TEM CONFIGURATOR

version 2.00 October 2024

by Dr David Allen, Groundwater Imaging Pty Ltd

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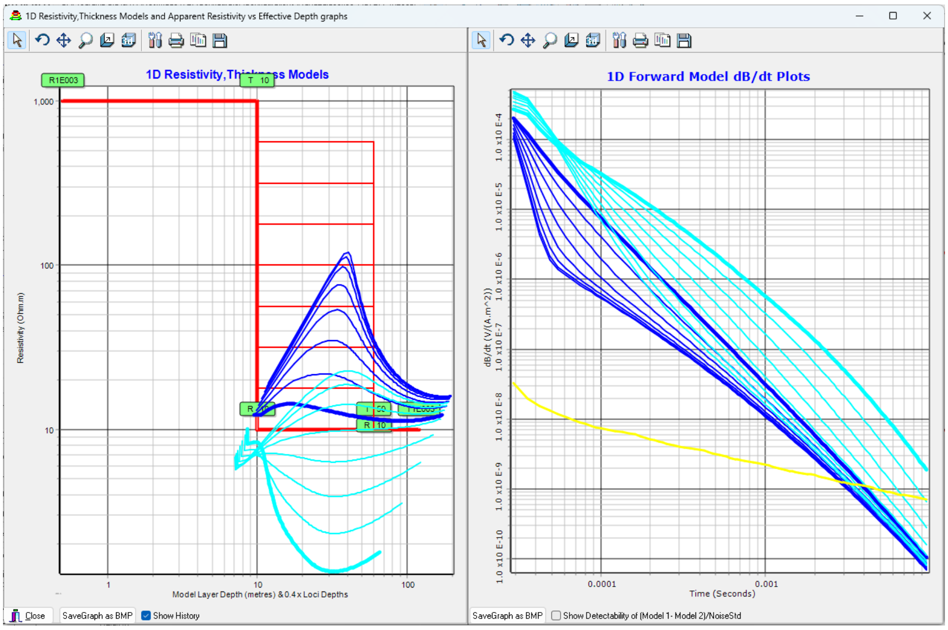

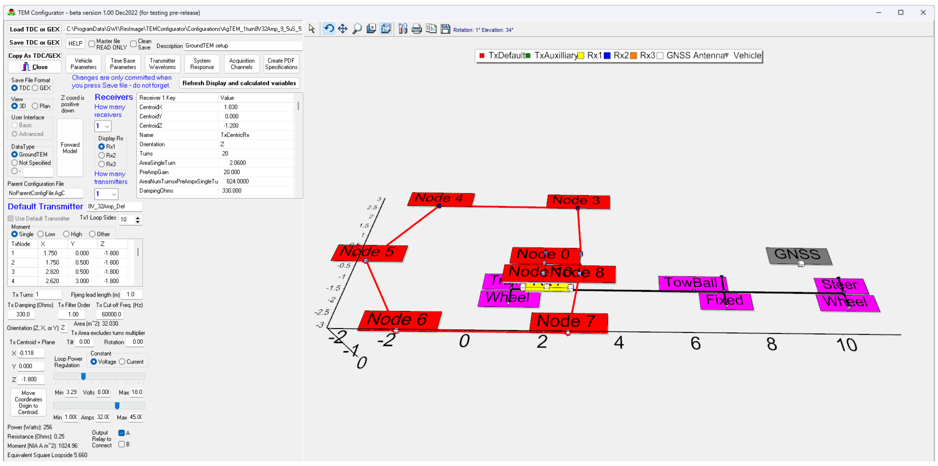

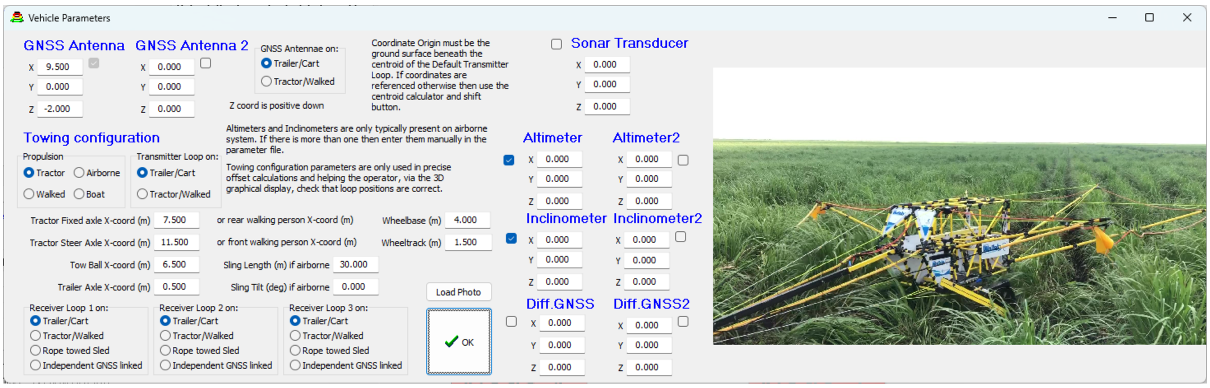

TEM CONFIGURATOR

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Version 2:00 October 2024 by Dr David Allen AgTEM@GroundwaterImaging.com phone +61(0)418964097

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INTRODUCTION

The TEM Configurator interface helps users understand and modify Transient ElectroMagnetic (TEM) geometry metadata files using graphics, calculated parameters, range checks, crosschecks, and data entry boxes. This is to make checking and changing TEM parameter files easier and less prone to failure as transient electromagnetic parameter files can be complicated and errors can be hard to spot.

New in version 2: A forward modelling facility is provided suitable for verifying the ability, of configurations, to resolve and contrast various layered models before encountering their noise floor. It is hoped that this facility will be quick to use in the survey quoting process for the purpose of demonstrating survey expectations to clients wary of being oversold geophysics. It is also for helping students to learn realistic expectations of TEM. This facility uses AarhusInv64.exe as its kernel so a licence is required (obtained externally as this is not our product).

TEM Configurator is a stand-alone program that facilitates manipulation of Windows INI format ASCII text metadata for TEM datasets. Filenames of such files can have either TDC or GEX suffixes depending upon their format. TDC metadata format is designed by Groundwater Imaging with compatibility with the Aarhus Workbench GEX format where possible however it facilitates greater flexibility than permitted by GEX format. TEM Configurator allows conversion from GEX to TDC formats and back again. Although as many keywords as possible, from both formats, have been mapped into the TEM Configurator user interface, full future compatibility cannot be guaranteed. To give the option to avoid loss of unrecognised keywords, read file changes can either be written to a clean file or back into existing files.

TEM configurator is also meshed into the ResImage TEM data imaging software that acts in conjunction with Aarhus Workbench to model and present AgTEM data.

TEM Configurator is designed to be compatible with all known TEM instruments, whether airborne, terrestrial or marine although the original inspiration was to support the AgTEM towed TEM systems.

New in version 2: Direct Current (DC) Configurator is like TEM Configurator but is applied to direct current geo-electric survey. Back-door access to DC Configurator is provided from the Forward modelling facility of TEM Configurator. DC Configurator uses our own forward modelling code so is free to use.

PROGRAMMATIC ACCESS

Written in Delphi (object pascal), TEM Configurator contains one open-source non-visual unit that acts as a programmatic interface with both GEX and TDC formats. It is requested that anyone wanting to work with this code contact Dr David Allen at AgTEM@groundwaterimaging.com to coordinate version control.

INSTALLATION

Installation is only supported for Microsoft Windows operating systems. It will work on versions 7, 10 and 11 at least.

TEM Configurator is provided as an installation file. Running the file will install the software in *C:\Program Files (x86)\GWI\ResImage\TEMConfigurator* and will place working and example files in *C:\GWI\ResImage\TEMConfigurator* and *C:\GWI\ResImage\AarhusInv_temp*

To conduct forward modelling of TEM data, a licenced copy of AarhusInv64.exe is required. By default, TEM Configurator will search for AarhusInv64.exe and its control file in standard locations but these can be changed.

TEM DATA FORMATS

TEM Configurator only deals with metadata for TEM datasets. The actual datasets may be stored in various formats that are not of consideration here.

AGTEM DATA FORMAT

As of 2024, during data acquisition, AgTEM datasets are stored as MONEX proprietary binary BIN files. Access to the format description is not supplied by MONEX. TDC format metadata files are to accompany the data files. AgTEM data files are converted into various formats for user access to the data. Indexable dBase files are the most used.

AGTEM GEOMETRY FILES

At least in post-processing, AgTEM data is coupled with geometry metadata files. The geometry file for raw data from the instrument will have the same filename core as the data but will have the extension TDC. Further through the processing stream, once gates are resampled to the minimum needed to avoid data loss entering inversion routines, and for purpose of compatibility with Aarhus Workbench, a slightly different geometry file with a GEX extension is generated.

SAMPLE GEOMETRY FILES

Sample TDC files are stored in C:\GWI\ResImage\TEMConfigurator\Configurations*.TDC as a basis for creating TDC files specific to individual datasets. This may be considered as a working directory. Within it, however, there is a subdirectory storing backups, not to be touched, of the sample files. Samples for the following instruments are provided:

- 50 x 50m in-loop with hand lain wire
- AgTEM Wallaby overlapping loop
- AgTEM Wallaby front loop (Slingram)
- AgTEM Wallaroo central loop with electric tractor
- AgTEM Wallaroo front loop (Slingram) with electric tractor
- tTEM 4x2
- SkyTEM (various files)
- AeroTEM
- Tempest
- VTEM

MASTER TDC FILES – CRC PROTECTION

So that critical documentation in TDC and GEX files is not lost, TEM Configurator can make files master files by adding a cyclic redundancy check and declare them as ‘Master’ files using keyword ‘IsMasterConfig=True’. TEMConfigurator will then check such files for corruption and warn users against saving any changes directly to that filename.

WHY TDC FORMAT?

GEX format has legacy derived limitations.

GEX is limited to one horizontal transmitter with either one or two moments. AgTEM is not limited in this way. GEX is also much harder to universally read due to lack of count variables and exception rules set up over time to extend from the simple legacy base format that did not allow for the variations required by modern systems. Time bases, transmitter variables and receiver variables are not separated and knowledge of their interrelationships requires knowledge of complex interpretation rules.

GEX FOR AGTEM WALLABY AND WALLAROO

It is possible now to document AgTEM Wallaby and Wallaroo data with GEX format but going forward, and for extended documentation not essential for Aarhus Workbench, a separately defined format is appropriate, but with as much compatibility as is sensible. GEX is managed without our control such that we cannot confirm forward compatibility.

GEX FORMAT DESCRIPTION

Because of compatibility requirements and extensive existing documentation, the GEX file is described first here. SkyTEM documents are the definitive source of information and the SKB document is most universally applicable and has been used as the main source for designing our reader/writer:

http://wiki.ags-cloud.dk/wiki/W_GeometryFileFormat

There is also good source information on description of timing variables accessible from this page – understanding these and how they may be used is of great importance.

For the tTEM instrument as of 2022, specific GEX documentation requirements are given in

https://hgg.au.dk/fileadmin/HGGfiles/Reports/Guide_tTEM.pdf

GEX for AgTEM: It is emphasised that variables FrontGateDelay, GateTimeShift and FrontGateTime are not relevant to AgTEM as it has no front gate cutting off signal until the transmitter is turned off, YET, Aarhus Workbench requires these parameters to be entered even when they are just default values that indicate they are not being used.

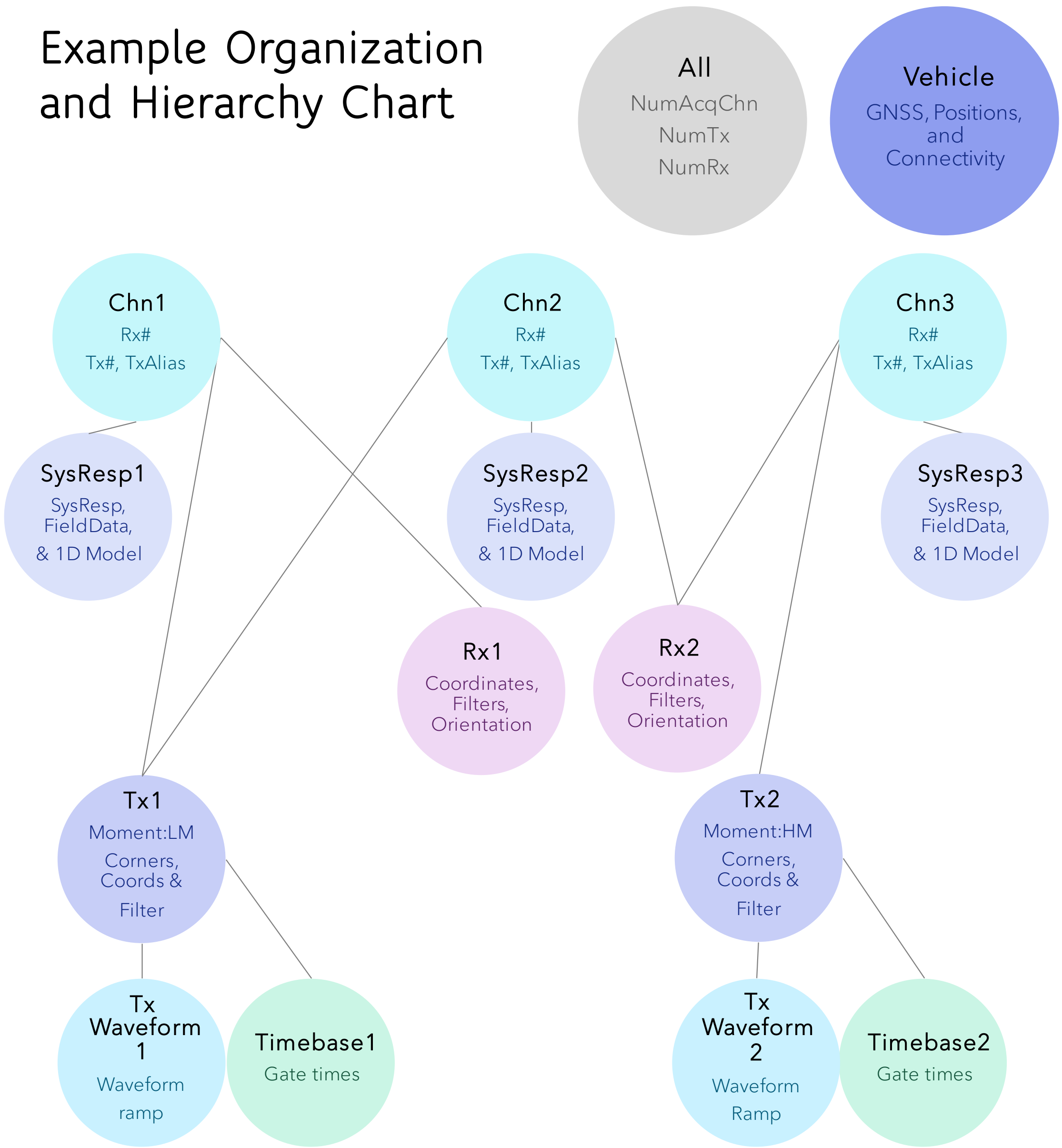
TDC FORMAT DESCRIPTION

The diagram below shows how sections of a TDC file may be organized and inter-connected.

TDC format can handle any number of transmitters and receivers all in any orientation. TEM Configurator will read and write all of this, yet the user interface will only display the first 3 receivers and first 2 transmitters.

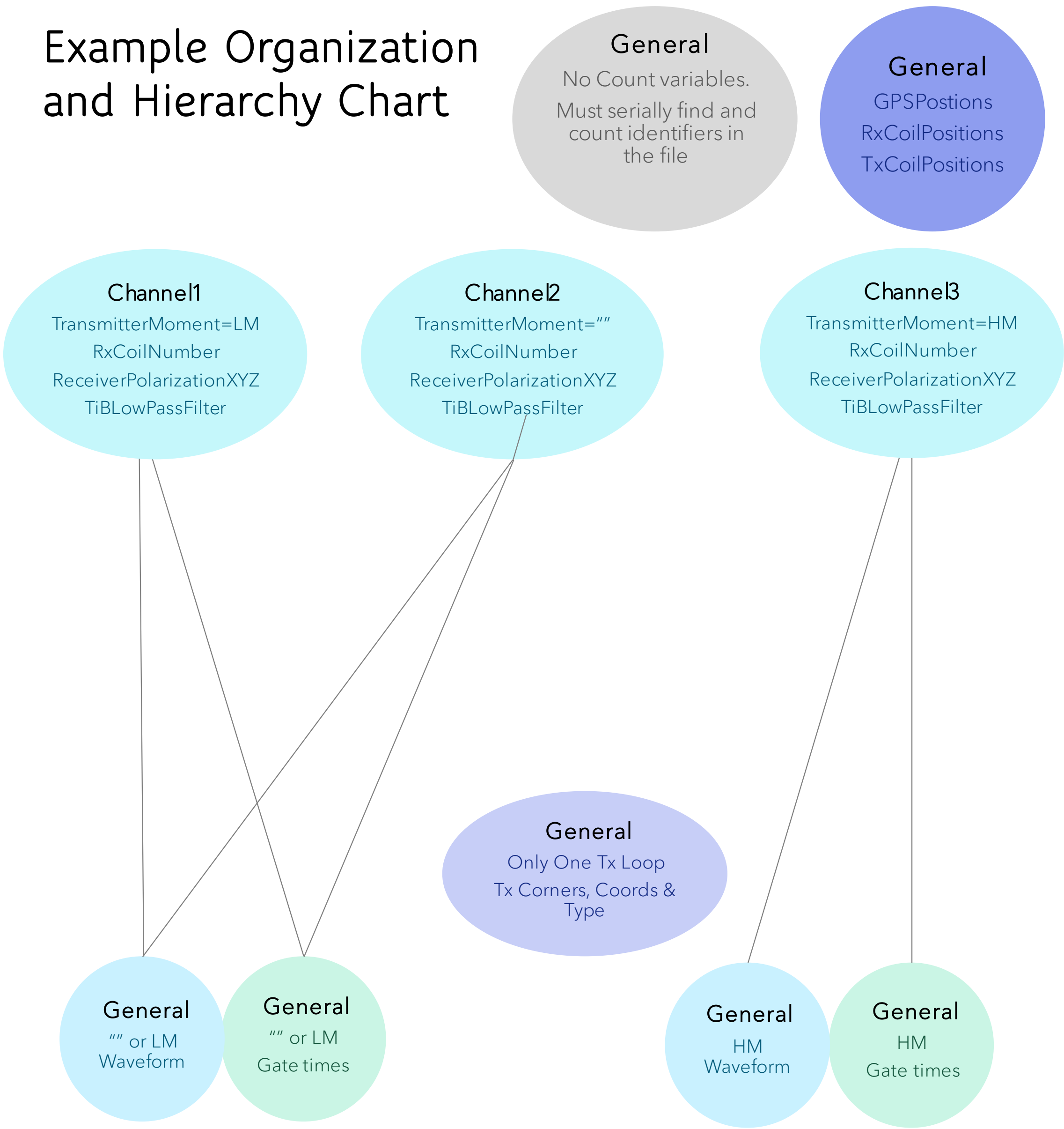
TEM Configurator - TDC format

Example Organization and Hierarchy Chart



For comparison, below is the equivalent, but more limited GEX structure.

TEM Configurator - GEX format



TEM CONFIGURATOR FORMS

MAIN FORM

TEM Configurator main form presents Transmitters, Receivers, File and General options as shown below. It also displays a geometric representation of the configuration.

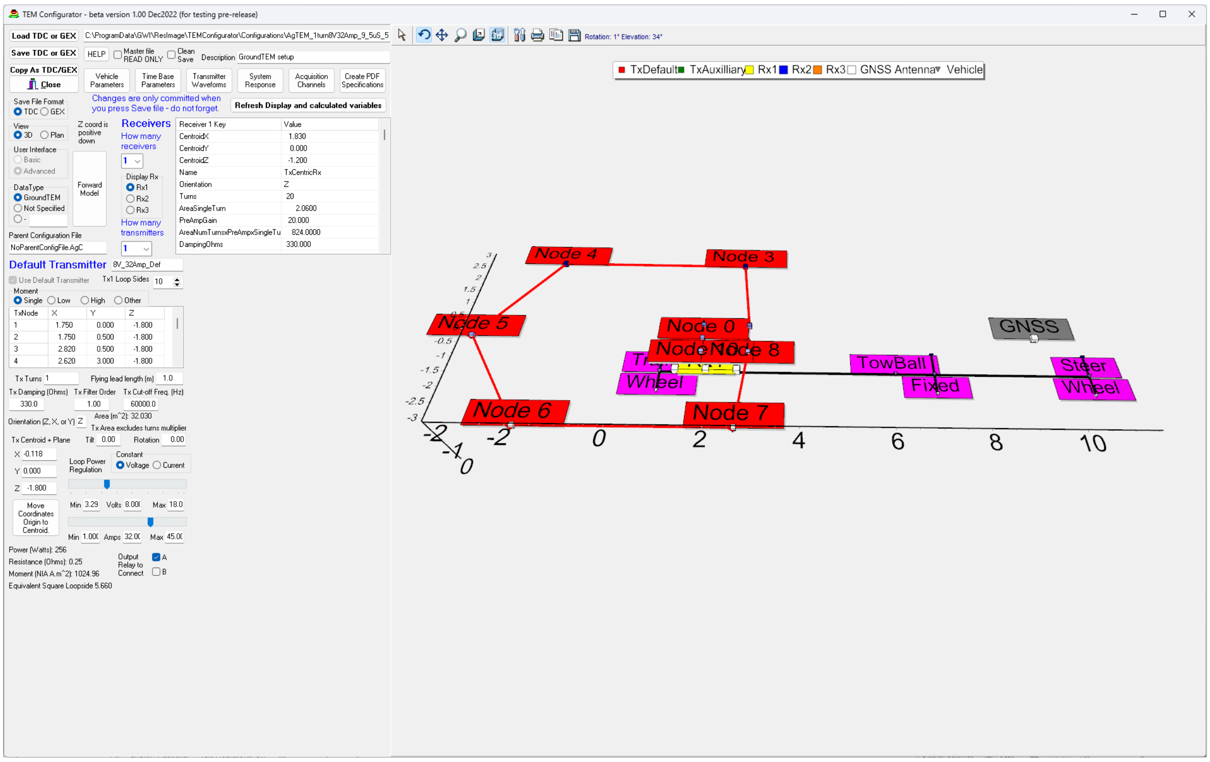


Figure 1 An overview of the TEM Configurator main form.

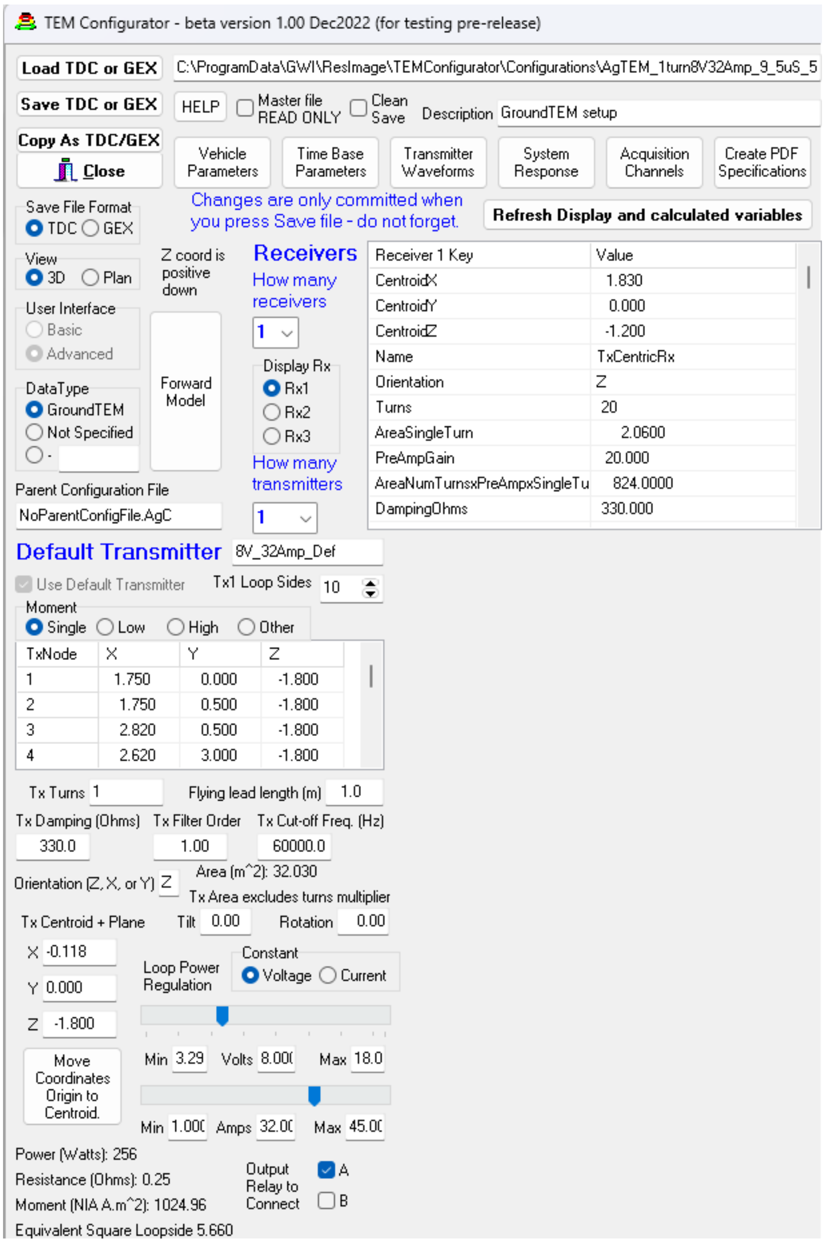


Figure 2 The left side of the TEM Configurator Main Form.

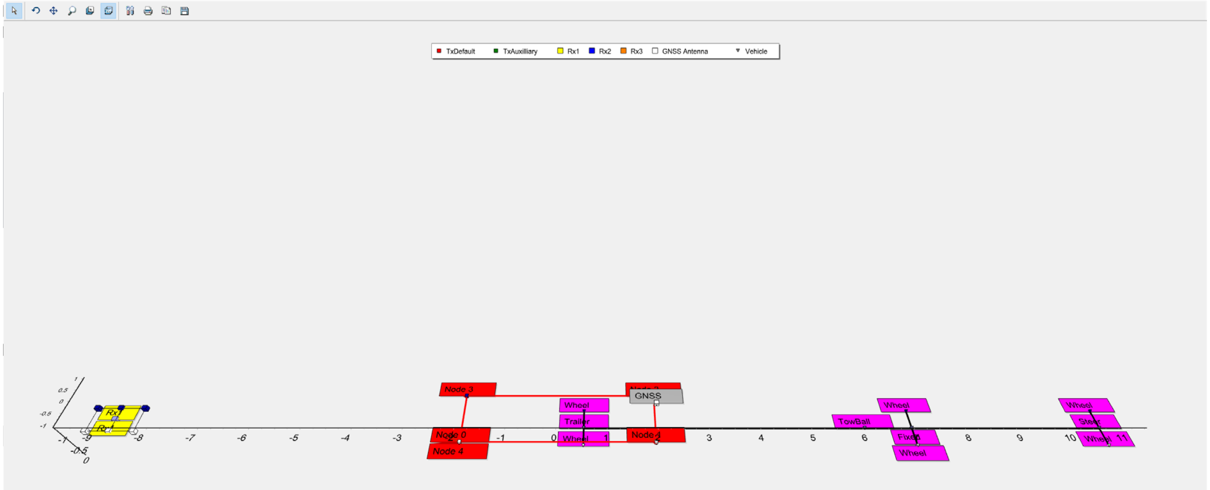


Figure 3 tTEM-configuration

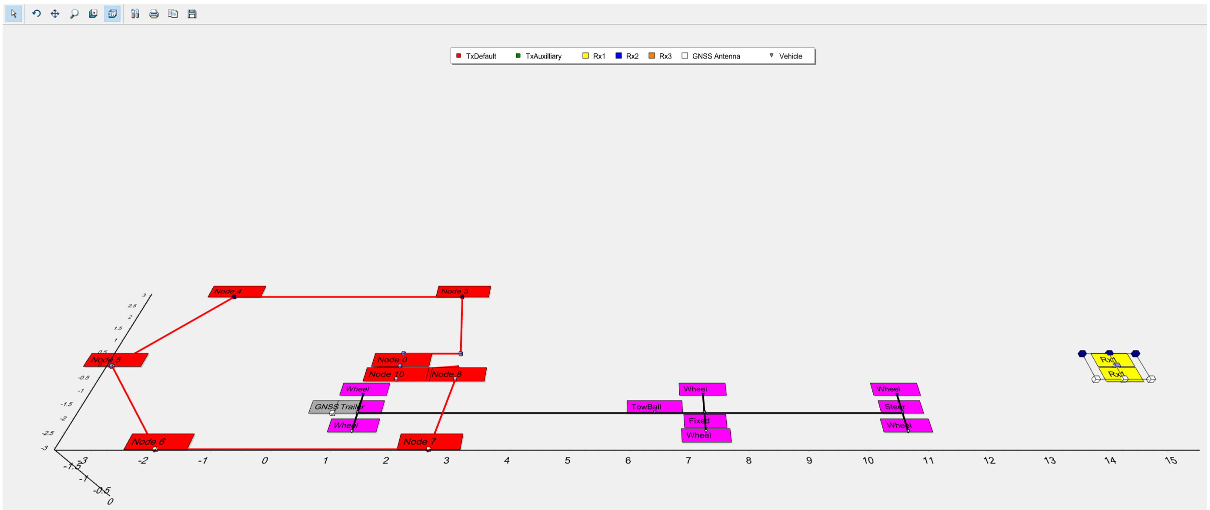
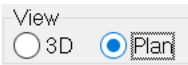


Figure 4 AgTEM Wallaby Slingram-only configuration

Switch to plan view using the radio buttons: 

or rotate, zoom, and pan using the controls.

