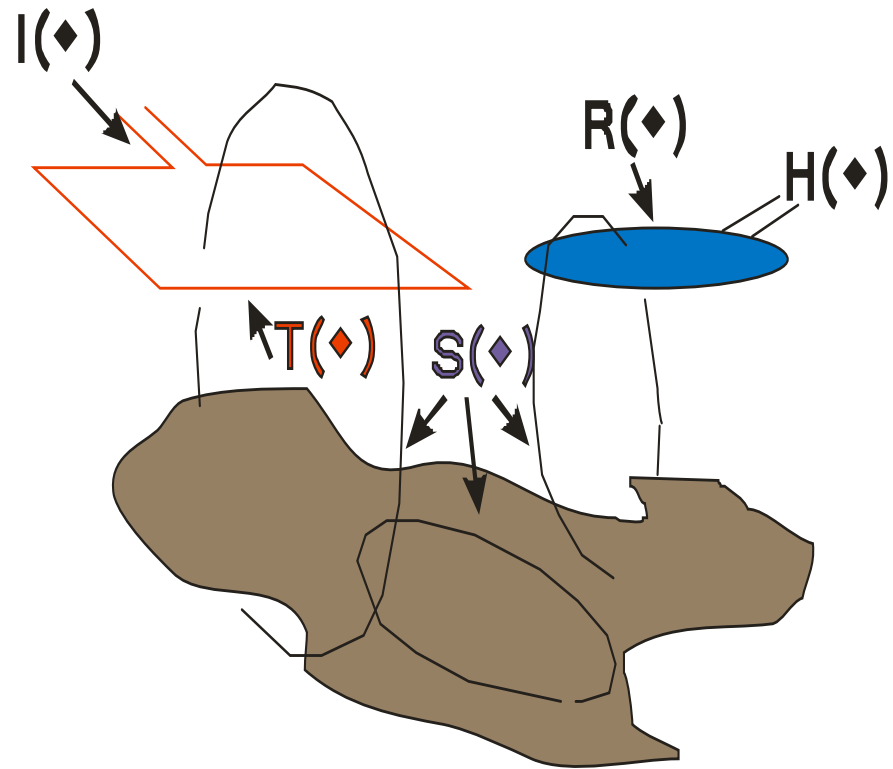


# Frequency to Time Domain Transformation



**Transformation to Time Domain Software  
for Frequency Domain Electromagnetic Modelling Programs**

## ***Our definitions:***

### **spectrum:**

the frequencies present in an electromagnetic signal and their strengths

### **waveform:**

A representation of the shape of a wave that indicates the wave's characteristics, such as frequency and amplitude.

### **periodic:**

A quantity,  $f(t)$ , is periodic when it behaves according to the relation

$$f(t) = f(t+kT), \quad \text{for all } t, \quad k = 0, 1, 2, \dots$$

where  $T$  is the smallest number such that this holds then  $T$  is called the period.

### **basefrequency:**

The inverse of  $T$  the period.

### **interpolation:**

the action of estimating values from known ones in the same range

FSEMTRS<sup>®</sup> (  $\omega \rightarrow T$  )

