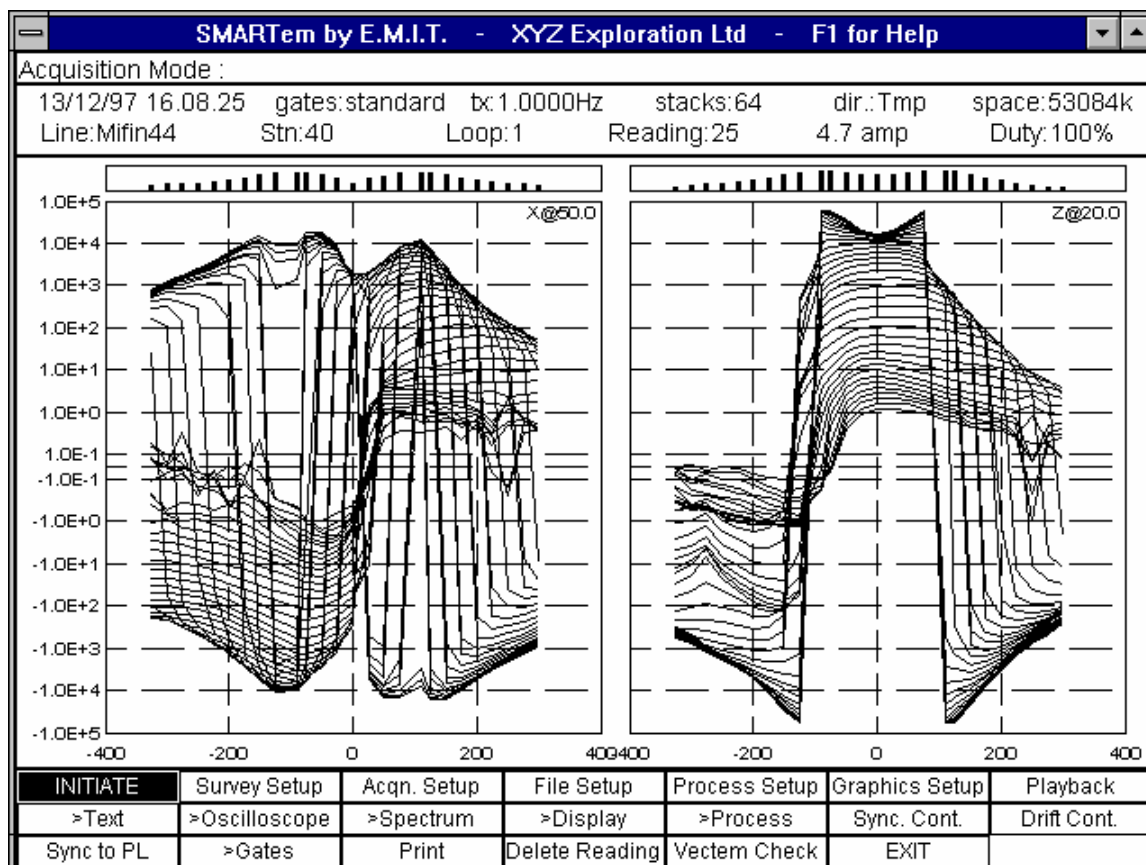


ElectroMagnetic Imaging Technology

SMARTem Electrical Methods Receiver System



USER DOCUMENTATION

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NOTE

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Introduction

SMARTem is new electrical methods receiver system designed around a purpose-built, ruggedised, weatherproof, dustproof Pentium PC. It is a completely programmable instrument that can acquire, record, process and display TEM data under software control using Zonge, Geonics and other transmitters. A full VGA resolution LCD screen is used in the display and analysis of electrical methods data.

A complete SMARTem system unit (including Transmitter Controller instrument) allows data collection in a direct trigger mode and a synchronised (remote transmitter) mode. SMARTem achieves high signal-to-noise ratios by virtue of rapid sampling of receiver voltages and novel digital signal processing techniques implemented in its control software. Unique techniques for the treatment of power transmission line, atmospheric, VLF transmitter and other interference have been developed to significantly attenuate noise with no deleterious effects on signals.

SMARTem was developed by ElectroMagnetic Imaging Technology (Perth, Western Australia) commencing 1995. It has been designed as a platform for the routine acquisition of surface, borehole and underground TEM data in fixed and moving loop formats. However, as a result of the programmable nature of its amplifiers, filters, analogue-to-digital converters, timing circuitry, processing algorithms and data storage formats, SMARTem can assist in the research and development of new electrical geophysical data acquisition and processing techniques. SMARTem can be configured quickly by the manufacturer to proprietary specifications.

The operations of the SMARTem receiver instrument are controlled by a Windows program. Aside from standard geophysical data acquisition functions, it functions as an 8 channel spectrum analyser and digital storage oscilloscope to aid in the assessment of signals and interference.

Synchronisation of crystal oscillators in the receiver and transmitter controller is carried out within software. This procedure takes several minutes to complete and no manual tuning of either crystal is required. Drift between the two crystals is presented to the user, at the touch of a button, in units of milliseconds. The VGA screen built-in to the SMARTem receiver instrument is used to display raw and processed electrical methods data in transient and profile formats and allows the instrument to function as a spectrum analyser and oscilloscope for the analysis of signal and noise.

The SMARTem data acquisition hardware consists of programmable boards which handle the amplification, analogue filtering and analogue-to-digital conversion functions. In total, eight signal channels are available. The gains, anti-alias filter corner frequencies, sampling rate and number of channels are completely under software control.

PC-compatible timing circuitry was developed specifically for the SMARTem instrument. It consists of a plug-in board which incorporates a low-drift oven-controlled crystal oscillator. The same type of oscillator resides also in the transmitter controller. The programmable timing circuitry allows the base frequency and sampling rate employed by the SMARTem system to be user chosen. A wide range of base frequencies is possible and the base frequency is finely tunable.

A range of purpose-designed digital signal processing tools is built into the SMARTem control software. These tools allow the SMARTem to operate effectively in environments where any other receiver would have problems performing well. Intelligent stacking and windowing filters assist with the removal of coherent interference such as that from power transmission lines and VLF communications stations (eg North-West Cape, W.A.). In addition, for the removal of power transmission line interference, SMARTem is capable of tuning its base frequency to exactly reject this coherent interference.

SMARTem can window (or “gate”) transients to emulate other TEM receivers and offers a standard windowing protocol that does not vary with base frequency, making modeling simpler. SIROTEM and Zonge receivers can be simply emulated. Data can be recorded in raw (unstacked time series), stacked or windowed formats. On-line help screens allow the user to get helpful information on any SMARTem function or mode.

Technical Specifications

Host Computer

- Pentium 400 MHz low power processor with 128 MBytes RAM
- 40 GByte hard disk
- AT-Compatible QWERTY membrane keyboard
- Graphics: monochrome LCD screen VGA 640x480 pixels
- Printer port and 2 serial ports (1 external)
- Sealed with internal fans

Acquisition Hardware

- A/D converter: 16 bit with staggered sampling on 8 channels
- All 8 signal paths are differential
- Sampling Frequency: user-selectable up to a total throughput of 100 kHz
- Number of Channels: 8 @ 10kHz sampling or 4 @ 25kHz sampling
- Receiver Bandwidth: programmable
- Anti-Alias Filter: 8 channel 8 pole linear phase
- Amplifier Gain: programmable 1-800
- Input Impedance: 2.0 M Ω each side to ground
- Maximum Input Signal Measured: +/-3V (gain=1)

Physical

- Weight (including internal battery): approx 12 kg
- Dimensions: 500mm x 330mm x 235mm
- Operating Temperature: nominally -10°C - 50°C
- Connectors:
 - 8 x 4mm banana socket pairs for input analogue signals
 - 2 x 4mm banana sockets for analogue and chassis ground
 - synchronization/serial/trigger cable connector (19 pin female)
 - external battery and charger connector (3 pin male)

Timing Circuitry

- Oven-controlled 10 MHz crystal oscillator
- Programmable base frequency controls for Zonge, Geonics and other transmitter systems
- Programmable sampling rate controls for A/D converter

Power Supply

- Internal rechargeable battery pack – lasts approximately 12 hours
- External user-supplied 12-24V DC battery

Transmitter Controller

- Oven-controlled 10 MHz crystal oscillator
- Programmable base frequency controls to Zonge, Geonics and other transmitter systems
- Internal rechargeable battery pack – lasts approximately 30 hours
- Dimensions: 260mm x 205mm x 150mm
- Weight: approx 5.0 kg
- Connectors:
 - synchronisation cable connector (19 pin female)
 - external battery and charge connector (3 pin male)

Battery Chargers (2 Supplied per full system)

28V DC supplies

Physical Layout

The SMARTem receiver and transmitter controller (refer later) are both built into aluminium cases. Access to the keypad, screen and most other functions of the SMARTem receiver computer is gained by opening the case which is locked by 2 clasps at the front of the case.

Once open, the front panel gives access to the computer functionality of the SMARTem receiver. Two separate power circuits are used in the SMARTem V receiver and transmitter controller. The main power circuit provides power to the computer in both instruments. The “sync” power circuit provides power to warm-up the precision crystal oscillator in both instruments. The “sync” power need only be enabled if the equipment is being used to do a survey requiring synchronization. The power switches for the computer (“Power”) and the precision crystal oscillators (“Sync”) are located at the top right of the front panel. These switches need to be held down for approximately 1 second to switch on or off. A green LED (labeled “On”) above the Power button on the receiver and controller indicates whether the main power is on. Yellow LEDs on both units labeled “Sync/Standby” indicate whether power to the precision timing crystals is enabled. When first switched on the yellow LEDs flash to show that power is flowing to warm-up the oscillators. Only when a crystal synchronization operation has been done do these yellow LEDs become continuously illuminated.

Repeating: the sync power is only required for surveys with synchronization. It is not required for surveys in which a transmitter is triggered directly from the receiver.

Also in the vicinity of the power switches on both the receiver and transmitter controller are LEDs labeled “Charge” and “Lockout”. The red “Lockout” LED is illuminated after the receiver and transmitter controller have been synchronized. The red “Charge” LED is illuminated during charging. It is continuously illuminated during internal battery charging and flashes when charging is complete.

Refer to the sections of this document on synchronization and battery charging for more details.

Also on the front panel of the receiver are the connectors for printer (1x 25 pin D connector), external monitor (15 pin high density D connector) and external keyboard ports. A mousepad is at the bottom right of the front panel. Left and right mouse buttons are provided, however the simplest way to “click” the mouse buttons is to tap the mousepad. A tap on the lighter coloured area of the pad is

equivalent to a left click and a tap on the darker area of the pad is equivalent to a right click.

The green “Disk” LED on the front panel of the receiver indicates hard disk access. The front panel of the receiver contains the LCD VGA screen and screen contrast and brightness knobs. On the front panel of both the receiver and transmitter controller are red LEDs labeled Transmit “-“ and “+” to indicate phasing of the transmitter. These LEDs are active when acquiring data.

The left side panel of the receiver incorporates the signal input terminals - 8 pairs of banana sockets (positive is the red socket at the top of each pair). These are labeled “1” to “8”. Two further banana sockets provide access to analog and chassis grounds for the instrument. The “Sync/Tx/Serial” has several jobs including carrying the signals for synchronization to the transmitter controller (if required), triggering of a local transmitter and a serial port. It is a 19 pin female bayonet military connector. The supplied sync cable should be used for synchronisation. Supplied trigger cables should be used for transmitter triggering. The other large military connector on this panel is labeled “Power/Charge” and is used for charging the internal battery and for the (perhaps rare) use of an external battery. It is a 3 pin male bayonet military connector. Charging and external battery connection should be done with the supplied cables.

The SMARTem receiver and transmitter controller are “smart” enough to make a smooth transition between internal and external battery power. There is no need to switch off the instrument prior to plugging in or unplugging an external battery.

A dongle is present in the receiver computer to ensure the security of the SMARTem software.

The front panel of the SMARTem transmitter controller is exposed by opening the 2 clasps locking the lid. The controller is powered, like the receiver, either by an internal rechargeable battery pack (which should have a life of around 30 hours) or by an external 12-24V battery connected with the supplied battery cable.

There are 4 keys on the transmitter controller's front panel to allow the user to interact with the software running on the transmitter controller. The SMARTem transmitter controller is actually a 386 PC running a DOS operating system. A 2 line LCD screen displays to the user the operating parameters of the transmitter controller. Normally the user will not need to do anything other than switch the transmitter controller on. In surveys where no synchronization is required, the transmitter controller is not required at all. The SMARTem receiver can trigger the transmitter directly and this is often a more satisfactory arrangement.

As per the receiver, the power switches for the main and sync power circuits are at the top right of the front panel.

Refer to the section of this manual on the transmitter controller for more details of the operation of this instrument.

Software Summary

The SMARTem V receiver computer uses the Windows 98 operating system. The software for acquiring, displaying and processing SMARTem data is all contained in the SMARTem directory.

The operator must be careful not to delete any of the system software when making space on the hard disk of the SMARTem receiver computer. The user can delete SMARTem data files (raw, stacked or windowed) from the hard disk to make space (presumably after they have been archived) if required. It is appropriate for the SMARTem operator to make a backup of all the SMARTem system software on the hard disk.