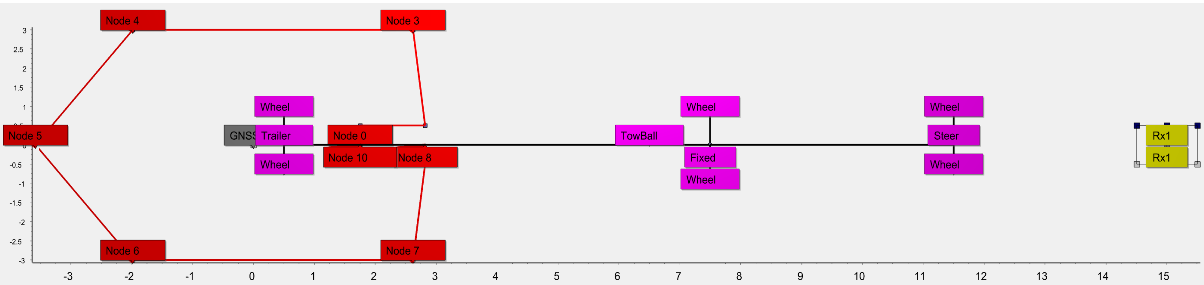


Figure 5 Plan view of AgTEM-Wallaby slingram-only configuration

RECEIVERS – PART OF MAIN FORM

Receivers 1, 2, and 3 (if they exist) are assessed via list on the main form as shown below. Many of the variables are not independent of each other. Dependencies can be calculated and checked by pressing Refresh display and calculated variables:

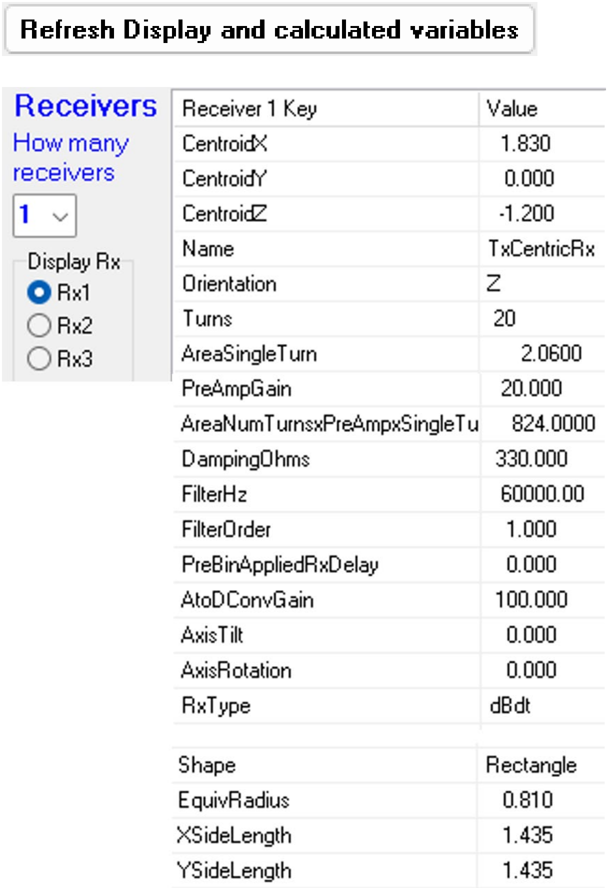


Figure 6 The receiver part of the main TEM Configurator Form.

TRANSMITTERS - PART OF THE MAIN FORM

Many transmitter variables are displayed in a section of the main form for just the first two transmitters.

Either 1 or 2 transmitters can be displayed (if there are more then just access them directly in the TDC files).

Select how many using the drop-down box: 

. Part of the form will remain blank if only 1 transmitter is selected. See an example of the Transmitter part of the form below:

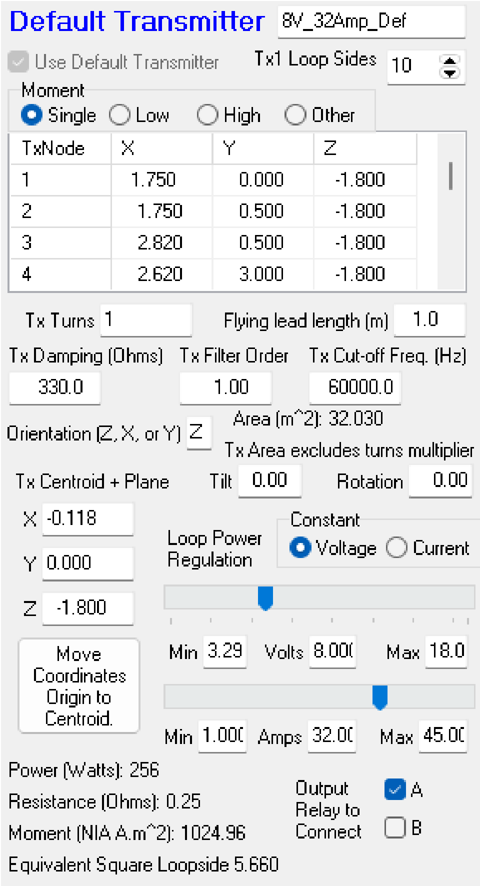
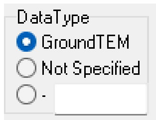


Figure 7 The Transmitter part of the main form - only the Default Transmitter section is displayed here.

If 'Refresh Display and Calculated variables' is clicked after changing loop coordinates, then the centroid and plane will be changed. All coordinates in Aarhus Workbench must be referenced to this centroid. For airborne the plane must be of reference zero, while for ground systems the transmitter reference plane, and everything else, must be referenced in height above ground with Z positive downwards. A parameter determines if the system is considered airborne or not as shown: 

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In addition to transmitter numbering, there is a legacy classification of transmitters by Moment: Single, Low, High, or Other in GEX files. In the Acquisition Channels section, this legacy is managed with some visualization tools.

VEHICLE FORM

Vehicle parameters independent of transmitters and receivers are grouped together on one form. There are enough parameters provided to suit centimetre accuracy positioning and orientation of all parts of systems while in motion even if the position sensors are not on the transmitters or receivers themselves provided that a suitable transposition algorithm is applied.

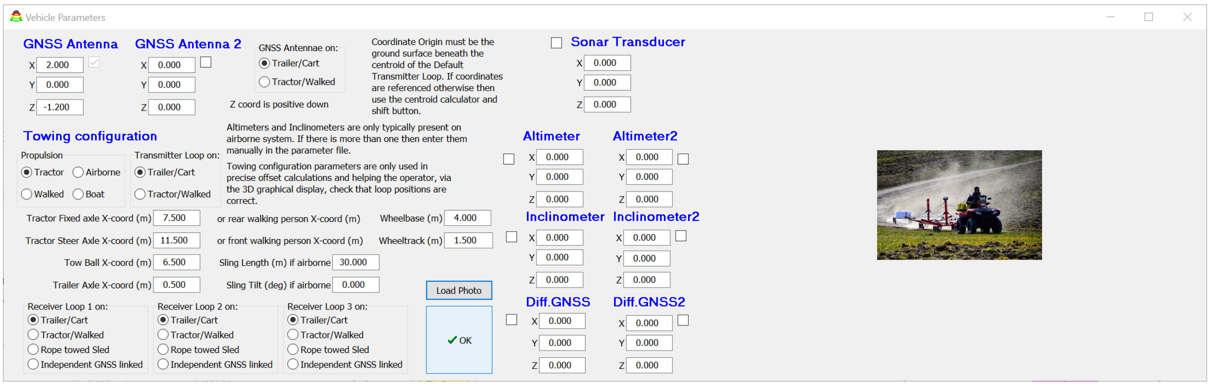


Figure 8 The vehicle parameters form

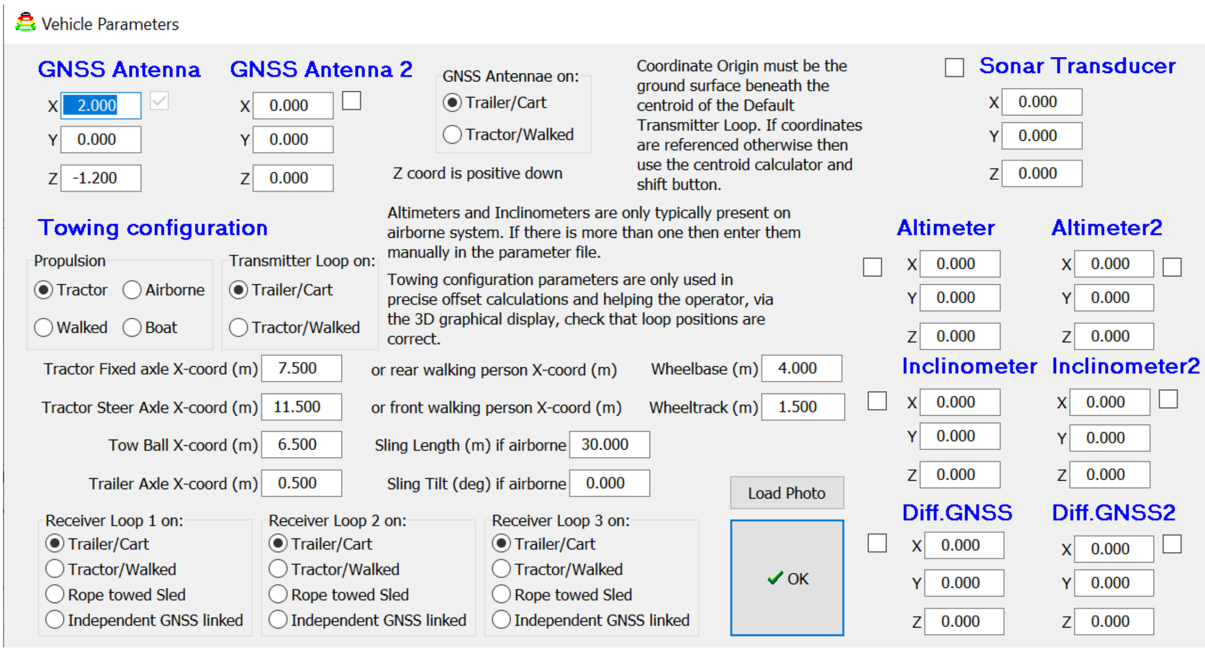


Figure 9 A close-up of the vehicle parameters form

TIMEBASE AND TIME PARAMETER FORM

Time base parameters are all grouped together on one form. Some are also duplicated under the transmitter and receiver form. Many data shifts, delays, periods and frequencies and their units can be difficult to define and understand so this form provides the facilities to iteratively try-and-see effects of changes to parameters. It also allows import of time gates form Monex format gate files.

The time scale comparison display at the base of the form reveals the shifted gate times and ramp for the selected Acquisition Channel.

Beware that time parameters are stored in many parts of the metadata hierarchy. Parameters on this form are from Timebase, Transmitter, Receiver and Channel parts of the object hierarchy and some parameters are calculations derived from parameters in multiple parts of the hierarchy.

Beware also that there are various reference frames through which to look at time parameters, especially the various shifts. This can make them difficult to get correct for modelling.

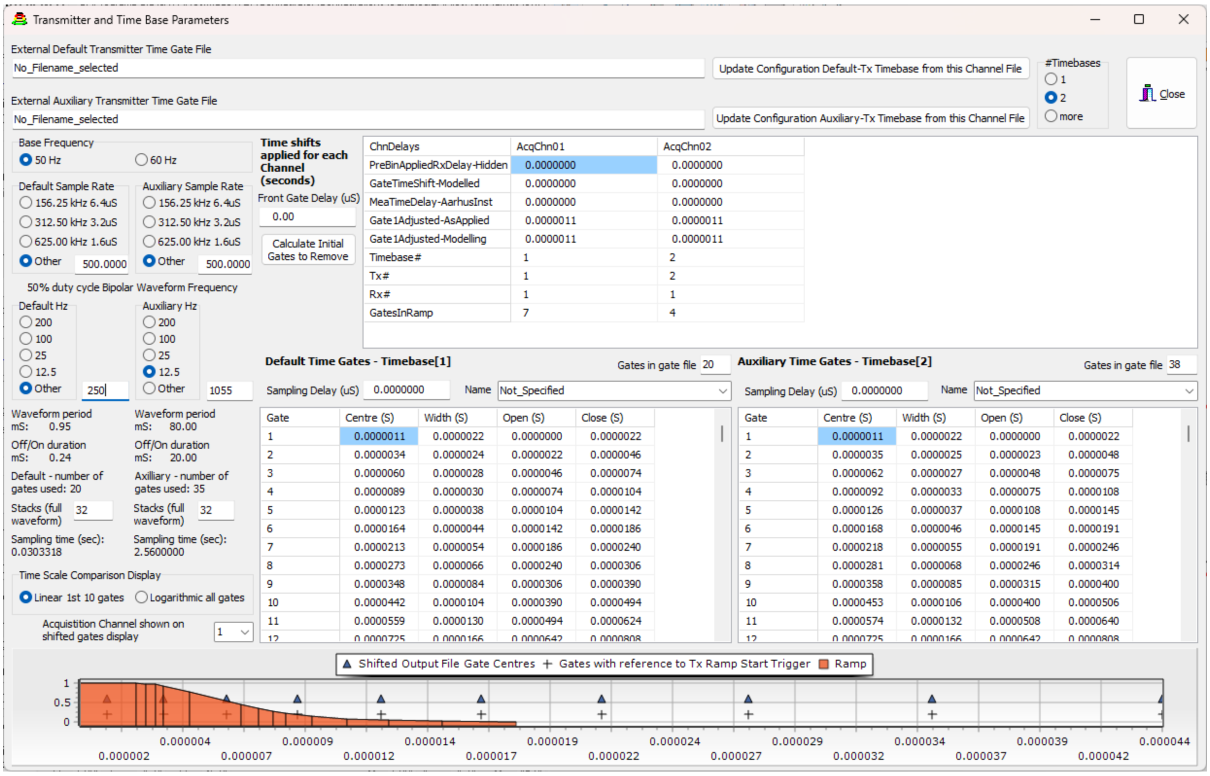


Figure 10 Time base display of TEM Configurator

TRANSMITTER WAVEFORM FORM

The Transmitter Waveform display allows for checking and adjustment of transmitter waveforms. This form presents the very different ways in which data is managed in inversion software. In the form below, with SkyTEM low and high moments and timebases, we see both negative and positive pulses are measured and fed into inversion software for modelling. This is important where decays extend past the end of off-time. Notice how on and off time can be rather different.

For AeroTEM the waveform is triangular. For Tempest it is a simple 100% duty cycle step response yet this is for data that has been artificially deconvolved as if it was created by such a transmitter waveform.

Differences in waveforms flow through also to differences in turn-off ramps.

Although transmitter waveforms continue through off-times, this is not allowed by the inversion software in the form displayed in this form. Off-time transmitter waveforms can be handled as system response defined separately.

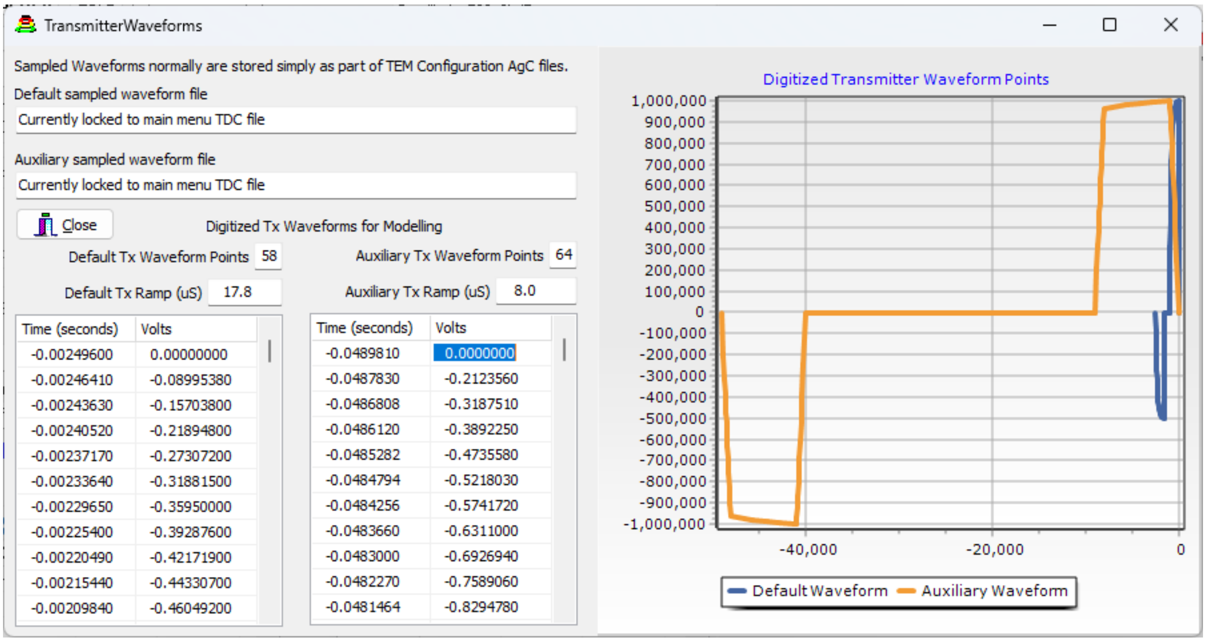


Figure 11 Transmitter Waveform display of TEM Configurator

SYSTEM RESPONSE FORM

The system response form is designed to help users visualize and analyse various aspects of system responses. The scale on the graph is deliberately enhanced in such a way as to accentuate the difficult awkward parts of the system response. The example below is for an AgTEM Wallaby overlapping loop configuration designed such that it is useful only for deep imaging. Most of the display is made up of digital delays, ramp time, the receiver loop's self-response to the ramp, the amplifier perturbation to overflowing and filter influence. In this example, system response is made by subtracting a modelled response from field data.

The green line in the example is modelling of system response using simple equations. In this case the equations are not used to seed the system response. Instead, some decaying oscillations, late time constant, and receiver self-response time constant are applied in proportions suitable for revealing the type of modelling that can be achieved. Remarkably good fit to system response can be achieved through equations without any influence from noise such as is added when determining system response from field data and modelling. The equation function typically is used more as a learning and verification tool rather than for production determination of system response. It verifies whether conceptualized components of system response are reasonable. If the concepts are reasonable then this is the first step towards minimization.

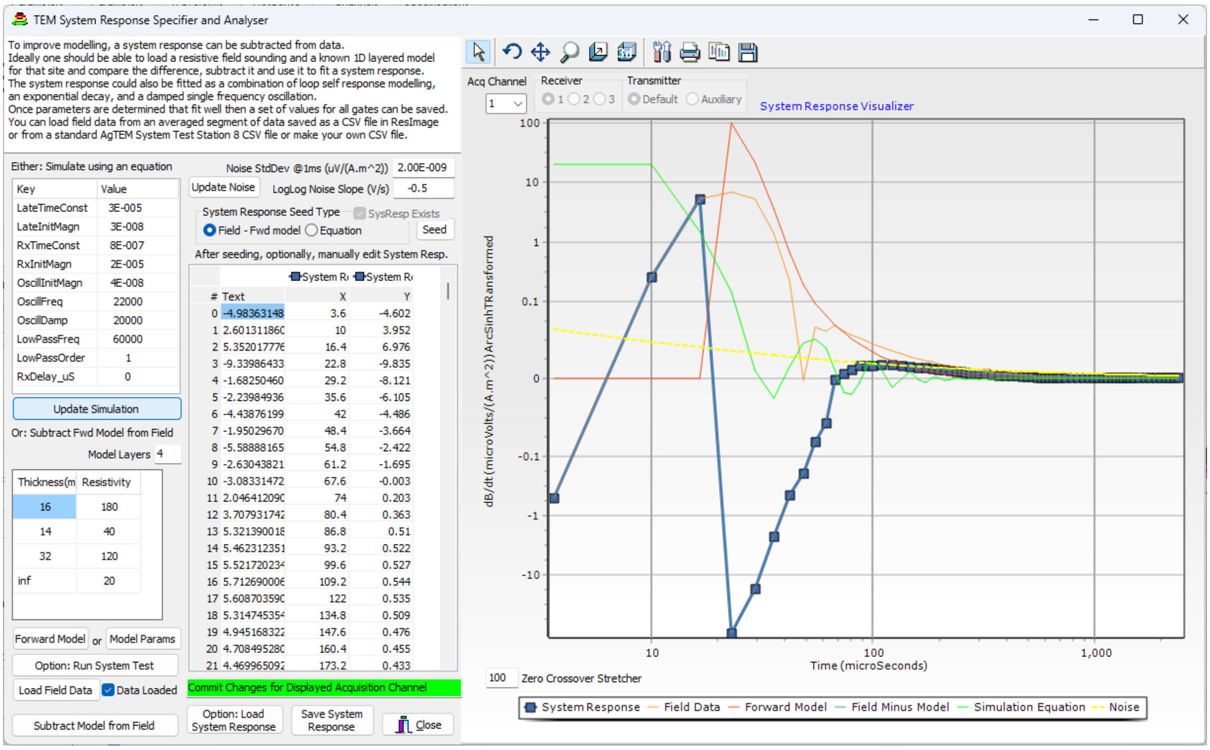


Figure 12 The system response display of TEM Configurator.

The button ‘Option: Run System Test’ is specific to AgTEM Wallaby and Wallaroo and any other systems for which system test datasets have been developed. System Testing is covered in a separate chapter.

SYSTEM RESPONSE DETERMINATION ON AIRBORNE VERSUS TERRESTRIAL SYSTEMS

It is easy to check system response of airborne systems – simply fly them a kilometre above the ground and take a measurement in a relatively conductor free environment. For a terrestrial towed system, towed for example by a Landrover or a Tractor, getting sufficiently airborne to conduct a conductor-free test just is not practical. This is why the system response test with modelled response subtraction was developed. Models will always be in error so it is certainly an imperfect but useful procedure.

SYSTEM RESONSE SUBTRACTION VERSUS DECONVOLUTION

Simple subtraction of system response from signal prior to modelling of data is not a theoretically correct method of removal. In the case where the transmitter waveform is a simple step response, and the transmitter is well removed from the receivers and the ground, simple subtraction is appropriate. In practice, it tends to be a good approximation too provided that extra shallow information need not be recovered.

Deconvolution is the theoretically correct method of system response removal and requires determination of system response over the entire transmitter waveform. Our visualization tool is insufficient for such determination.

ACQUISITION CHANNEL FORM

The Acquisition Channel display presents how selected combinations of transmitter and receiver are selected for acquisition and data storage. From the processing perspective some values in the Acquisition channel table can override transmitter and receiver parameters while from the field electronics perspective the situation needs to be the other way around. This form maps such interconnectivity as well as Aarhus transmitter aliases ‘Single’, ‘LM’ and ‘HM’.

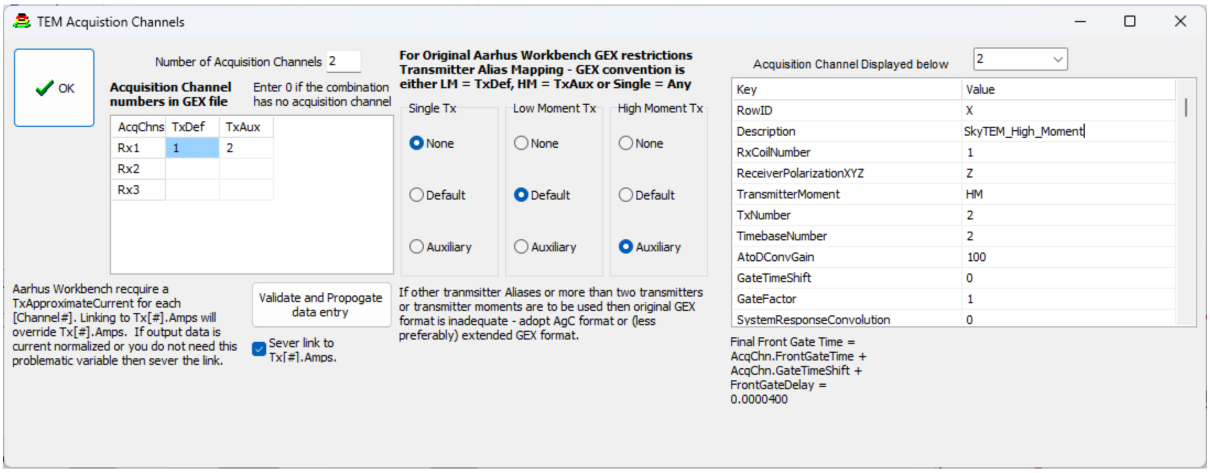
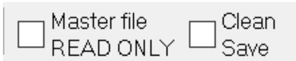


Figure 13 The Acquisition Channels display of TEM Configurator

CREATE PDF SPECIFICATIONS FORM

In version 2 this is still pending. At present it only makes an image file of the system geometry graphics.

SAVE OPTIONS

Files can be saves as master files so that later attempts to tamper with them then save to the same filename are either not permitted (if accessed through the TEM Configurator) or detected (if applied by a text editor or programmatically). To save a master check the box- 

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If 'Clean save' is selected then the file will be erased completely and resaved – losing comments and any un-recognised parameters.

Two data types can be loaded and saved - 

so, within limitations of each format, transfer from one to the other is feasible. An extension of GEX format, not yet recognised by Aarhus, will store TDC parameters not possible in the 2022 documented GEX format.

Backup and File Cleaning

Before saving files, TEM Configurator must move any comments that are in-line with keywords. Before doing so it backs up the files to *.TDCBAK or *.GEXBAK if this is not already done. Multiple backups are numbered with cascading numbers. Comments are just moved to separate lines just below the key=value pairs because generic readers are confused by such comments.

FORWARD MODELLING FORM

The forward modelling form is accessed via the main form, but also from ResImage, or from DCConfigurator. It has many sub-forms and will be discussed in a separate chapter. It is also accessed by the System Response Form, but typically this is non-visual access.

FORWARD MODELLING

The forward modelling form is designed to allow comparison of two sets of 8 type curves on graphs of both apparent resistivity versus loci depth and dB/dt versus time. We can provide direct current forward modelling for free so that users can get educational familiarity with the behaviour of electrical geophysics (see below) but for TEM, a licence to AarhusInv64.exe is required and this is available from Seequent https://www.seequent.com/products-solutions/ags-software/ . Seequent allow educational use of AarhusInv64.exe for free once a licencing arrangement is established.

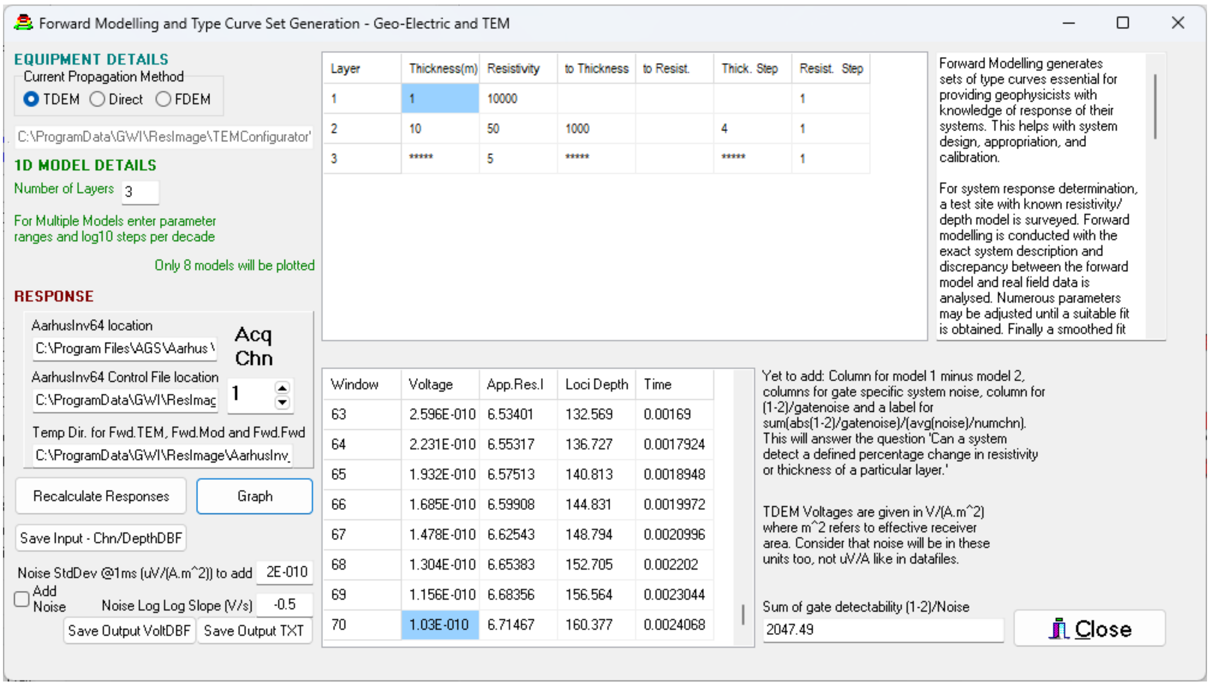


Figure 14 The forward modelling form of TEM Configurator.

