applications

Identifying gold reefs in granites



Identifying water

Propagation from underground mine up through limestones to surface river



Air (ε_r = 1)

Water (ε_r = 81)

Limestones (ε_r = <3,9+>)

Air (ε_r = 1)

Advantages of migrating to a space platform

Why go to space?

- Can access "inaccessible" locations

- Remote operation
- Larger swathe area – big data
- Build knowledge of subsurface non-invasively & non-destructively in environmentally friendly ways

Specific space applications

- Icecap thickness measurements (like MARSIS)
- Minerals in permafrost (EAGE 2019)[5]
- Ground water detection and monitoring in resistive environment (CSEG 2018)[2]
- Monitoring structural integrity of urban foundations due to rising sea levels

[2] van den Doel, K. and Stove, G., Modeling and Simulation of Low Frequency Subsurface Radar Imaging in Permafrost. Computer Science and Information Technology, 2018 6(3), 40–45.

[5] van den Doel, K. and Stove, G., Calculation of Optimal Noise Levels for the Detection of Conductive Lenses in Permafrost with Radar Scans, 81st EAGE Conference and Exhibition 2019 (1), 1-5.

Technical challenges for orbital deployment

Technical challenges

- How will ADR system fit on satellite?
- How will it be operated remotely?
- Modifications of earth based ADR system for space deployment
- Considerations for data rates, transmissions, bandwidth
- Technology Readiness Levels
  - Earth based system TRL9
  - Space system will be starting TRL1

TRL		
	9	Commercialized
	8	Pre-production
	7	Field Test
	6	Prototype
	5	Bench / Lab Testing
	4	Detailed Design
	3	Preliminary Design
	2	Conceptual Design
	1	Basic Concept

Forward engineering

Stage

Product Idea

Go/ No-Go

Gate

DESIGN

Requirements:
- Design Brief & MoSCoW
- Customer need (Client & Adrok)
  - Program of Demands
  - Environmental
- Benchmarking
  - Direct competition
  - Related disciplines

Functional Specification:
- Technical description of needs
- Feasibility Report
- Business Case
- Science Input
- Technical Challenges

Theoretical Modelling:
- ADR theory
  - Beam propagation forward modelling
  - System set-up parameters
- Earth modelling
- E-M theory
- Electronics theory
- S/W theory

Go/ No-Go

BUILD

Physical Modelling:
- Cardboard/Foam models
- Breadboard prototypes
- Proving tests

Detailing (selection & sourcing):
- CAD drawings
- Materials selection
- Costing (Bill of Materials)
- Manufacturing plan
- Testing plan

Supplier & Manufacturer Selection:
- B2B relationship
- Capability
- Electro-Optics
- Electronics
- Mechanics
- Raw Material

Embodiment
- sub-systems
- systems integration
- Software writing & testing
- Pre-production prototypes (alphas, beta)

Go/ No-Go

TEST & EVALUATE

Internal testing & verification:
- Testing Procedures
- Test Equipment
- Debug
- Verification of Specification

External testing & verification:
- System Integration
- Certification of standards

Product/Prototype ready for release
- Operating Instructions
- User Guides

Go/ No-Go

Release

(for operation)

Selected publications

1. van den Doel, K., Jansen, J., Robinson, M., Stove, G.C. and Stove, G.D.C.,Ground penetrating abilities of broadband pulsed radar in the 1-70MHz range. In: SEG Technical Program Expanded Abstracts 2014, Denver. 1770–1774.
2. van den Doel, K. and Stove, G., Modeling and Simulation of Low Frequency Subsurface Radar Imaging in Permafrost. Computer Science and Information Technology, 2018 6(3), 40–45.
3. Stove, G. and van den Doel, K., Large depth exploration using pulsed radar. In: ASEG-PESA,Technical Program Expanded Abstracts 2015, Perth. 1–4.
4. Stove, G., Robinson, Fourie, M. L., Neufeld, P. and Ferguson, M., Identification and delineation of potash deposits in Saskatchewan, Canada using pulsed radar technology, GEOPHYSICS 2019, 0: 1-46.
5. van den Doel, K. and Stove, G., Calculation of Optimal Noise Levels for the Detection of Conductive Lenses in Permafrost with Radar Scans, 81st EAGE Conference and Exhibition 2019 (1), 1-5.
6. van den Doel, K., Modeling and Simulation of a Deeply Penetrating Low Frequency Subsurface Radar System, 78th EAGE Conference and Exhibition 2016.
7. van den Doel, K. and Robinson, M., Numerical Simulation of Aquifer Detection Using Low Frequency Pulsed Radar, PIERS 2015, Prague.

Dr K. van den Doel (CSO Adrok Ltd, Vancouver, Canada)
kdoel@adrokgroup.com

4 Volumes of case studies at www.adrokgroup.com