Important files in the C:\SMARTemV directory are the following:

<i>smartem.exe</i>	SMARTem executable for Windows
<i>*.opt</i>	SMARTem options settings
<i>smartem.hlp</i>	SMARTem help file
<i>siroerly.stw</i>	Early time SIROTEM window file
<i>sirohirs.stw</i>	High res SIROTEM window file
<i>sirostnd.stw</i>	Standard SIROTEM window file
<i>sirocomp.stw</i>	Composite SIROTEM window file
<i>standard.stw</i>	Standard SMARTem window file
<i>sync.log</i>	Log of controller sync and drift operations
<i>zong0062.stw</i>	Zonge 0.0625 Hz window file
<i>zong0125.stw</i>	Zonge 0.125 Hz window file
<i>zong025.stw</i>	Zonge 0.25 Hz window file
<i>zong05.stw</i>	Zonge 0.5 Hz window file
<i>zong1.stw</i>	Zonge 1 Hz window file
<i>zong2.stw</i>	Zonge 2 Hz window file
<i>zong4.stw</i>	Zonge 4 Hz window file

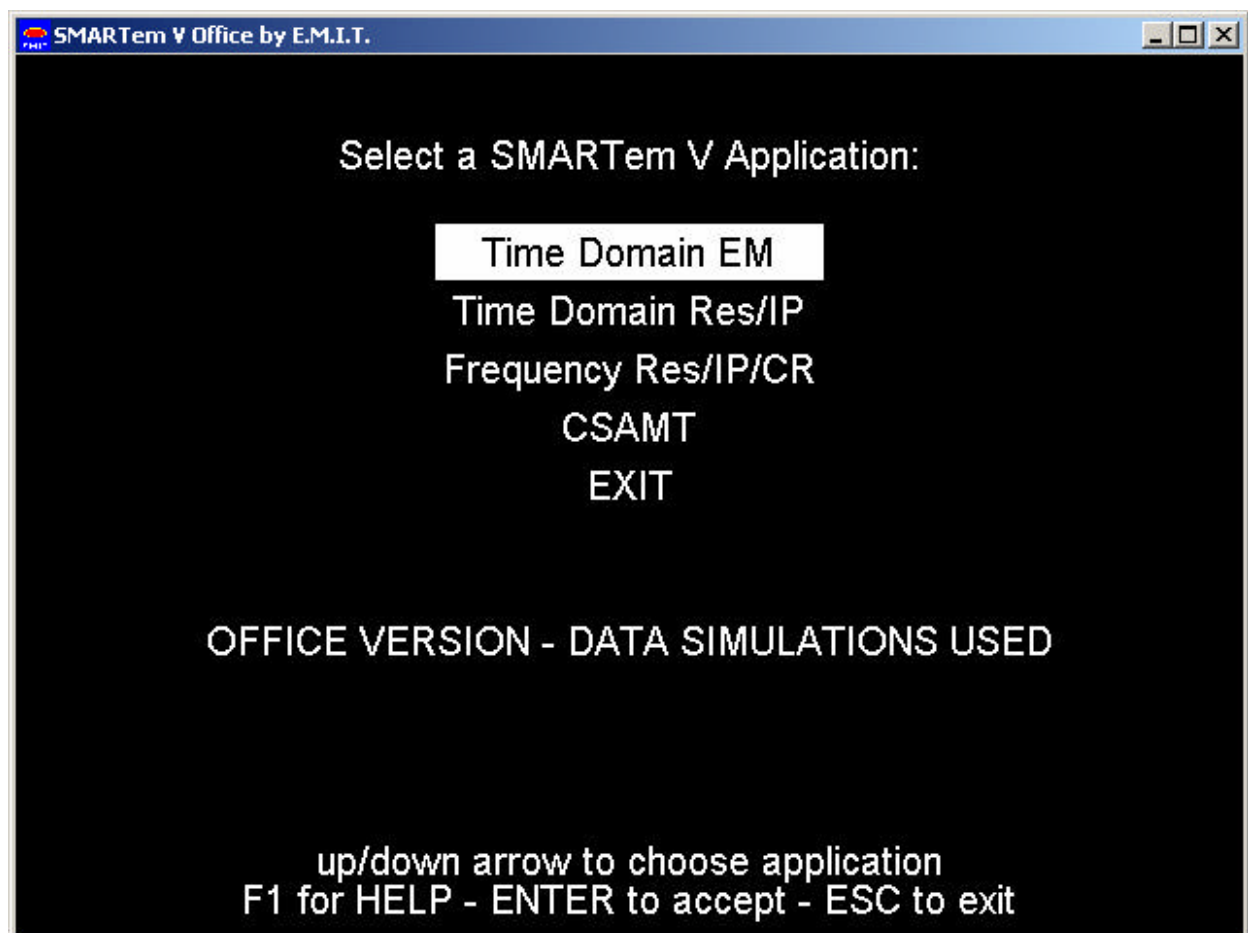
The smartem.exe program runs only under Microsoft Windows 98. It can be initiated from Windows 98 by double clicking on the SMARTem icon (or hitting the return key when the SMARTem icon is highlighted).

The C:\SMARTem files with extension “.stw” are SMARTem windowing files - they contain the start and end window times for various windowing configurations. They allow SMARTem to emulate SIROTEM and Zonge TEM systems. These files should not be edited. The *smartem.opt* file saves all the settings of the SMARTem receiver - it too should not be edited unless the user is familiar with this

operation. The *sync.log* file contains a log of all the times at which a synchronisation operation was carried out and the times at which a drift measurement was made (refer to section in this manual on synchronisation of the receiver and transmitter controller).

It is assumed that the user is reasonably familiar with the basics of the Microsoft Windows 98 operating system. If not, it would be useful to become familiar with techniques for swapping windows, opening and closing windows and swapping programs. Original SMARTem systems were designed to be used without a mouse - most Windows functions (including those in the SMARTem software) can be invoked without a mouse.

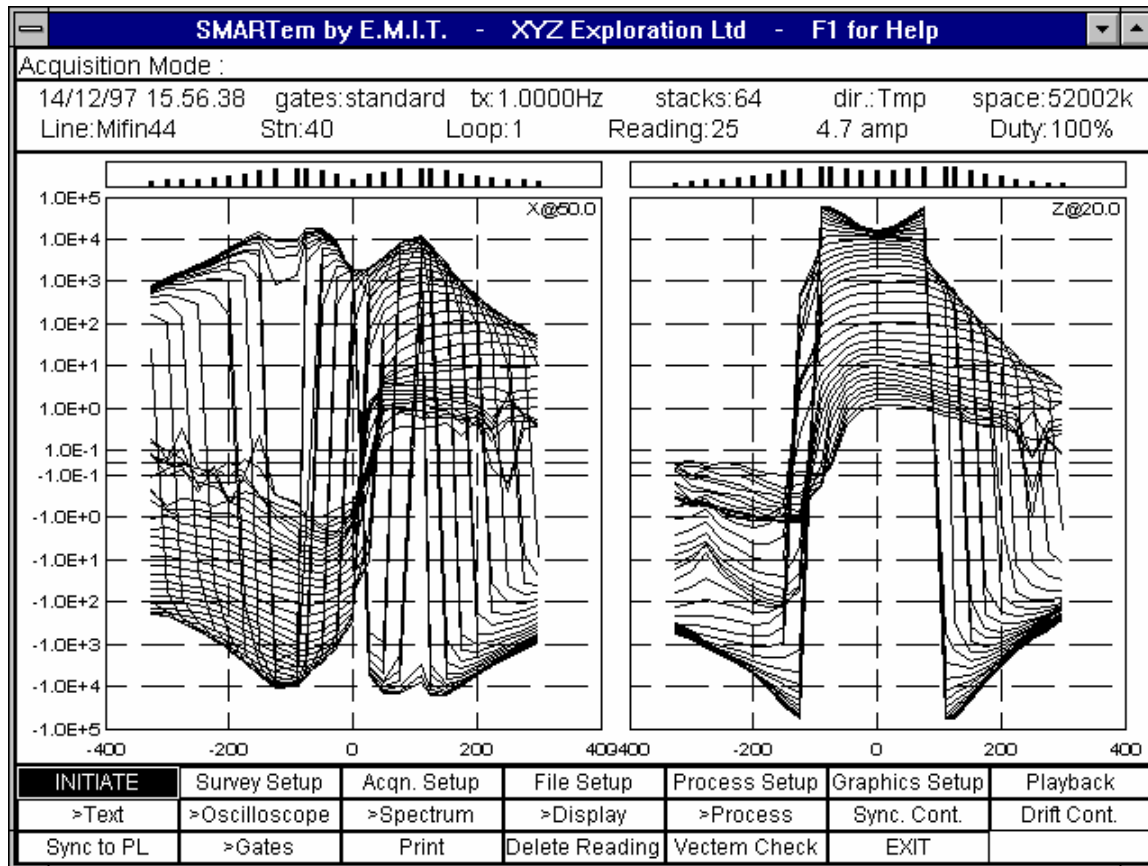
The operator is presented with a screen similar to the following when starting the SMARTem program:



This screen allows the user to select the SMARTem V application to be used in the session. At time of writing, only the first 3 options are available, software for CSAMT has not been written.

The following discussion mainly concerns the setting up of the TEM software, the first option in the above screen. Other applications are similar, however.

The following screen is an example of the type of display in the Acquisition Mode of the TEM software. This type of screen is presented to the operator on entry to the TEM application.



This is a typical screen from the SMARTem software. In this case the screen is showing data for the current survey line, on which 2 components are being collected.

There are eight modes of operation. Each has a similar feel. In each mode, the screen is divided into four areas as follows. 1) The largest area (central) is reserved for graphic display of SMARTem time series, transients or profiles. 2) Underneath this are several rows of buttons for initiating functions, changing modes, setting options etc. The highlight button can be moved with the arrow keys to select the desired function. The <F1> key gives help on each button. 3) One row of text at the top of the screen gives the operator messages and gives the name of the mode currently invoked (when the program is started it is always in Acquisition Mode). 4) Immediately underneath the message area are several rows of text giving information about the current settings of the instrument.

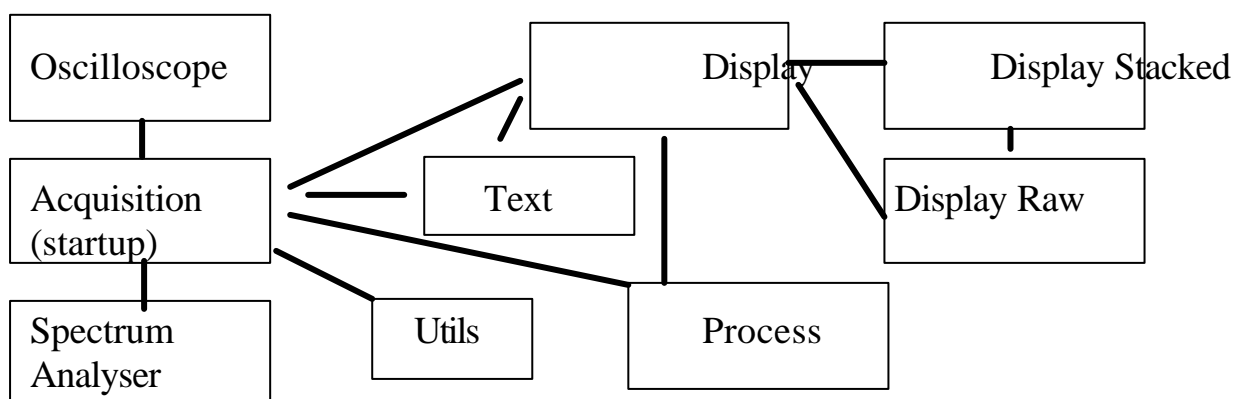
The SMARTem software incorporates several data entry forms of the following format:

Base Frequency (Hz)	2.0833333
Sampling Rate (Hz)	37878.788
Stacks	64
Clocks	normal
Channel 1	X
Channel 2	Z
Channel 3	UNUSED
Channel 4	UNUSED
Gain Channel 1	50.000000
Gain Channel 2	20.000000
Gain Channel 3	5.000000
Gain Channel 4	10.000000
Gain Setting	Automatic
Duty Cycle	100
Triggering	Local
Bandwidth	User_Set
Vectem/BH43 Port	COM1

up/down arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

These data entry forms can be easily navigated with the up and down arrow keys. Move the highlighted bar to the setting required and then adjust it either with the PgUp and PgDn keys or type in a new value. When finished hit return to accept all the new information in the form or <ESC> to reject it. The <F1> key pops up a help screen on each item in the form.

The nine **modes** of operation of the SMARTem software are represented in the diagram below:



As indicated, the SMARTem software starts up in Acquisition mode, which is the mode from which all data is collected. The function of the nine modes can be described as follows:

Mode	Function
Acquisition	Acquire data, display and print it, modify acq. parameters
Oscilloscope	Use SMARTem receiver as an oscilloscope
Spectrum Analyser	Use SMARTem receiver as a spectrum analyzer
Utils	Various utilities including synchronization, playback and battery capacity
Text	Display and print decay or spectrum voltages in text form
Display	Display and print existing data files
Display Stacked	Display and print existing stacked data files
Display Raw	Display and print existing raw time series files
Process	Reprocess and print existing data files

Setting up for a Survey

The following short checklist of tasks should be carried out prior to a SMARTem survey:

- Read this manual
- Charge the batteries in the receiver and transmitter controller – charge lights flash at the completion of a charge cycle. Fully charging a discharged battery pack in the receiver or transmitter controller will take 4-6 hours.
- Charge any external battery(ies) required for the survey. No external batteries should be required for the receiver instruments unless they surveys will be lengthy.
- Occasionally it may be necessary to carry out Widows house-keeping tasks such as defragmenting the hard disk and carry out routine tasks such as setting the computers own clock (it is used to time-tag the SMARTem measurements).
- Ensure that there is enough disk space to collect the data required for the survey. Don't delete any system software in haste to make some space on the hard disk.
- Take all required power and signal cables. Don't forget the synchronisation cable and the transmitter trigger cable.
- Ensure that the SMARTem receiver does not receive rough handling, especially when it is powered ON.
- Organise the survey procedure so that the receiver antenna is 5 metres or more from the SMARTem receiver.

If the transmitter controller will be used for the survey, it is suggested that the crystals in the SMARTem transmitter controller and SMARTem receiver are turned on at least one hour prior to the crystal synchronisation operation. In addition, the main power for the SMARTem receiver and transmitter controller should be turned on at least 10 minutes prior to the synchronisation operation, to allow temperatures inside the instrument cases to stabilise somewhat.

If the controller is not required for the survey then the crystal in the receiver does not require powering on.

Powering the crystal on and off frequently must be avoided. This affects the useful lifetime of the crystals. It is appropriate to leave the crystals ON all day once they are switched ON. For extended surveys over more than one day requiring synchronization, leave the crystal (sync) power on for the whole job. The internal batteries in receiver and transmitter controller will require charging each evening. There is no need to switch crystals off to change transmitter base frequencies or for any other reason whilst carrying out a survey.

Allowing the internal battery in the receiver or controller to run completely flat should be avoided. This is also true for the external battery supplying power to the receiver computer. Don't let batteries run flat. The receiver and controller both provide an indication on their displays of the remaining capacity of their internal batteries.

The crystals in the receiver and transmitter controller can be synchronised (if required) after a warm-up period of one hour, or less if necessary. Refer to the sections in this manual on the synchronisation of receiver and transmitter controller and the general operation of the SMARTem transmitter controller.

After crystals are synchronised, both the main and sync power to the SMARTem receiver and transmitter controller must remain on for synchronisation to exist. The sync power circuit allows the crystals to stay warm and stable but this power circuit does not enable synchronization. The sync power circuit maintains the ovens of the accurate crystal oscillators at a stable temperature and does not use much power. Main power to the receiver and transmitter controller can be switched off to save battery life if no data is being collected for an extended period, for example overnight. The instruments can be recharged while they are being used to collect data but the internal batteries will not be charged at the same rate as they would with the instruments switched off. If only sync power is on there is only a small current draw and charging can proceed fairly rapidly.

The polarity of the signals being measured should be understood prior to undertaking a large survey. Consistency is important from one measurement to the next.

Having completed any synchronisation and other tasks, the SMARTem software should be configured for your particular survey. Once all configuration options have been set, they will be saved so that they need not be entered again, even after powering off the SMARTem receiver computer.

Prior to carrying out synchronization, the transmitter frequency should be set – this is done in the Timing Setup screen – see below.