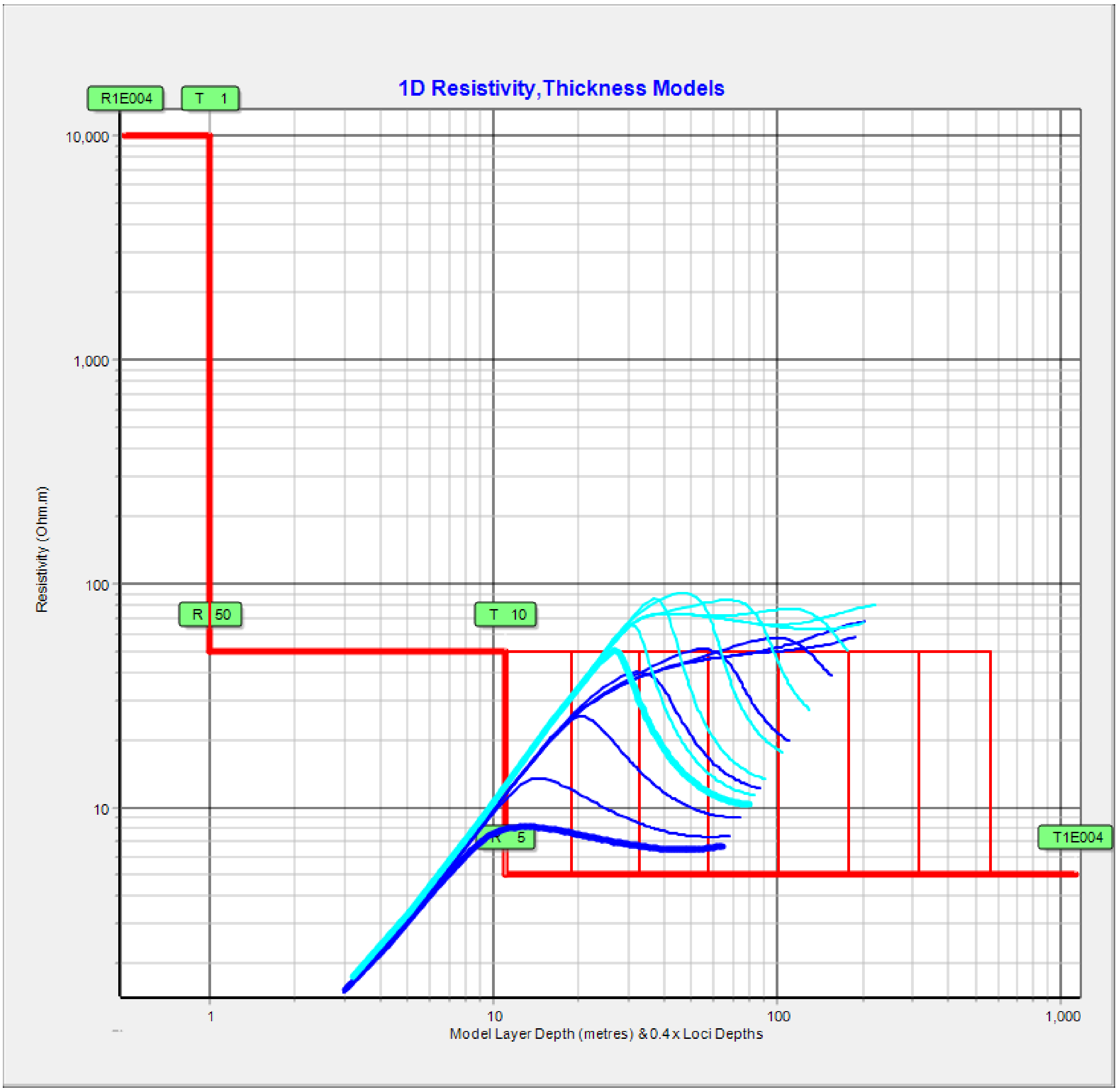


Figure 15 A resistivity versus 0.4 x loci depth example from the forward modeller. Red lines present modelled resistivities and depths, green boxes display resistivity of the layer below, and thickness of the layer above each box. Type curves for eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne.

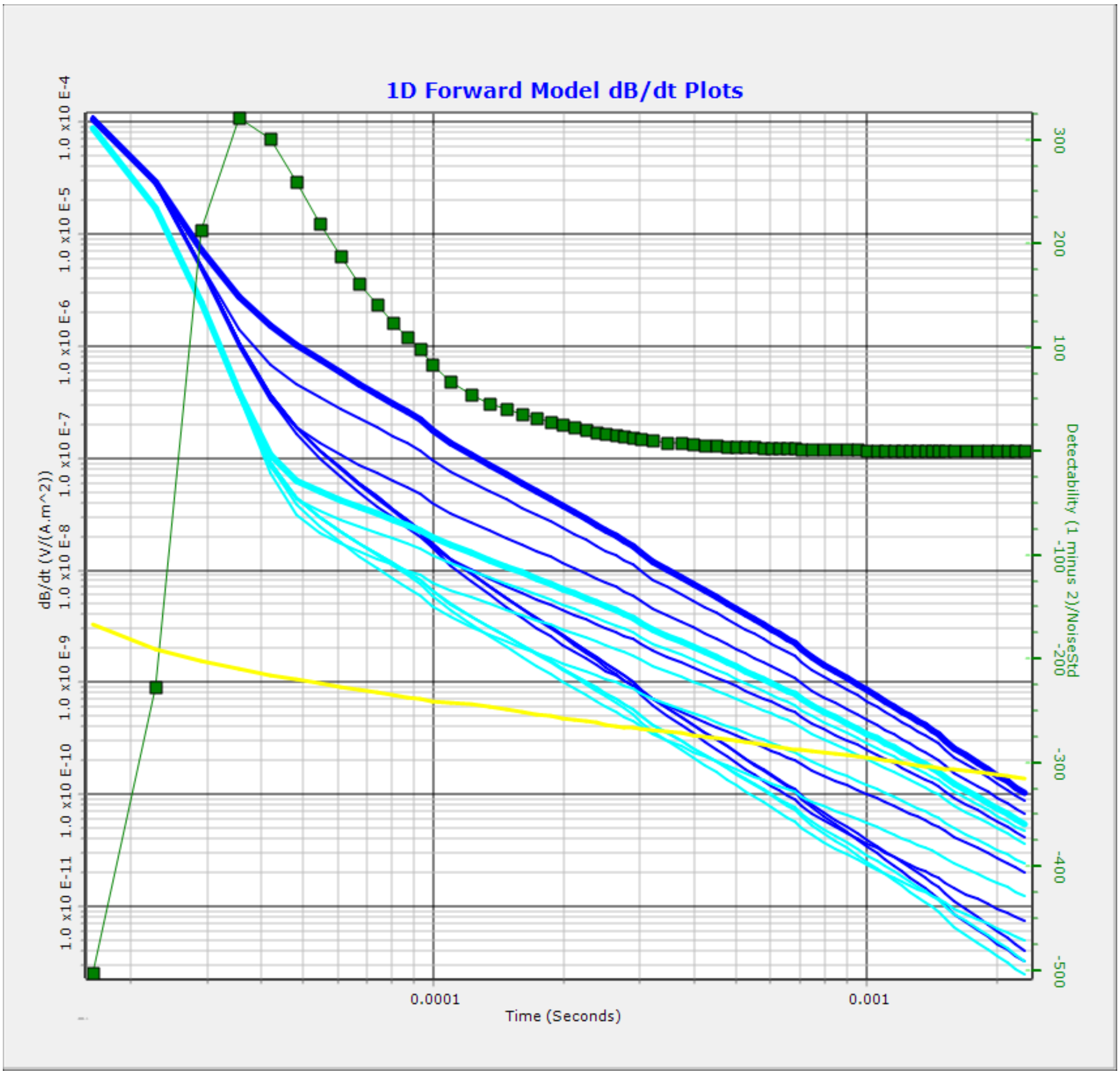
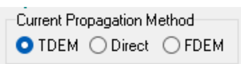


Figure 16 For the models in the previous graph, this is example from the forward modeller of dB/dt versus time type curve generation. Eight models are displayed in dark blue. Aqua coloured lines display the last chosen models and configuration. In this case, the dark blue lines are for the overlapping loops configuration of AgTEM Wallaby and the Aqua colour lines present equivalent models but with layer 1 changed to 30m thick to simulate what would happen if Wallaby was used airborne. A green detectability curve displays relative contrast between model 1 and 2 normalized to noise standard deviation, which is provided in the yellow curve.

DIRECT CURRENT FORWARD MODELLING

The forward modelling form allows back door access to our Direct Current (DC) Configurator so that DC forward modelling can also be achieved. This can be useful for educational purposes in cases where a licence for TEM forward modelling has not yet been acquired. To get back door access, select the 'Direct' radio button:



. This will add a button allowing access to the DC Configurator main form, from which many additional analyses can be achieved. It is almost equal in comprehensiveness to TEM Configurator so all the details cannot be documented here. See Dr David Allen's PhD thesis 2007- Electrical Conductivity Imaging from Watercourses of the Murray Darling Basin (https://www.groundwaterimaging.cm/documents/Allen2007PhDThesisFinal.pdf?downloadable=1) for more information.

In version 2.01, FDEM forward modelling is not provided.

Once 'Direct' is selected, you will be asked for a configuration filename. A directory (C:\GWI\ResImage\DCConfigurator\Configurations\ ) containing sample files will be displayed. Some of our HERBI waterborne streamer and Wombat soil resistivity profiler files will be there.

The Geo-electric Delphi kernel code in DC Configurator is extended from VESGEN which computes vertical electrical sounding apparent resistivity data for a generalised 4-electrode array over a horizontally stratified earth. Vesgen was created by Noel Merrick - Copyright Heritage Computing. Nominal limits : 25 electrode positions 1000 models 10 model layers. Reference : O'Neill, D.J. & Merrick, N.P., 1984, A digital linear filter for resistivity sounding with a generalised electrode array. Geophysical Prospecting, vol.32, 105-123.

Tutorial 2A provides explanation of Direct Current forward modelling and configuration.

SYSTEM TESTING

It is common, for equipment routinely afflicted by the rigours of cross-paddock driving and harsh environments, as well as commercial freighting, to develop faults, typically in cables. Connectors can get tugged and cables stretched and flexed, connector back-shells sometimes get twisted, shearing off conductors, and sometimes faults only show up only on cold humid mornings after condensing humidity builds up within cable sheaths, and shorts shielding to conductors through tiny cracks in insulation caused by stretching and flexing.

Another common problem is confusion about specifications of a system, where operators try to process data assuming the wrong specifications.

Both of these problems justify some basic system testing at the beginning of every survey.

System testing has been developed specifically for AgTEM Wallaby and Wallaroo which both have switchable transmitter loop turns. In one of the tests, one loop turn is connected to the receiver while another is alternately shorted and made open-circuit to provide a contrast in signal that is practically, but not theoretically, independent of ground effects which cannot be entirely removed in routine testing of towed TEM systems.

For specific equipment, for which calibrated closed loop inductor response data is available, the system test form provides a test facility. It is highly recommended for testing if matters such as cable faults or dimensional distortion have affected calibration at the start of every job. It is not as universal as much of the TEM Configurator package and is designed with AgTEM Wallaby and AgTEM Wallaroo in mind.

The tests are comprehensive so we will start with a simple subset showing response to a closed loop of wire. See the graph below.

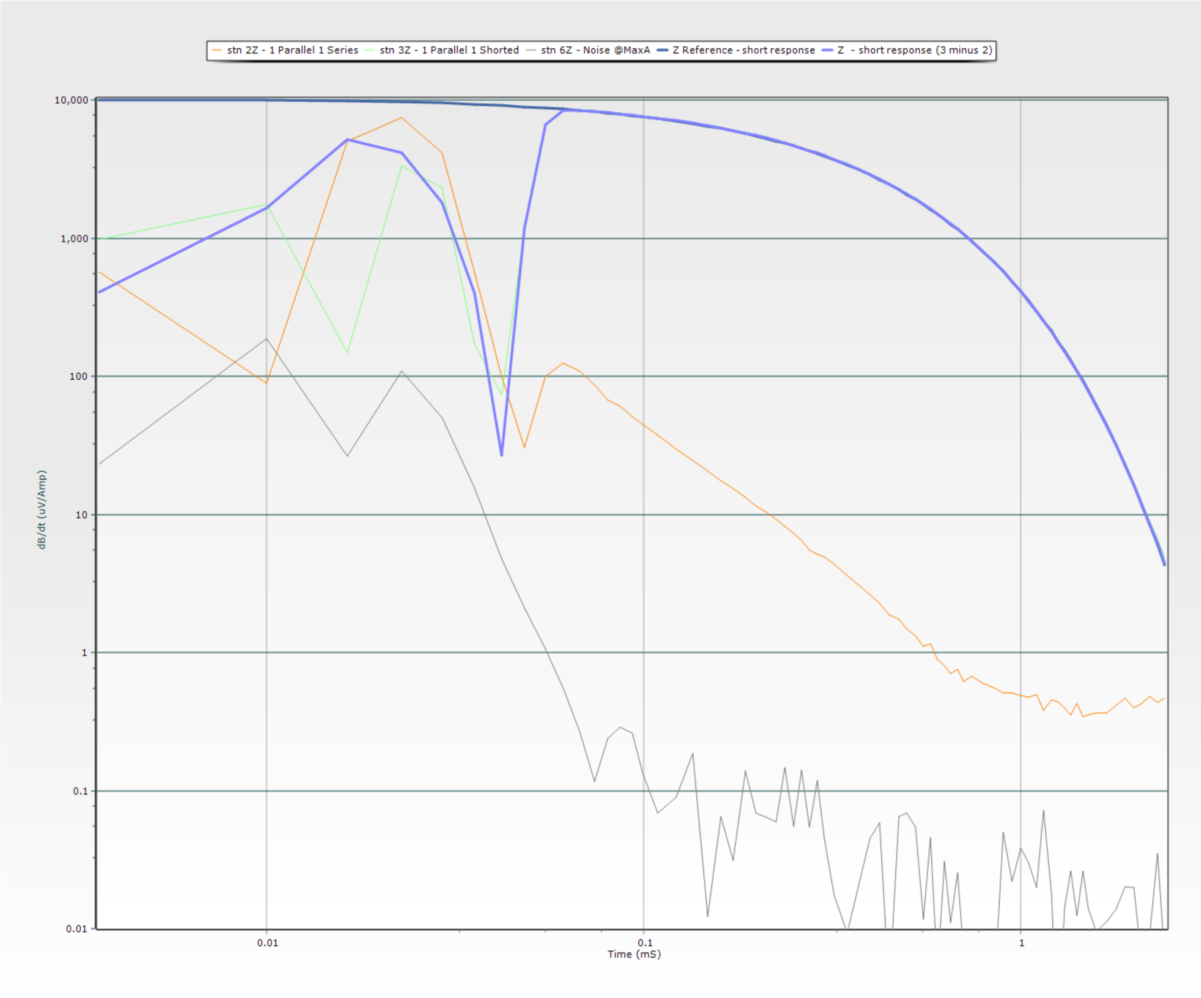


Figure 17 AgTEM Wallaby In-loop system testing - shorted loop turn test. In this test a stored reference shorted loop decay constant response is compared with contrast of shorted loop measured data minus single loop data with the 2nd loop open circuit. This establishes a largely ground response free dataset for comparison. Noise data is plotted also for comparison. Observe that the shorted loop response excellently matches the decay constant equation response beyond where digital delays, ramp, and coil self-responses are significant.

System tests require diligent and specific field procedure and, in this case, procedure specific to AgTEM Wallaby and Wallaroo instruments is established and documented in the separate system test documentation not provided here. The figure below presents the full set of test graphs in just the basic test sequence – they are too complex to consider all at once as displayed. Part of the basic set of tests is generation of a file that can be used to establish system response should a site model be available.

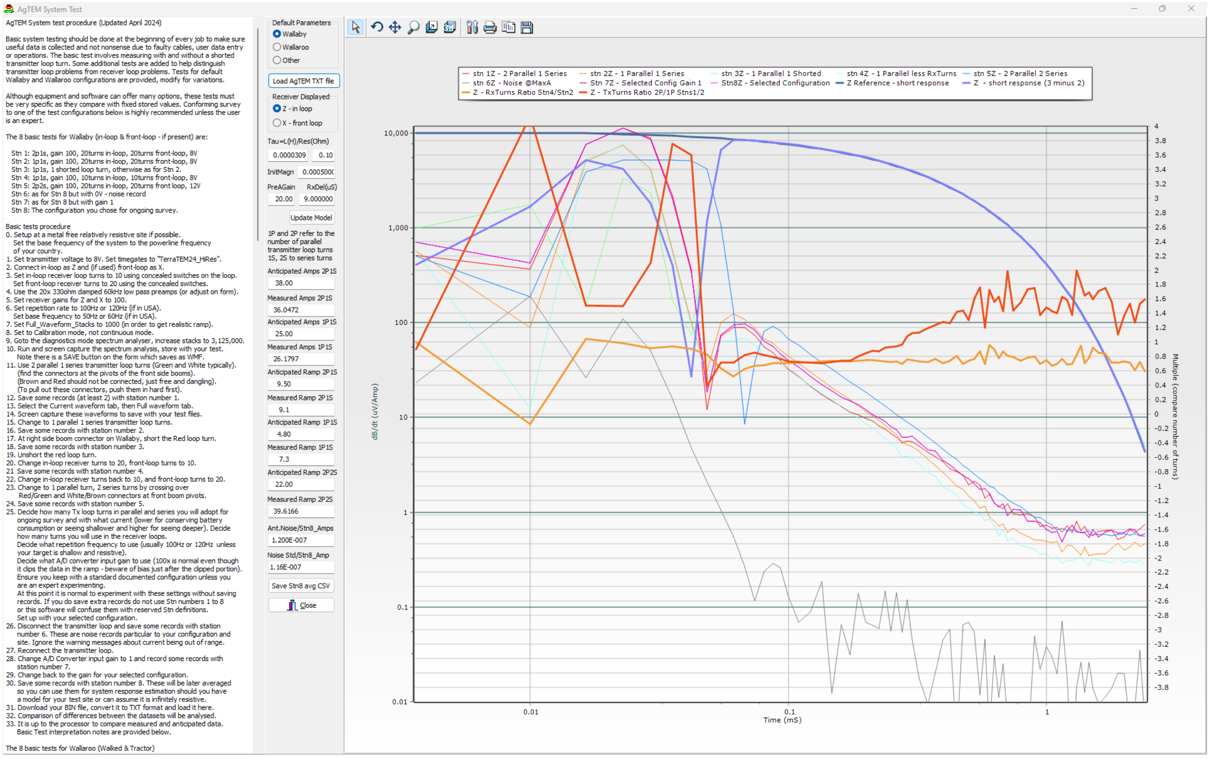


Figure 18 The full set of system test graphs is displayed here - they are too numerous to consider all at once.

TUTORIALS

TUTORIAL 1 – DISPLAYING A CONFIGURATION

Towed TEM configuration documentation can be confounding, requiring very specific understanding of definitions and understanding of what time and spatial reference frame each definition is allocated. In this tutorial, we first view an AgTEM Wallaby TDC configuration file in a text editor, then view parameters graphically. We then save the file again as a GEX file, then look at the GEX file in a text editor.

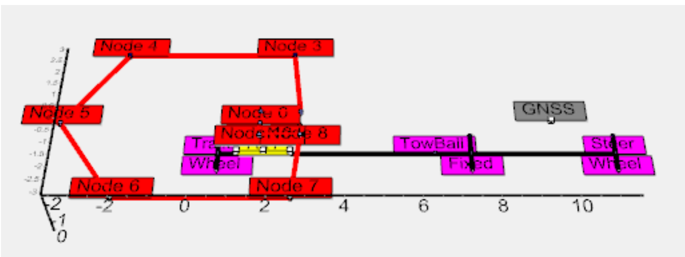
STEPS

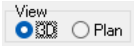
1. Install *TEMConfigurator* on an MS Windows operating system computer by running the installation file.
2. Find the file C:\GWI\ResImage\TEMConfigurator\Configurations\AgTEM_1turn8V32Amp_9_5uS_50kHzTxCentric.TDC and open it in a text editor. It is of INI file format with sections hosting Keyword=value pairs as shown:

```
AgTEM_1turn8V32Amp_9_5uS_50k... ✕
[All]
IsMasterConfig=0
MasterTamperCheckCRC=0
ParentConfigFile=C:\ProgramData\GWI\ResImage\TEMConfigurator\Configurations\AgTEM_1turn8V32Amp_9_5uS_50kHzTxCentric.TDC
Description=Wallaby Overlapping Loops
DataType=GroundTEM
LinkTxApproximateCurrenttoTxAmps=0
CalculateRawDataSTD=0
NumAcqChn=1
NumTx=1
NumRx=1
SysRespExists01=1
NumTimebases=1
/________________________________________________________________________________
[Rx1]
CentroidX=1.83
CentroidY=0
CentroidZ=-1.2
Name=TxCentricRx
Orientation=Z
EffectiveArea=824
```

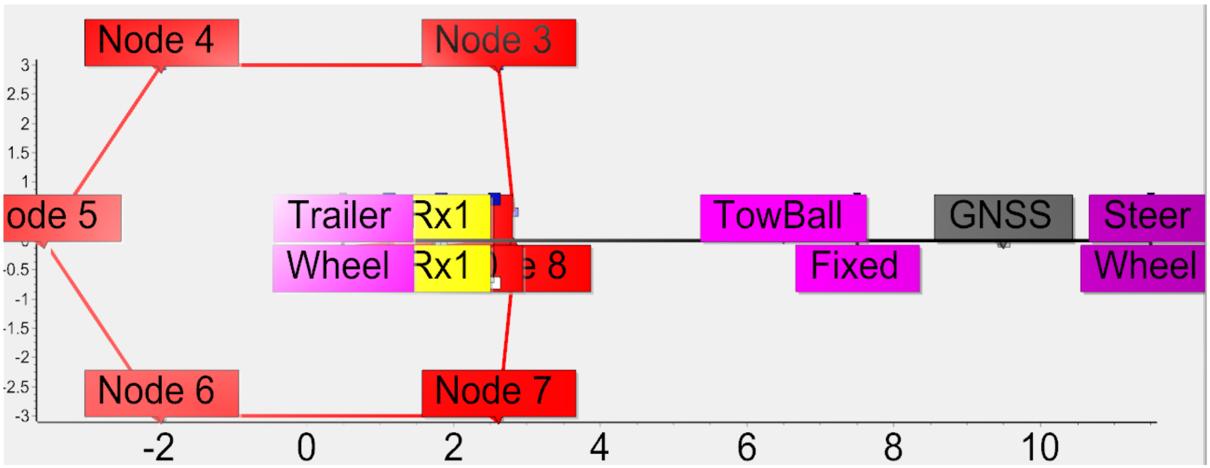
Only the top of this file is displayed. You can view the rest to see the information relevant to towed TEM survey, provided in a semi-readable format that is efficient for machine reading and writing. Provided variables are in the correct sections, their order is not important and comments starting with '/' can be anywhere. Upon saving from TEMConfigurator, comments on keyword lines are moved to separate lines as some INI file readers cannot tolerate having them on keyword lines. Missing keyword=value pairs are replaced by default values by INI file readers. For this reason, many of the variable can be optional and do not need to be present. Now to make sense of this information more efficiently we can display it in TEMConfigurator.

3. Open TEMConfigurator and Load the file mentioned above.
4. Observe the geometric graphics on the main form and it should look as shown:



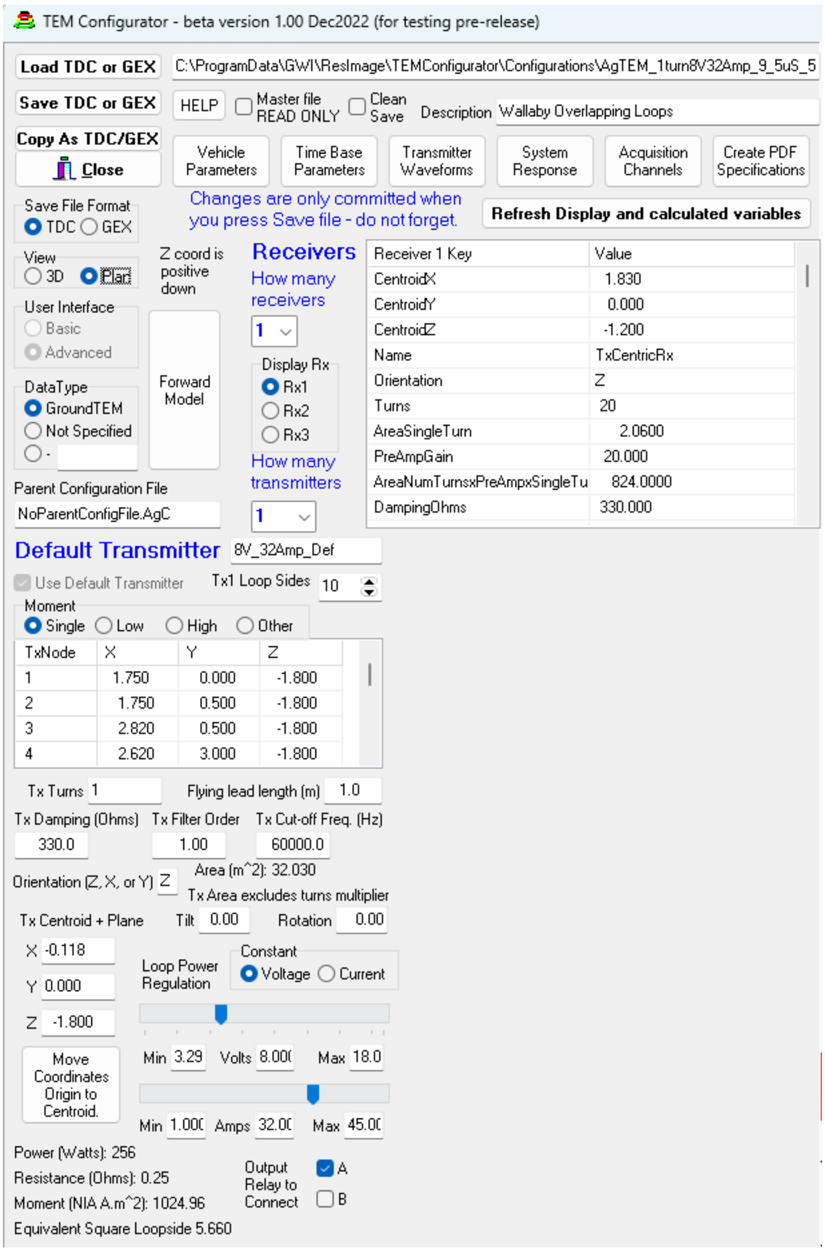
5. Toggle back and forth to plan view using the Radio Buttons 

and/or adjust 3D orientation, pan, and zoom using the hotkeys  . Below, plan view is presented:

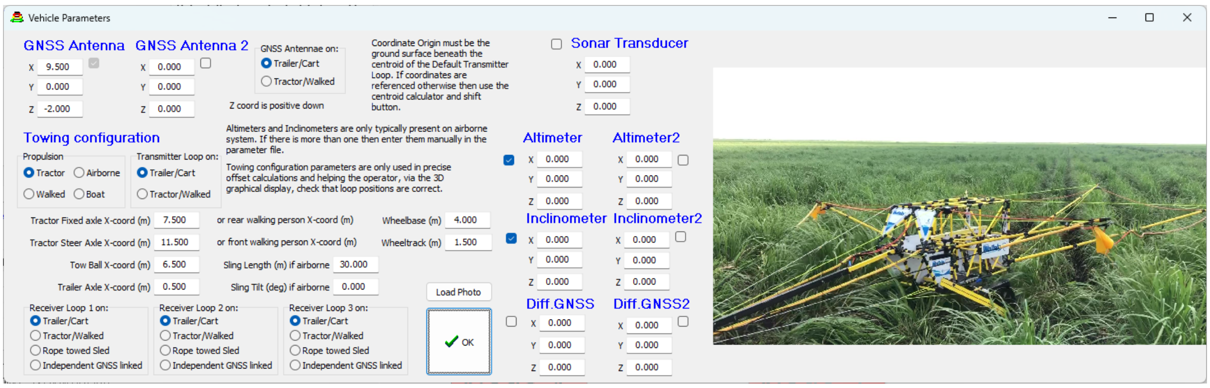


In this configuration, transmitter and receiver loops overlap so that mutual inductance is stably nulled. The actual receiver position is replaced by a dipole centred receiver as this is how it is modelled in inversion software. The actual shape and position is slightly different. Similar modelling simplifications are applied to many airborne systems in examples provided. The graphical display is suited to quickly making configuration description mistakes obvious.

6. Observe the main form display as shown. From here it is possible to view transmitter and receiver specifications, both required in modelling, and required for operational purposes. There is also a row of buttons across the top which we can describe now. The ‘Forward Modelling’ button will not be described in this tutorial, but is described in the remaining tutorials.