$$H(\omega) = I(\omega)T(\omega)S(\omega)R(\omega)$$

**$I(\omega)$**  – impulse response of current as defined by the instrument

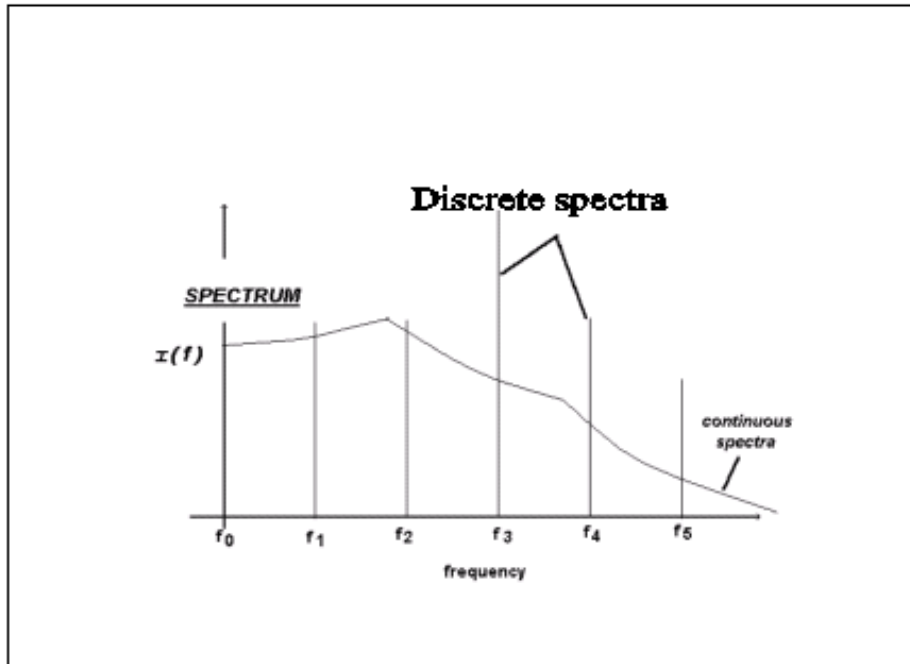
**$T(\omega)$**  – impulse response of transmitter as limited by the instrument

**$R(\omega)$**  – impulse response of receiver as physically defined by the sensor characteristics

**$S(\omega)$**  – impulse response of the ground

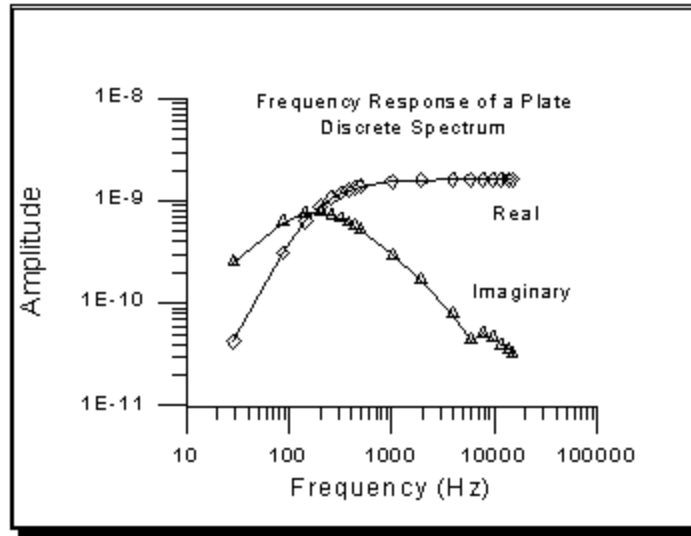
this is what we simulate with the model

## 2. The spectrum



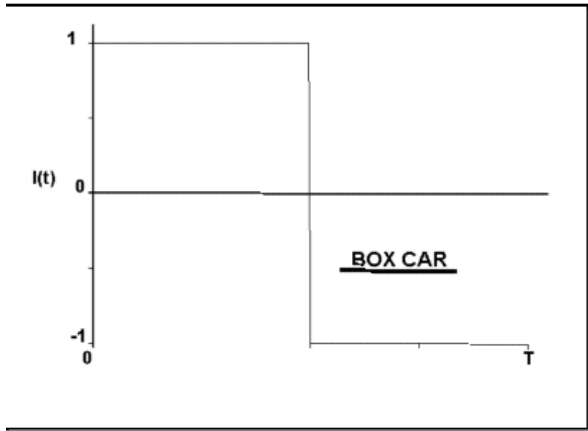
While often it is thought that the EM instrument has a continuous spectra (power) from DC to infinity, in practice this cannot be so. The instrument measures a periodic signal with the response repeated and stacked many times during the measurement. Because of this, the fundamental or lowest frequency is that of the repetitive frequency set during data collection. This is the basefrequency. As the measurement measures only a real or inphase component, then only odd harmonics of the basefrequency are contained in the measured signal. This is termed discrete spectra or power.