Setting up for TEM

To fully set up SMARTem for a survey, there are 6 screens of parameters that can be set. They are accessed through the 2nd through 7th buttons at the base of the Acquisition mode screen. The 6 screens are the Survey Setup, Timing Setup,

Chan Setup, File Setup, Proc Setup and Graphics Setup screens. All parameters are saved for future use after they are set.

Hit <return> while the Survey Setup button is highlighted to display the Survey Setup form:

Station Name (numeric)	1000	change with " [" or "] "
Transmitter Current	10.000000	
Loop Number	1	
Line Name (max 8 chars)	1000	
Survey Type	Coinc.Loop	
Loop Side	10	
Operator Name	Fred	
Auto Station Increment	10.000000	
Collar Easting	0.000000	
Collar Northing	0.000000	
Collar Elevation	0.000000	
Current Monitor (V per A)	0.040000	

up/down arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

Acquisition Mode - Survey Setup form

There are several parameters to set. Many of the parameters are set for house-keeping only and don't have an effect on the operation of the receiver. This data entry form is the one used most commonly during a survey, as the user will frequently change the station name, and perhaps the loop number and transmitter current. When changes are complete, hit <enter> to accept them or <ESC> to disregard them - then you will be taken back to the main Acquisition mode screen.

Some of the parameters allow you to type in a new value and some only allow changes to be made from an established list by using the PgUp and PgDn keys.

Station Name is used in the tagging, sorting and plotting of data. For borehole surveys this value should be the depth down-hole.

Transmitter Current is used in the normalization of TEM data. It is written to the data file also.

Loop Number is a means of separating data from different runs or loops. At any one time, only the data from the given loop will be displayed. Data from all loops will be written to the same data file.

Line Name controls the name of the data file. For TEM, the name of the processed output data file is [Line Name].dat

Survey Type can be chosen from a range of options which include borehole types. If doing a 3-component TEM survey the appropriate Survey Type must be chosen. The Survey Type parameter can be set to Fixed_Loop, Borehole, BH43, BH43-3D, Vectem_A, Vectem, Slingram, In_Loop or Coinc.Loop. In most cases this parameter does not change the functionality of the receiver, however when set to BH43, BH43-3D, Vectem or Vectem_A the SMARTem software invokes routines to communicate with the Vectem or Geonics BH43-3D borehole logging systems. In the BH43-3D and Vectem modes the SMARTem acquisition software automatically collects 3 components of borehole TEM response, reads the rotation of the probe and rotates cross-hole components to a standard set of coordinates.

Loop Side is written to the data file and is not used for any other function.

Operator Name is written to the data file.

Auto Station Increment is the amount by which the Station Name is incremented when the “[” and “]” keys are pressed. The auto station increment function saves the operator having to enter long names for stations.

Collar Easting, Northing & Elevation are written to the data file for borehole surveys.

Current Monitor (V per A) is the conversion factor (in volts per amp) applied to measurements of transmitter current (if required) to convert them from volts to amps.

The next setup screen is the Timing Setup screen.

There are 8 parameters to set in this data entry screen. The Base Frequency for the system is at the top of the list. A range of commonly used base frequencies can be accessed by using the PgUp and PgDn keys - these base frequencies are chosen to reject 50 Hz (and higher harmonics) power transmission line radiation.

Parameter	Value
Base Frequency (Hz)	12.500000
Sampling Rate (Hz)	100000.000
Stacks	512
Duty Cycle	50
Transmitter Type	ZT-20
Tx Continuous?	NO
Auto Stacks?	NO
Local Powerlines	50-Hz

up/down arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

Acquisition Mode - Timing Setup form

The most appropriate Base Frequency options for removal of power transmission line interference (at 50 Hz) are those that satisfy:

$$\text{Base Frequency} = 50 / n \quad n = \text{even whole number}$$

Examples of these Base Frequencies are 1.0 Hz and 2.0833 Hz. The worst Base Frequencies to use are those that satisfy $\text{Base Frequency} = 50/n$ where n is an odd number - an example is 2.0 Hz - this is a very poor Base Frequency to use where power transmission lines are present. Only base frequencies that reject 50 Hz will be allowed.

The Sampling Rate (2nd in list) chosen should be, as a rough guide, somewhere between 25 kHz and 40 kHz for conventional TEM. This parameter can be changed with the PgUp and PgDn keys as with the Base Frequency. A default Sampling Rate of 25 kHz is adopted but the sampling rate can be set as high as 100 kHz if only one channel is activated.

The Stacks parameter sets the total number of transients used in a reading. Typically one might use around 128 stacks, or perhaps higher if a high base frequency (eg 12.5 Hz) was employed. This number does not have to be a power of 2 but these numbers are used for convenience. The user may type in a number here. The total duration of the data acquisition can be calculated by the following expression:

$$\text{duration of acquisition (sec)} = \text{Stacks} / (2 \times \text{Base Frequency})$$

For a Base Frequency of 2.083 Hz, 128 stacks will require approximately 30 seconds to acquire.

The Duty Cycle option sets whether the system operates at 50% or 100% duty cycle. Operation at 50% duty cycle is standard for TEM. Operation at 100% duty cycle means that the transmitter never switches off and simply switches from one polarity to the other with no off-time. Normally, Duty Cycle should be set to 50, but (refer later) operation at 100% can have advantages, especially for battery-powered transmitters.

The Transmitter Type parameter selects between possible types of transmitter unit. The main choice is between Zonge and Geonics transmitters. There is no difference in operation amongst the different Zonge transmitter options.

The Tx Continuous? parameter can be set to YES or NO. If YES then, if the transmitter is being triggered directly from the receiver, the transmitter will run continuously. If NO then, if the transmitter is being triggered directly from the receiver, the transmitter will only be activated when a reading is being taken or the receiver is put into Oscilloscope mode. In general, battery powered transmitter systems should use NO and generator powered transmitter systems should use YES. Consult the manual for your transmitter equipment if you are unsure whether it should be operated continuously or not.

If Auto Stacks? is set to YES then the Stacks parameter will change with any alteration to base frequency in order that the acquisition time for the new frequency will be about the same as for the old frequency. This is a rarely used option and it defaults to NO.

Local Powerlines is very important. It controls the range of Base Frequencies available. In regions with 50 Hz power transmission lines (Australia, Africa) set this to “50-Hz”. In regions with 60 Hz power transmission lines, set this to “60-Hz”.

The next form is the Chan Setup form.

	Channel Name	Gain Setting	Gain
Channel 1	Z	AUTO	20.00
Channel 2	Z	MAN	20.00
Channel 3	OFF		
Channel 4	OFF		
Channel 5	OFF		
Channel 6	OFF		
Channel 7	OFF		
Channel 8	OFF		

up/down/left/right arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

Acquisition Mode – Chan Setup form.

This form lets the operator turn on/off the 8 channels of the receiver. It also allows the gain setting method (either AUTO or MANUAL) to be established and allows the gain to be set. Gains set to AUTO will be able to change at the start of a reading under control of the software. Gains set to MANUAL will remain at the value that is set in the “Gain” column.

Navigate around this screen using the arrow keys and then use the PgUp and PgDn keys to set values. When turning channels on and off a clicking noise will be heard from the receiver. This is the sound of electric relays enabling or disabling the channel circuitry.

Channel Names can be set to any 1 or 2 letter name by typing it in. Normally the PgUp/PgDn keys are used for this and the name of the channel would be something simple like “Z”, “X” or “Y”. To turn off a channel, cycle through the list of names with PgUp/PgDn until “OFF” is displayed.

There are no restrictions on which channels are ON or OFF. Channels may be skipped. For example, channels 1 and 3 could be enabled for a 2 channel survey,

with 2 and 4 UNUSED. If sample rates are too high for the number of channels ON then a message will appear saying that and it will advise of the highest possible sample rate for that channel selection. Two channels may have the same name, however it is advisable to name each channel differently for simplicity of the data set.

When the Gain Setting parameter is set to AUTO then SMARTem sets the gains of the enabled channels individually upon initiation of every reading - gains are set so that all samples on the measured waveform are within the $\pm 3V$ range of the filters and A/D converters. That is, there is no saturation of any of the waveform.

To use manual gain setting it is useful to estimate signal size with an oscilloscope display. Remember that the largest signals output by the amplifier stage are $\pm 3V$. Thus the largest non-clipping signals at the input to the system are of magnitude $(3.0 / \text{gain})$ on each channel.

The next setup screen is the File Setup screen.

This screen sets the file handling aspects of the SMARTem software. The first two parameters set what type of data files (other than fully processed data) should be written. Raw data files are bulky (typically several megabytes in size) to store but do allow the luxury of reprocessing raw data and playing back raw data at a later time. Stacked files are much less bulky and do allow most reprocessing options (all except sferic filtering). SMARTem windowed data files are always recorded - the operator has no choice in this matter. SMARTem windowed data files (always written with the extension ".dat") are used by the SMARTem software in the display and analysis of data.

The Folder for Data option sets the name of the directory in which all data will be stored. Raw files are written in the folder RAW underneath the Folder for Data and stacked files are written in the folder STACKED underneath the Folder for Data. All SMARTem windowed data files and WMC format files (refer below) are written to the Folder for Data. If a drive other than C: is configured on the receiver then it can be used to store SMARTem data. For example, if Folder for Data is set to D:\OREBODY then this folder on the D: drive will be used. If folders are not present when data collection is initiated then they will be created.

Parameter	Value
Record Raw Data Files	NO
Record Stacked Data Files	YES
Folder for Data	C:\DATA
Active Coordinate	East
Record WMC Format Files	NO
WMC Cost Code (4 dig)	9999

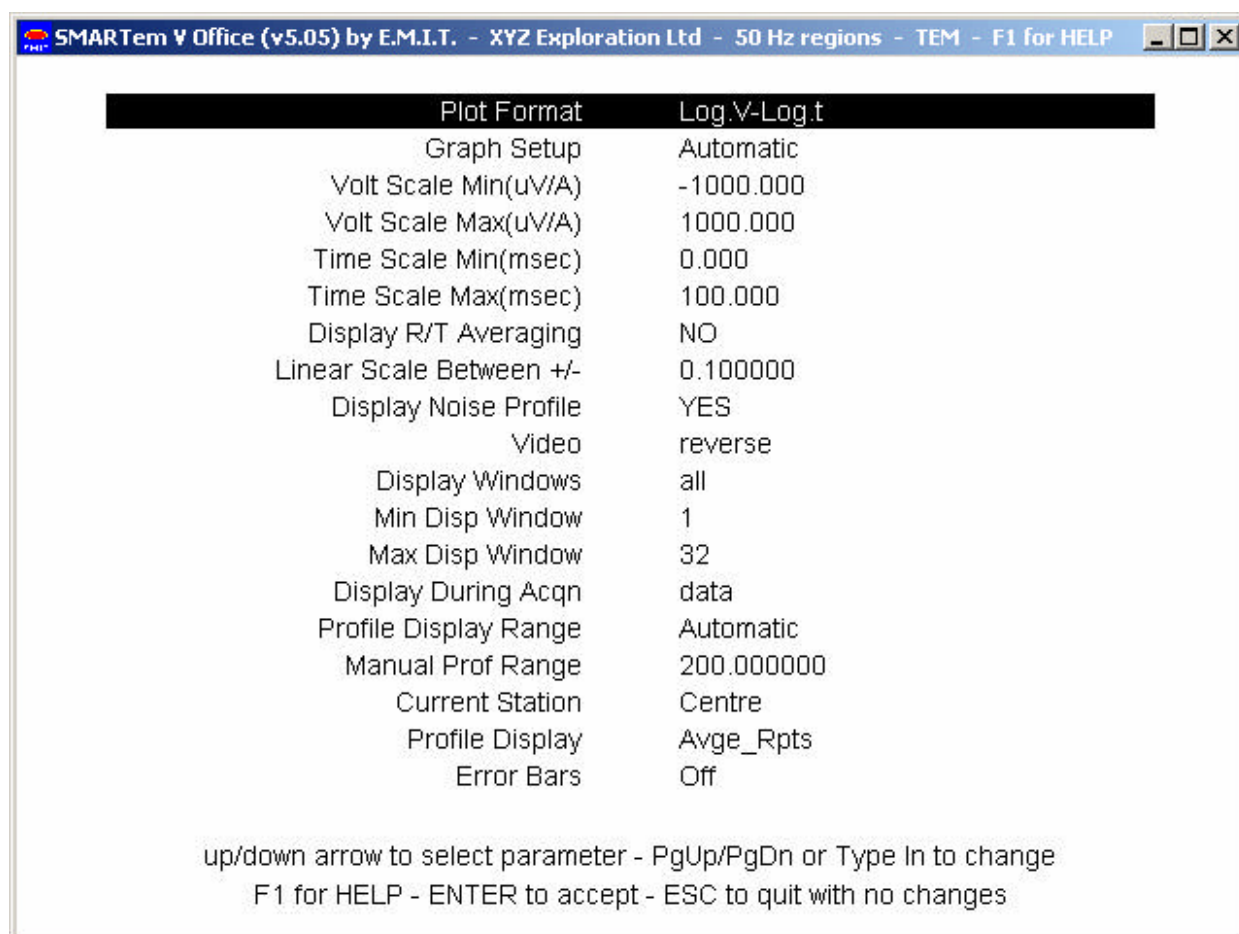
up/down arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

Acquisition Mode - File Setup Screen

The last 3 options in this form are a legacy from an older version of SMARTem system. It is not anticipated that they will be used. WMC format files (extension “.wmc”) are small in size and do not take up much disk space. They are not used by the SMARTem software. WMC format files can be generated later from SMARTem windowed data files. The WMC Cost Code is written to WMC format files.

The Process Setup screen is very important for data acquisition. It is the next setup screen to be configured. The processing options are dealt with in the next section.

The Graphics Setup screen sets parameters that affect the way data is displayed.



Acquisition Mode - Graphics Setup Screen

The first option, Graph Format, sets whether processed data is displayed as a profile or a single transient. For profile display, a log or linear vertical axis can be chosen. For transient display, a log-log, log-linear or linear-linear plot can be chosen. The scaling of the axes can be done automatically (Graph Setup = Automatic) or manually (Graph Setup = Manual). If Graph Setup is chosen to be Manual then the next 4 parameters are used to set bounds on the horizontal and vertical axes (unless a profile display is chosen, in which case the horizontal axis is scaled independently of these 4 parameters).

The Display R/T Averaging (or Display Real-Time Averaging) parameter is used during the recording of SMARTem data. If it is set to YES, then an averaged (ie partially stacked) waveform is displayed during recording; if NO then raw data is displayed during recording. Refer to the section in this manual on collecting data. The LINEAR SCALE BETWEEN +/- parameter sets where a linear scale is applied in logarithmic presentations that cross the zero axis. This is conventionally set to 1.0 uV/A but may be set to other values (eg 0.1 uV/A or 0.01 uV/A) to enhance resolution of small signals near zero.