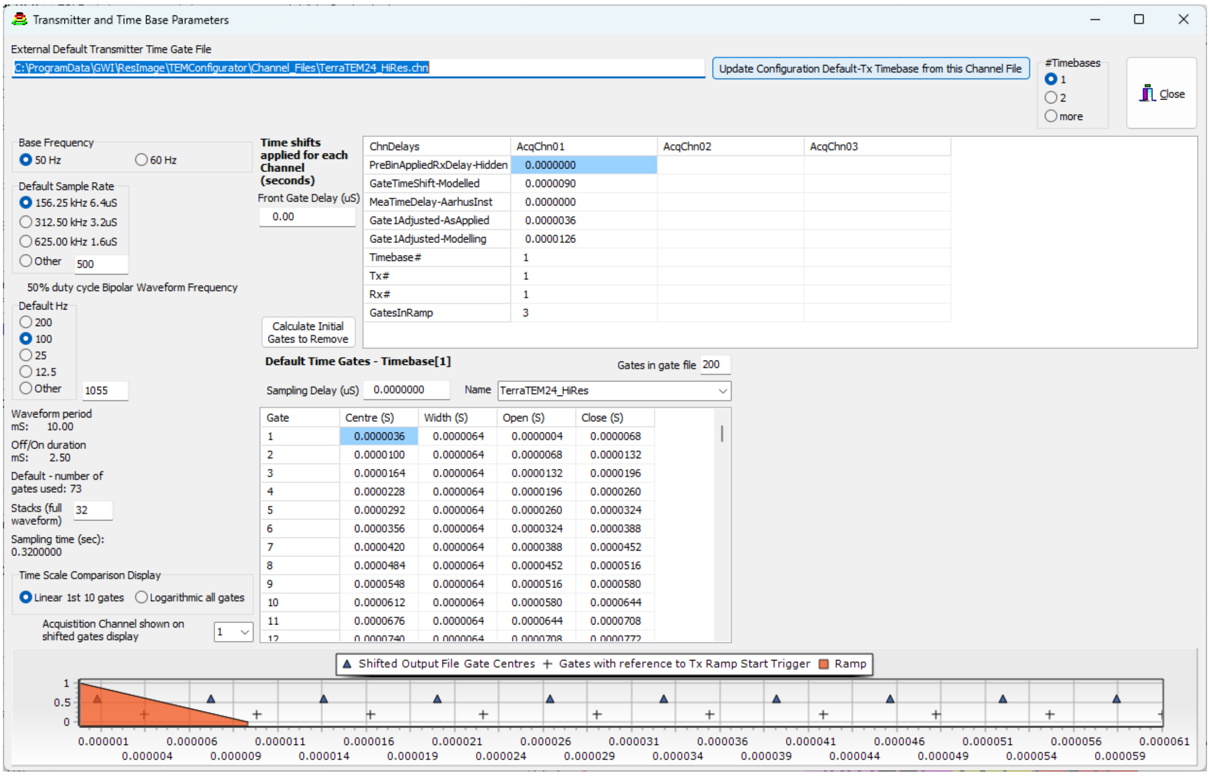


7. Press the 'Vehicle Parameters' to reveal the vehicle parameters as shown:



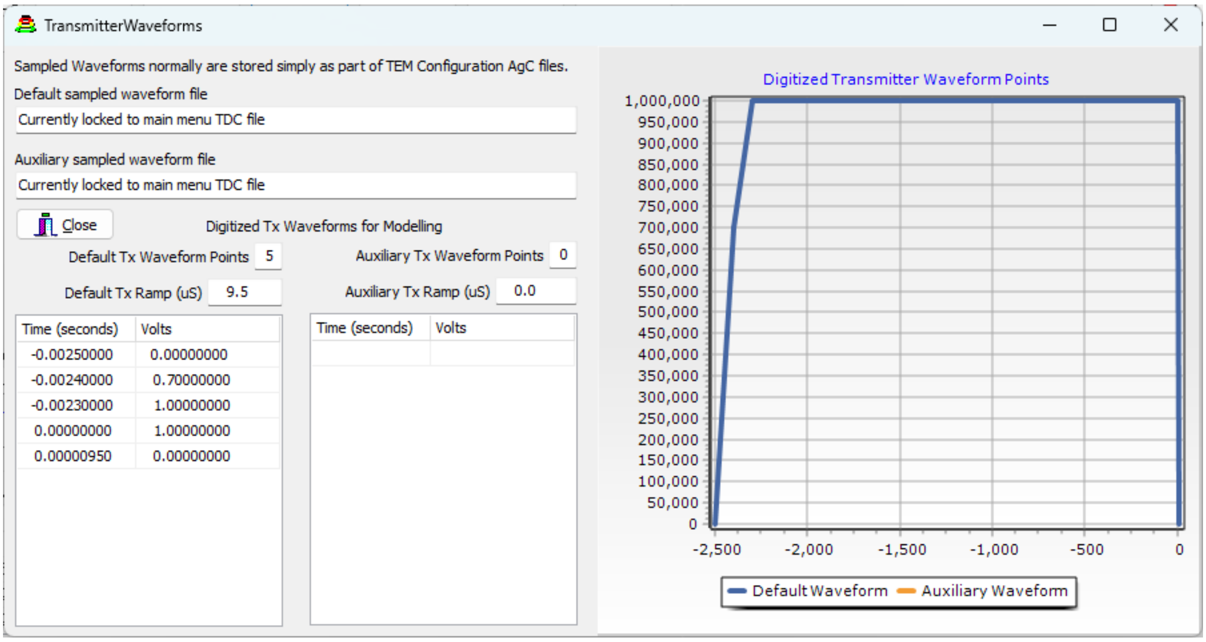
This form allows enough options for description of most towed and airborne systems – check boxes can indicate if they exist and are saved or not.

8. Exit the vehicle form and press the 'Timebase Parameters' form to display:



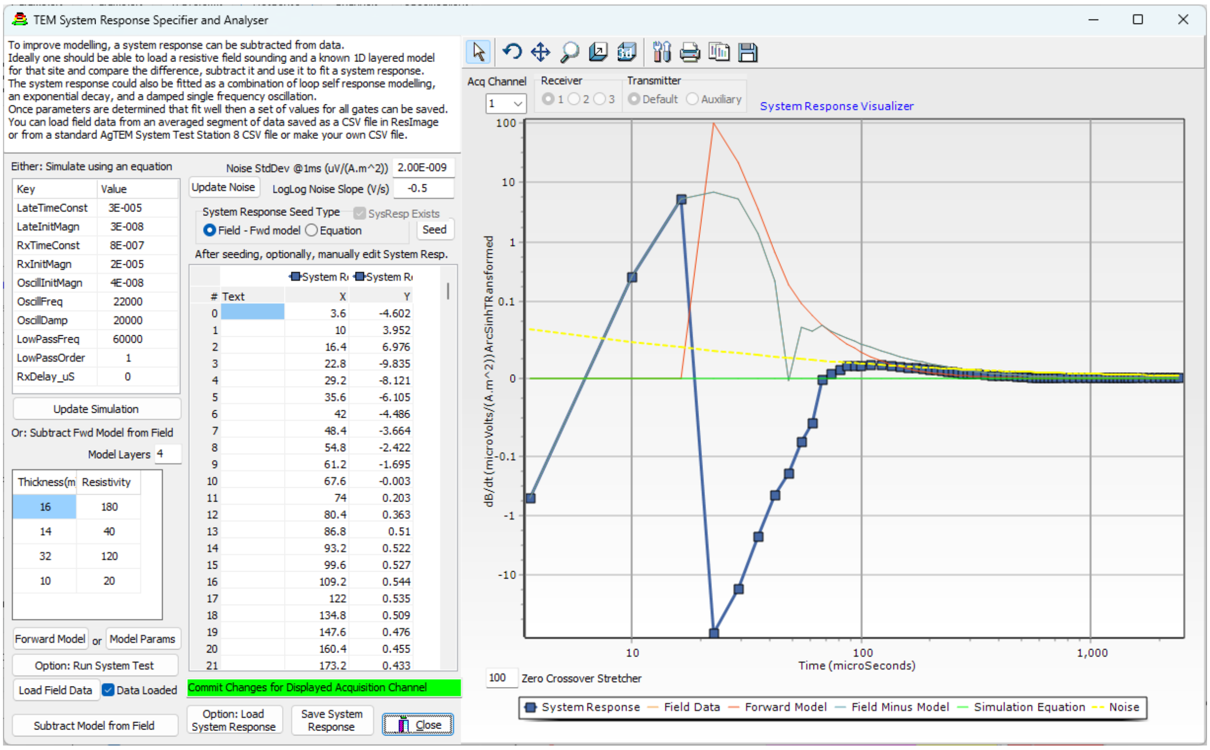
Variables can be changed and driven variables will be recalculated so you can double check they have been input with correct understanding. A Graph of the ramp and gate centres is displayed with gate centres both with reference to the machine reference trigger time, and with reference to their position in modelled time so that correct understanding of all the various complicated shifts and delays can be assessed. Gates can be displayed for any acquisition channel as each channel may use a different time base, shifts, delays, transmitter waveform, or front gate parameters.

9. Exit the Timebase Parameters form and press the 'Transmitter Waveforms' button to show:



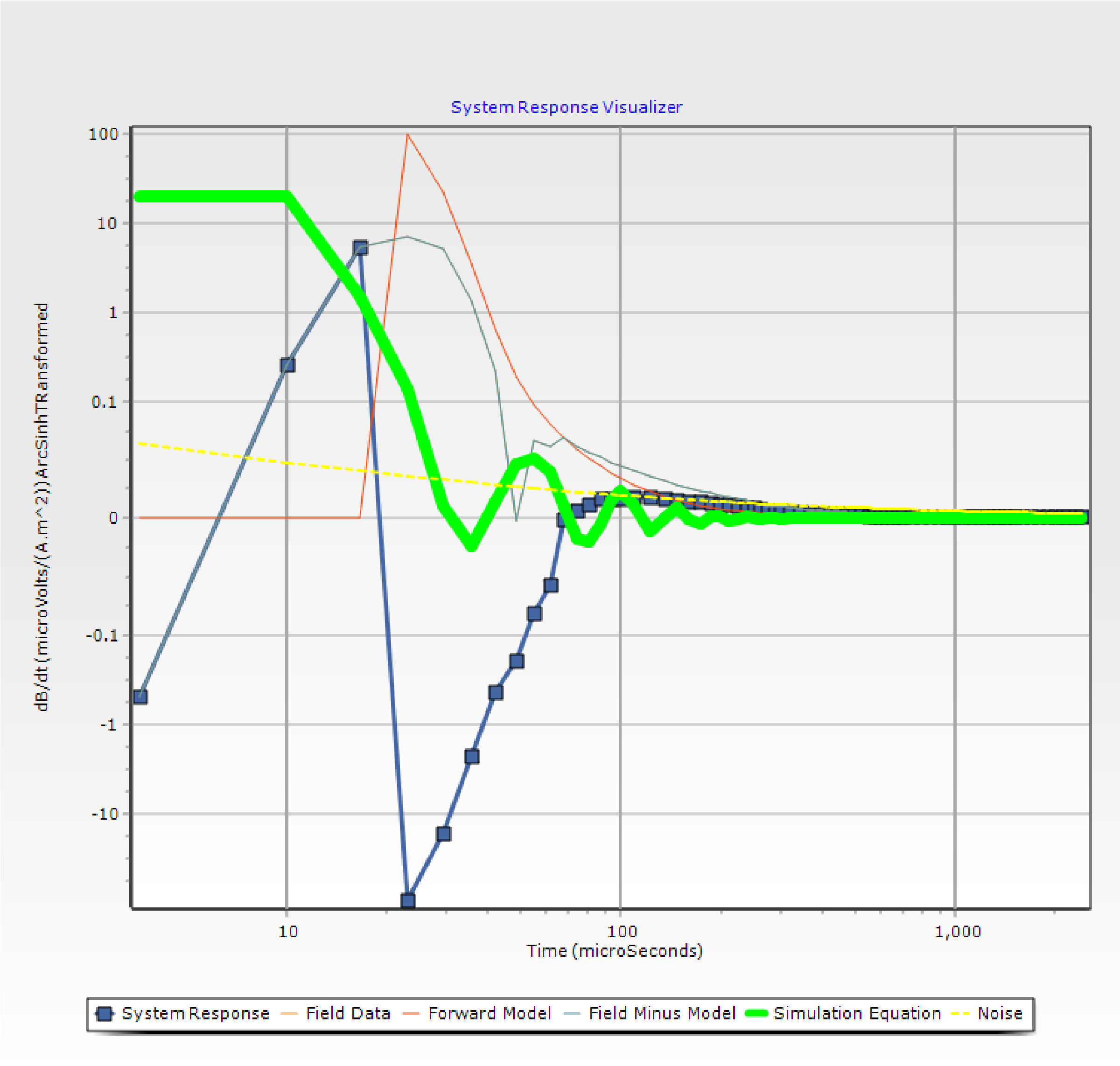
The ramp is a read only parameter here, driven by the last line of the waveform description table. Modelling software AarhusInv64.exe operates only with the entire waveform and treats the ramp only as a 'sub-wavelet'.

10. Exit the Transmitter waveforms form and press the 'System Response' form to show:



This form provides facilities for estimating receiver system response – not detailed transmitter waveform. It will typically only be manipulated at control sites where a layered geological model has been estimated. Forward modelling of the layered model can be used in conjunction with field data to difference system response or an equation can be used to model system response. After seeding with either, the system response can be manually manipulated as is helpful if field data used for estimation was noisy. A noise level is graphed for consideration in comparison with the system response but is not used in any other way. Using the forward modelling function will require an AarhusInv64.exe licence so we will not attempt that here. The graph axes are scaled to enhance display of troublesome parts of the system response.

11. Press update simulation to populate the green equation-based calculation of system response. This is used mainly for conceptual understanding rather than actual system response removal. You can tweak the values in the Simulation equation table and press update again to see their effect. Each variable provides typical response of various parts of LRC (Inductor, Resistor, Capacitor) circuits which can resonate. The example here has some resonance simply for showing what can happen if coils, cable shielding and/or electronic components couple in inappropriate ways:

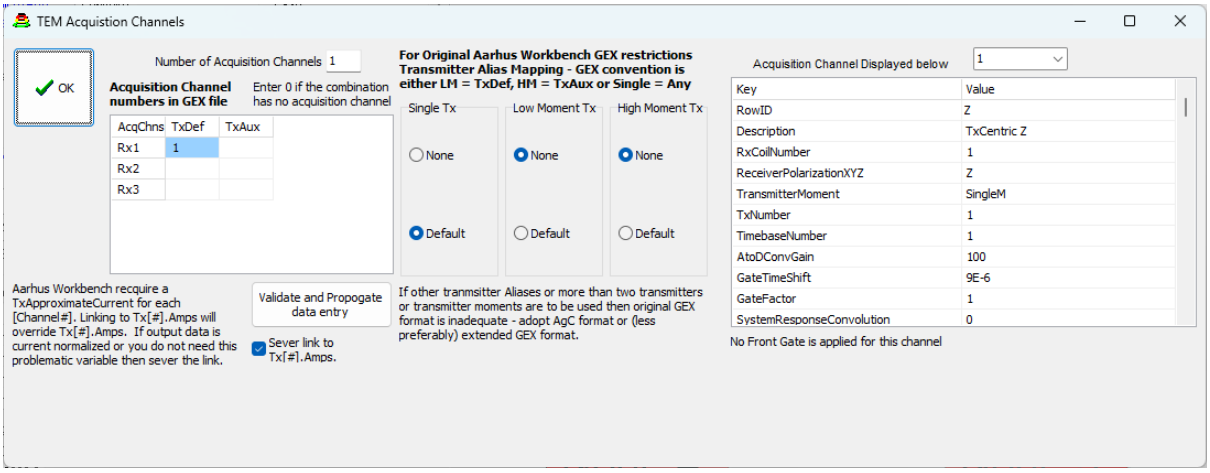


This equation response is not active in this configuration so its effect is nil unless used to seed the system response. If the forward modelling option is used, parameters such as delays on other forms will affect the model, shown in red, here. If you iteratively change the equation variables, you will find you can very closely mimic the system response.

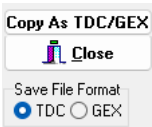
If parts of the system response beyond the transmitter ramp do not influence the ground response and vice versa (ie. independence), we can simply subtract system response, calculated for a resistive site, to provide quality modelling of resultant data. As the near surface becomes more conductive, independence is not a good assumption, yet the effects of dependence become swamped by high ground response such that the modelling results remain reasonable. The same would not be true if system response was calculated for a site of high near surface conductivity.

Determining a system response involves acquisition of data which cannot be achieved in this tutorial so we shall not proceed through the full process. Nor will we attempt the ‘System Test’ as also requires acquisition and is specifically optimized to AgTEM Wallaby and Wallaroo.

12. Exit the system response form and press ‘Acquisition Channels’ to show:



This form provides parameters specific to each acquisition channel of a system, whether synchronously acquired or acquired in multiplexed groups of stacks. All receiver, transmitter, waveform, system response, and timebase information is ultimately owned by the acquisition channel but it is referenced in our data management structure through these just mentioned classes of objects. In the GEX data format, these objects are partly referenced in an alternate way by either no, high or low moment prefixes or suffixes. This form provides some facilities for managing these alternate, but complicated, ways of managing these suffixes and prefixes. The software will then manage their application to make format cross-compatibility feasible.

13. Exit the Acquisition Channels form. The 'Create PDF Specifications' button only has limited functionality in version 2.00 so we need not press that.
14. Change the output format to GEX and copy the file using 'Copy As TDC/GEX' to 'DummyTemp.GEX' where shown: 

15. Open DummyTemp.GEX in a text editor to see how it differs from TDC format. This file is extended GEX format and holds lots of information beyond the capabilities of GEX format alone however, in the transition to more complicated cases, its logic follows very complicated rules, that are hard to understand, so that compatibility can be maintained without loss of information.
16. Now for comparison of a most minimal GEX file requiring all essential modelling metadata we may compare C:\GWI\ResImage\TEMConfigurator\Configurations\GroundTEM-geometry-example.GEX as shown here:

```
/.gex file for import of GroundTEM data to Aarhus Workbech - August 2018

/Note:  SI-units are used for all variables

/Text after a forward slash '/' are comments and are not read.

[General]

Description=GroundTEM gex file

DataType=GroundTEM

/-------- Device Positions ---------------------------------------

/Device x y z (m) with origin on the ground at the center of the transmitter coil and with z-positive downward

GPSPosition1=       0.00 0.00 0.00

RxCoilPosition1=    -0.19 0.00 -1.20

TxCoilPosition1=     0.00 0.00 -1.80

/--------- Transmitter Loop Definitions --------------------------

LoopType= 72                                    /LoopType for GroundTEM is 72 (segmented loop) which must be followed by:
```

```
TxLoopArea=32.52                          /Area of the TX-loop (m2)
TxLoopPoint1=   2.85 2.85                 /Loop points x y (m). Counter clockwise order, the last point connects back to the first.
TxLoopPoint2=  -2.85 2.85                 /This is just a format example, the GroundTEM loop can have more than 4 TxLoopPoints.
TxLoopPoint3=  -2.85 -2.85
TxLoopPoint4=   2.85 -2.85
NumberOfTurns= 1
                    /Number of Tx-loop turns
/---------- Low Pass Filter Definitions -------------------------
RxCoilLPFilter1= 1 200E+3
                /Filter order. Cut-off frequency (Hz)
/-------- Waveform Definition -----------------------------------
/WaveformPoint    Time (s)      Normalized amplitude [0;1]
WaveformPoint01=-2.000E-02 0.000E+00
WaveformPoint02=-1.950E-02 7.000E-01
WaveformPoint03=-1.850E-02 1.000E+00
WaveformPoint04=0.000E+00 1.000E+00
WaveformPoint05=5.400E-06 0.000E+00
/------- Gate Time Table --------------------------------------
/GateTimeNumber  Center (s)  Open (s)  Close (s)
GateTime01=1.500E-06 5.000E-07 2.500E-06
GateTime02=3.500E-06 2.500E-06 4.500E-06
GateTime03=5.500E-06 4.500E-06 6.500E-06
/NOT ALL SHOWN – MANY GATES REMOVED FOR DISPLAY HERE
GateTime33=1.793E-03 1.568E-03 2.016E-03
[Channel1]
GateTimeShift=0                          /Calibration time shift of gatetime (s)
GateFactor=1.0                           /Calibration factor shift of db/dt values (factor)
RemoveInitialGates=5                       /Automatic disabling of time gate 1 to RemoveInitialGates in Aarhus Workbench
PrimaryFieldDampingFactor=0.10                  /Primary field damping factor. used in the modeling/inversion of the data
UniformDataSTD=0.05                        /Relativ uniform STD for db/dt-data (all gates). 0.05 = 5%
RepFreq=25                               /Repetition frequency
TxApproximateCurrent=1                      /Approximate transmitter current must be within 25% of  actual curr. Set to 1 if the current has been normalized out
ReceiverPolarizationXYZ=Z                   /Receiver Polarization (X. Y. or Z)
```

TUTORIAL 2A – FORWARD MODELLING – NOT REQUIRING THE AARHUSINV64 EXECUTABLE

TEM Configurator relies on AarhusInv64.exe to create forward models, but a licence is required for access to that product. We provide a free forward modelling kernel capable only of direct current geo-electric modelling. In this tutorial, back door access to another one of our products 'Direct Current Configurator' is provided so that users can at least appreciate electric field forward modelling without the need for an AarhusInv64.exe licence.

Type curves for a towed Schlumberger Array streamer will be modelled for the four types of 3 layer models:

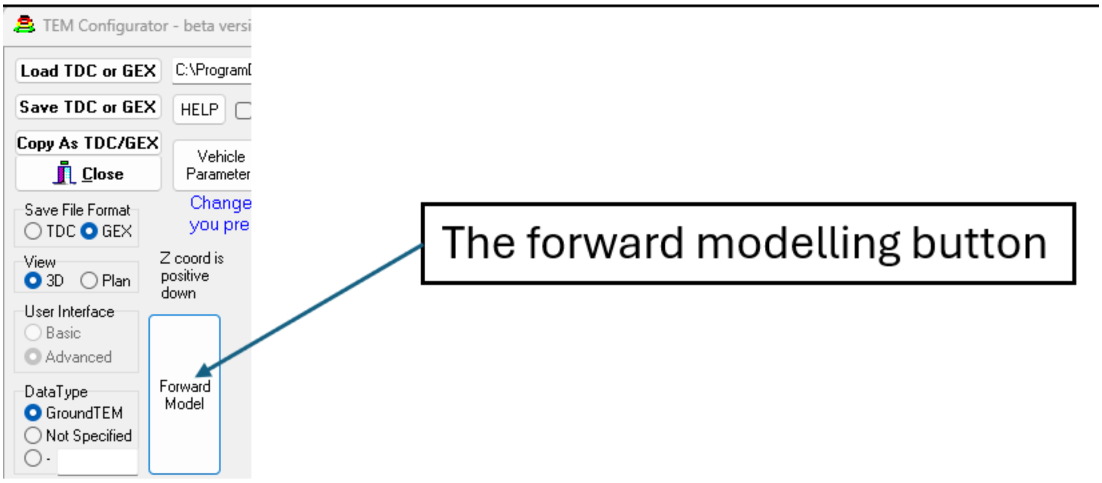
- Resistivity increasing with depth
- Resistivity decreasing with depth

- Conductive with middle layer resistive
- Resistive with middle layer conductive

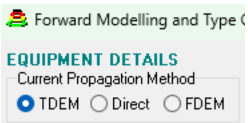
Sensitivity of the streamer to changes in each model will be observed.

STEPS

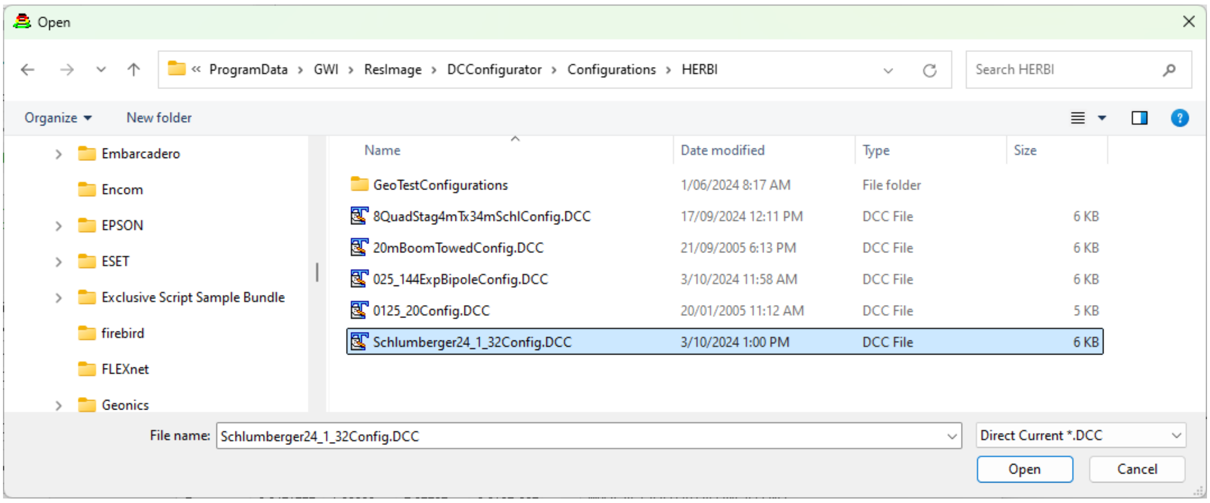
1. Open TEM Configurator and go straight to Forward Modelling by pressing the button as shown:



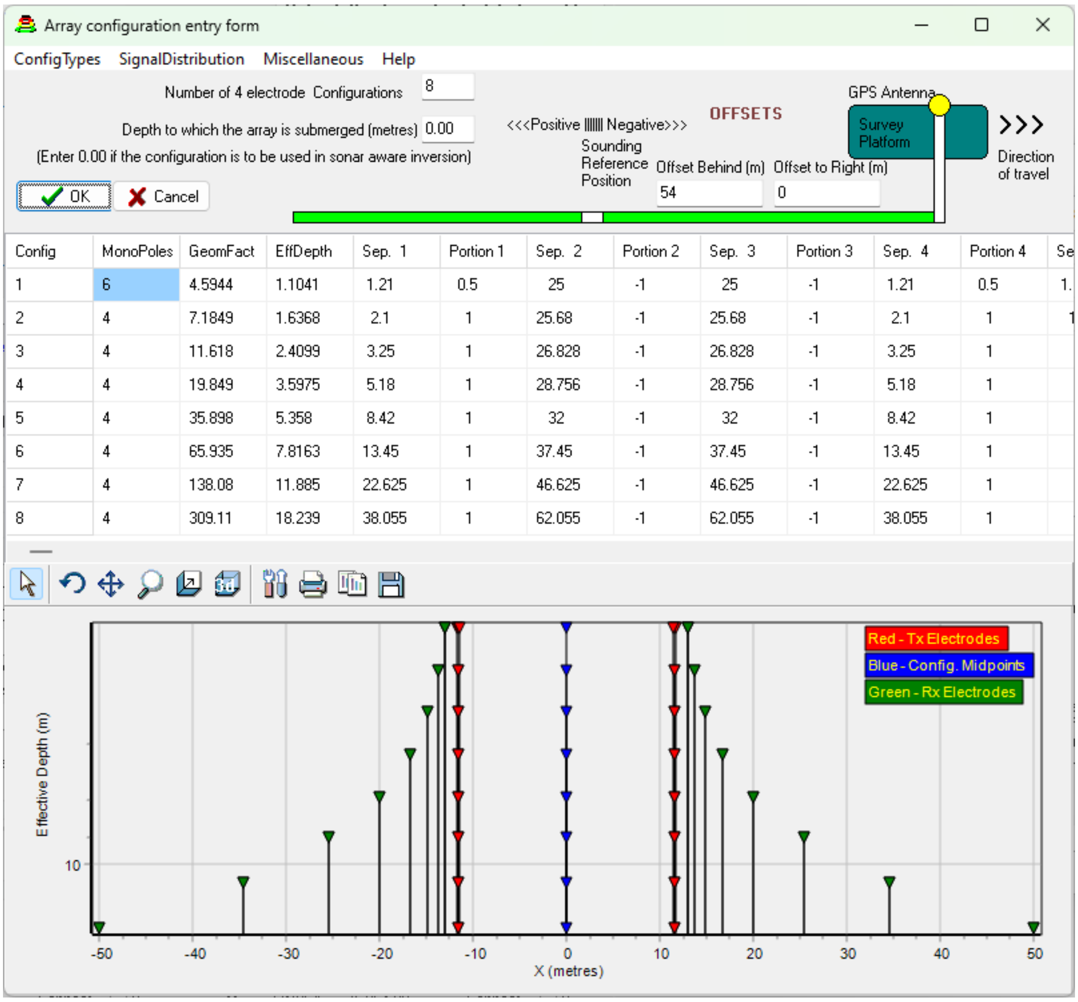
2. Enter the *Direct Current Configurator* by the 'back door' method of selecting the 'Direct' radio button:



You will be asked for a filename. Select the 'HERBI' subdirectory then select 'Schlumberger24_1_32Config.DCC' as shown from C:\GWI\ResImage\DCConfigurator\Configurations\HERBI\



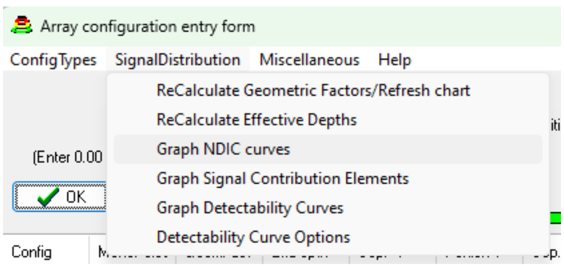
3. The configuration will be graphically shown with electrodes of each quadrupole displayed the effective depth of that quadrupole:



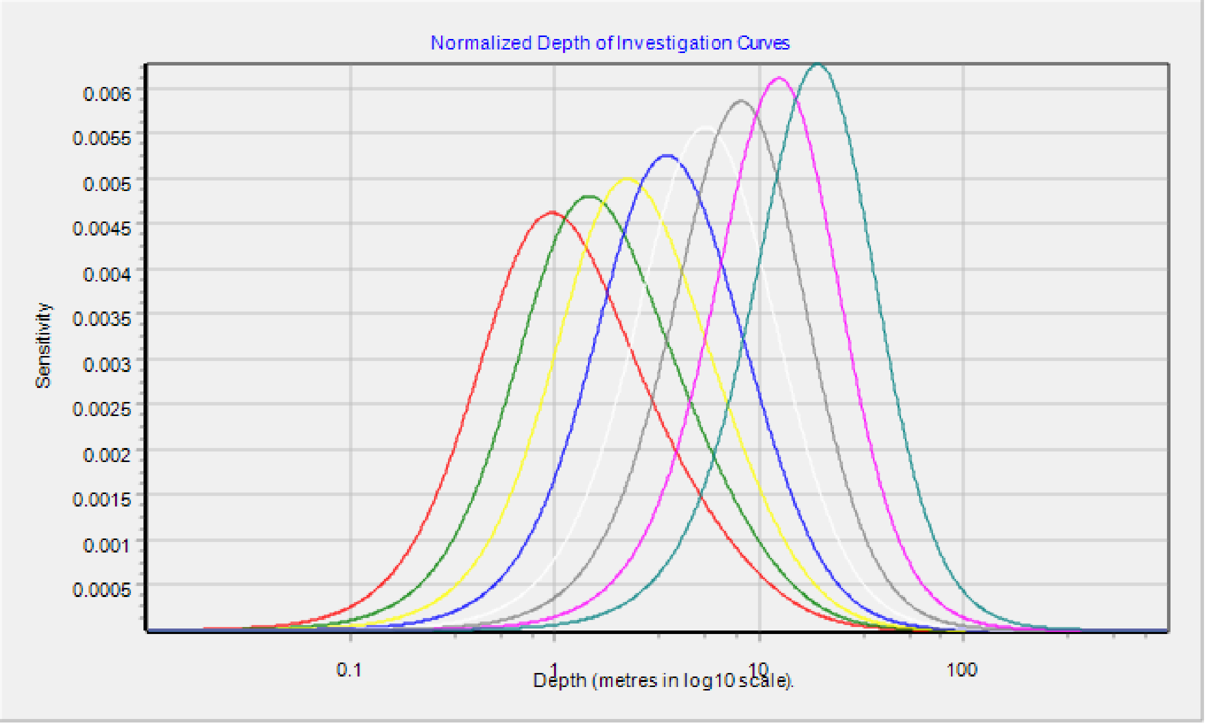
Config	MonoPoles	GeomFact	EffDepth	Sep. 1	Portion 1	Sep. 2	Portion 2	Sep. 3	Portion 3	Sep. 4	Portion 4	Se
1	6	4.5944	1.1041	1.21	0.5	25	-1	25	-1	1.21	0.5	1.
2	4	7.1849	1.6368	2.1	1	25.68	-1	25.68	-1	2.1	1	1
3	4	11.618	2.4099	3.25	1	26.828	-1	26.828	-1	3.25	1	
4	4	19.849	3.5975	5.18	1	28.756	-1	28.756	-1	5.18	1	
5	4	35.898	5.358	8.42	1	32	-1	32	-1	8.42	1	
6	4	65.935	7.8163	13.45	1	37.45	-1	37.45	-1	13.45	1	
7	4	138.08	11.885	22.625	1	46.625	-1	46.625	-1	22.625	1	
8	4	309.11	18.239	38.055	1	62.055	-1	62.055	-1	38.055	1	

Note that this facility breaks long electrodes up into parts when they are close to other electrodes so there are, in this case, 6 monopoles in quadrupole 1.