The Display Noise Profile parameter enables or disables a noise profile plot at the top of a profile display. Noise at each reading is displayed in a logarithmic sense by a small vertical bar. The next option changes the Video from normal (white lines on black background) to reverse (black lines on a white background). It may be useful to experiment with this parameter under different lighting conditions.

The Display Windows parameter can be set to “SOME” (manual) or “ALL” (automatic). When it is set to SOME, the range of channels to display is read from the Min Disp Window and Max Disp Window options. When ALL is selected, all windows are displayed, regardless of the values of the Min Disp Window and Max Disp Window parameters. These options allow the user to control which parts of the decay are displayed in transient and profile modes. A typical application would be to remove very early time windows from a profile in which a late time anomaly is to be emphasised.

The Display During Acqn parameter in the above menu can be set to “SCOPE” or “DATA”. When set to SCOPE, the software gives an oscilloscope presentation during acquisition and processing of data. If set to DATA, during acquisition the screen displays the current data set in the same format (profile or transient) as it would be displayed when SMARTem is not acquiring and processing. This allows the operator to view data collected thus far while collecting new data. Messages at the top of the screen alert the operator to the status of the acquisition and processing operations as before.

The Profile Display Range parameter can be set to “MANUAL” or “AUTOMATIC”. When AUTOMATIC, the whole profile from the selected data file is displayed. When MANUAL, the range of values displayed is a function of the Manual Prof Range and the Current Station parameters.

The Manual Prof Range parameter sets the total length of the profile in “Manual” scaling mode. The actual displayed profile may be slightly longer due to rounding to make the profile length a whole number of tick intervals. The Current Station parameter affects how the profile is displayed: when equal to “LEFT”, the current station is plotted at the left of the picture; when “CENTRE”, the current station (or data point) is plotted at the centre of the picture; and so on.

In Acquisition mode the current data point is the one that has just been acquired or about to be acquired. It is listed at the lower right hand corner of the screen and it is set in the Survey Setup menu - Station Name. To view a section of the profile not near the current data point, just change the Station Name - there is no need to acquire data at that point - no changes will be made to the data file - simply change the Station Name back to your current location before collecting further data.

If using the Manual Profile Display Range option during data acquisition, you would typically set Current Station as follows:

<u>Activity</u>	<u>Current Station setting</u>
Traversing with increasing station location	Right
Traversing with decreasing station location	Left
Infilling	Centre

In Display and Processing modes, the current data point is listed at the bottom right hand corner of the screen. The point at the left hand end of the profile is always selected immediately after a file is loaded. The location nominated as the current point can be changed easily in the Graphics Setup menu - Station Name parameter.

The second last parameter in the Graphics Setup screen is called Profile Display. This parameter can be set to Avge_Rpts (average repeats) or Last_Rpt (last repeat). When set to Avge_Rpts all measurement repeats are averaged in a profile presentation of data. When set to Last_Rpt only the latest measurements at a station are used in a profile presentation.

Finally, the Error Bars parameter allows the plotting of error bars on profile presentations. If multiple repeats have been taken at a single station then the error bar shows the maximum and minimum value for each delay time.

Signal Processing Options

In Acquisition mode and Process mode, the operator has access to a number of signal processing options which change the way that data is processed. It is worth gaining a reasonable understanding of these options so that optimal quality data can be generated in the quickest time. Some processing stages are somewhat time-consuming, others do little to increase the time of a measurement.

Following is the Process Setup screen from Acquisition mode:

Window Scheme	standard
SMART Stacking	ON
SMART Windowing	ON
Tuned Windows	OFF
Sferic Filter	OFF
Sferic Filter Threshold (mV)	20.000000
Ramp Time (msec)	0.200000
Ant.Delay (msec)	0.040000
PED Digital Filter	OFF
# PED Harmonics	1

up/down arrow to select parameter - PgUp/PgDn or Type In to change
F1 for HELP - ENTER to accept - ESC to quit with no changes

Acquisition Mode - Process Setup Screen

Windowing Algorithms

Windowing of stacked transients is basically the last in the series of signal processing operations that is carried out on the SMARTem TEM data. The user has several choices here via the Window Scheme parameter. The default is “STANDARD”. This is a basic windowing scheme that allows windows (or gates) out to very late times and very early times. In addition, windowing schemes from Zonge and SIROTEM instruments have been programmed into the SMARTem. There are four SIROTEM windowing schemes - standard, high resolution, composite and early time. The STANDARD window scheme uses the same window times for all base frequencies, as do SIROTEM schemes. This is not the case with Zonge windowing schemes. The STANDARD scheme is the default and is recommended.

In addition to the Window Scheme parameter, the user can further modify windowing procedures with the Smart Windowing and Tuned Windows parameters. When Smart Windowing is enabled, window filters have a slightly tapered shape instead of the normal box-car shape. This taper gives the windows an enhanced level of immunity to high frequency interference such as from the North-West Cape VLF communications station. The taper adjusts the pass band of the window filter. The tapering is applied without significantly modifying the start or end time of the window. In survey areas where VLF is a problem, always use Smart Windows. In most cases there is no reason not to use them.

Tuned Windows allow the windows to participate in selective filtering of noise sources. With this parameter the user can choose to make windows an optimal length to remove a) power transmission line or b) PED signals. Thus there are 3 choices for this parameter: OFF, POWERLINE or PED. If enabled, the window widths are adjusted slightly to attenuate the chosen interference. Only windows of sufficient width are modified and the modifications are subtle enough so there is no significant change to the start or end time of the window.

Whilst on the subject of windowing, it is worth summarising the timing relationships employed in windowing operations in SMARTem, SIROTEM and Zonge TEM receivers. For the SMARTem and SIROTEM instruments, a window time is defined by its delay after the *end* of the transmitter ramp. For Zonge TEM receiver systems, a window time is defined by its delay after the *start* of the transmitter ramp.

Stacking Techniques

The stacking operation turns *raw data* (which may or may not have been treated with the Sferic Filter) into *stacked data*, thus reducing its volume significantly. Two stacking algorithms are available to the user. They are SMART and DUMB respectively. The SMART algorithm is invoked by choosing ON in the Smart Stacking option. The DUMB algorithm adds into the stack an equal contribution from all transients (this emulates all other TEM systems). The SMART algorithm uses a short taper at each end of the stack to sharpen spectral acceptance peaks at the odd harmonics of the system fundamental frequency (correspondingly increasing the attenuation of signals near even harmonics of the fundamental frequency). The SMART algorithm should be used exclusively. Power line noise, and any other narrow bandwidth, coherent interference, is removed far more effectively with the SMART algorithm. The only disadvantage of the SMART algorithm is that it takes slightly longer to carry out than the DUMB algorithm but with the higher speed processors included in later versions of the SMARTem V receivers this is not an issue.

Sferic Rejection Algorithm

The Sferic Rejection software can be turned ON or OFF in the Process Setup screen. If enabled, Sferic Rejection is the first processing operation undertaken in the processing sequence. It is carried out on the raw data and is thus somewhat time-consuming, but less so on recently produced SMARTem V systems. This filter detects perturbations from a 'best estimate' of the transient shape. Excursions larger than a user-selectable value (Sferic Filter Threshold, typically 1-5 millivolts) are identified and the rogue values are replaced by an appropriate value. This filter is not designed to remove repetitive or coherent noise - it is for spikes such as those generated by atmospheric electrical events. The envelope value should be at least as large as any coherent noise present so that the sferic rejection is not triggered by coherent noise. This filter should allow SMARTem to collect data in sferic conditions which would badly affect any other TEM receiver system.

Ramp Time and Antenna Delay

In Acquisition mode, the Process Setup screen gives the operator access to the two system parameters Ramp Time and Antenna Delay.

These parameters are important in positioning early windows accurately after the ramp down of the transmitter waveform. The Antenna Delay is typically small (of the order of 0.05 milliseconds), but the ramp time may be as large as 0.5 milliseconds or more for a large transmitter loop. There is a small delay (of the order of 50-100 microseconds) from the filters and amplifiers in SMARTem - this delay is calculated by the SMARTem software and is automatically incorporated, it is transparent to the user.

PED Filter

The PED filter can be operator-selected ON or OFF with the PED Digital Filter parameter. It was designed specially to attenuate the effects of PED (Personal Emergency Device) transmissions on TEM data sets collected in or near operating mines. Only surveys in the vicinity of active PED systems need consider using this parameter. PED signals are not particularly monochromatic (singular in frequency). The fundamental PED frequency is 374 Hz but transmissions occur over the range 362-386 Hz approximately. PED signals are not particularly sinusoidal and thus have some power at higher harmonics - notably the 3rd, 5th and 2nd. The operator can select how many (up to 4) harmonics of the PED to filter (# PED Harmonics parameter), according to the following table:

<u># PED Harmonics</u>	<u>PED Harmonic Numbers Filtered</u>
1	1
2	1,3
3	1,3,2
4	1,3,2,5

Past practice has shown that most PED damage is done to data by the lower frequency harmonics - especially the fundamental (ie harmonic number 1) which is significantly more powerful than any of the higher harmonics. Increasing the # PED Harmonics parameter results in significantly longer processing times. The processing time required for PED filtering depends on the Base Frequency also. Lower Base Frequencies result in longer processing times. While it may only take about 5 seconds to filter one PED harmonic from a single channel of 2 Hz data, it may take approximately 100 seconds to filter two PED harmonics from three channels of 1 Hz data.

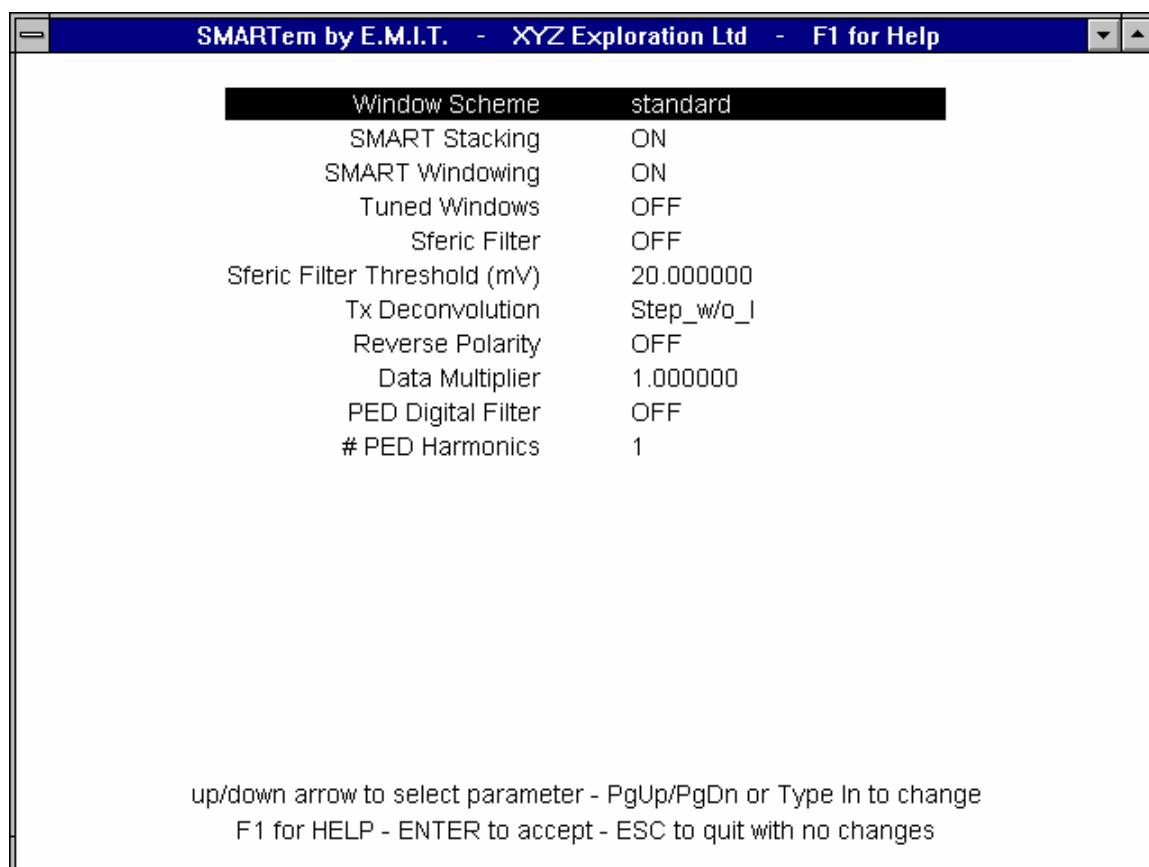
It is suggested that # PED Harmonics is set to “1” when PED signals are present - this should clean up data enough to establish the character of data sets during acquisition. Also, only use very low base frequencies if really necessary - otherwise processing time will be unnecessarily long. However, the PED filter is not designed to work at base frequencies of 8 Hz or higher. As an aside, powerline filtering will improve at higher base frequencies.

The filter works in the frequency domain on the stacked waveform - fairly late in the processing sequence - but can take a considerable amount of computer time to carry out. PED interference is notched out and the resulting gap in amplitude and phase is filled by interpolating “PED-free” signals from either side of the noisy area. Windowing techniques can also be usefully applied to PED removal. To carry out PED filtering in post-acquisition processing, only the stacked waveforms are required to be stored on disk - raw data is not required.

Special Processing Options

In addition to most of the options described above, there are several more choices that can be made when reprocessing data in Process Mode. Below is the Process Setup Screen from Process Mode. The parameters Tx Deconvolution, Reverse Polarity and Data Multiplier do not appear in the Process Setup screen for Acquisition Mode.

The Reverse Polarity function is either ON or OFF and is fairly self-explanatory. If turned ON, the data set has its polarity reversed as the final stage of its reprocessing. This allows data that has inadvertently been recorded with the wrong polarity to be corrected simply. The Data Multiplier parameter allows a scaling of data at the reprocessing stage - this may be useful if the wrong current has been entered during acquisition or if it is desired to change the units of a data set. The Tx Deconvolution operation is described in the following section.



Process Mode - Process Setup Screen

Deconvolution Operations

As part of the research into SMARTem measurements at a duty cycle of 100% (ie no off-time), a number of routines have been programmed into the standard SMARTem processing software. These routines use frequency domain decompositions (multi-radix FFT) of whole receiver waveforms to correct for the effect of variations in the on-time transmitter current and to allow analysis of data from a different perspective.

Deconvolution operations in the SMARTem processing software are enabled using the Tx Deconvolution parameter in the Process Setup screen of Process Mode. The options for this parameter are OFF, Imp.Resp (impulse response), Step_Resp. (step response) and Step_w/o_I (step response without current). These are explained below. The default setting for this parameter is OFF, indicating that no special processing be carried out. All options result in data in units of microvolts/amp. In the case of step response data, the given results are in microvolts per peak-to-peak ampere of the (effective) triangular current waveform (see below).

These special operations were designed for use with 100% duty cycle waveforms but can be used with 50% duty cycle data as well.

Operation of TEM transmitters at 100% duty cycle has some advantages. The switch in transmitter current polarity at 100% duty cycle is of a size twice that of the switch-off achieved in 50% duty cycle surveys. This causes a geological signal effectively twice that achieved in 50% duty cycle surveys, the normal mode of operation. In addition, for a given base frequency, 100% duty cycle surveys allow double the maximum delay time. The result is that the user could choose to measure out to a later delay or choose to increase the base frequency and get double the number of stacks for the same acquisition time. Either way, there is an advantage for data quality and productivity. Surveys at 100% duty cycle have the potential to collect higher quality data in a shorter time than 50% duty cycle surveys.

The presence of a time-varying transmitter current during a 100% duty cycle measurement is the major potential disadvantage of this type of survey. It has been demonstrated that transmitter current variations are almost insignificant (after a certain delay time) with battery-powered Zonge transmitter systems such as the ZT-20 and NT-20. This is not true of the generator-powered systems such as the GGT-25, which can not control transmitter current effectively enough during on-time to allow 100% duty cycle TEM surveys yet in most cases.

Operators considering 100% duty cycle surveys with battery-powered transmitters (highly recommended under most circumstances) should read the following material in conjunction with the chapter on Measuring Transmitter Current.

At a 50% duty cycle, measurements made during the off-time have no primary field “interference” from the transmitter loop. This is not the case with 100% duty cycle measurements. Experience in surveys with a Zonge NT-20 (24V battery-powered) transmitter has shown that there is a slight distortion of 100% duty cycle decays (mainly at delay times earlier than approximately 10 milliseconds) that can be seen when compared with standard 50% duty cycle decays. This distortion results from a non-flat on-time current waveform. Measurements made with a generator-powered Zonge GGT-30 transmitter have documented the significant interference affecting measurements made during the transmitter on-time at both 50% and 100% duty cycles.

Deconvolution is a process that can correct a received waveform for interference in the transmitted waveform. If the transmitted current is documented, then the effect of any abnormalities or undesired features in the transmitted current waveform on the receiver waveform can be removed in theory. This is most simply carried out

in the frequency domain by multiplication and division operations. Deconvolution functions in the SMARTem software are implemented in this way.

In addition to the correction of received waveforms for undesired features in transmitted waveforms, deconvolution operations can be simply applied to transforming received data into new formats. Transformations to *impulse response* and *step response* are incorporated in the software. Impulse response is effectively what you normally get from a 50% duty cycle survey. By transforming to impulse response, you effectively get rid of any distortions in the transmitted current waveform and it is as though a perfect square wave was transmitted. This can be used to correct for the non-flat on-time current waveforms observed in 100% duty cycle measurements.

Transformation to impulse response is carried out by setting the Tx Deconvolution parameter to Imp.Resp. This transformation requires a transmitter current waveform and there must be an entry in the .dat file being processed that corresponds to the current measurement. A current measurement should have the name “I”. Refer to the section on Measuring Transmitter Current.

Step response is not a conventional form of TEM data presentation for most TEM interpreters but is utilised in the Lamontagne Geophysics UTEM system, developed in Canada and used worldwide. Step response data has some advantages and disadvantages - most of the advantages occur when exploring for very conductive targets.

Step Response

A step response TEM system is one that shows a step-shaped primary field waveform at the receiver. UTEM uses a coil receiver antenna (dB/dt measurement as normal) but a triangular transmitter waveform. The primary field response at the dB/dt antenna is step-shaped. With impulse response systems, the primary field shape is a spike (or impulse) at the receiver antenna (dB/dt for a square transmitter waveform).

Transformation to step response is carried out by setting the Tx Deconvolution parameter to Step Resp. This transformation requires a transmitter current waveform and there must be an entry in the .dat file being processed that corresponds to the current measurement. A current measurement should have the name “I”. Refer to the section on Measuring Transmitter Current. As an alternative, setting the Tx Deconvolution parameter to Step w/o I invokes an approximate step response conversion that does not require a measurement of the transmitter current.

The best way to look at the differences between step response and impulse response measurements is to consider them in the frequency domain. A step response measurement is a time-domain equivalent of a measurement of “inphase” signal (only sensitive to targets for which a proportion of current flowing in the target is inphase with the current flowing in the transmitter). Impulse response measurements are sensitive to targets for which a proportion of the current excited in the target is *quadrature* (out of phase) with current flowing in the transmitter.

In geological terms, TEM step responses are most sensitive to moderately conductive and very conductive targets; TEM impulse responses are sensitive to resistive and moderately conductive targets. Both types of presentation cover the broad middle ground of EM target types. A target must be extremely conductive before it becomes invisible on impulse response profiles and, conversely, it would have to be quite resistive before becoming invisible on step response data. Step responses are the time integral of impulse responses.

Another advantage of step response data, when compared to impulse response, is that it emphasises the low frequency end of the spectrum. More weight is given to receiving low frequency signals than high frequency signals. For a UTEM survey, transmitter power is focused more at the low frequencies, when compared with a SIROTEM or Zonge survey using the same transmitter current and base frequency.

Step responses probably are sensitive to a wider range of targets than impulse responses but there are several reasons why they are not commonly acquired and/or considered. As a result of being sensitive to secondary currents that are inphase with the transmitter current waveform, step responses are sensitive to the primary current flowing in the transmitter loop. Without employing a technique to remove primary field interference, primary signals swamp the desired secondary signals. The primary field must be estimated from either (i) consideration of the geometry of the transmitter and receiver antennas or (ii) using the total received primary + secondary signal to estimate the primary field given what you know about the general characteristics of primary and secondary fields. Method (i) is difficult in most cases, especially if the receiver antenna is close the transmitter. Errors in geometry calculations can be enough to conceal a significant secondary field step response by primary field. Method (ii) relies on a low frequency estimate of primary field and works better with a lower base frequency. The technique employed in the SMARTem processing software to convert raw data to step response is (ii) above, but the instrument can be programmed to treat this problem in a number of ways.

In the case of a truly superconducting mineral deposit (with no disseminated halo), method (ii) above, for removing primary field, will not work. The primary and

secondary fields look exactly the same at all frequencies. In the time domain, these responses are non-decaying. To detect a superconductor with TEM, one must get the transmitter away from the target and get the receiver near it. Then calculate step response, using geometry considerations to remove primary field. The superconducting target will show up on inphase frequency domain data, assuming primary field can be removed properly.

Step responses require more sophisticated instruments to measure directly - UTEM triangle waveform transmitters are substantially more complex than a standard square wave transmitter. BUT, it is quite simple to calculate step responses from impulse responses if a reasonable amount of information is collected about the system and the secondary field.

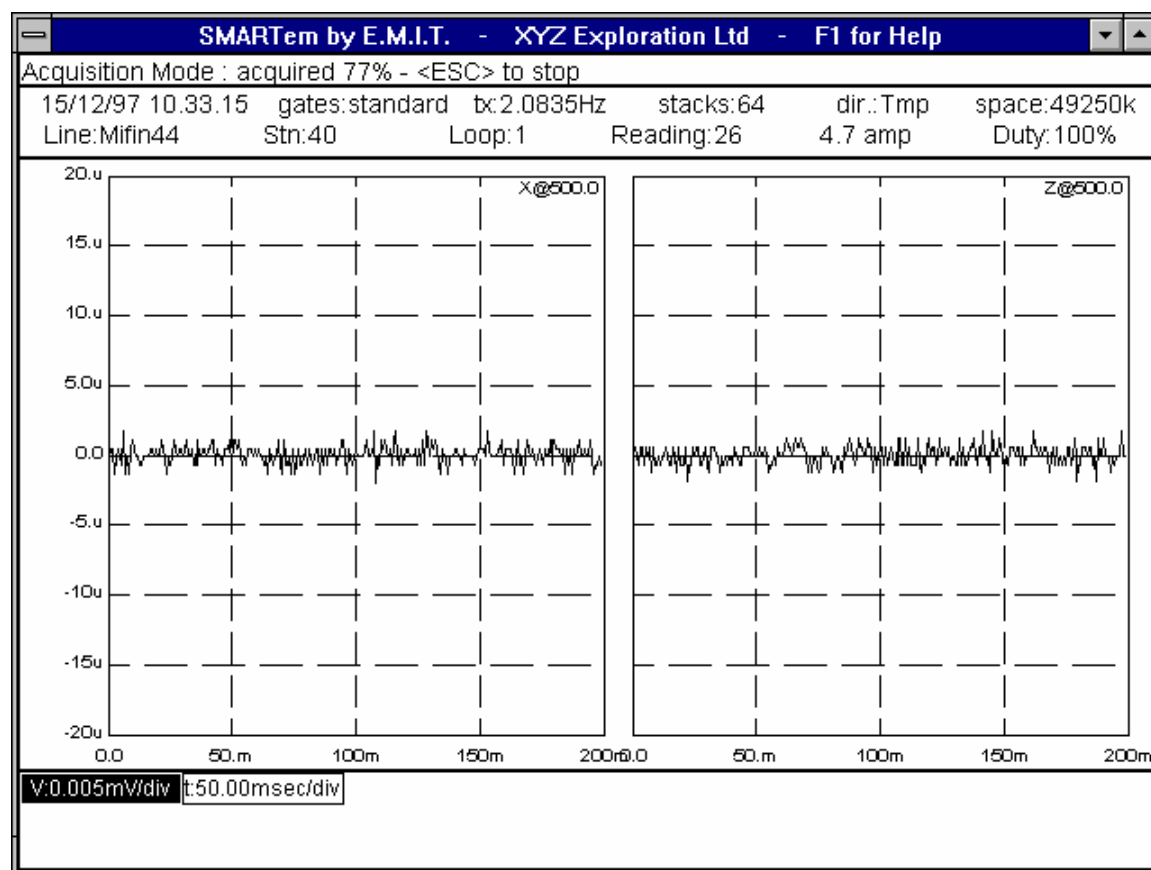
In the case of SMARTem measurements, the system records full on-time and off-time receiver waveforms and can digitise transmitter waveforms - this is enough information to do a rigorous step response transformation. There are two types of step response transformations available in the SMARTem processing software - one that uses a digitised transmitter waveform and one that doesn't. Transformations done using a measured transmitter current waveform are more rigorous but more time-consuming and require extra measurements to be made in the field. Transformations without use of transmitter current measurements will suffice for generating a profile that gives a new look to an old data set.

To remove primary field from calculated SMARTem step responses, the late-time step response is assumed to be the result of primary field. This is then subtracted from all earlier windows. Thus, all decays go to zero at late time. The units of SMARTem step responses are microvolts per ampere peak-to-peak of a triangular current waveform (in the same way that impulse responses are expressed in units of microvolts per ampere peak-to-peak of a square current waveform).

Collecting Data - Acquisition Mode

A previous section of this manual dealt with setting up the SMARTem software for acquisition of data. This section deals with what happens during collection of data.

Prior to collection of data: (i) turn on the SMARTem computer, (ii) turn on the SMARTem crystal oscillator, (iii) synchronise local crystal with crystal in transmitter controller if required (see chapter on synchronisation), (iv) connect direct trigger cable to either SMARTem receiver or transmitter controller (v) connect signal lines into banana sockets on the right side panel of the SMARTem receiver computer and short unused channels.



Acquisition Mode - a typical screen during acquisition

Proper operation of the transmitter can be checked prior to data collection by entering the Oscilloscope mode (see next section). This also allows the operator to note the transmitter current and enter it into the SMARTem. Using Oscilloscope mode allows the operator to check the magnitude of signals prior to recording them.

Data collection starts when the Initiate button is pressed in Acquisition mode. The operator can also hit the “I” key to initiate data collection. During data collection, incoming data is displayed, one plot per channel, on the computer screen (unless the Display During Acqn option is set to “DATA” - see previous section on Graph Setup). Data displayed may be in either stacked form or raw form - depending on the setting of the Display R/T Averaging parameter in the Graphics Setup screen.

During collection of data, the transmitter (if connected, switched on and initiated) will cycle at the appropriate frequency and duty cycle. It should cease cycling upon completion of the appropriate number of stacks. If automatic gain setting is enabled then gains of each channel’s amplifier will be set prior to collecting the required number of stacks. During this process, the DC offset (typically less than 10 millivolts) of each channel is estimated and the maximum amount of signal is measured - this allows calculation of the maximum gain that can be applied to each channel.

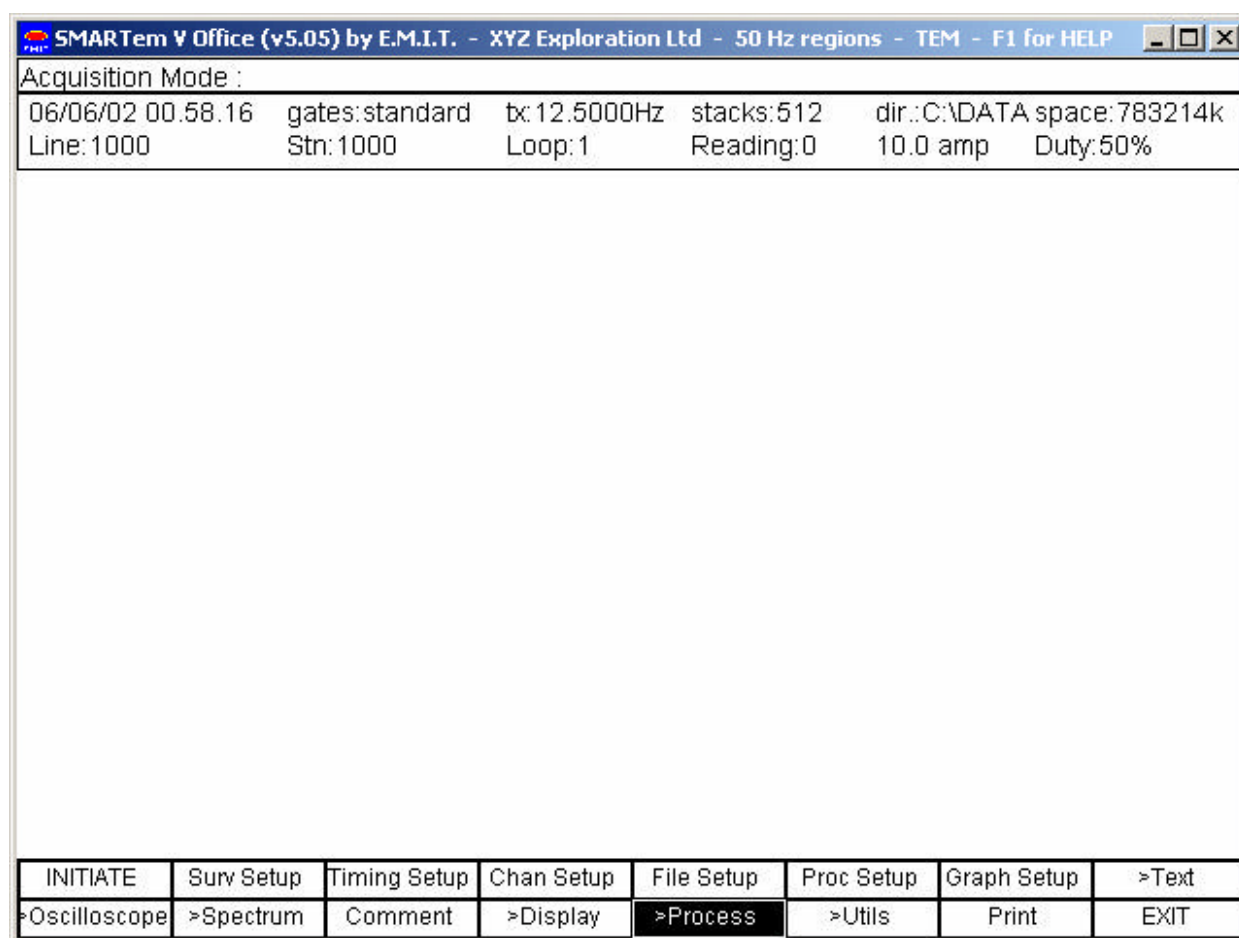
After execution of the automatic gain calculation routine, the DC offsets of all channels are known - they are subtracted from subsequent oscilloscope displays of data, allowing signals to be viewed by the oscilloscope, even with a large gain applied.