4. Before going back to forward modelling, let us find out a bit about this electrode array. Its intended use is as a streamer for waterborne survey. First let observe the effective depths and geometric factors of the quadrupoles. See the two columns of these parameters – this array is focused from 1m to 18m deep and, due to the large centre portion, has a small range of geometric factors from 4.5 to 310. This is a factor by which data must be multiplied to calculate apparent resistivity. Let us now plot Signal contribution curves to observe the focal ranges and depths of each quadrupole. Select 'Signal Distribution > Graph NDIC curves':

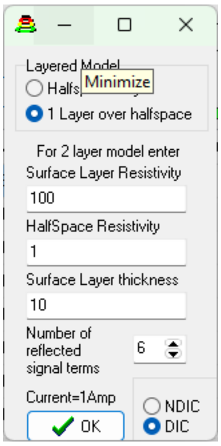


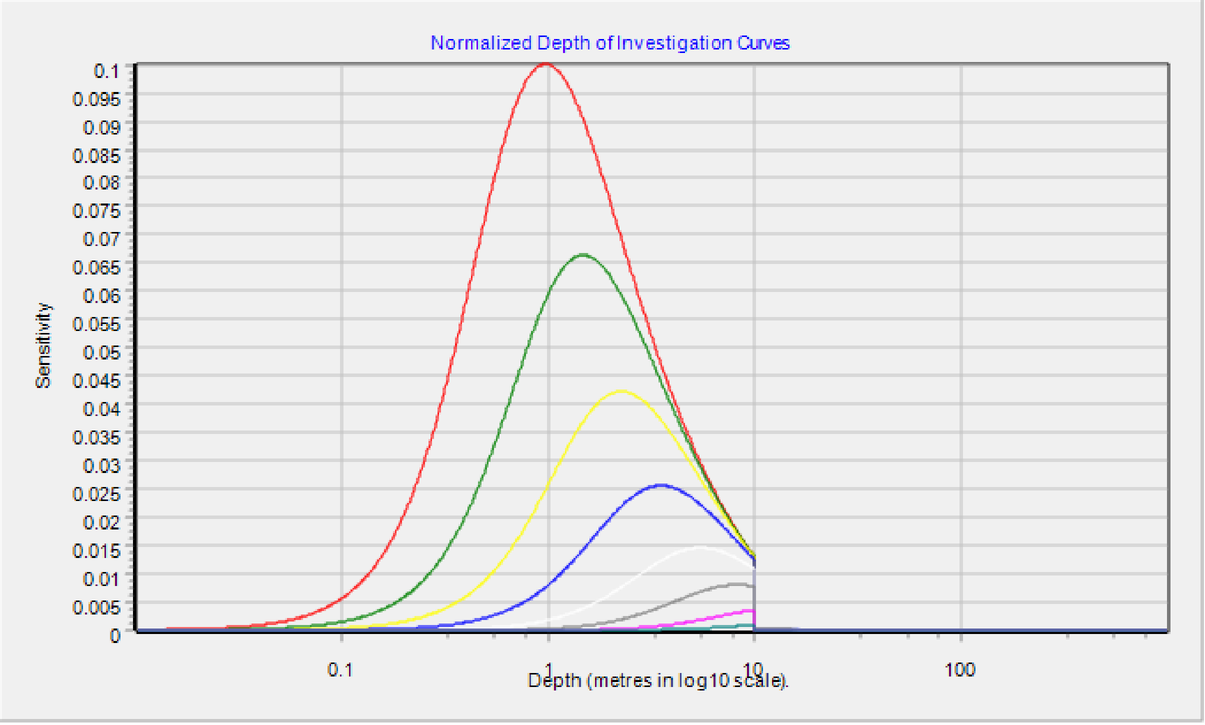
A box with options is displayed. Accept the defaults:



Normalized depth of investigation curves are displayed. Observe that some signal is returned from as deep as 100m but the mean 'Effective Depth' of the last curve is at 18m. This is what makes specifying exploration depth of electrical and electromagnetic equipment ambiguous. Once modelling is conducted with this array it would be reasonable to quote its exploration depth as 25m whereas aggressive salespersons may claim, by an alternate definition (95% signal contribution depth), that it can see 100m. For electromagnetic methods the situation is more ambiguous as signal contribution is dependent not only on geometry but also on conductivity outside of 'low induction number' approximation conditions.

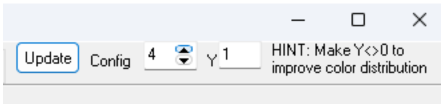
5. Let us investigate depth of investigation further. Go back into 'Signal Distribution > Graph NDIC curves' and fiddle with options – first by selecting radio button '1 layer over halfspace' and the radio button 'DIC' – Depth of investigation. Press OK again to display curves showing how signal contribution is made up for this model, but without normalization for signal strength of each quadrupole:

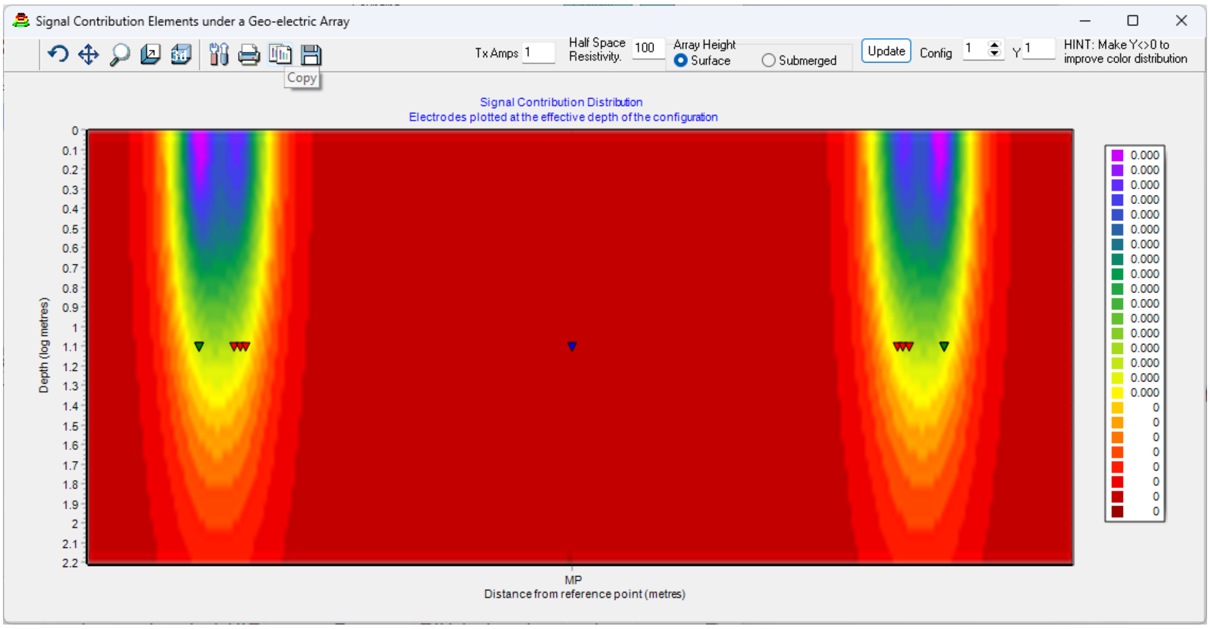


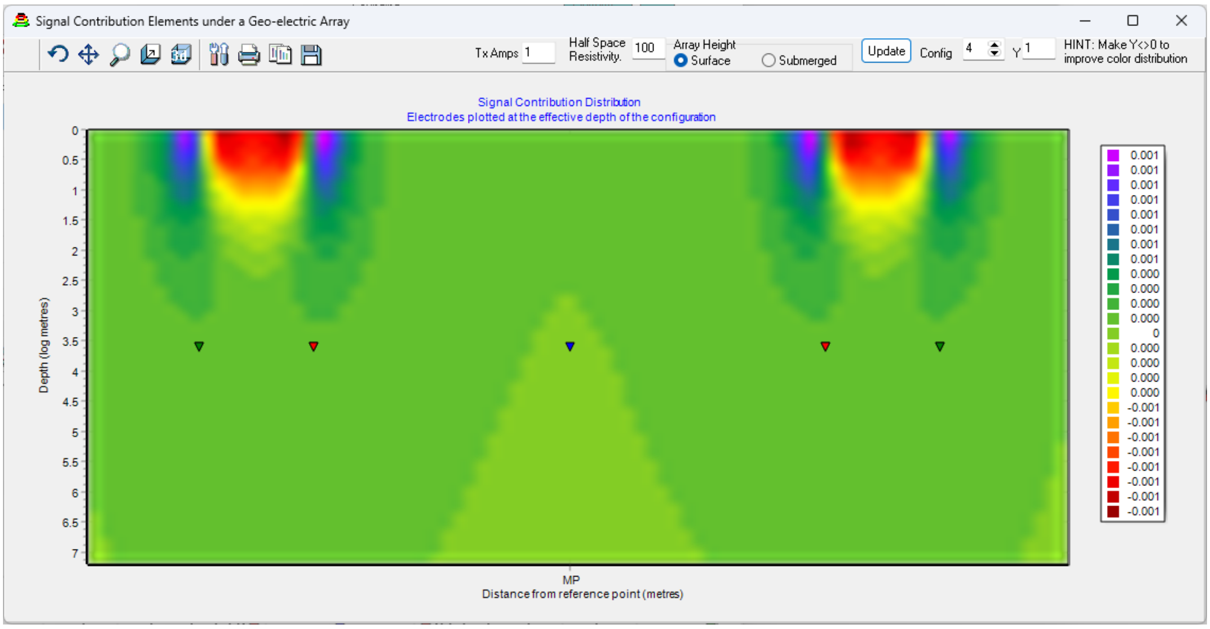


See how signal contribution basically disappears once the conductive basement is reached. This is why direct current resistivity methods are recommended more for use detecting resistive features, while electromagnetic methods are used for detecting conductive features.

6. We have been investigating signal contribution in 1 dimension vertically. Now select 'Signal Distribution > Graph signal contribution elements' to display a two-dimensional section of signal contribution. At first the display will be on the plane of the streamer which means there is an infinite contribution from the electrode contact points so the display will be washed out. Offset the section 1m from the plane of the streamer to get meaningful results as shown:

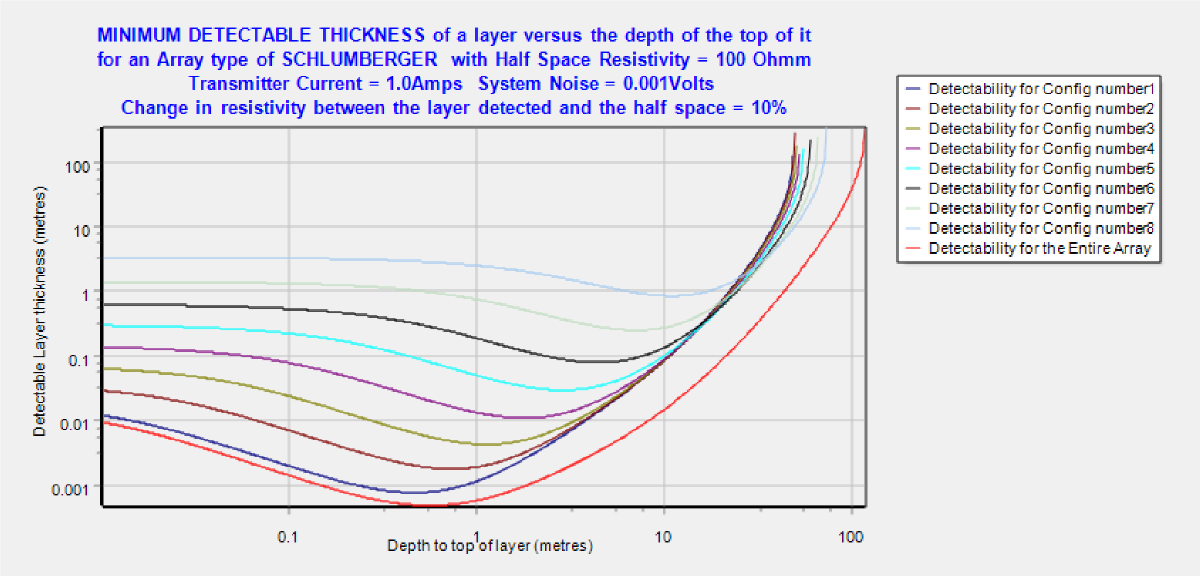




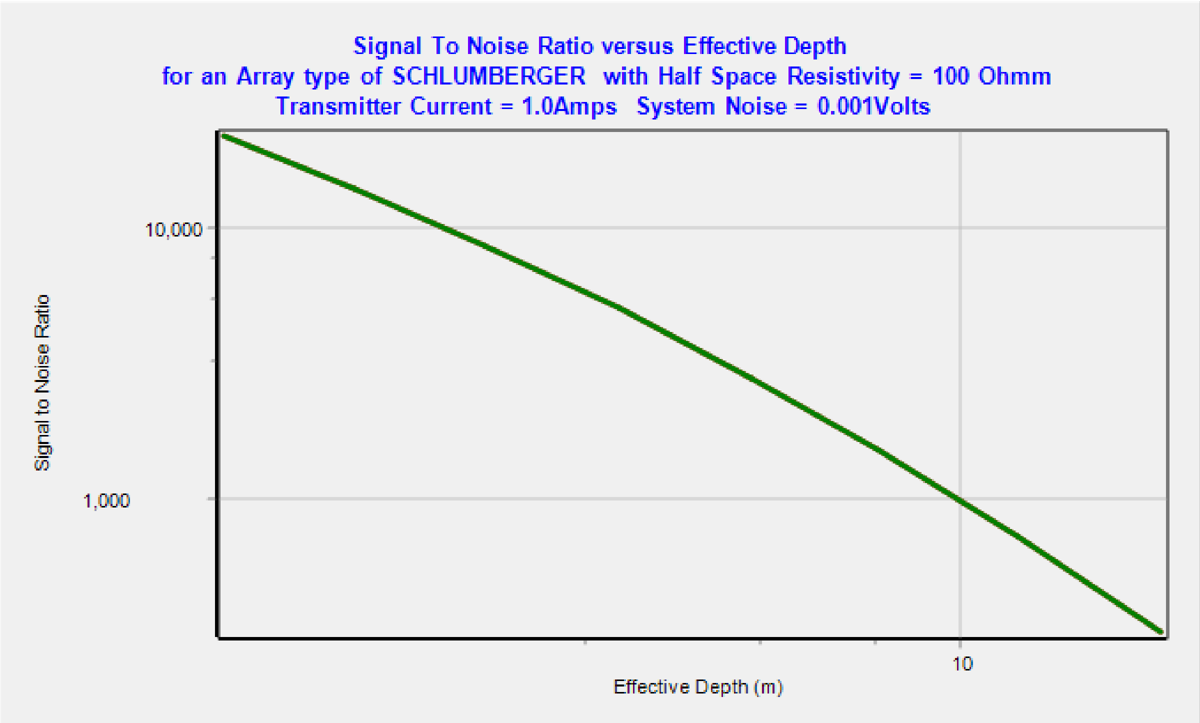


Results for both quadrupole 1 and quadrupole 4 are displayed. Notice how the contribution distribution becomes complicated as electrode separation is increased. It is far from the 1D layered case suggested by the NDIC curves plotted previously so remember that electric, and electromagnetic, methods are strongly dependent on 3D distributions of conductivity.

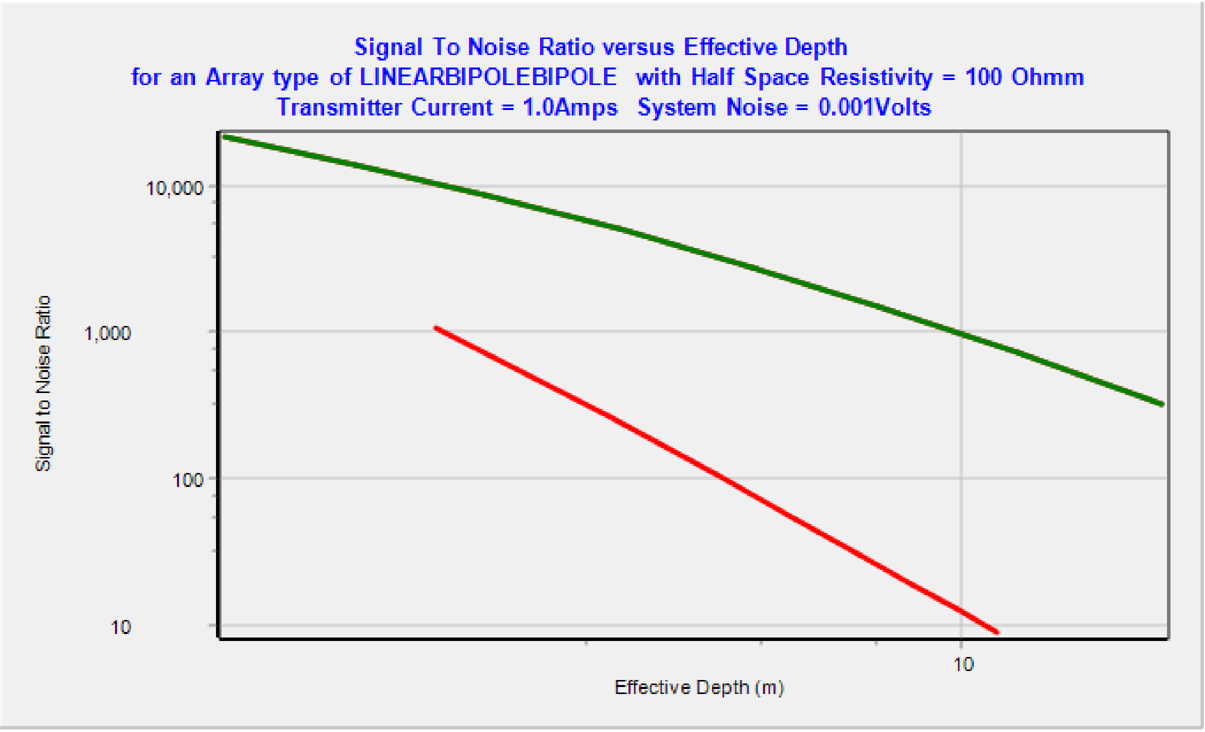
7. Now select 'Signal Distribution > Graph detectability curves' and you will get a display of ability to ability to detect a layer at a particular depth. For electromagnetic methods we will also assess detectability but by means of comparison of forward model type curves as for electromagnetic methods detectability is strongly model dependent:



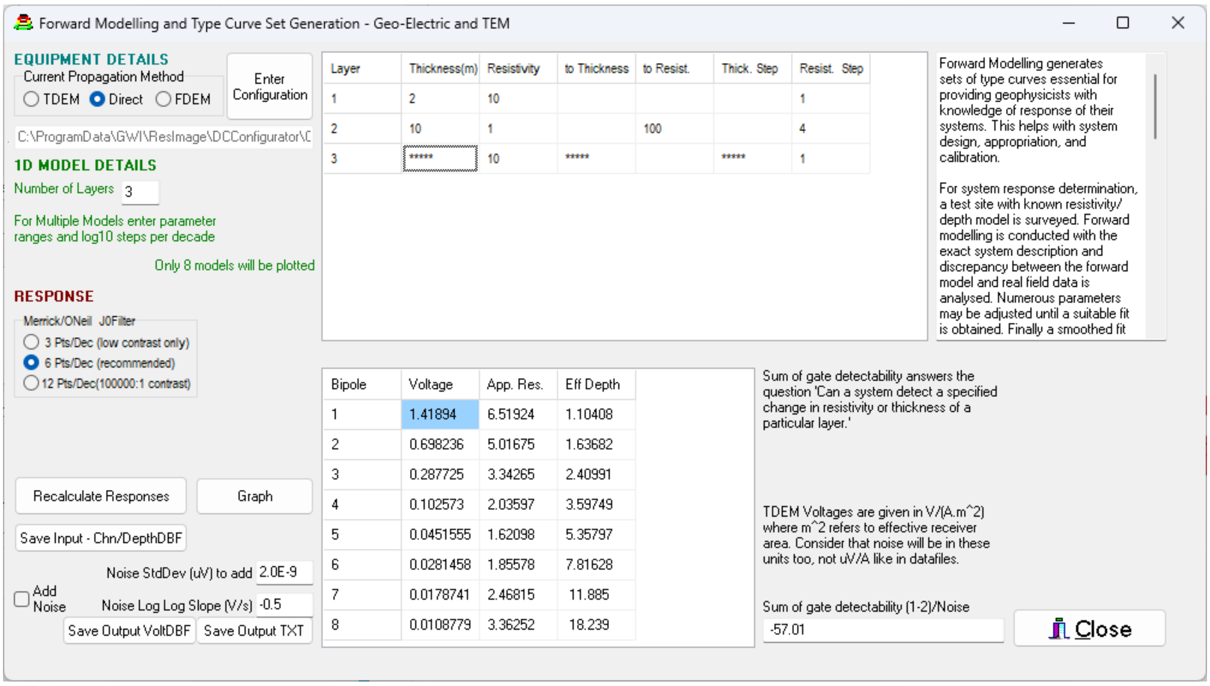
8. Now select 'Miscellaneous > Graph Signal w.r.t. Effective depth' to see not only how deep a configuration can see geometrically but also how deep it can see before signal drops below noise:



Under 'Miscellaneous' there are options for changing parameters used to determine this graph. Should you go and change configuration parameters then you can replot and the remaining plot will remain superimposed for comparison. As an exercise, if you change to a bipole-bipole configuration with a=5 metres and n= 8 then redisplay then you will see the merit of the Schlumberger array. The bipole-bipole array is displayed in red below – see that it lacks both depth range and signal strength:



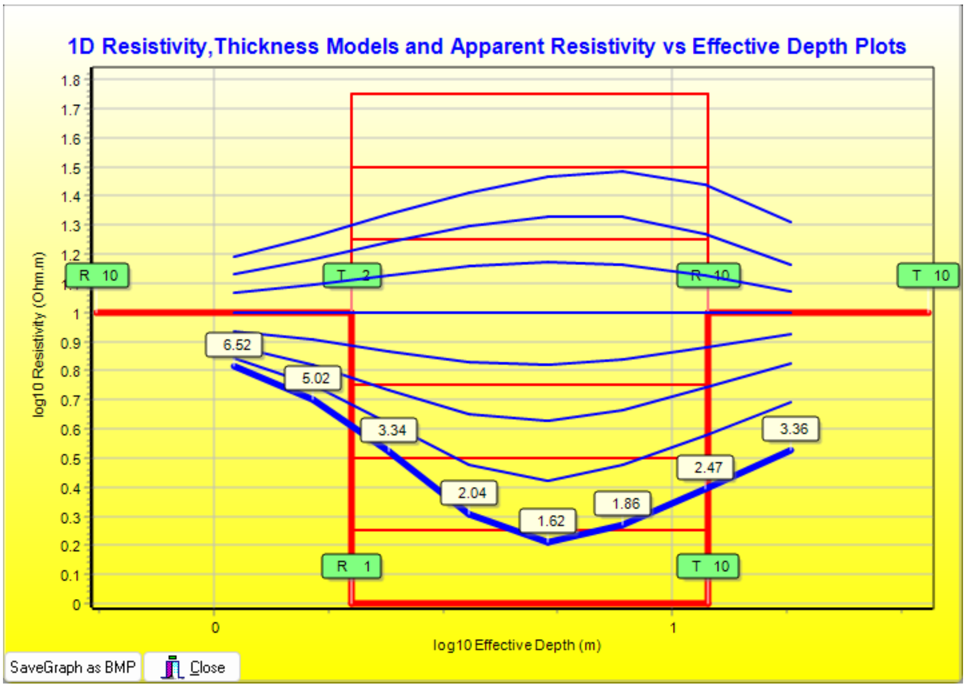
9. To avoid overwriting the *.DCC configuration file with any changes you may have made, escape out of the configuration form by pressing cancel and we will move on with conducting forward modelling.
10. On the forward modelling form, select ‘Number of layers : 3’ and fill out the table of layers as shown:



Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	2	10				1
2	10	1		100		4
3	*****	10	*****		*****	1

Bipole	Voltage	App. Res.	Eff Depth
1	1.41894	6.51924	1.10408
2	0.698236	5.01675	1.63682
3	0.287725	3.34265	2.40991
4	0.102573	2.03597	3.59749
5	0.0451555	1.62098	5.35797
6	0.0281458	1.85578	7.81628
7	0.0178741	2.46815	11.885
8	0.0108779	3.36252	18.239

Now press ‘Recalculate Responses’, followed by ‘Graph’ and you will see a set of type curves will be generated as shown:



This set reveals contrasts observed in apparent resistivity data for models of the type from top to bottom of conductive-resistive-conductive and resistive-conductive-resistive as the middle layer ranges from 1 ohm.m through decade steps 1.8 ohm.m, 3.1 ohm.m, 5.6 ohm.m, 10 ohm.m, 18 ohm.m, 31 ohm.m and 56 ohm.m. Because there is considerable contrast between adjacent type curves we can have confidence that this array will resolve these types of models well.

11. Now repeat for a Resistive-neutral-conductive case as shown:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	2	1000				1
2	10	10		1000		4
3	*****	10	*****		*****	1

Would you still be happy commissioning a survey using this streamer to resolve these types of models?

12. Now repeat for a Conductive-neutral-resistive case as shown:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	2	10				1
2	10	10		1000		4
3	*****	1000	*****		*****	1

Now we see that type curves for the more resistive middle layers are very close together indicating a very poor resolution of this type of model contrast.

13. Now we see a resolution problem, let us try the same type of model but now changing layer thickness instead of resistivity. Enter the following in the layers box:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	2	10				1
2	1	100	100		4	1
3	*****	1000	*****		*****	1

See that the resolution problem remains whether we adjust resistivity or thickness of this middle layer. It is a problem of equivalence. Despite resistivity methods obtaining more signal from resistive features, while electromagnetic methods obtain less signal from resistive features, if considered in terms of signal returned for unit of power delivered, they both lose most resolution for cases where conductive layers overly resistive layers.

14. After finishing your own modelling, close the form. If you are not equipped with an AarhusInv64.exe licence then you cannot move on to Tutorial 2B.

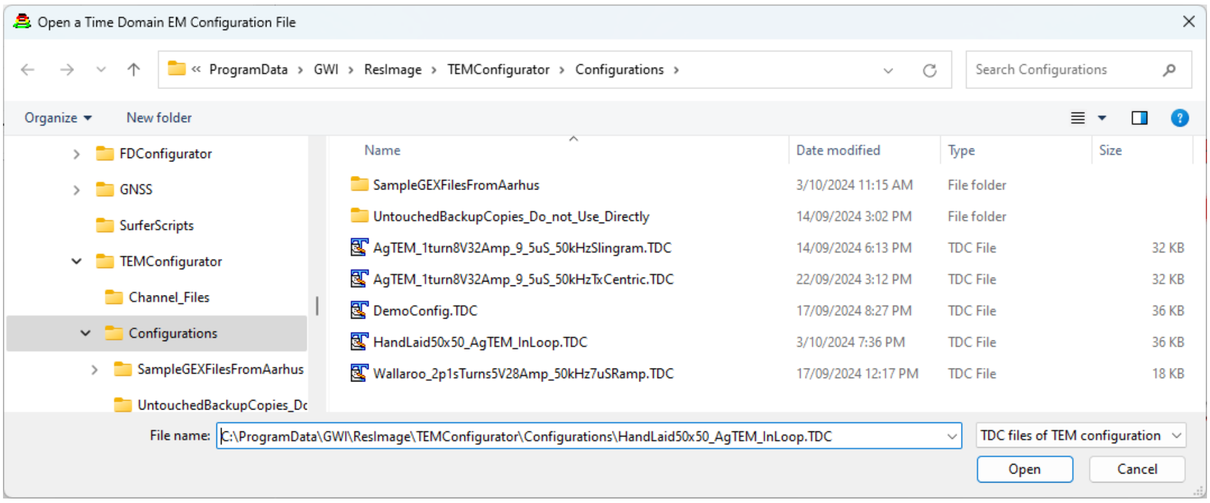
TUTORIAL 2B – FORWARD MODELLING OF 3 LAYERED MODELS

This tutorial is like tutorial 2, but the 3 layer models are generated for a towed ground TEM system. Contrast these models with those of tutorial 2 to see the difference in how TEM and direct current imaging respond to the same geology.