Above is a screen captured during data collection. Two channels of data are being acquired - they are named X and Z (from the top right of each sub-window). These channels are currently all being acquired with a gain of 500.0 (ie Z@500.0 etc).

During data collection, the SMARTem program has switched to an oscilloscope type display with 2 scale buttons to allow the real-time adjustment of the vertical and horizontal scales of the displayed plots for all channels. At the top of the screen, note the message that 77% of the full reading has been made. Across the top of the screen, configuration information is displayed. Note that the reading being collected will have 64 stacks when completed and that the base frequency is approximately 2.083 Hz. The “standard” SMARTem windowing scheme has been chosen for the processing of this data. The transmitter current, loop number, station name and line number are noted. The date and time are also written at the top left of the screen.

While data is being collected, raw time series are written to the hard disk of the SMARTem computer. The data is not processed until all data has been recorded. While collecting data it is written to a binary file in the RAW directory beneath the chosen data directory (see section on Setting up for a Survey), which in the case of the screen illustrated is the C:\TMP directory. The name of the binary file is constructed from the date and time and has an R (for raw) prefix.

Upon completion of the recording of, in this case, 64 stacks, the binary file of raw data is read back and processed by the SMARTem program. If required (File Setup screen) a file of stacked data is produced by the processing and is written to the C:\DATA\STACKED directory. After processing, the raw data is deleted from the hard disk if it is not required (File Setup screen). At this point the program asks for a comment to be appended to the newly-acquired reading, then returns to its normal Acquisition mode screen and displays the newly-acquired data in either profile or transient form (depending on the Graph Setup parameter in the Graphics Setup screen). The following is an example of a profile mode display of data in Acqn mode:



The windowed SMARTem data is written to the file with name generated by appending “.dat” to the line name - in the above case 1000.dat - in the C:\DATA folder. Any WMC format data would be written to the 1000.wmc file in the same folder.

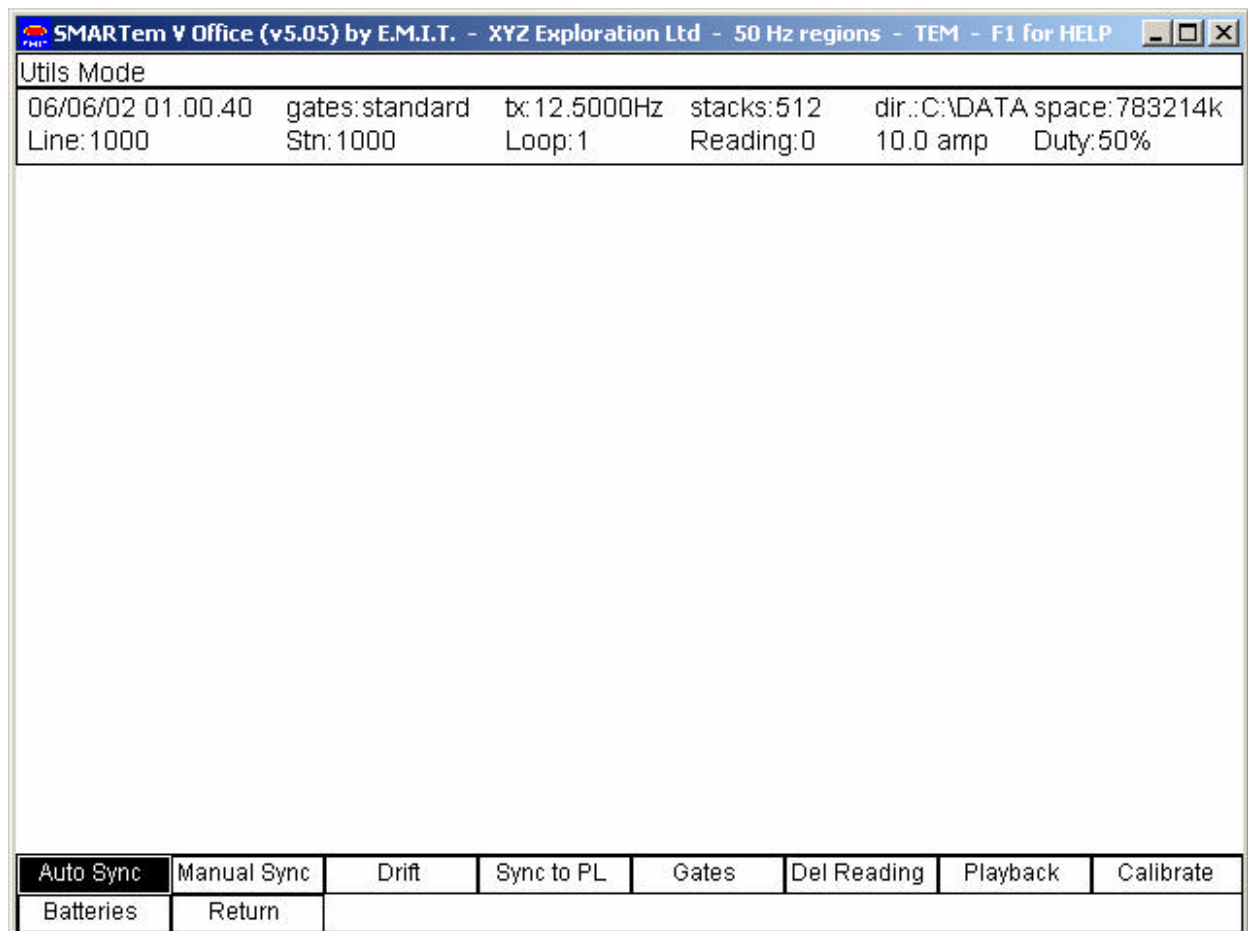
When processed data is displayed, the vertical axis units are always microvolts per amp. During data collection (except when a Real Time

Average is being calculated and displayed), or when using the Oscilloscope or Spectrum Analyser functions, raw data is displayed in units of Volts.

When processed data is displayed in transient form, the time axis units are always milliseconds. During data collection or when using the Oscilloscope function, raw data is displayed with time scales in units of seconds. Window times are always expressed in units of milliseconds.

The Print button generates a basic plot of the screen contents and the EXIT button terminates the SMARTem program and returns control to Windows. The Playback function replays the last measurement collected if raw data has been saved for it.

The Utils Mode screen is as follows:



The synchronization and drift functions will be described in a later chapter. The Sync to Power Line function chooses the optimal Base Frequency for removal of the measured power transmission line interference. This function should only be invoked in surveys where the receiver is directly triggering the transmitter. Follow the instructions on the screen to retune the Base Frequency. The transmitter must

be turned off for this function. This function is not commonly used and may be considered a legacy of older versions of SMARTem software.

The Gates function displays the current window (or gate) times. The Del (Delete) Reading function deletes the last reading acquired. The user is prompted with the details of the last reading before any data is deleted. The Playback function displays the raw waveform from the last reading in the same way as the Display Raw function behaves.

Using the Oscilloscope and Spectrum Analyser

The Oscilloscope and Spectrum Analyser modes or functions can be accessed from the Acquisition mode screen. These functions essentially duplicate the functionality of simple oscilloscope and spectrum analyser instruments - these instruments are useful in the analysis of signal and noise.

To invoke the Oscilloscope, hit <ENTER> when the ">Oscilloscope" button is highlighted. If a transmitter is connected and powered on then it will cycle. This is the best way to cycle the transmitter prior to a survey to test current flow, correct operation etc. No data is recorded, but the transmitter and A/D cycle as they would during data collection.

The user is presented with a screen like the one presented at the start of the last section of this manual - there is one plot per channel illustrating raw data being digitised by the SMARTem. Vertical scales are in units of Volts and horizontal time scales are in units of seconds.

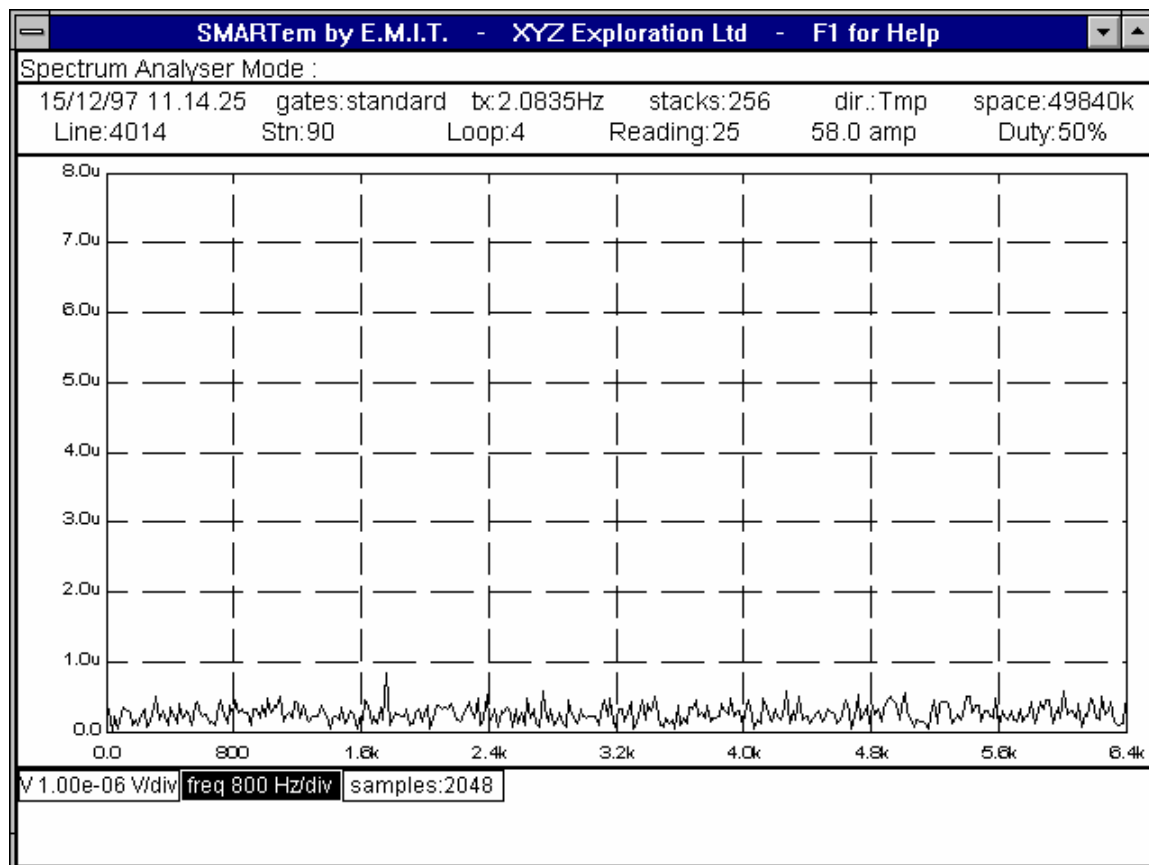
While SMARTem is in Oscilloscope mode acquiring data, the operator may adjust the vertical and horizontal scales of the display. This is a matter of using the left and right arrow keys to select the appropriate parameter and then using the PgUp or PgDn key to change the scale.

Hit the <ESC> button on the computer keyboard to return from Oscilloscope mode to Acquisition mode. This stops the cycling of the transmitter.

Displays in oscilloscope mode (and during data collection) always treat the time at which the off-time is triggered (or in the case of 100% duty cycle, the time at which the current polarity is switched) as time zero. This normally allows the length of the ramp to be established from visual inspection because the ramp always happens after time zero. This is a small delay from amplifiers, filters and the antenna too.

The Spectrum Analyser works in much the same way. Just hit <ENTER>, when the >Spectrum button is highlighted, to start it. Hit <ESC> to stop it. The Spectrum Analyser mode presents the user with a spectrum of the *noise* on each enabled channel.

It is not desirable to incorporate the effects of a transmitter into the noise spectrum analysis measurement, so it is best to switch off a transmitter while doing spectrum analysis. If the transmitter is being directly triggered from the receiver it will be switched off during a Spectrum Analysis unless it is being triggered continuously (Tx Continuous? ON in Timing Setup form).



Spectrum Analyser - Typical Display

If a 100% duty cycle survey is being undertaken, spectrum analysis carried out with the REMOTE Triggering option while a remotely-triggered transmitter is cycling will be affected by any variations in the transmitter current during the on-time. This may be significant during 100% duty cycle surveys with a generator-powered transmitter.

The above is a typical presentation from Spectrum Analyser mode. In this example, only 1 channel is enabled and no signal cables are connected so there is very little noise at all. The vertical axis is the magnitude axis (units of Volts) and the horizontal axis is the frequency axis (units of Hz). There are 3 buttons at the base of the Spectrum Analyser screen. These allow the operator to change the vertical scale, horizontal scale and the number of data samples in each Fourier transform computed for display. Use the arrow keys and PgUp/PgDn as usual to change these parameters.

The larger the number of points used in each Fourier transform, the slower the screen updates with new spectra. However, increasing the number of points in each Fourier transform increases the resolution of the spectrum displayed, giving superior diagnostic information about noise sources.

Operators should become familiar with the appearance of power transmission line (50 Hz + harmonics) noise, PED interference (360-380 Hz), North-West Cape (19.8 kHz) interference and other sources of noise in spectral presentations.

The maximum frequency calculated by the spectrum analysis procedure is the Nyquist frequency - this is exactly half the sampling rate. The operator should be aware of the *aliasing* condition when viewing spectra. This phenomenon surfaces when signals of frequencies higher than the Nyquist frequency are digitised. One way to detect aliasing is to change the sampling rate and see if the signal appears at the same point in the spectrum.

Power transmission line spectra will typically show many harmonics, as will PED transmissions. For reference, the main PED frequency is approximately 374 Hz.