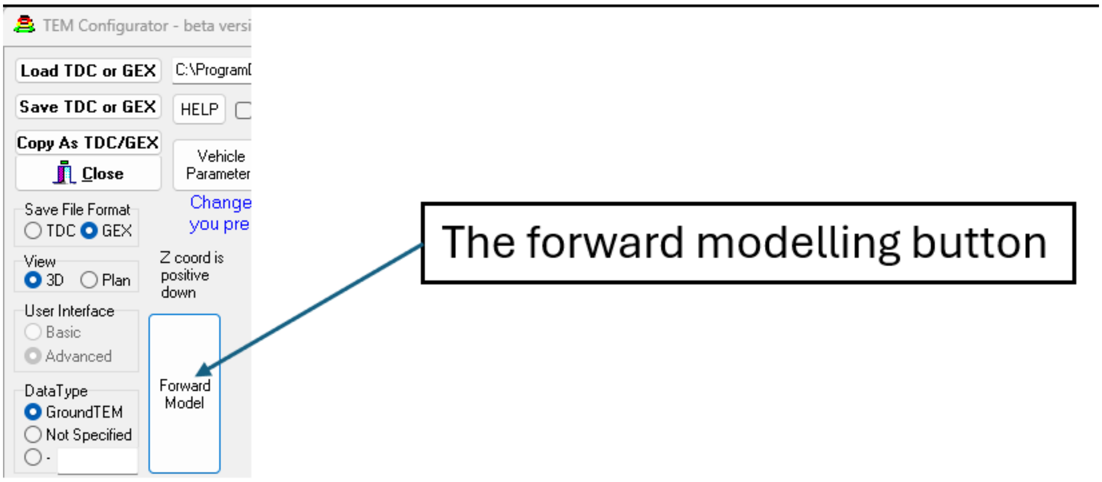
STEPS

An AarhusInv64.exe licence is required for completing this tutorial.

1. Run 'TEMConfigurator'
2. Load 'HandLaid50x50_AgTEM_InLoop.TDC ensuring you have 'TDC files of TEM configuration' selected in the drop down box. For the path see the top line shown below – this is the default location for storage of the example files.



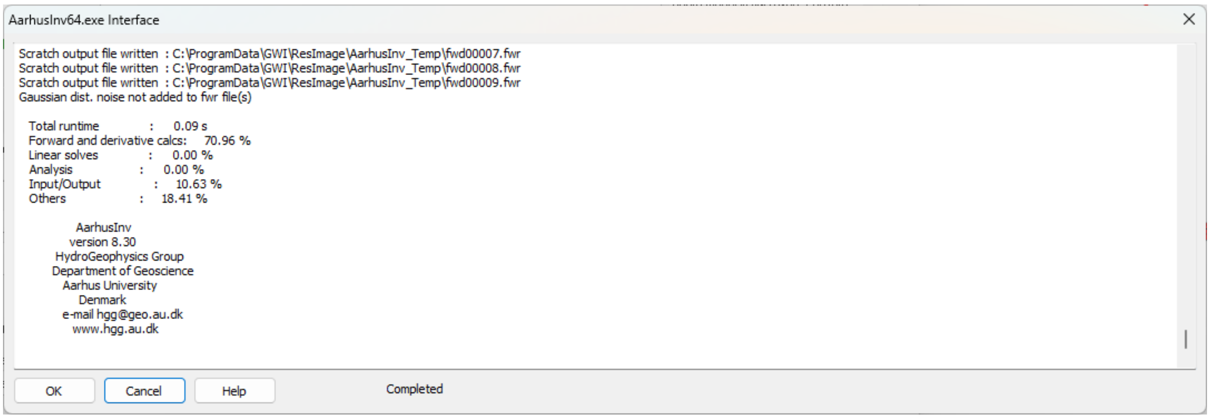
3. Press the 'Forward Model' button as shown:



4. We now follow the steps 10 to 14 of tutorial 2A but with slight changes. On the forward modelling form, select 'Number of layers : 3' and fill out the table of layers as shown:

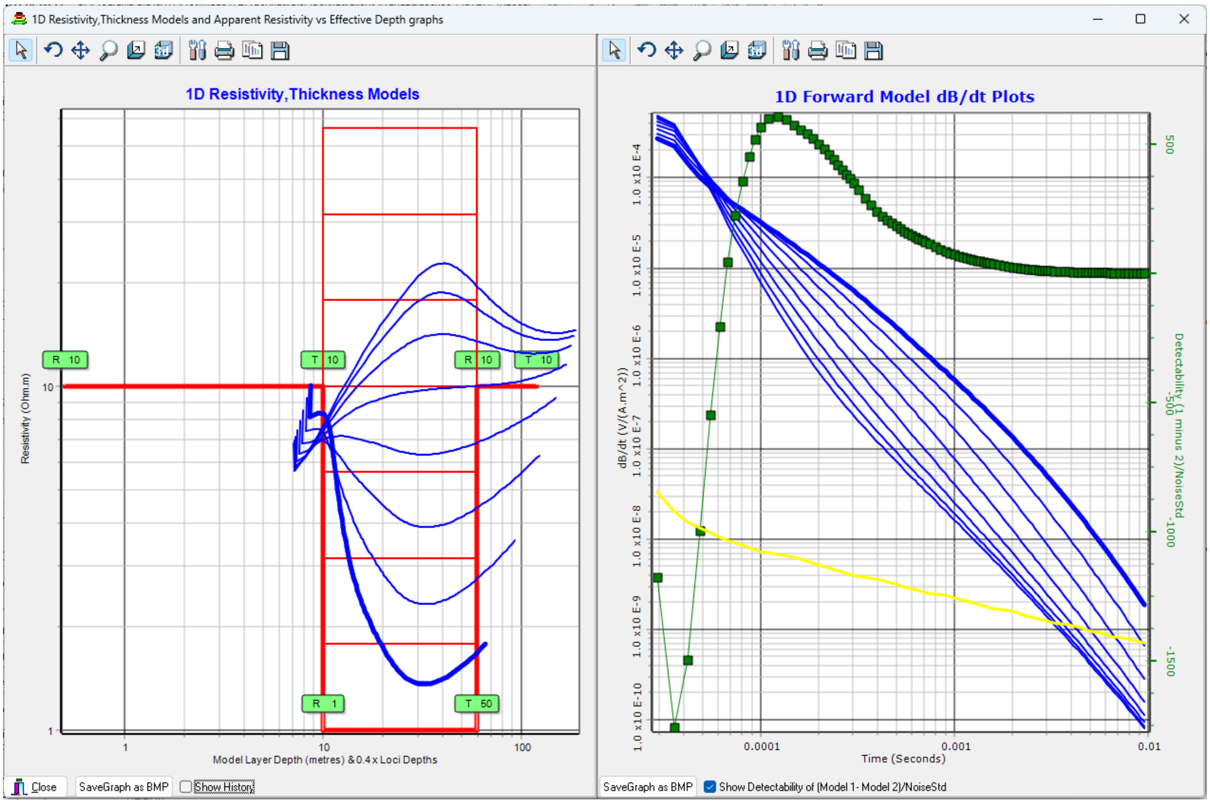
Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	50	1		1000	4	4
3	*****	10	*****		*****	1

Now press 'Recalculate Responses'. A shell for AarhusInv64.exe will appear and after a reasonable pause, messages on progress will be streamed into the shell as shown:



Once this is complete, check for error messages then press OK. The first time you run this, then after a licence interval is lapsed, Seequent will display a message requiring that licence checking occur – your web browser will open, and the check results will be displayed. Close the browser and return to the Shell form. When licence checking runs, processing can get interrupted and fail. If this happens just run it again.

5. Scratch files will be generated in the directory 'C:\GWI\ResImage\AarhusInv_temp\ so if you want to investigate further what is being fed into and being returned from AarhusInv64.exe then look in this directory. You can even rerun the files from a DOS prompt, although it is suggested that the TEMConfigurator shell will save you a lot of frustration in comparison.
6. Press 'Graph' and you will see a set of type curves will be generated as shown:

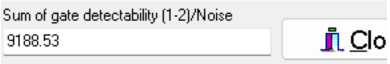


This set reveals contrasts observed in apparent resistivity data for models of the type from top to bottom of conductive-resistive-conductive and resistive-conductive-resistive as the middle layer ranges from 1 ohm.m (shown with the heavier lines) through decade steps 1.8 ohm.m, 3.1 ohm.m, 5.6 ohm.m, 10 ohm.m, 18 ohm.m, 31 ohm.m and 56 ohm.m. Because there is considerable contrast between adjacent type curves we can have confidence that this array will resolve these types of models well, just struggling to resolve between the 31 ohm.m and 56 ohm.m models. Observe that at early times there is a crossover in the decay curves on the right graph – this is normal behaviour and marks the boundary between early times and late times. On the left graph is displayed late time apparent resistivity versus 0.4 x Loci depth which is the depth of the most intense zone of the current ring moving down through the ground at the time of each measurement. Because this is a late time formula, and because it does not recognise the influence of low-pass filters, its response for the first few channels can be somewhat complicated and not worthy of much consideration. Being derived assuming a simple step response, the apparent resistivity and loci depth formulae also will behave unusually where there is a strong departure in waveform from a simple step response. The value in these highly approximated equation graphs is in revealing what parts of the data are properly responding to ground response and what parts are just reflecting system response. We multiply loci depth on the bottom scale by 0.4, as is common practice, because the response at the surface is not focused on the loci depth alone. Rather, it is affected by the preferential inductive coupling of the receiver loop to near surface current.

On the decay curve graphs, there is a noise graph displayed in yellow. You are required to set this level yourself and it may reflect matters including: random noise, smoothing filters applied, movement noise from rough travel, and many other matters. It is suggested that minimum achievable noise will not be achieved often in pragmatic circumstances. This can have a major affect on depth of investigation.

The green detectability curve is related to the contrast between models 1 and 2 only and is normalized by the noise curve to indicate how well each channel detects the contrast. In TEM survey it is very foolish to simply quote an exploration depth for an instrument regardless of geology. The robust approach is to compare type curves for anticipated models and a particular configuration. Clients can have realistic survey expectations demonstrated to them by type curve comparison examples.

7. Now close the Graph form and observe the total detectability sum as shown:

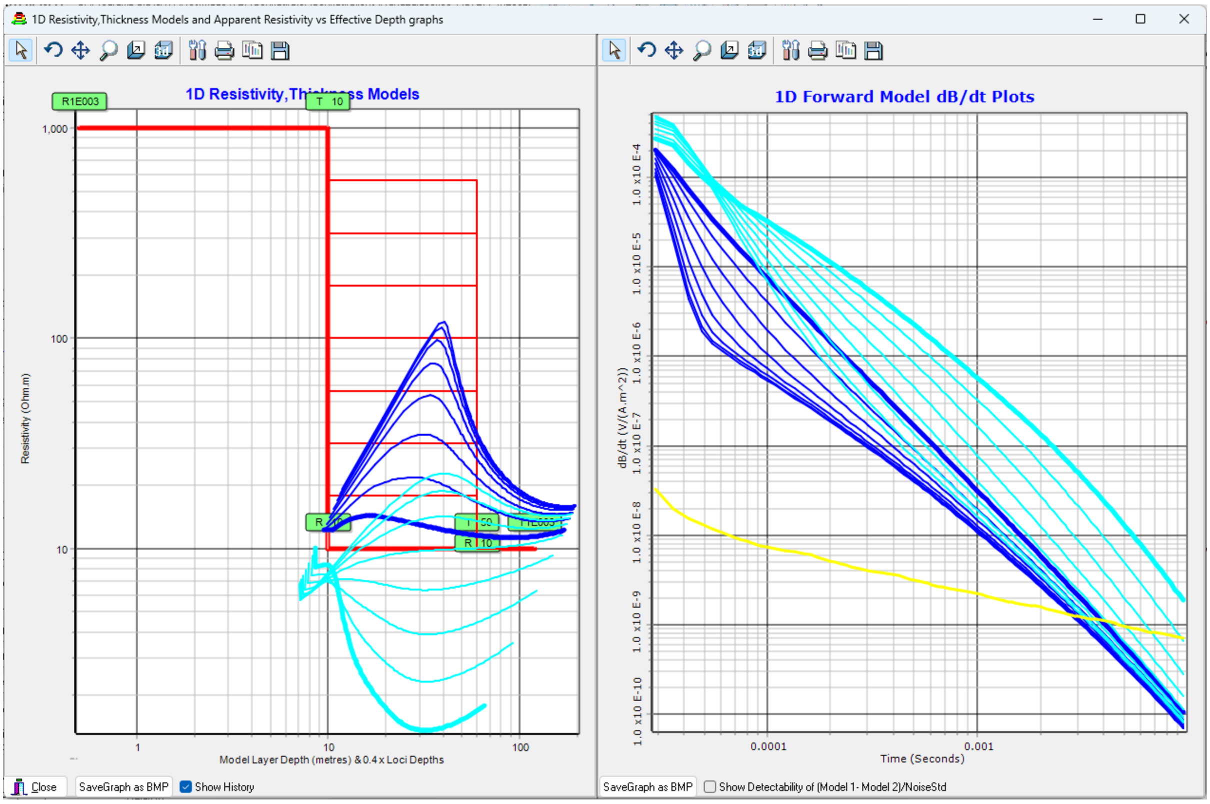


If the value of this figure exceeds 2 then theoretically model one and two can be distinguished. In practice, due to equivalence and the pragmatic requirement to accept persistent as well as random noise into consideration, as well as conceptual model simplifications compared to reality, a much higher sum really should be sought to justify commissioning a survey.

1. Now repeat for a Resistive-neutral-conductive case as shown:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	1000				1
2	50	10		1000	4	4
3	*****	10	*****		*****	1

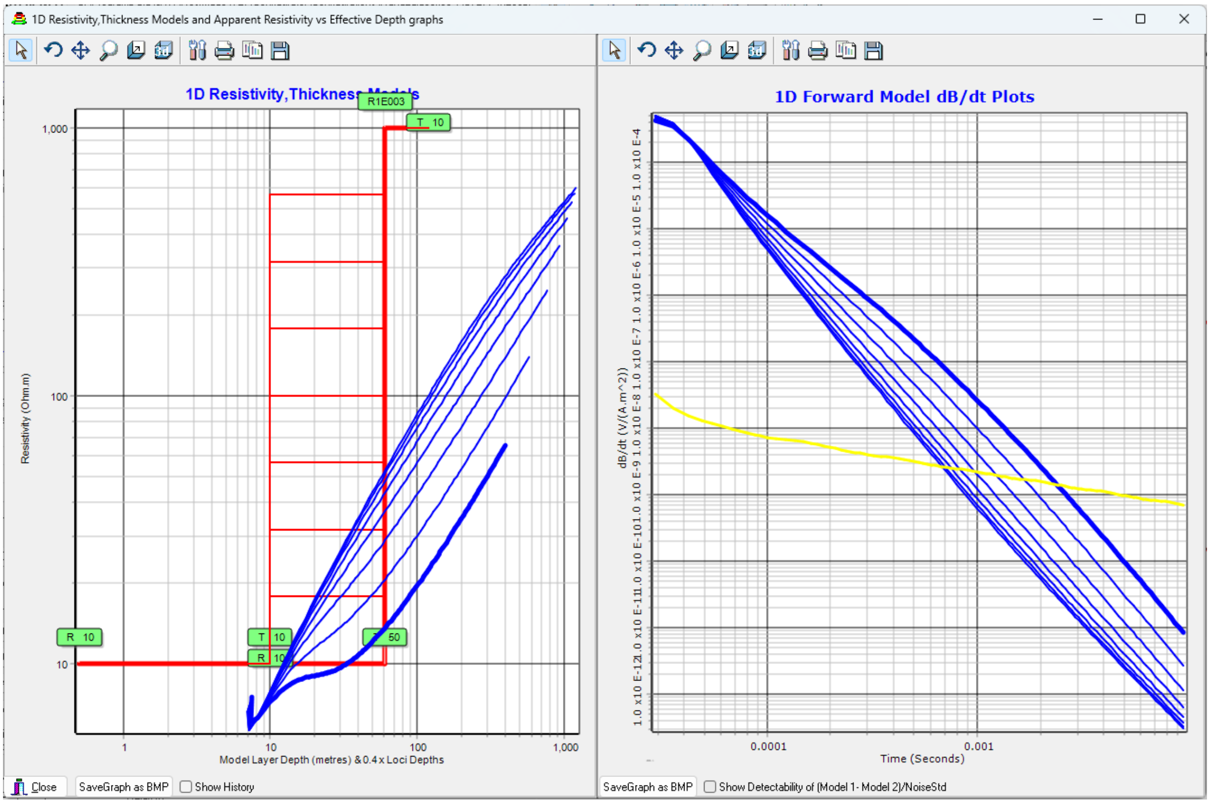
Would you still be happy commissioning a survey using this configuration to resolve these types of models?



Notice how the type curves for the previous models are still shown on graphs. This is handy for comparison, including tweaking of configuration parameters – that is it is not only layered model parameters that can be changed between runs such as has been done in this example. Try toggling the 'Show History' and 'Show Detectability' check boxes to change what is displayed on the graph. Above the detectability graph has been turned off to reduce complication.

2. Now repeat for a Conductive-neutral-resistive case as shown:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	50	10		1000	4	4
3	*****	1000	*****		*****	1

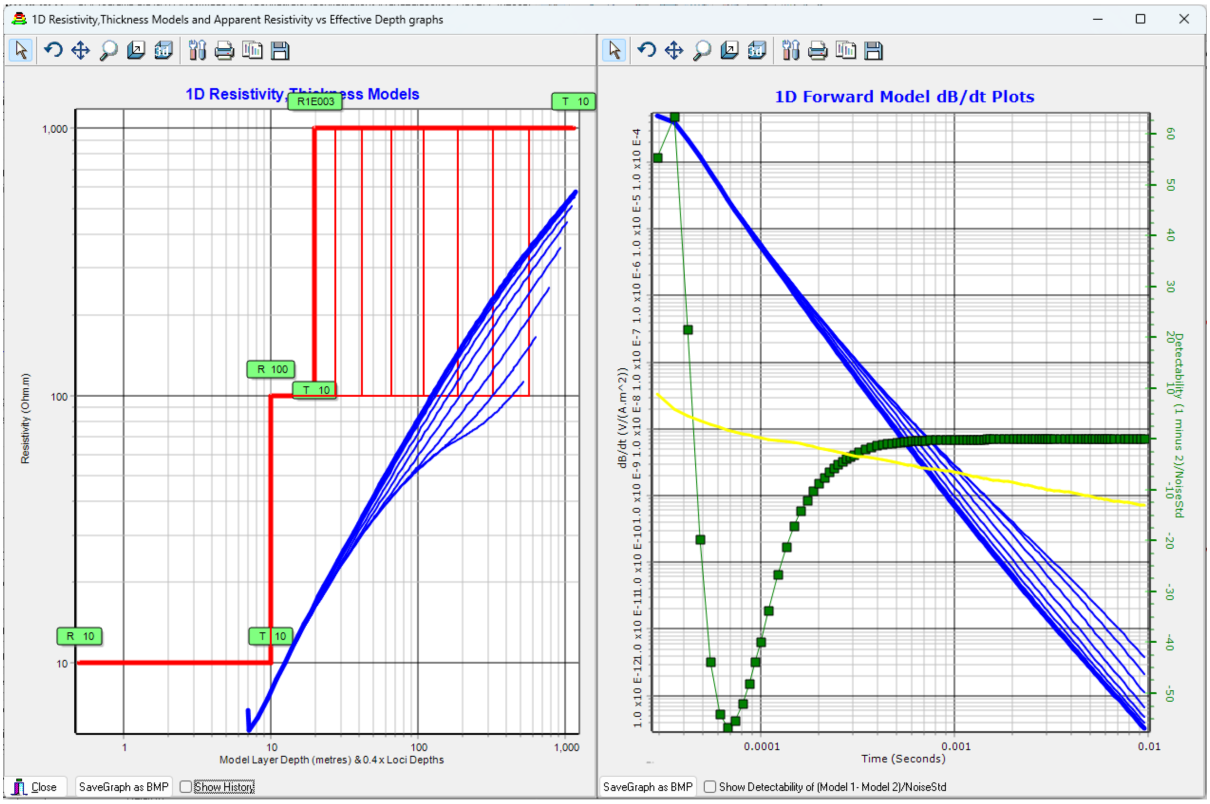


Now we see that type curves for the more resistive middle layers are very close together indicating a very poor resolution of this type of model contrast.

3. Now we see a resolution problem, let us try the same type of model but now changing layer thickness instead of resistivity. Enter the following in the layers box:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	10	10				1
2	10	100	1000		4	4
3	*****	1000	*****		*****	1

Now we see a detectability problem because the decay curves only start to separate one from another as the decay plummets beneath the noise floor:



See that the resolution problem remains whether we adjust resistivity or thickness of this middle layer. It is a problem of equivalence. Despite resistivity methods obtaining more signal from resistive features, while electromagnetic methods obtain less signal from resistive features, if considered in terms of signal returned for unit of power delivered, they both lose most resolution for cases where conductive layers overly resistive layers.

The next shorter tutorial focuses on a most common scenario to which towed and airborne TEM is applied – looking for gravel filled palaeochannels incised into conductive basement.

TUTORIAL 3 – FORWARD MODELLING DECLINING DEPTH TO CONDUCTIVE BASEMENT

This tutorial describes the most anticipated use of TEMConfigurator – estimating depth of investigation for particular surveys.

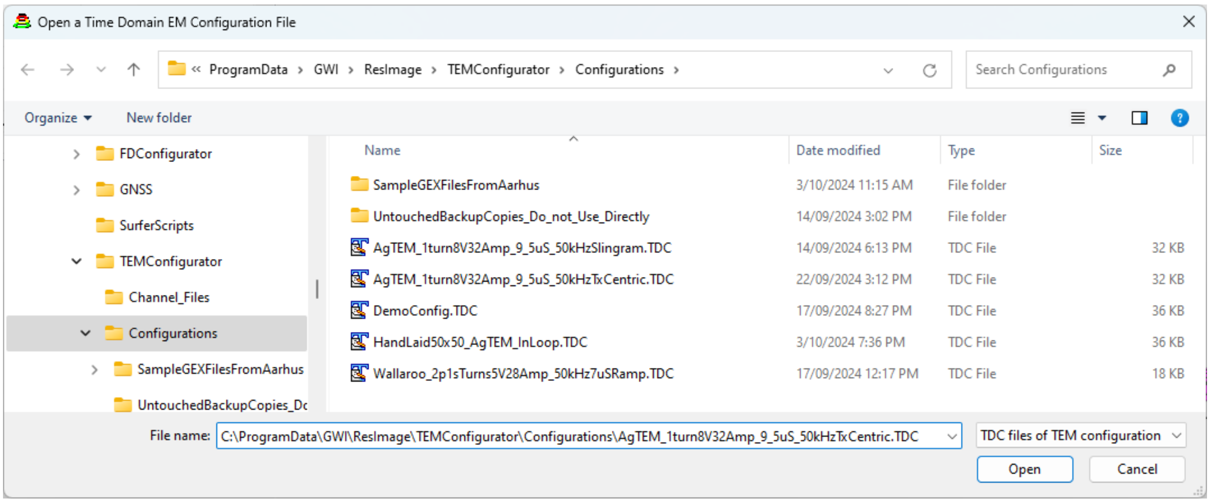
It is useful to know to what depth a configuration can detect conductive basement before committing to a survey. If anticipated depth of basement is too great then a more costly configuration can be substituted, attention to noise reduction can be increased, or marketing of the survey can be abandoned.

In this tutorial, an AgTEM Wallaby overlapping loops configuration will be loaded, and forward modelling, of resistive cover over conductive basement, conducted for 8 different cover thicknesses. Decays will be compared, considering noise level, for estimating distinguishability.

STEPS

An AarhusInv64.exe licence is required for completing this tutorial.

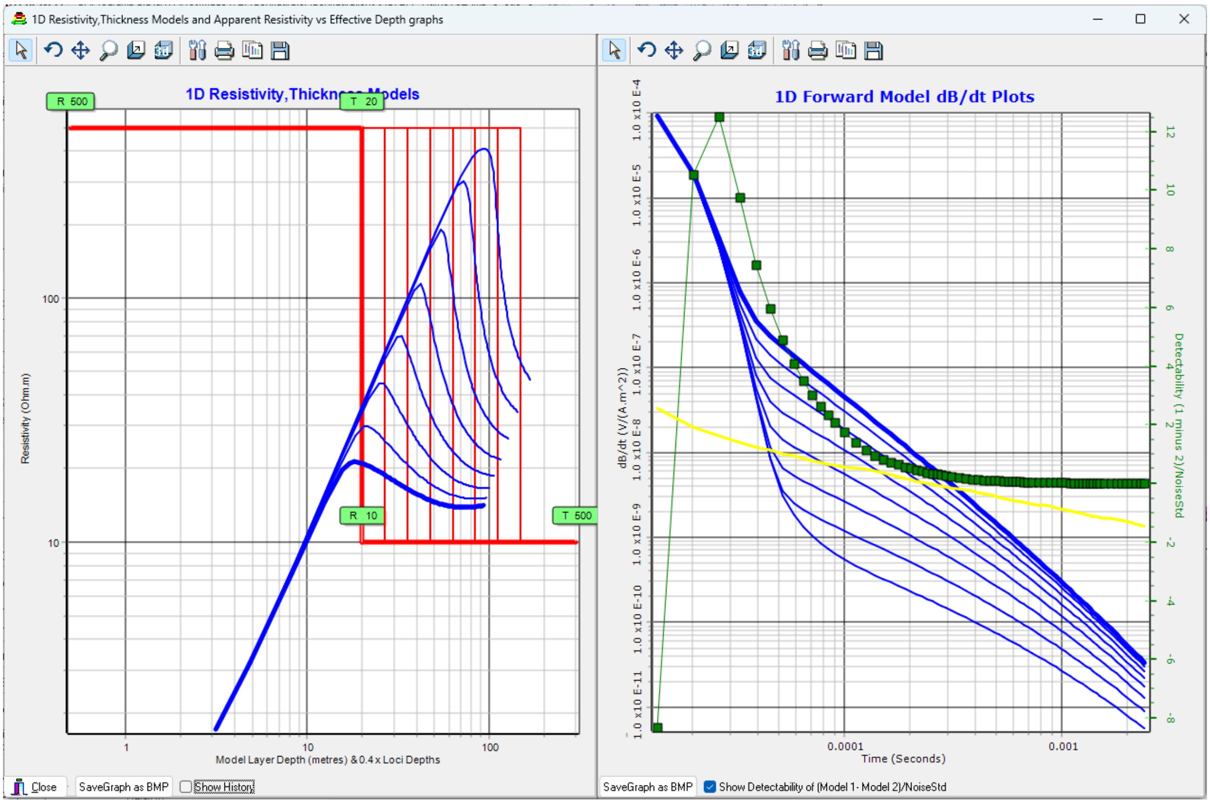
1. Run TEMConfigurator and load the AgTEM Wallaby single turn txCentric loop configuration as shown:



2. Press the 'Forward Model' button.
3. Change the number of model layers to 2 and enter the models shown:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	20	500	200		8	1
2	*****	10	*****		*****	1

4. Run the forward model and graph the results for surface layer thicknesses of 20, 26, 36, 48, 62, 84, 112 and 150 metres:



The results show excellent contrast between type curves however the distinguishable segments of the curves for models with depth to basement exceeding 60 metres drop beneath the designated noise level of 2e-9 V/(A.m^2). This noise level is chosen assuming rough travel over tussocky vegetation and with systematic noise sources poorly resolved as can be normal under production pressure. If deeper basement were to be resolved, then attention to improving these matters could bring noise level down to 1e-10 V/(A.m^2) such that depth to basement of 150m could be reliably resolved however the slower driving and greater rigour required could double the survey cost. Additionally, the transmitter loop turns could be increased from 1 to 2 doubling the signal to noise ratio but shifting the unresolvable part of the decays later in time. If 150m deep palaeochannels must be resolved, then the extra effort will be worthwhile.

TUTORIAL 4 – FORWARD MODELLING GROUND AND AIRBORNE ACQUISITION

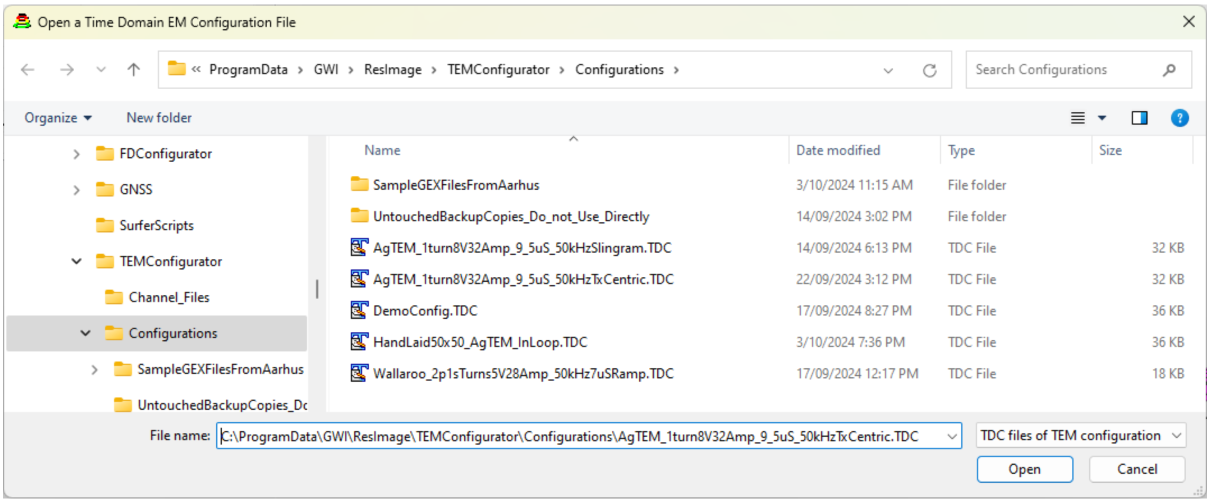
In oversimplistic theory, a small towed-TEM system, given sufficient stacking time, while covering the footprint of a large powerful airborne system, should be able to detect features of equal depth should towed TEM data collected be spatially smoothed sufficiently to match the footprint of the airborne system. In forward modelling comparison, the smoothing comparison is achieved simply by decreasing the noise floor.

In this tutorial we show that complications from differences in near-surface coupling favour airborne system ability to detect deeper features where metallic culture clutter is absent. Further, we compare both Slingram and in-loop towed TEM systems and find that in-loop systems suffer more from near-surface feature influence but Slingram loop, which is less sensitive to near surface conductors, suffers from tilt sensitivity. Slingram loops are Transmitter and Receiver loops separated by significant distance so that they can be approximated as dipole sources (not that they always are).

STEPS

An AarhusInv64.exe licence is required for completing this tutorial.

1. Load the AgTEM Wallaby 1 turn Tx Centric TDC files as shown:



2. Press 'Forward Model'
3. Enter the following 3 layer conductive basement model with layer 1 as air (10,000 ohm.m):

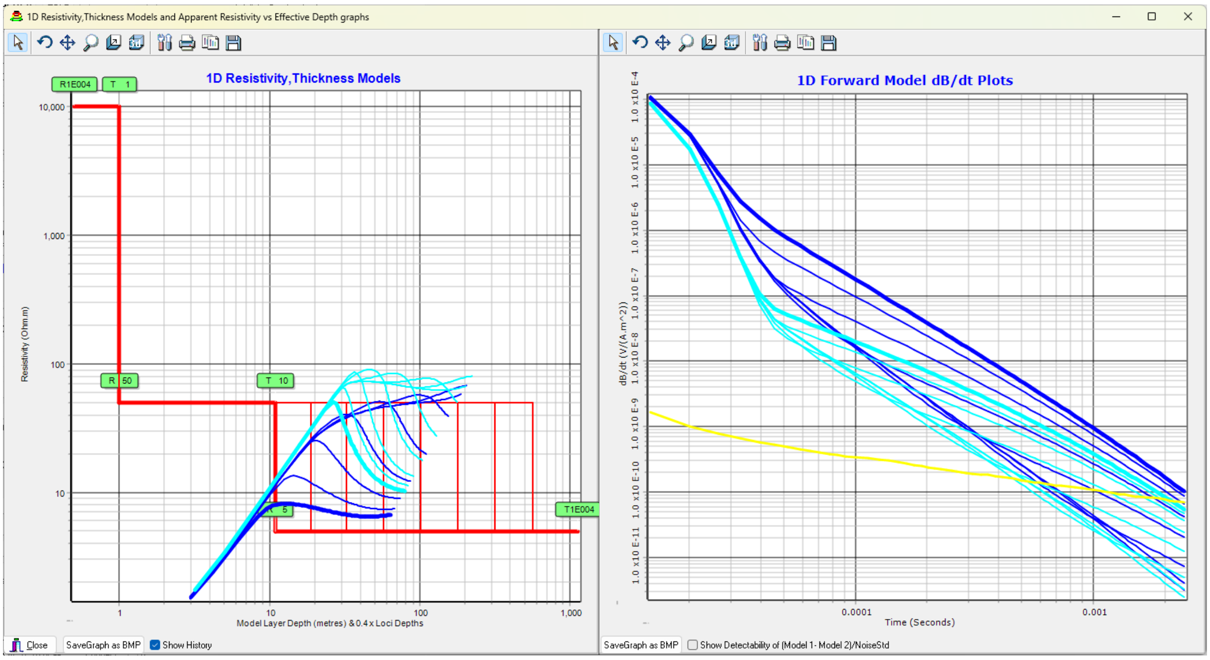
Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	30	10000			1	1
2	10	50	1000		4	1
3	*****	5	*****		*****	1

In this model we give the air layer a 30m thickness to simulate Wallaby flying at typical minimum airborne system height.

4. Change the noise level to a value practical for this scenario:

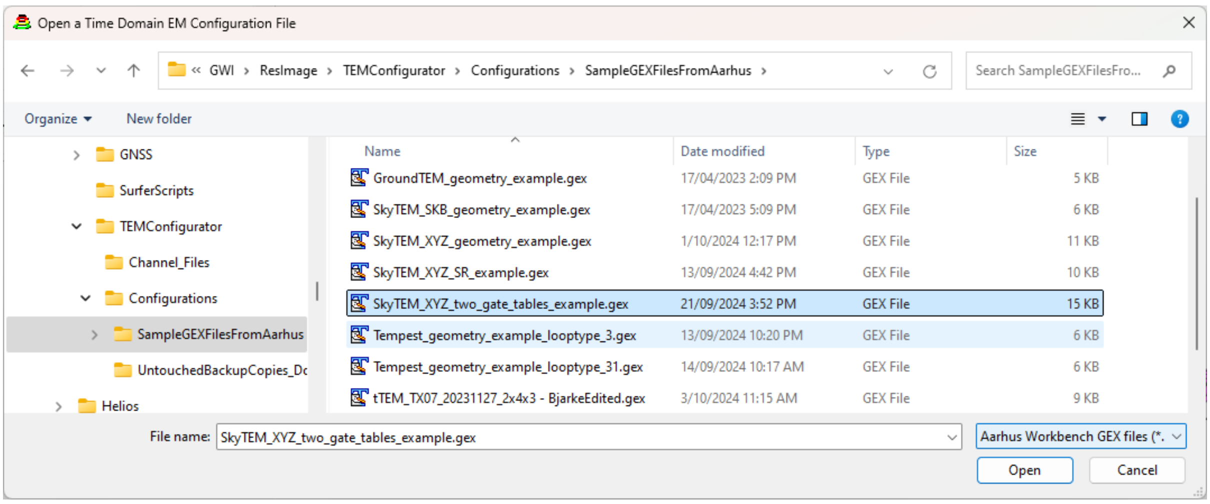
Noise StdDev @1ms (uV/(A.m^2)) to add 1E-010

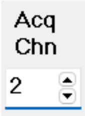
5. Press 'Recalculate Responses' and 'Graph'. You will see how AgTEM might function at 30m above the ground. Now we must compare how it performs at ground level.
6. Change layer 1 thickness to 1m (not 0m as it will cause a mathematical problem). Recalculate responses and graph again ensuring the 'Show History' check box is displayed so that the following comparison graphs are displayed:



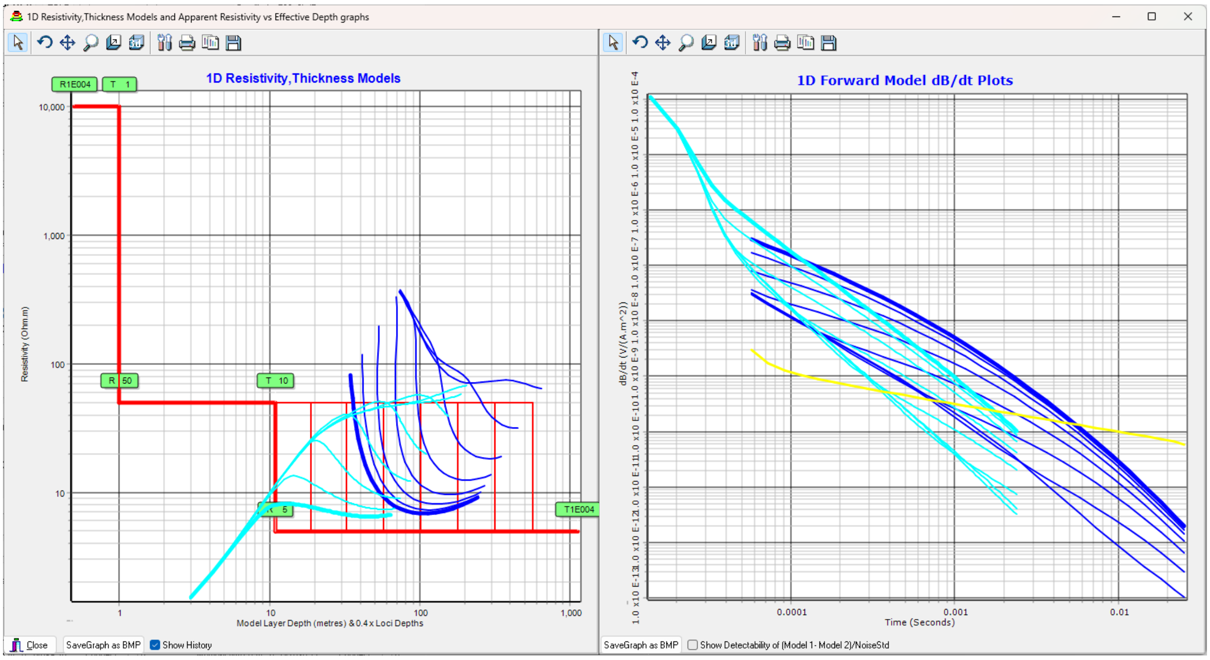
Resistive layer thicknesses are 10, 18, 31, 56, 100, 180, 310 & 560 metres. See that the main difference is a drop in effective returned signal strength, particularly at earlier times. This means that if Wallaby, with one Tx loop turn and 32 Amps, is airborne it can only distinguish basement in this set of models to a depth of <100m but if on the ground it can distinguish basement to a depth of <180m.

7. Now let us compare the towed TEM Wallaby system with SkyTEM High Moment at 30m high. Exit out of the forward modelling form but, importantly, not out of TEM Configurator as we need to retain a history of type curves for comparison. Select to load a SkyTEM configuration as shown, ensuring you change file type to GEX to see the file:



8. Press ‘Forward Model’ again and change layer 1 thickness back to 30 metres in the layered model table. Noise level will remain at 1e-10 simply for comparison – actual noise levels of these systems are probably different and both operations dependent.
9. Immediately change Acquisition channel to 2, High Moment, as shown. Do not leave this for later or you will overwrite the history of Wallaby type curves: 

10. Press Recalculate Responses’ and ‘Graph’ to display:



Recall that the resistive layer thicknesses are 10, 18, 31, 56, 100, 180, 310 & 560 metres. We can see that SkyTEM high moment can resolve the first 5.5 depths to basement before signal falls below the noise level we selected. This indicates that under such conditions for such models, the system can see the conductive basement to <180m. In this situation see that it is a waste imaging at 12.5Hz repetition frequency. Over more conductive models that would not be the case. Note that as with the previous ground/airborne comparison, that the main difference is the type curves start at lower values and have a flatter gradient initially if airborne. Note well that the 1.0e-10 V/(A.m^2) equal noise comparison is not accurate – SkyTEM has a very large loop and transmits many amps so real noise normalized to amperage and transmitter loop area would be significantly lower and it can see much deeper than 180m.

TUTORIAL 5 – FORWARD MODELLING FILTERS AND RAMP CHANGES

Filters and ramp time contribute considerable influence on the early part of decay curves.

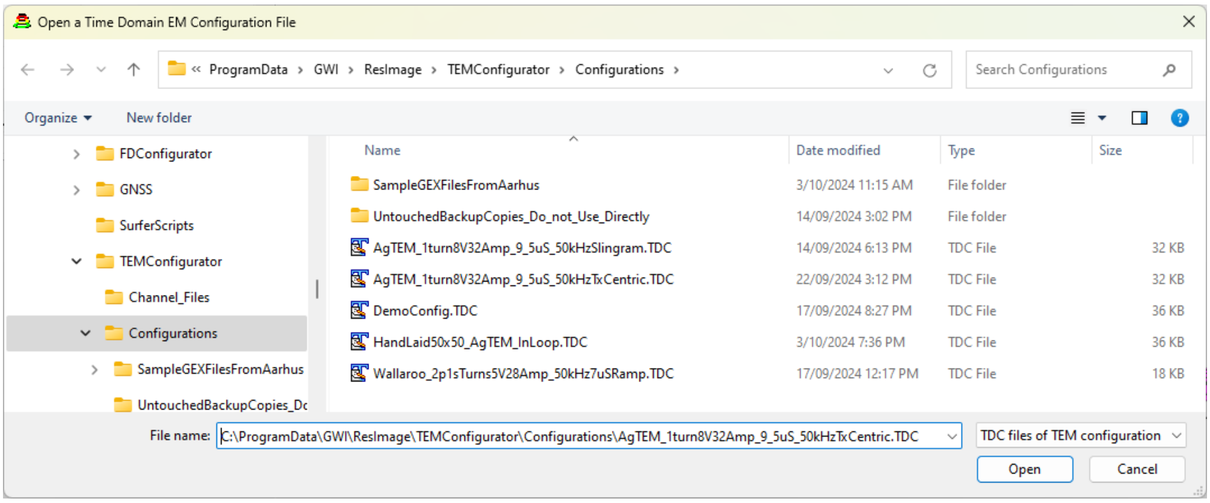
In this tutorial the reason why filters cannot be ignored by inversion software is demonstrated.

Sets of 8 type curves can be created in the forward modelling routine but only for changes in layered models. To compare effects of configuration parameters for a whole set of 8 models, one simply exits the forward modelling form after creating some type curves, changes a parameter, and re-enters the forward modelling form, generating the same models again but with the changes. Graphs of the models, both before and after are then displayable.

STEPS

An AarhusInv64.exe licence is required for completing this tutorial.

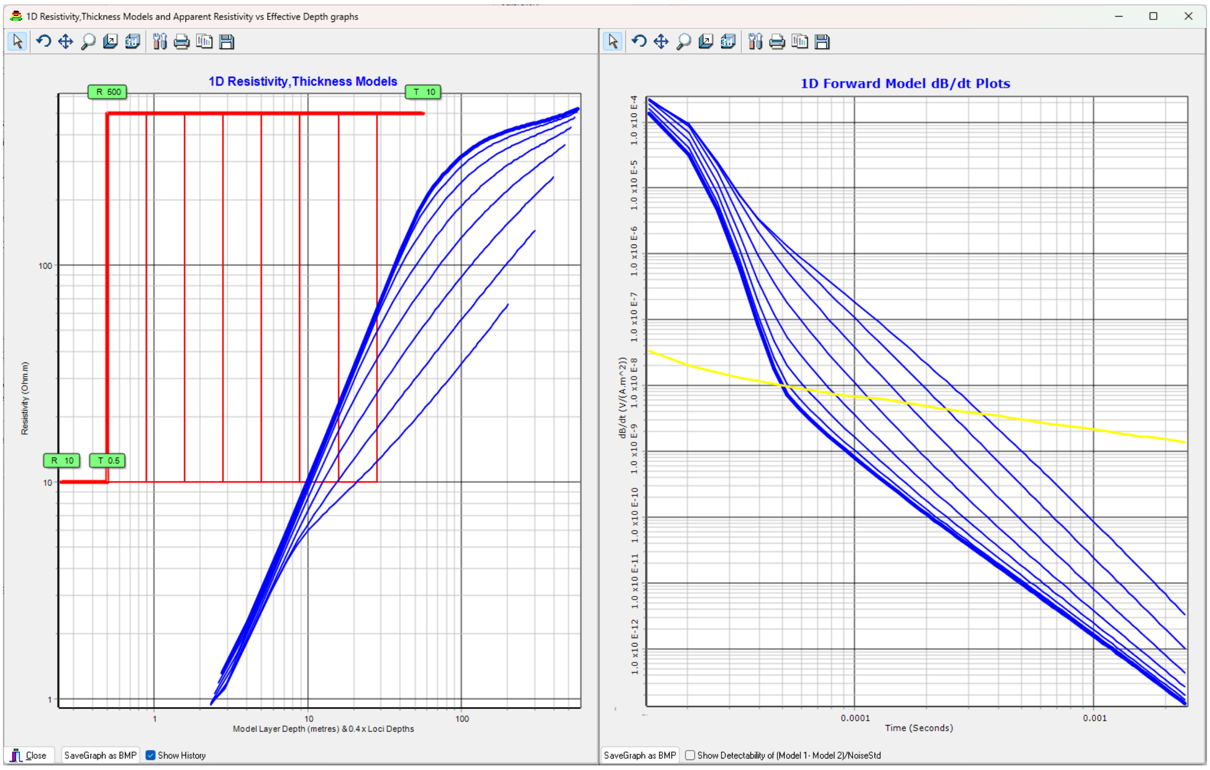
1. As per the previous example, load a configuration – the Wallaby_TxCentric overlapping loops configuration is recommended. Realise that there are filters modelled on both the transmitter and receiver even though the transmitter filter is only a damping resistor combined with parasitic capacitance and inductance of the system. Loading of this configuration is presented here:



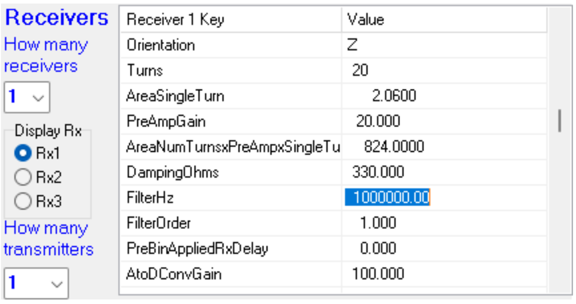
2. Press 'Forward Model'
3. To observe the worst possible scenario, generate 2 layer models with a variable thickness, slightly conductive surface layer and resistive basement. 10 ohm.m over 200 ohm.m with layer 1 thickness ranging from 0.5 to 50m should suffice. Here is an example:

Layer	Thickness(m)	Resistivity	to Thickness	to Resist.	Thick. Step	Resist. Step
1	0.5	10	50		4	1
2	*****	500	*****		*****	1

4. Press 'Recalculate Responses' and 'Graph' to reveal:



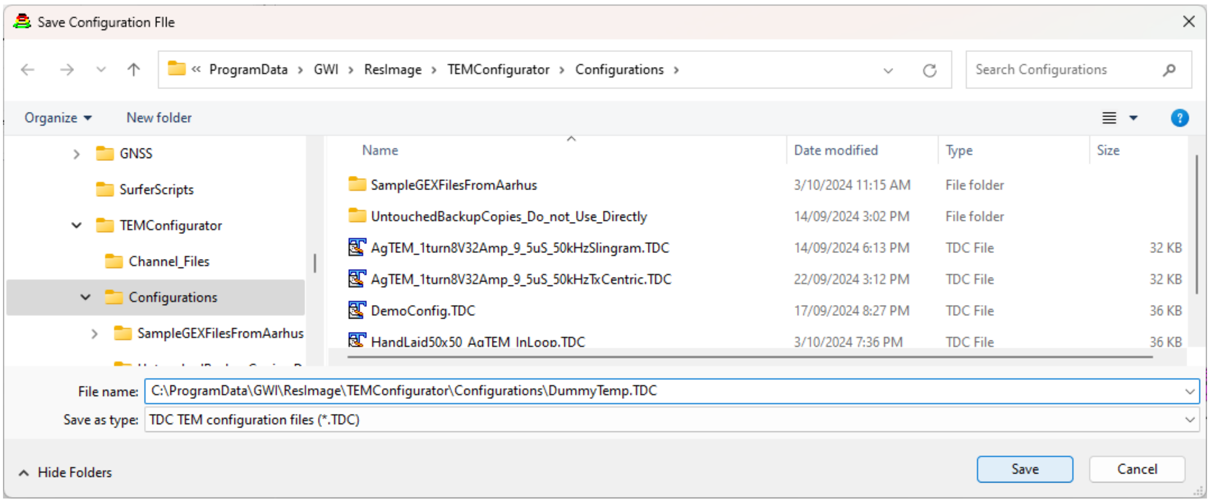
5. Now move out of the forward modeller, reduce both transmitter and receiver filters by increasing their frequency to say 1MHz. The Receiver filter is accessed as displayed (note that the damping here is reference only and not actively incorporated into the filter algorithm):



Also change the transmitter filter from 60000 to 1000000 on the main form as shown:

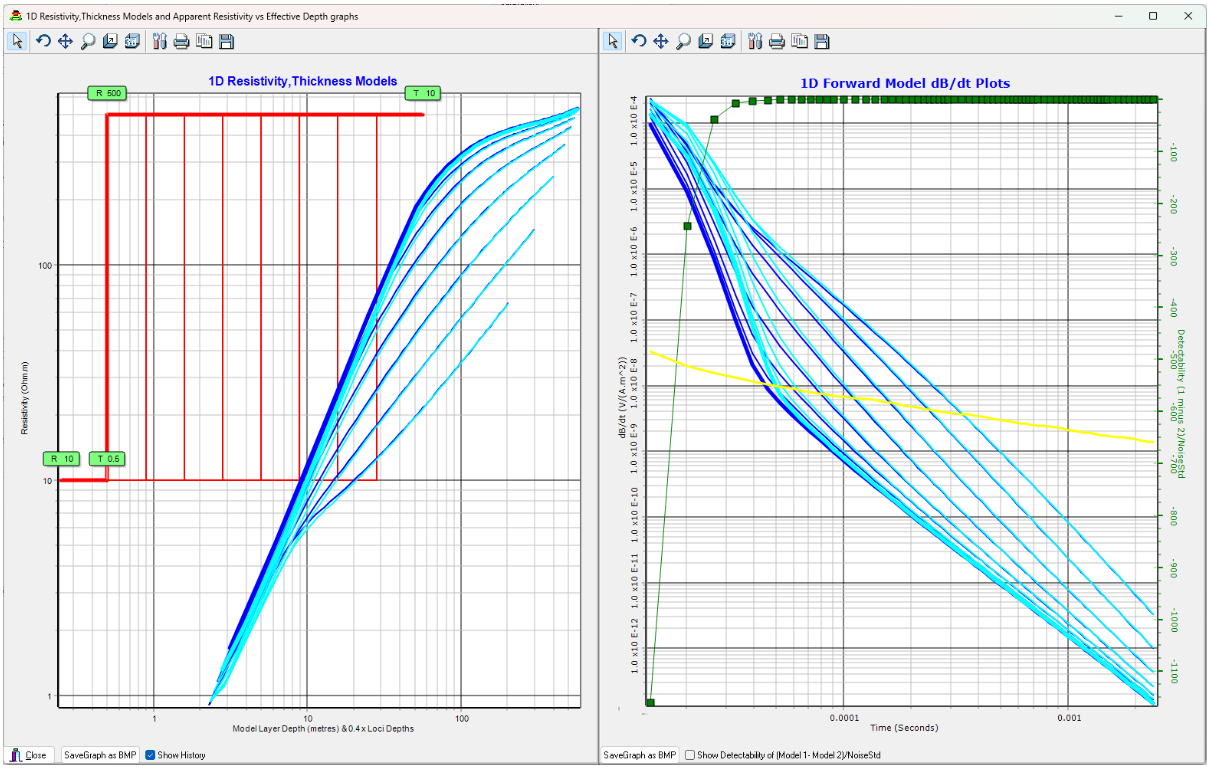
Do not forget to press ‘Refresh display and calculated variables’. For these filters it is not necessary but for many variables, changes affect other variables, so for them the update is required – if unsure it is best to implement this update.

6. Select ‘CopyAs TDC/GEX’ and save to DummyTemp.TDC as shown:



Saving back to the original file name would be detrimental as we just wiped out the filters so it is safer to save to an obviously temporary filename. The forward modeller reads from the file so any changes not saved will not have an effect.

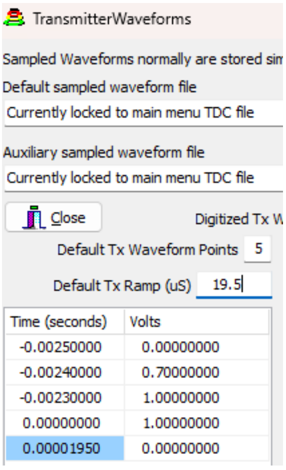
7. Go back to the forward modeller, recalculate the models and graph again. Now compare the new models with the historic models to see the difference that has occurred. See the result here:



Notice the change in early times. Getting filters wrong will result in inversions generating artefacts near the surface, and, if inversion cannot accommodate the error this way, it will typically either drop the layers modelled deeper into the earth or generate a spurious conductive layer that absorbs deep response and hides deep features.

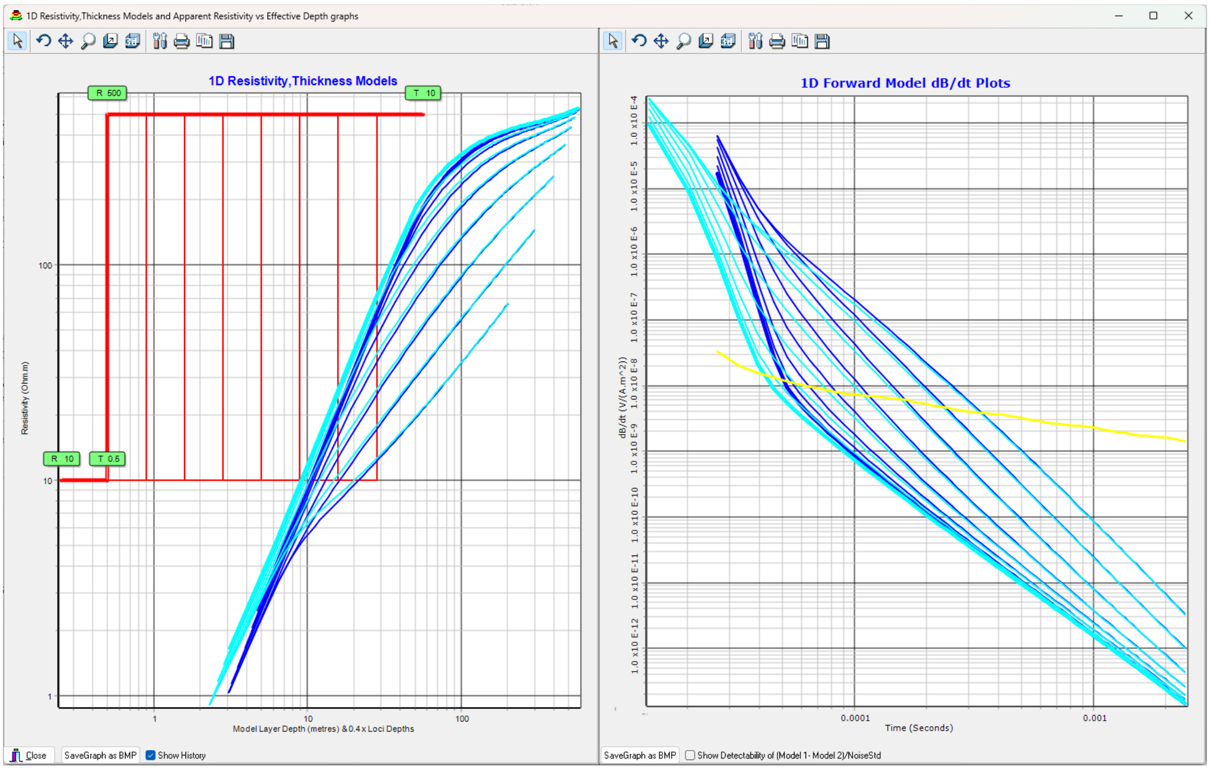
5. Try the same procedure but changing ramp time in the Tx Waveform form instead of the filters – again saving to *DummyTemp.TDC*. The change in the 'Waveform' form is shown, from 9.5 to 19.5. It must be made in the table as the ramp box is read only. Click on the ramp box after making the

change to update the ramp (it is a cosmetic entry not used in forward modelling which gets the ramp straight from the waveform definition.



Remember to resave *DummyTemp.TDC* before rerunning forward modelling.

6. The type curves comparison results for changing turn off time from 9.5uS to 19.5uS are as shown:



Notice that the extra 10uS makes it hard to resolve the contrast in the 10 ohm.m layer until it exceeds 1 metre in thickness. Also notice that changing filters and changing ramp time have similar effects on forward models if the early channels are excluded from observation.

FILE FORMATS AND EXAMPLES

DEMOCONFIG.TDC SAMPLE FILE

Here is a sample file in TDC format – see Aarhus documentation for GEX format.

Some entries are redundant but remain to show what is possible. Default entries are assumed whenever a key is missing.