Measuring Transmitter Current

The most rigorous method of converting data to step or impulse response requires measurement of the transmitter waveform. With the 24V battery-powered Zonge transmitters, this is a matter of using the SMARTem to measure the voltage on the current shunt provided in the transmitter (yellow and green terminals on the rear of the transmitter).

For transmitters running off any more power than 24V, some isolation is required because the small voltage across the shunt rides on top of the input power voltage. The Zonge iso-amp has been used to allow digital measurement of the transmitter waveform from a Zonge GGT-30 transmitter, but this system of measurement appears to be reasonably noisy and contain unwanted phase shifts.

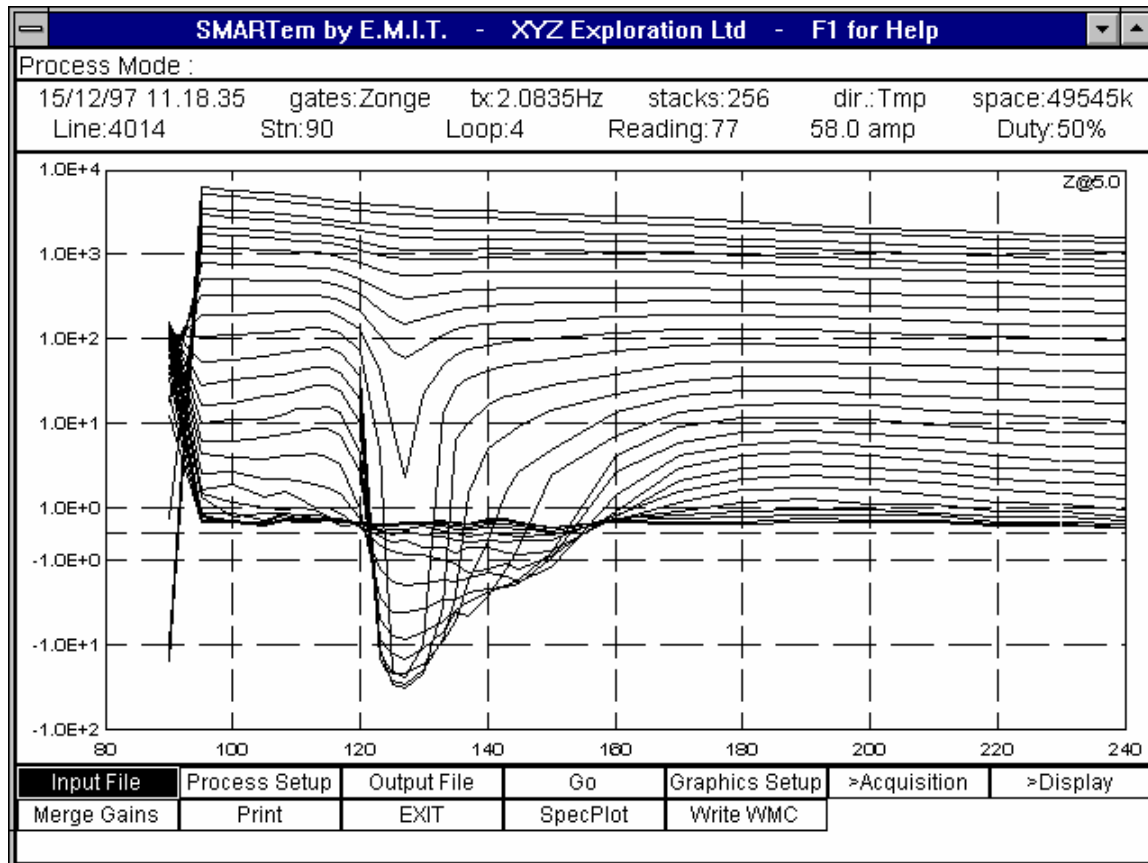
All of the modern Zonge transmitters incorporate a shunt resistor in the transmitter current output circuit. The resistor is 0.05 ohms (50 mV/A) for high powered transmitters and 0.1 ohms (100mV/A) for low powered transmitters.

At the time of writing this manual, research into the best system for current measurement is ongoing. In the meantime, the following points should be observed when carrying out a measurement of transmitter current:

- never plug the signal from the shunt in high-powered Zonge transmitters directly into the SMARTem without some form of voltage isolation;
- only the shunt voltages from 24V powered Zonge transmitters can be measured directly with the SMARTem;
- do not attempt to measure a current waveform, using a built-in shunt, while measuring any other signals, ie signals from a receiver coil, unless there is isolation between the shunt and the receiver;
- the channel for current measurement should be called “I”;
- properly enter the conversion from volts to amps in the Survey Setup menu.

Reprocessing - Process Mode

Process Mode can be accessed from Acquisition Mode or Display Mode. Its function is to reprocess existing data files. It requires a SMARTem windowed data file as input and creates a new SMARTem windowed data file as output.



Process Mode - Main Screen

Prior to reprocessing data (the “Go” button), the user must select an existing file of SMARTem data and must name the output file required. SMARTem will reprocess all readings listed in the input file - this file can be edited to leave only the readings required for reprocessing.

After selecting an input file, it will be displayed in transient or profile mode (according to the Graphics Setup screen).

The Process Setup screen for Process Mode is almost identical to the Process Setup screen for Acquisition Mode (refer to Signal Processing Options). Use the Process Setup screen in Process Mode to set the processing parameters for your data. The processing parameters for Process Mode are not the same as those for Acquisition mode - so check the Process Setup screen before doing any

reprocessing. Importantly - check that the windowing scheme used in the reprocessing is the one that you want.

At the completion of a reprocessing run, the newly-created data file will be displayed.

To return to Acquisition Mode or Display Mode use the >Acquisition or >Display buttons as appropriate. The SpecPlot function is a new function to output noise spectra to a file for plotting. It creates a two dimensional grid of the variation of noise magnitude with station and frequency.

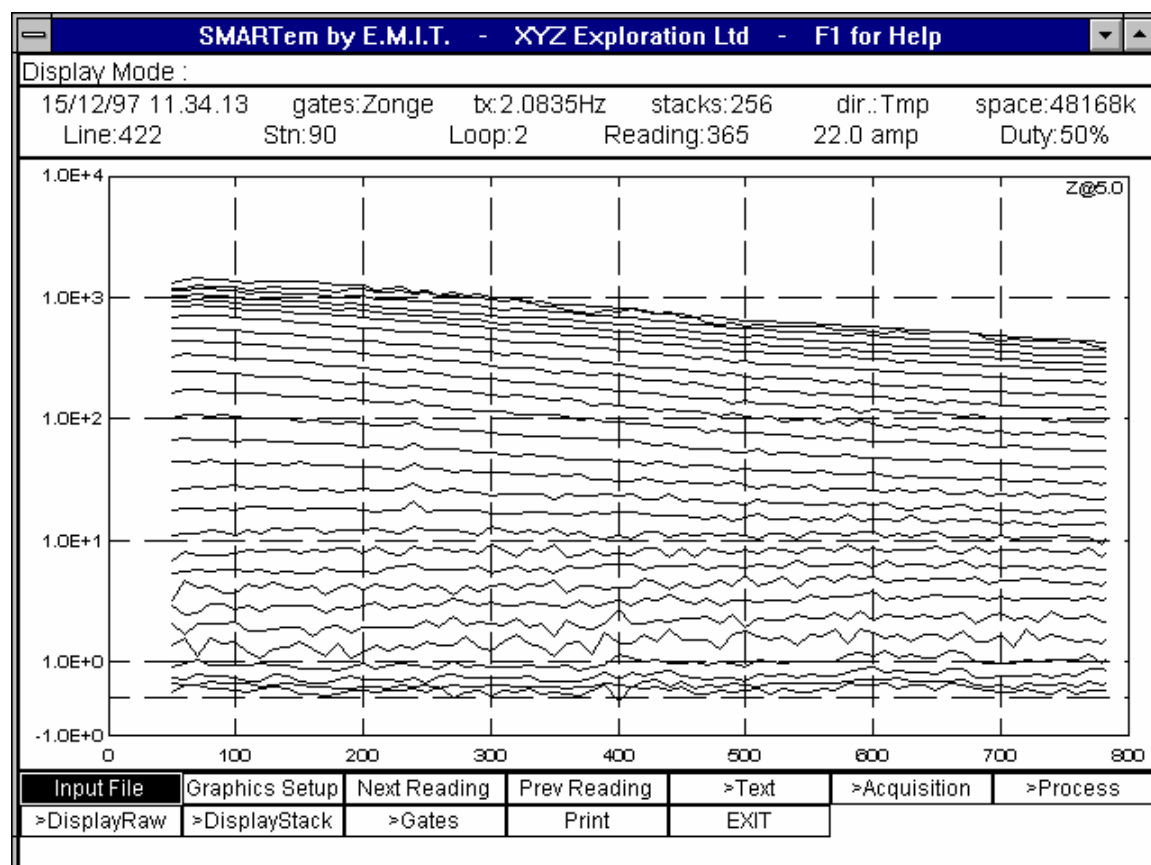
As mentioned above, the reprocessing operation generates a SMARTem windowed data file. To create a WMC format file from any SMARTem file on the computer you can use the Write WMC function. Prior to using this, you should select the SMARTem file you wish to convert as the Input File and select the WMC file name as the Output File.

As shown, there is a Merge Gains function in the Process Mode menu. This function allows readings at the same station with different gains to be merged into one reading - early time values are calculated from the low gain measurement and late time values are calculated from the high gain measurement.

As with Acquisition and Display Modes, a Print button allows the operator to make a plot of the contents of the screen. The EXIT button returns the operator to Microsoft Windows.

Displaying - Display Mode

Display Mode can be accessed from Acquisition or Process Modes. Its purpose is to display and print SMARTem windowed data files, however, the Display Stacked and Display Raw Modes (which can be reached from Display Mode) allow display and hardcopy of stacked and raw data respectively.



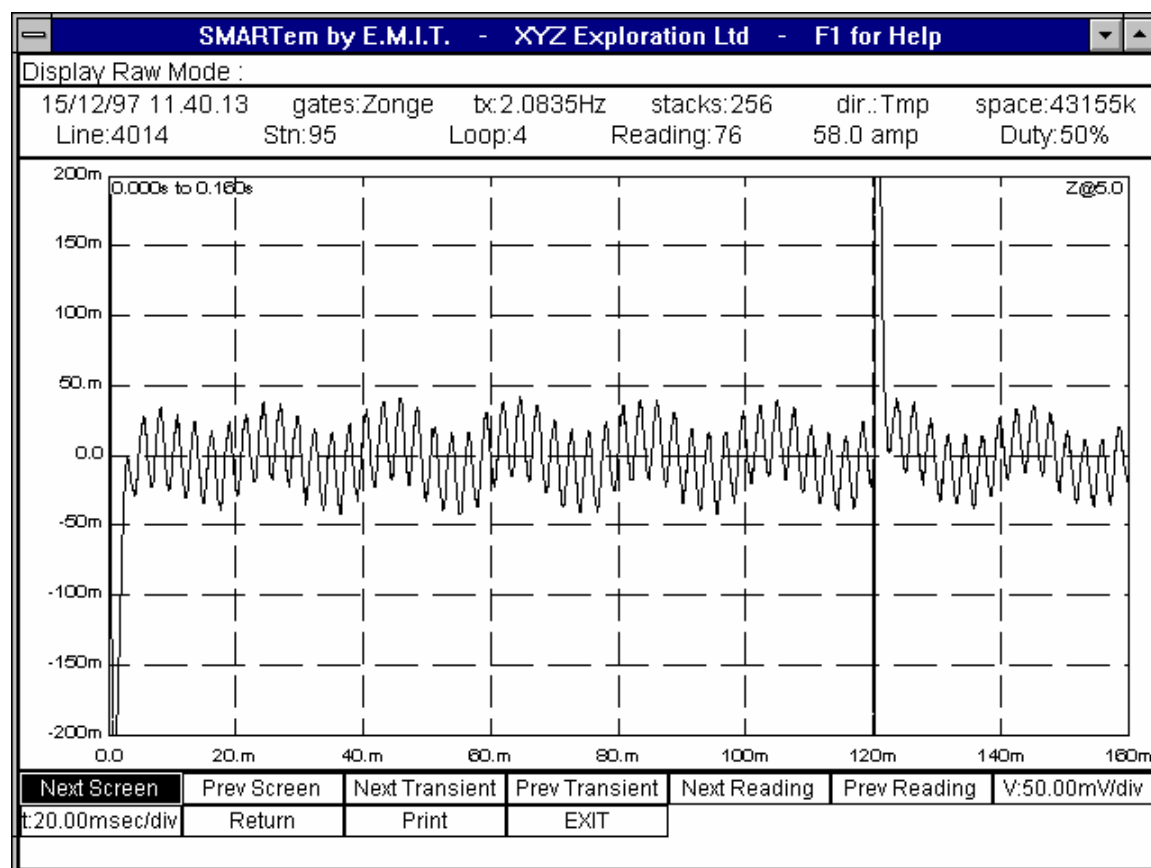
Display Mode - Main Screen

The operator is prompted for the name of the data file to be displayed upon entering Display Mode, however to display another file of SMARTem windowed data, simply select it using the Input File function. The Graphics Setup screen allows formatting of the graphics display as per normal and allows you to display single transients or whole profiles. To select a particular station or loop to display, select it in the Graphics Setup screen.

The Next Reading and Previous Reading functions are useful for quickly going through data files in transient display mode. The Print button allows hardcopy of the contents of the screen and the EXIT button returns to Microsoft Windows. The >Text mode shows the decays at the current station in text form.

The Display Raw and Display Stacked Modes are entered from the Display Mode screen pictured above.

Display Raw Mode allows viewing of raw binary time series data:



The plot above illustrates one channel of raw data acquired in a borehole TEM survey. This time series is affected by PED (approx 2.5 msec period sinusoid) and power transmission line (20 msec period) interference (plot time scale is 20 msec per division). Also shown are the borehole TEM response of the transmitter switching on (at t=0) and off (t=120 msec). The file can be gone through, in forward or reverse direction, one screen at a time or one transient at a time. The Next Reading and Previous Reading buttons display the raw time series for the next and previous readings, respectively, in the SMARTem windowed data file (if raw files are present).