[All]

IsMasterConfig=0

MasterTamperCheckCRC=0

TDCFilename=C:\AgTEM\Configurations\DemoConfig.TDC

ParentConfigFile=C:\AgTEM\Configurations\DemoConfigMaster.TDC

Description=GroundTEM setup

DataType=GroundTEM

LinkTxApproximateCurrenttoTxAmps=0

CalculateRawDataSTD=0

NumAcqChn=2

NumTx=1

NumRx=2

SysRespExists01=0

SysRespExists02=0

/____

[Rx1]

CentroidX=18.2

CentroidY=0

CentroidZ=-2.4

Name=The_receiver

Orientation=Z

EffectiveArea=205

SingleTurnArea=2

Turns=10

PreAmpGain=10.25

LowPassFilterOrder=1

LowPassFilterHz=50000

DampingOhms=330

AtoDConvGain=100

PreBinAppliedRxDelay=0

Shape=Circle

EquivRadius=0.564

XSideLength=1

YSideLength=2

AxisTilt=0

AxisRotation=0

/____

[Rx2]

CentroidX=1.83

CentroidY=0

CentroidZ=-1.2

Name=The_receiver

Orientation=Z

EffectiveArea=164

SingleTurnArea=1.6

Turns=10

PreAmpGain=10.25

LowPassFilterOrder=1

LowPassFilterHz=50000

DampingOhms=330

AtoDConvGain=100

PreBinAppliedRxDelay=0

Shape=Circle

EquivRadius=0.564

XSideLength=1

YSideLength=1.6

AxisTilt=0

AxisRotation=0

/____

[Tx1]

MomentID=Single

Name=Name_not_provided

LoopSides=10

LoopType=72

TxLoopPoint1= 1.750 0.000 -1.800

TxLoopPoint2= 1.750 0.500 -1.800

TxLoopPoint3= 2.820 0.500 -1.800

TxLoopPoint4= 2.620 3.000 -1.800

TxLoopPoint5= -1.980 3.000 -1.800

TxLoopPoint6= -3.580 0.000 -1.800

TxLoopPoint7= -1.980 -3.000 -1.800

TxLoopPoint8= 2.620 -3.000 -1.800

TxLoopPoint9= 2.820 -0.500 -1.800

TxLoopPoint10= 1.750 -0.500 -1.800

NumberOfTurns=2

DampingOhms=330

FlyingLeadLength=1

AreaSingleTurn=32.03

CentroidX=-0.118314600894994

CentroidY=1.12073715671392E-16

CentroidZ=-1.8

EquivalentSquareLoopside=5.65950527873241

Volts=8

VoltsMin=3.3

VoltsMax=18

Amps=36

AmpsMin=1

AmpsMax=45

ConstantVoltsOrAmps=0

PowerWatts=288

ResistanceOhms=0.222222222222222

MomentNIA=2306.16

RelayA_Connected=1

RelayB_Connected=0

AxisOrientation=Z

AxisTilt=0

AxisRotation=0

/____

[TimebaseTx1]

TimebaseFilename=No_Filename_selected

AnalDigConvSamplingRate=-1

PreBinAppliedSamplingDelay=0

PowerlineBaseFrequency=50

FullWaveformRepetitionFrequency=120

drivenNumGatesUsed=30

NumGatesInSet=30

FullWaveformStacks=32

GateSetName=Not_Specified

Gate_Times=Centre Start End Width (Seconds)

GateTime01=3.60000E-006 4.00000E-007 6.80000E-006 0.00000E+000

GateTime02=1.00000E-005 6.80000E-006 1.32000E-005 0.00000E+000

GateTime03=1.64000E-005 1.32000E-005 1.96000E-005 0.00000E+000

GateTime04=2.28000E-005 1.96000E-005 2.60000E-005 0.00000E+000

GateTime05=2.92000E-005 2.60000E-005 3.24000E-005 0.00000E+000

GateTime06=3.56000E-005 3.24000E-005 3.88000E-005 0.00000E+000

GateTime07=4.20000E-005 3.88000E-005 4.52000E-005 0.00000E+000

GateTime08=4.84000E-005 4.52000E-005 5.16000E-005 0.00000E+000

GateTime09=5.80000E-005 5.16000E-005 6.44000E-005 0.00000E+000

GateTime10=7.08000E-005 6.44000E-005 7.72000E-005 0.00000E+000

GateTime11=9.00000E-005 7.72000E-005 1.02800E-004 0.00000E+000

GateTime12=1.15600E-004 1.02800E-004 1.28400E-004 0.00000E+000

GateTime13=1.41200E-004 1.28400E-004 1.54000E-004 0.00000E+000

GateTime14=1.73200E-004 1.54000E-004 1.92400E-004 0.00000E+000

GateTime15=2.18000E-004 1.92400E-004 2.43600E-004 0.00000E+000

GateTime16=2.75600E-004 2.43600E-004 3.07600E-004 0.00000E+000

GateTime17=3.46000E-004 3.07600E-004 3.84400E-004 0.00000E+000

GateTime18=4.38800E-004 3.84400E-004 4.93200E-004 0.00000E+000

GateTime19=5.60400E-004 4.93200E-004 6.27600E-004 0.00000E+000

GateTime20=7.07600E-004 6.27600E-004 7.87600E-004 0.00000E+000

GateTime21=8.80400E-004 7.87600E-004 9.73200E-004 0.00000E+000

GateTime22=1.08200E-003 9.73200E-004 1.19080E-003 0.00000E+000

GateTime23=1.32520E-003 1.19080E-003 1.45960E-003 0.00000E+000

GateTime24=1.61960E-003 1.45960E-003 1.77960E-003 0.00000E+000

GateTime25=2.06760E-003 1.77960E-003 2.35560E-003 0.00000E+000

GateTime26=2.73960E-003 2.35560E-003 3.12360E-003 0.00000E+000

GateTime27=3.62280E-003 3.12360E-003 4.12200E-003 0.00000E+000

GateTime28=4.74920E-003 4.12200E-003 5.37640E-003 0.00000E+000

GateTime29=6.22120E-003 5.37640E-003 7.06600E-003 0.00000E+000

GateTime30=8.14120E-003 7.06600E-003 9.21640E-003 0.00000E+000

/____

[Vehicle]

GNSSX=0

GNSSY=0

GNSSZ=0

GNSSExists=1

AltimeterX=0

AltimeterY=0

AltimeterZ=0

AltimeterExists=1

InclinometerX=0

InclinometerY=0

InclinometerZ=0

InclinometerExists=1

Propulsion=propTractor

GNSSAntennaFixture=0

TransmitterLoopFixture=0

ReceiverLoop1Fixture=0

ReceiverLoop2Fixture=0

ReceiverLoop3Fixture=0

TractorFixedX=7.5

TractorSteerX=11.5

TractorTowBallX=6.5

TrailerX=0.5

Wheelbase=4

WheelTrack=1.5

SlingLength=30

SlingTilt=0

PhotoFilename=NoPhotoAvailable.jpg

/____

[WaveformTx1]

WaveformFilename=No_Filename_selected

WaveformPointsDigitized=5

drivenRamp=2.1E-5

WaveformPoint01= -0.1000000 0.0000000

WaveformPoint02= -0.0985000 0.7000000

WaveformPoint03= -0.0965000 1.0000000

WaveformPoint04= 0.0000000 1.0000000

WaveformPoint05= 0.0000210 0.0000000

/____

[Chn01]

RowID=Z

Description=Dummy Channel Description

RxCoilNumber=1

ReceiverPolarizationXYZ=Z

TransmitterMoment=Single

TxNumber=1

AtoDConvGain=100

GateTimeShift=0

GateFactor=1

SystemResponseConvolution=0

RemoveInitialGates=12

PrimaryFieldDampingFactor=0.3

UniformDataSTD=0.05

MeaTimeDelay=0

SignPattern=1 -1

NoGates=30

overridingFullWaveformRepFreq=25

FrontGatetime=-1

TiBLowPassFilter=-1 1

drivenAarhusTxApproximateCurrent=1

/____

[Chn02]

RowID=X

Description=Dummy Channel Description

RxCoilNumber=2

ReceiverPolarizationXYZ=Z

TransmitterMoment=Single

TxNumber=1

AtoDConvGain=100

GateTimeShift=0

GateFactor=1

SystemResponseConvolution=0

RemoveInitialGates=12

PrimaryFieldDampingFactor=0.3

UniformDataSTD=0.05

MeaTimeDelay=0

SignPattern=1 -1

NoGates=30

overridingFullWaveformRepFreq=25

FrontGatetime=-1

TiBLowPassFilter=-1 1

drivenAarhusTxApproximateCurrent=1

TDC FORMAT SECTIONS AND KEYWORDS – FULL LIST

The ConfigurationVariables.pas unit interface and is the internal variables is the definitive updated version of the sections and keywords and can be viewed in a text editor.

Here is a full list of the TDC format keywords defined as of December 2022. The User interface gives controlled access to almost all of these. Internal variables listed are not always the same as keywords – this is most so in cases where variables are stored as text lists converted, when read, to arrays. The full list below reveals possibilities not included in the sample file above. To find other possibilities – make up a configuration in TEM Configurator and save it as either TDC or extended GEX. This will reveal any keywords and structure you do not already know. In order to extend GEX format some complex structure decisions had to be made.

[ALL] SECTION

Master:Boolean /Indicates if tamper recognition is invoked.

MasterTamperCheckCRC:UInt32 /A code that detects tampering.

ParentConfigFile:String /Filename

Description:String /A description of the whole file.

DataType: GroundTEM, or other /String

GateNoForPowerLineMonitor:Integer

CalculateRawDataSTD:Integer

FrontGateDelay:Double

LinkTxApproximateCurrenttoTxAmps:Boolean /If data is normalized this link will need to be false.

NumAcqChn: Integer /Number of acquisition channels

NumRx: Integer /Number of receivers

NumTx: Integer /Number of Transmitter (moments)

[TX#] SECTIONS

MomentID: Single, LM, HM, or Other / - note that this is not a direct correlation with Channel[#].TransmitterMoment as that is a string (in case users enter non recognised identifiers).

Name: String;

TimebaseNumber: integer; //assumed equal to TxNumber for now - this means duplicating in some cases - added here in case useful for future compatibility

LoopSides: Integer;

LoopType: Integer; /Typically 72 but for waveform modelling in Aarhus Workbench it is 73 – see Aarhus documentation.

TXLoopPoint#: //Loop vertices. These may be XY and use Z from TxCoilPosition or may be XYZ.

Turns: Integer;

Damping: Double;

LPFilterOrderandCutoff: Array[0..1] of Double;

FlyingLeadLength: Double;

Area: Double;

CentroidX: Double;

CentroidY: Double;

CentroidZ:Double;

EquivalentSquareLoopSide: Double;

Volts, VoltsMin, VoltsMax: Double;

Amps, AmpsMin, AmpsMax: Double;

ConstantVoltsOrAmps: Boolean; /Specifies if Tx holds voltage constant or holds current constant as loop resistance changes due to temperature.

Power: Double;

Resistance: Double;

MomentNIA: Double;

RelayA: Boolean; /Transmitter connects loops via relay A

RelayB: Boolean; /Transmitter connects loops via relay B

AxisOrient: Char; /Z, X or Y

AxisTilt: Double; /Perturbation of orientation – spherical coords.

AxisRotation: Double; /Perturbation of orientation – spherical coords.

[RX#] Sections

CentroidX: Double;

CentroidY: Double;

CentroidZ: Double;

Name: String;

Orientation: String;

AreaSingleTurn: Double;

Turns: Integer;

PreAmpGain: Double;

AreaNumTurnsxPreAmpxSingleTurn: Double;

FilterHz: Double;

FilterOrder: Double;

DampingOhms: Double;

DefaultGain: Double;

AxisTilt: Double;

AxisRotation: Double;

PreBinAppliedRxDelay: Double;

IsCircle:Boolean;

IsRectangle:Boolean;

EquivRadius: Double;

XSideLength: Double;

YSideLength: Double;

Loopsides: Integer;

NodeX: Array[0..99] of Double;

NodeY: Array[0..99] of Double;

NodeZ: Array[0..99] of Double;

[TIMEBASE#] SECTIONS

TimeGateFileName: String;

AnalDigConvSamplingRate: Integer;

PreBinAppliedSamplingDelay: Double;

PowerlineBaseFrequency: Integer;

FullWaveformRepetitionFrequency: Double;

drivenWaveformPeriod:Double;

drivenWaveformOffOnDuration:Double;

drivenNumGatesUsed: Integer;

NumGatesInSet: Integer;

FullWaveformStacks: Integer;

drivenSamplingTime: Double;

GateSetName: String;

drivenGateStart: Array[0..255] of Double;

GateCentre: Array[0..255] of Double;

drivenGateEnd: Array[0..255] of Double;

GateWidth: Array[0..255] of Double;

[TXWAVEFORM#] SECTIONS

WaveformFilename: String;

WaveformPointsDigitized: Integer;

drivenRamp: Double;

WaveformPointTimes: Array[0..63] of Double;

WaveformPointAmplitudes: Array[0..63] of Double;

[VEHICLE] SECTION

GNSSX: Double;

GNSSY: Double;

GNSSZ: Double;

GNSSExists: Boolean;

GNSS2X: Double;

GNSS2Y: Double;

GNSS2Z: Double;

GNSS2Exists: Boolean;

DifferentialGNSSX:Double;

DifferentialGNSSY:Double;

DifferentialGNSSZ:Double;

DifferentialGNSSExists:Boolean;

DifferentialGNSS2X:Double;

DifferentialGNSS2Y:Double;

DifferentialGNSS2Z:Double;

DifferentialGNSS2Exists:Boolean;

AltimeterX:Double;

AltimeterY:Double;

AltimeterZ:Double;

AltimeterExists: Boolean;

Altimeter2X:Double;

Altimeter2Y:Double;

Altimeter2Z:Double;

Altimeter2Exists: Boolean;

InclinometerX:Double;

InclinometerY:Double;

InclinometerZ:Double;

InclinometerExists: Boolean;

Inclinometer2X:Double;

Inclinometer2Y:Double;

Inclinometer2Z:Double;

Inclinometer2Exists: Boolean;

SonarX: Double;

SonarY: Double;

SonarZ: Double;

SonarExists: Boolean;

Propulsion:TPropulsion;

GNSSAntennaFixture:Integer;

GNSSAntenna2Fixture:Integer;

TransmitterLoopFixture:Integer;

ReceiverLoop1Fixture:Integer;

ReceiverLoop2Fixture:Integer;

ReceiverLoop3Fixture:Integer;

TractorFixedX:Double;

TractorSteerX:Double;

TractorTowBallX:Double;

TrailerX:Double;

WheelBase:Double;

WheelTrack :Double;

SlingLength: Double;

SlingTilt: Double;

PhotoFilename:String;

[SYSRESP#] SECTIONS

Note this section remains in draft at time of writing and may change

SysRespExists: Boolean;

SysRespApplied:Double;

DecayConst: Double;

OscillFreq: Double;

OscillDamp: Double;

InitMagn: Double;

SelfInd: Double;

LowPass: Double;

FieldDataFilename: String;

FwdModelLayers: Integer;

LayerThicknesses: Array[0..16] of Double;

LayerResistivities: Array[0..16] of Double;

drivenLayerBottomDepths: Array[0..16] of Double; //Operational variable not stored in INI files - depth of bottom layer is arbitrary

FieldAmplitudes: Array[0..255] of Double; //training dataset averaged to one sounding

ModelAmplitudes: Array[0..255] of Double; //Forward Model using specified layered model

SysRespAmplitudes: Array[0..255] of Double; //Final system response selected using the analysis available

[CHN#] SECTIONS

RowID:String;

Description:String;

RxCoilNumber:Integer;

ReceiverPolarizationXYZ:String;

TransmitterMoment:String; //not directly comparible with Tx[#].MomentID which is of enumerated type TMomentID

TxNumber:integer; //TxNumber = 0 for Noise in which case TransmitterMoment will be 'Noise'.

DefaultGain:Double;

GateTimeShift:Double;

GateFactor:Double;

SystemResponseConvolution:Integer;

RemoveInitialGates:Integer;

RemoveGatesFrom:Integer;

PrimaryFieldDampingFactor:Double;

UniformDataSTD:Double;

MeaTimeDelay:Double;

SignPattern:Array of Integer;

NoGates:Integer;

overridingFullWaveformRepFreq:Double;

FrontGateExists :Boolean;

FrontGatetime:Double;

TiBLowPassFilter:array[0..1] of Double;

TxApproximateCurrent:Double;

GateConstantsExist:Boolean;

GateFactorsExist:Boolean;

GateSTDsExist:Boolean;

GateConstants:Array of Double;

GateFactors:Array of Double;

GateSTDs:Array of Double;

AARHUSINV64 TEM FILES

Many of the variables listed also map to AarhusInv64.exe *.TEM and *.FWD file variables. Unlike GEX and TDC files however, they also include data, each for a single sounding. On rare occasions, including forward modelling, there is reason to convert from GEX or TDC files to these filetypes directly without using Aarhus Workbench. Behind the scenes, forward modelling within the System Response analysis form of TEMConfigurator is one such occasion.

As of 2024, these *.TEM files are not INI files but rather are old Fortran style lists of space and <CR><LF> separated values so all keywords are absent. Values are only identifiable by their sequence in the file and that sequence is dependent on those values which makes reading the files hard and maintenance of compatibility to any changes to the file format very hard.

The AarhusInv *.TEM files have one special characteristic in that they allow data for each gate in a sounding to be sourced with a different filter and transmitter waveform.

COMPARING GEX AND TDC FORMATS:

Aarhus GEX format and AgTEM TDC format are both Windows INI formats with KEYWORD=VALUE pairs within sections with section headers. Both are read by keyword such that unwanted information is ignored and any order of presentation is accepted. Most GEX and TDC keywords are the same, as of 2022, so Aarhus Workbench documents can be relied upon to describe the keywords.

TDC format has sections [Tx1] and [Tx2] for Default (Low moment normally) and Auxiliary (High moment normally) transmitters. In contrast, GEX format just has one [General] section with keywords for both. Because of this, it needs generic transmitter keywords, high moment keywords, and low moment keywords as well as complex search algorithms to verify which keywords to look for. Further GEX format has no tally keywords for number of time gates or waveform points such that a computer must read until none more are found to determine, retrospectively, how many there are. Further, numeric suffixes mixed into text can have variable numbers of digits, so a simple search is not adequate.

GEX TO TDC:

GEX files can be thoroughly converted to TDC files as of 2022.

Forward compatibility cannot be confirmed.

TDC TO GEX:

TDC files can be converted to GEX files but because GEX files do not have separate transmitter sections, essential [Tx1] variables go in [General] while others go in [Transmitter1] and essential [Tx2] values go in [General], where possible, and otherwise in a [Transmitter2] section not read by Aarhus Workbench. No more than two transmitters are possible, and they must share coordinates and be horizontal loops.

GEX Keys Explanation:

Many difficult to understand GEX variables are described in the documents at

http://www.ags-cloud.dk/Wiki/W_GeometryFileFormat

Of challenge are LM HM nomenclature optionally substituted with unspecified moment Keywords. Also challenging are timing variables – There is nothing simple about these and a good job of explaining them has been made in the Timing document.

These conventions are used where possible to facilitate modelling using Aarhus Workbench.

X: Centroid in direction of travel

Y: Centroid transverse right to direction of travel

Z: Centroid vertically down – The centroid is however defined in the plane perpendicular to the axis of orientation – the third co-ordinate is just for establishing a reference plane and should be the average of coords of points perpendicular to the plane.

Orientation: Orientation Z (positive down) or X (travel direction) or Y (transverse).

Some Aarhus Workbench parameters are difficult to understand due to legacy structure of that format.

TiB_Low_Pass_FilterHz is listed under the acquisition channel but it is actually the transmitter filter applied with the receiver in that Acquistition Channel. TiB stands for Transmitter in a Box.

TiBLPFilterOrderDamping and Low_Pass_Filter_Order are for the order of the filter, or damping for gaussian filters or -1 for no filter.

Receiver orientations in GEX format are delivered under [Channel#] sections.

TDC AND GEX DATA STRUCTURES COMPARED

The table below presents the INI format Section names for both TDC format and GEX format and explains what they contain and how they are used.

TDC Section	TDC Range	TDC Description	GEX Section	GEX Range	GEX Description
All	Unique	Count variables that make access to other keys easy. General parameters.	**None**	Missing	GEX defines no count variables – all keywords of multiple optional formats ‘’, ’LM’, & ’HM’ must be discovered and counted to read the file.
Chn#	1 to NumAcqChn	Acquistion Channels. Transmitter number and receiver number, and system response number are all referenced from here.	**Channel#**	Must count	Acquisition Channels – must search for and count sections Receiver Coil Number Receiver orientation Transmitter Moment – optional Transmitter filter characteristics
Rx#	1 to NumRx	All receiver coil/loop parameters	**General,** **Channel#**	Must count – all together in General section.	Receiver parameters have number suffixes on General section keys except Orientation which is in the Channel# with corresponding RxCoilNumber.

TDC Section	TDC Range	TDC Description	GEX Section	GEX Range	GEX Description
					LP filter characteristics of the receiver coils are in the General section – must physically search for and count them.
Tx#	1 to NumTx	All transmitter loop and moment parameters. Timebase number and Waveform number are referenced from here.	**General,** **Channel#**	'','LM','HM'	Transmitter Loop Definitions – must search for different versions to determine how many and how they are defined. Filter characteristics are listed under the Channel# with corresponding moment identifier.
Vehicle	Unique	Vehicle and positioning parameters other than transmitter and receiver positions	**General**	Unique	Device Positions – must physically search for and count them
Timebase#	1 to NumTx	Timebase parameters for each transmitter (moment)	**General**	'','LM','HM'	Gate Time Definitions - must search for different versions (unspecified, LM or HM) to determine how many and how they are defined.
TxWaveform#	1 to NumTx	Transmitter waveforms of each transmitter (moment)	**General**	'','LM','HM'	Waveform Definitions – must search for different versions (unspecified, LM or HM) to determine how many and how they are defined.
SysResp#	1 to NumAcqChn	System response documentation for each acquisition channel.	**Separate Files**	Out of scope	GEX files do not store System Response information
All	Unique	Front Gate Delay	**General**	Unique	Front Gate Delay
All	Unique	Power line monitor description	**General**	Unique	Power line monitor description
All	Unique	Various General variables	**General**	Unique	Various General variables

TDC Section	TDC Range	TDC Description	GEX Section	GEX Range	GEX Description
/	Unique	/Comment lines are ignored. In-line comments adjacent to variables are moved to the next line	/	Unique	/Comment lines are ignored. In-line comments adjacent to variables are moved to the next line
			GEX EXTENSION		These remaining sections and variables are not recognised by Aarhus Workbench as of 2022 but do permit further definition and flexibility within the GEX restrictions.
			General	Together	Additional Count variables – redundant to the Aarhus Workbench GEX parser.
			RxCoil#	1 to NumRx	Receiver variables not listed in standard GEX format
			Transmitter#	1 to NumTx	Transmitter variables not listed in standard GEX format
			Timebase#	1 to NumTx	Timebase variables not listed in standard GEX format
			TxWaveform#	T to NumTx	TxWaveform variables not listed in standard GEX format
			SysResp#	1 to NumAcqChn	System response variables not listed in standard GEX format

TIMING WITH AGTEM OR TERRATEM COMPARED WITH AARHUS INSTRUMENTS TTEM OR SKYTEM

Shifts may be applied prior to logarithmic binning or just documented for later modelling

AgTEM and TerraTEM both permit shifting of sampled data before it is logarithmically binned. We have 'PreBinAppliedSamplingDelay' for both the timebases and for the receivers to document and manage such shifting. It is usually conducted pre-binning in cases of pre-amplifier delays, Low Pass filter delays and synchronization delays. If low pass filters are to be modelled in Aarhus Workbench then it does not make sense to hide them from Aarhus Workbench by applying them pre-binning. Workbench will ignore these shifts.

Aarhus Instruments such as tTEM and SkyTEM record binned data according to the Transmitter ramp top trigger time, without most shifts, such that most shifts needed to correct data in modelling must be applied to the data retrospectively. Their shift options are complicated – it is important to read their documentation on the matters before attempting modelling with Aarhus Workbench. The MeaTimeDelay is applied pre logarithmic binning but only to the high moment data.

Aarhus have what they call a 'Front Gate' which requires lots of shifts and adjustments. It is not the first gate but rather a relay that leaves the receiver loop disconnected until after a period of time to reduce problems with pickup of high magnitude primary field. If there is no front gate then 'FrontGateDelay' is obviously 0.

'GateTimeShift' is for accommodating non-modelled shifts in processing. If pre-amplifier and synchronization delays were not removed pre logarithmic binning then use this shift to hide them from Aarhus Workbench modelling algorithms.

TEM Configurator Timebase form provides calculations and a timeline suitable for observing the sense of corrections made by adjusting the many shift variables.

ADVANTAGES AND DISADVANTAGES

GEX files have the advantage that they work in Aarhus Workbench and perhaps that they are the minimum that is required for tTEM and SkyTEM data processing. Aarhus have taken great care to ensure that only essential information is stored and stored only once in most cases to avoid confusion derived from choice of duplicates.

Other than that, perhaps GEX, and our extension of GEX, has no other advantages.

TDC format has the following Advantages:

- Separate identity to GEX suitable for future development of independent forward compatibility. It is good to maintain support of GEX and TDC but GEX is managed independently beyond our control.
- Extensible to multiple Transmitters, receivers, and Transmitter Orientations.
- Clean distinction of parameters into automatically managed sections.
- Receiver, transmitter, and Acquisition parameters are not mixed in sections.
- Keyword lists do not need counting.
- Complex conditional unspecified/LM/HM read and write routines are not necessary.
- Can index transmitter numbers to/from unspecified/LM/HM nomenclature to actual transmitter numbers.
- One file is designed for both acquisition and processing stages of metadata management.

TDC AND GEX COMPATIBILITY

Each format, as of 2022, uses common keywords where sensible but section headers are all deliberately different. This means both formats can co-exist in a single file.

DIFFERENCES

GEX places most transmitter and receiver parameters in a 'General' section and distinguishes with use of unspecified/LM/HM distinguisher suffixes on Keys combined with either single digit or double digit numeric suffixes.

Tabular GEX parameters must be counted by a search as there are no additional keywords that exist for the number of items in the lists. This avoids complexity and possibility of over-definition but is probably one shortcut that is fraught with danger.

CONFLICTING STRUCTURES AND PARAMETER GROUPING

There are a few parameters stored in GEX Channel sections that really should belong to transmitters or receivers, yet Channel sections are not unique for a particular transmitter or receiver. For this reason, we have had to implement some multiply defined variables and a hierarchy of overrides and linkages to manage the over-definition. This is almost by definition, confusing, yet unavoidable. It is due to a legacy of expansion of old formats to accomplish more than they were originally intended to accomplish.

For the receiver – there is the Channel[#].ReceiverPolarizationXYZ variable which we apply in Channel sections which overrides and links to Receiver[#].orientation.

For the transmitter, there is the TiBLowPassFilter variable which we store as a transmitter variable but also store override versions in Channel sections.

Also for the transmitter there is the RepFreq – again stored as a transmitter variable but also stored as an override version in Channel sections.

Most front gate variables are owned only by Channel[#] sections.

Also for the transmitter, there is 'Amps' that we store yet in GEX Channel sections there is 'TxApproximateCurrent' which overrides Transmitter[#].Amps. Aarhus Workbench uses TxApproximateCurrent as a filter – any current deviating by more than 10% results in record rejection so it needs to be right or you get an empty dataset. Because data is typically current normalized, it may need to be a real value for raw datafiles and '1' for files submitted to Aarhus Workbench. Tx current should not be stored under the Channel section as it is a Transmitter variable and this creates a mess – a mess manageable only with mapping and indexing and acceptance of non-uniqueness of Tx Current for a particular Tx. I have introduced another boolean variable 'LinkTxApproximateCurrentToTxAmps' to disable the link to Tx[#].Amps particularly for cases where either AcqChn[#].TxApproximateCurrent is not needed or where data is normalized to 1 Amp for output. In this case use Tx[#].Amps as actual current and AcqChn[#].TxApproximateCurrent as output file Amps = 1 after normalization. With the option of adjusting loop voltage iteratively during acquisition Tx[#].Amps does not need to be approximate however data files also typically have Amps data for every record.

GEX adopts only two transmitter moments, both with the same horizontal-only transmitter loop. The first is '' if singular or LM if dual combined with the second which is HM. TDC format can accommodate many transmitters so we have had to develop a linked duality of transmitter definitions in order to keep ability to write to GEX format. In an extended GEX format we can accommodate multiple transmitters but this extension is yet to be approved by Aarhus GeoSoftware (Dec 2022). The '','LM','HM' nomenclature is indexed to our transmitter numbers by link variables both ways. Such nomenclature can be considered as transmitter aliases. In TEM Configurator, The 'Single'/'LM'/'HM' aliases act as slaves to 'TxNum' so changing AcqChn[#].TransmitterMoment will be subservient to any entry in AcqChn[#].TxNumber should the two conflict. This is the most complicated compatibility measure needed to extend GEX and convert to/from TDC. As GEX files do not specify AcqChn[#].TxNumber it must be determined by searching through [Channel#] sections for TransmitterMoment entries and sequentially allocating TxNumbers.

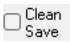
Additional grouping and sections could have been developed grouping variables for Acquisition cycles but it has been decided to force ownership of Acquisition cycles to Transmitter[#] sections. For instance, one cycle could have stored data with one repetition frequency then another with a different repetition frequency. In the TDC format this must be done by duplicating the Tx[#] section while in the GEX format it could be done with Channel[#].RepFreq yet this leaves no instruction on how the system is to group acquisition channels with transmitters and receivers into acquisition cycles. It works at the processing stage but is inadequate at the acquisition stage.

MAPPING AND INDEXING

From acquisition perspective metadata needs to be indexed and mapped differently than from a processing perspective.

For instance, in acquisition the instrument needs to know what receivers and acquisition channels are used with each transmitter while from a processing perspective software needs to interrogate what transmitter and receiver were used with each acquisition channel. TEM Configurator and TDC attempt to facilitate the former directly without need for running of unnecessary algorithms. In the code there are matrices and variable that map from Acquisition Channels to Transmitters and Receivers and back again. There are also transmitter Alias mapping variables.

FILE COMMENTS MANAGMENT

TDC and GEX files permit comments in files following the ‘/’ character. Keyword=Value readers do not however segregate comments appended to values. For this reason, TEM Configurator moves such comments to the next line in the files. Generic INI file readers do not manage positions or perpetuation of existence of comment lines so their positions may become separated from the data to which they were initially adjacent. Comments will be lost if a save is executed using the ‘clean save’ option: 

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