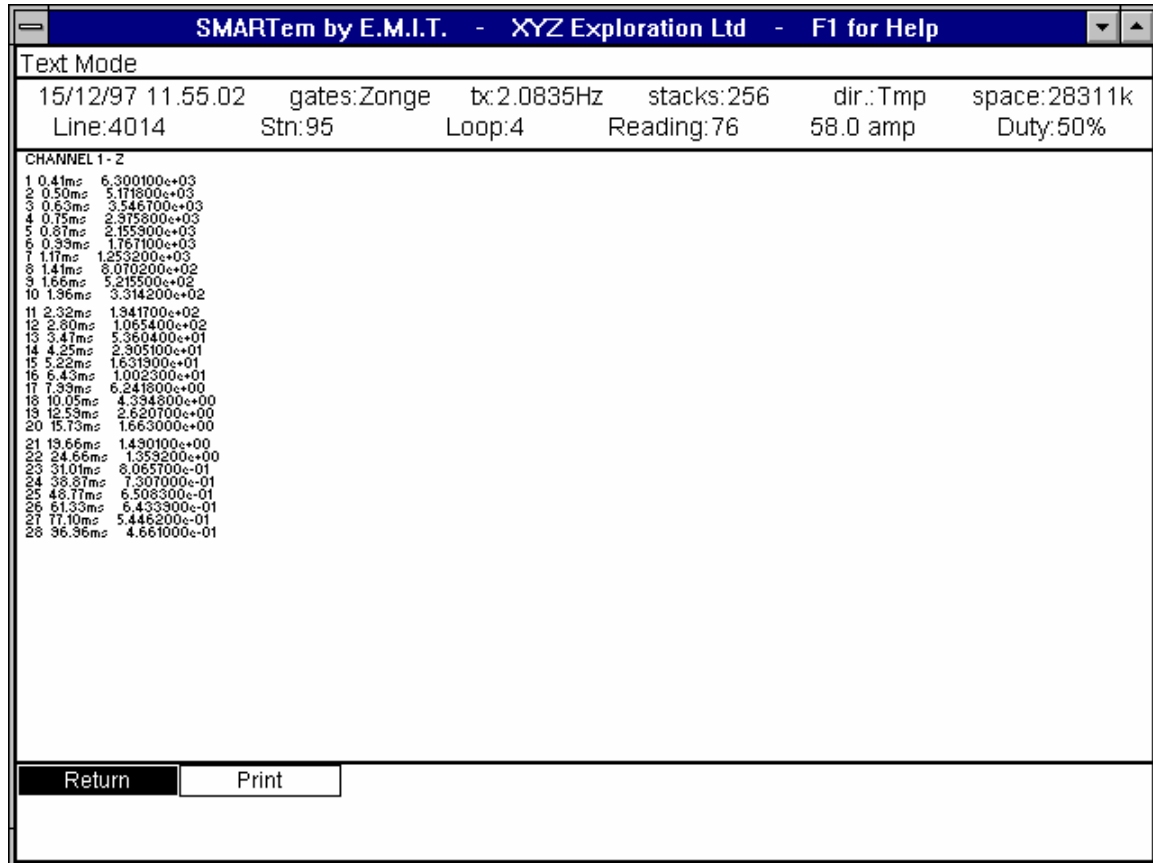
The horizontal and vertical scales can be changed, using the appropriate buttons and the PgUp/PgDn keys. The segment of raw data being currently viewed is noted in the upper left of the graph - this gives the time in seconds from the start of the file to the start and end of the displayed segment of data.

Units for display are Volts and seconds.

The Display Stacked Mode offers similar functionality for the display of stacked data. Units for display are $\mu\text{V}/\text{A}$ and milliseconds. The Next Reading and Previous Reading buttons display the stacked time series for the next and previous readings, respectively, in the SMARTem windowed data file (if stacked files are present).

Text Mode

From Acquisition Mode and Display Mode, the SMARTem software can be put into Text Mode to give an alphanumeric representation of the voltages in a particular decay. Text Mode allows the user to view and print a text display of a particular transient measurement. The style of display is indicated in the following picture:



Typical Text Mode display

Decays are listed in a column, with one column devoted to each channel of the particular measurement. The decay voltages for the selected measurement are shown. In Acquisition Mode, if text mode is entered immediately after making a measurement, then that measurement will be displayed. In Display Mode, the response from the selected station is given. In the above example, a single channel (Z) measurement is displayed in text form. To return to Acquisition or Display modes, hit the Return button. To print, hit Print.

SMARTem Transmitter Controller Operation

The SMARTem Transmitter Controller is used to remotely control a Zonge or other transmitter during a SMARTem survey. If remote control is not required, the transmitter can be controlled directly from the SMARTem receiver computer. The SMARTem Transmitter Controller has few controls and is simple to use. Its front panel layout is illustrated in the Physical Layout section of this manual.

The SMARTem transmitter controller incorporates the same circuitry as in the SMARTem receiver computer. This includes a precise oven-controlled crystal oscillator which is used as a timing reference for the triggering of the transmitter.

As discussed in the section Setting up for a Survey, sync power to the Transmitter Controller should be powered on for preferably 1 hour before synchronisation with the SMARTem receiver.

Use the supplied synchronisation cable plugged into the SYNC connectors to carry out the synchronisation. Note that a transmitter can not be connected to the receiver or transmitter controller during the synchronization because the same connector is used for both operations.

The base frequency for transmitter triggering supplied by the controller is set during the synchronisation operation and only remains valid while the controller is switched ON. After a synchronisation the controller is ready to trigger the transmitter. Triggers are provided continuously from the transmitter controller.

Both power switches (labelled Power and Sync) must be left ON for the controller to remain in synchronisation with the receiver. Turning the power OFF shuts down all circuitry including the crystal oscillator.

The battery inside the controller has an endurance of approximately 30 hours without recharging, if fully charged. If this is not sufficient, then it can be boosted with an external 12-24V battery plugged into the charging port or, if access to 240V power is gained, with the charger attached.

Only recharge the internal battery with the supplied battery charger and cable.

Synchronisation / Drift Checking with the Transmitter Controller

Synchronisation and drift checking is carried out with software running on the SMARTem receiver computer.

To synchronise, firstly warm up the crystals in both units by powering them on for at least 60 minutes. This can be done sooner but crystals do take some time to stabilize after being off. Also ensure that the SMARTem receiver computer has been powered ON for at least 10 minutes to ensure it is reasonably warm. Then connect the supplied synchronisation cable to the receiver and the controller. The sync cable must be connected to the SYNC connector on both units. The connectors are 19 pin bayonet connectors.

Initiate the synchronisation procedure with functions in the Utils menu. There is an Auto Sync and a Manual Sync function. Follow the instructions on the screen to synchronise. Invoking the synchronisation operation causes the SMARTem computer to tune the crystal on its timing board to match that in the controller unit. It does this by varying the voltage output from a 12 bit digital-to-analogue converter.

In manual mode use the up/down arrow keys and PgUp/PgDn to tune the Receiver's oscillator to the oscillator in the Transmitter Controller. When complete hit <Enter> to synchronise.

After each synchronization, check the Drift function to ensure the sync operation has succeeded. Some SMARTem V systems can produce bad syncs. If the drift message says "SYNC BAD" then the sync must be repeated.

When the synchronisation operation is complete, a message to that effect is posted on the screen, in addition to the calculated drift - which should be very small because the crystals have just been synchronised. At this time the synchronisation cable can be disconnected from both units and the transmitter triggering cable can be connected to the controller. The transmitter can be powered up and initiated.

The main and sync power circuits in the SMARTem receiver and the transmitter controller must be left powered ON for the two units to remain in synchronisation. If either is switched OFF, then the two units must be brought together and resynchronised prior to further work. To change the base frequency of operation does not require resynchronisation - the frequency used by both the transmitter controller and the receiver can be changed on each of the instruments without interrupting the synchronisation. This is useful if the receiver and controller are some distance apart and the frequency needs to be changed.

After synchronization the red Lockout LED on the front panel of the receiver and transmitter controller is illuminated. This LED indicates that the sync power circuit has been locked. The Sync power can not be switched off by the Sync button when the Lockout LED is illuminated. The Lockout LED will be disabled when the main Power circuit is switched off. At that time the Sync power can be switched off also.

To measure the *drift* between the crystals in the receiver and controller use the Drift function. The sync cable must be connected as with a synchronisation. Drift is calculated in units of milliseconds.

The results of all synchronise and drift checking operations are written to a file *sync.log* in the C:\SMARTTEM directory. Entries in this file include the date and time of any synchronisation or drift operations and their results.

Data File Formats

SMARTem data is written into several data file formats including a (legacy) WMC format. The basic SMARTem windowed data file is a free format ASCII file written in AMIRA format:

- The first record of the file is a comment and is unused by any of the software that reads the file.
- The second record sets constants in the form `CONSTANT: value`. This record can hold many of these constants. SMARTem sets some AMIRA constants in this record of its windowed data files (*datatype*, *config*, *line*, *initdelay*, *channelfile*, *units*), however it may be appropriate for users to add further constants to SMARTem data files here for use with interpretation or processing software.
- The third record in a SMARTem windowed data file contains column headings for the subsequent columns of SMARTem data. All data is written in column format and each column has a heading identifying it. Column headings do not necessarily sit directly above corresponding data in the file but the order and number of headings is important.

An example SMARTem windowed data file is displayed on the following page. Note that the creation time of the file is written into the comment at the start of the file. The right hand end of the long records have been truncated for simplification. Not shown is the comment field at the end of each record, where the comment given by the operator after each reading appears. SMARTem data files can be edited using any ASCII file editor. To delete a reading from the file, simply delete the line corresponding to that reading.

SMARTem data file - created Sun Oct 08 11:54:17 1995

LINE:7770500 DATATYPE:TEM UNITS:(uV/A) CONFIG:COINCIDENT INITDELAY:0.4 CHANNELFILE:standard

STN LOOP RDNG ADC C NADC TIME OPERATOR FREQ CURR SAMP_RATE GAIN NSTACKS DIR FLAGS SFTHRES RAMP DELAY NOISE NCH CH1 CH2 ...

456300 1 58 1 Z 1 5100811.51 Andrew 0.999968 5.200 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 1.192455 34 7.3375e+04 4.7766e+04 ...
456500 1 64 1 Z 1 5100813.30 Andrew 0.999968 5.200 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 1.149560 34 6.5643e+04 3.4650e+04 ...
456700 1 66 1 Z 1 5100814.05 Andrew 0.999968 5.200 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 1.025211 34 6.4117e+04 3.3785e+04 ...
456900 1 72 1 Z 1 5100815.17 Andrew 0.999968 5.200 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 1.269597 34 7.0445e+04 3.6914e+04 ...
457100 1 74 1 Z 1 5100815.54 Andrew 0.999968 5.200 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 0.989170 34 6.2756e+04 3.2874e+04 ...
457300 1 87 1 Z 1 5100910.21 Andrew 0.999968 5.400 37878.788 5.0 128 Fc13 111101122202000 5.0 0.22 0.00 1.057232 34 6.0771e+04 3.2057e+04 ...

This is a small portion of a SMARTem windowed file showing only 2 windows out of a total of 34 for each reading. Data has been removed to allow this portion of the file to plot on a single page.

Columns written to SMARTem data files always follow the same free format but naturally vary in record length with a different base frequency. The columns written are:

- | | | |
|--------------------------------------|-------------------------------------|---------------------------------|
| 1. station name | 11. sampling rate | 21. the data - multiple columns |
| 2. loop number | 12. gain | 22. comment |
| 3. reading number | 13. number of stacks | |
| 4. ADC number, or channel number | 14. directory where data is written | |
| 5. component name | 15. a flags string | |
| 6. total number of channels recorded | 16. sferic filter threshold | |
| 7. date/time string | 17. ramp time (msec) | |
| 8. operator name | 18. antenna delay | |
| 9. base frequency | 19. noise number | |
| 10. transmitter current | 20. number of windows (or gates) | |

SMARTem Windowed Data File Format

Things to note about SMARTem windowed files are that:

- there is one record per transient recorded - thus if 3 channels are enabled for a particular reading then 3 records are added to the data file
- files can contain data from more than one transmitter loop
- files can contain data from more than one base frequency, sampling rate, transmitter current etc.
- all data from a particular line is written into the same data file - to generate a new SMARTem data file while recording data it is necessary to change the line name
- the name of the data file to which SMARTem windowed data is written is constructed from the line name with a “.dat” extension
- each record in a file has the same number of entries - if a smaller number of windows is recorded for a particular station then its record will be padded with null values
- the SMARTem software expects data in this format - any modifications to the layout of the columns will result in SMARTem software not being able to read the file (and display it or reprocess it).
- SMARTem always sorts its windowed data files so that station numbers are in ascending order.

SMARTem also records data in WMC format, stacked format and raw format.

WMC format files will not be described here, however SMARTem WMC files are compatible with WMC processing software. WMC files generated by SMARTem are not sorted and will require sorting before any further operations.

Stacked format SMARTem files are ASCII lists of stacked, but not windowed, data values. The whole waveform, on- and off-time is recorded. For each reading there is only one stacked file - all components (or channels) measured in the reading are written into the same file, first a list of channel 1 data, followed by channel 2 and so on. These files are quite long as there is one record for each sample over a whole waveform for each channel. At the top of the data for each channel is a one record header giving information similar to that at the front of each record in a windowed data format - ie transmitter current, number of stacks etc etc. SMARTem stacked format files can be viewed from Display Stacked mode in the SMARTem software.

SMARTem raw format files are large binary files containing all digitised data points for a reading. Only one file is generated for each reading, this file contains all data for all channels. SMARTem raw format files are recorded during acquisition and then read back into the SMARTem software when it is processing the reading.

Data is written to SMARTem raw files in multiplexed 2 byte integer format. Each analogue-to-digital conversion is 16 bits in size (2 bytes) and multiple channels are multiplexed so that channels appear in sampled order in the file. SMARTem raw format files can be viewed in Display Raw mode in the SMARTem software.

Archiving Data - What to Archive

To archive SMARTem data, use the parallel port cable and transfer software provided. Connect the SMARTem receiver to another computer with the supplied cable via the parallel (printer) port on the front of the SMARTem chassis.

A good amount of compression is never achieved when archiving the binary SMARTem raw time series files. Expect archiving to be carried out at a rate of approximately 5 MBytes per minute.

The choice of which files to archive is up to the user, but in general one would not archive raw data files unless there was a need for subsequent reprocessing or research. To identify particular readings or stations to archive, the user can cross-reference raw and stacked format file names from the windowed data files. The date/time string written in the seventh column of the windowed data files effectively gives the name of the associated stacked and raw files.

As a guide to what should be kept for reprocessing, consider the following:

<u>Operation</u>	<u>Requirement for Processing</u>
Stacking	Raw Data
Sferic Filtering	Raw Data
PED Filtering	Stacked Data
Rewindowing	Stacked Data
Deconvolution	Stacked Data

Battery Charging

The battery packs in the receiver and transmitter controller are nickel metal hydride technology. A special charging circuit has been built into each unit for the charging of these packs. Two 28V power supplies are supplied – these act as a power source for the recharging circuitry inside the receiver and transmitter controller.

The red Charge LED on the front panel of the instruments is continuously illuminated during charging and flashes when charging is complete.

Batteries can be left attached to the charger after charging has finished.

Always connect the batteries to the charger before switching on the charger - this is good practice for any battery charging operation.

The power supplies can be attached while the main or sync power of either the receiver or transmitter controller is activated. For best charging of the receiver the main power should be off. For the controller only a small amount of power is consumed by both the main power and sync power circuits.

END OF DOCUMENTATION