### 3. Interpolation

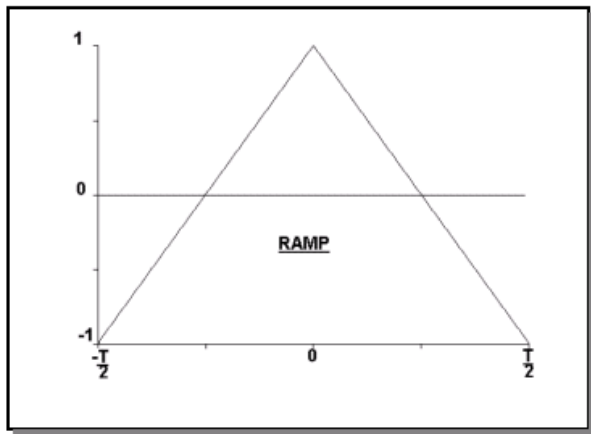


- power spectrum consists of discrete odd harmonics of basefrequency
- simulating all harmonics is time consuming
- response is a smooth function of frequency
- therefore harmonics may be interpolated
- specific sampling of frequencies must be simulated for accurate interpolation
- interpolated harmonics are combined to produce time domain responses

## 4. Current Waveforms

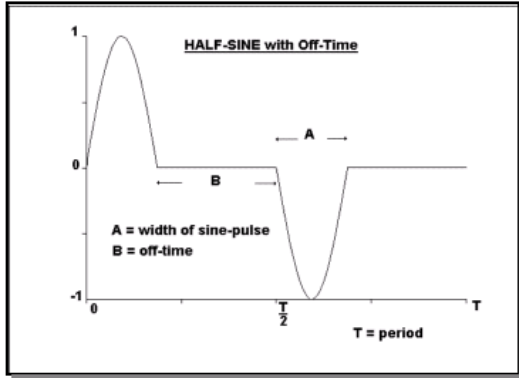


**Box Car – theoretical step off  
close approximation to time domain IP equipment**

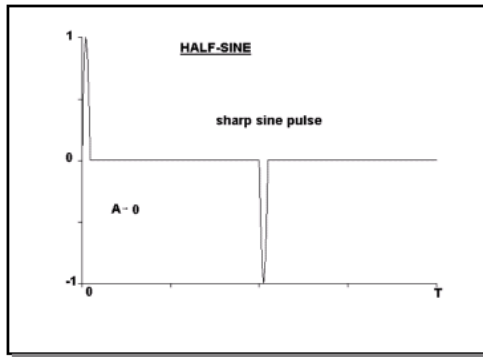


**Ramp – UTEM, Spectrem, AeroQuest**

## 4. Current Waveforms

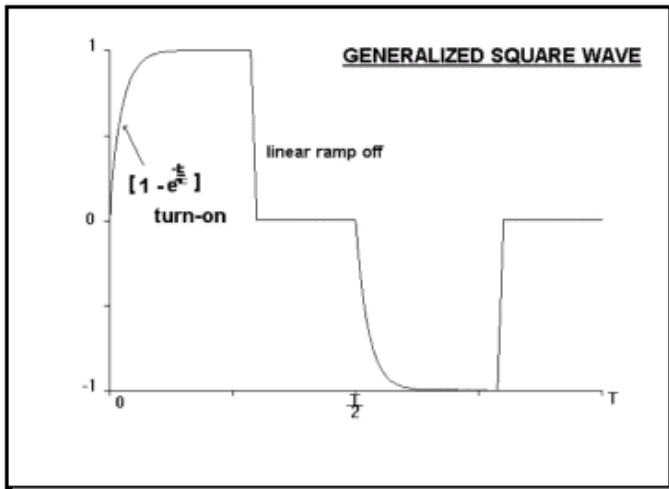


**Half Sine – INPUT, GeoTEM, MegaTEM, HeliTEM**



**Half Sine – short pulse**

## 4. Current Waveforms



### *Generalized Square Wave*

- inverse exponential turn on
- linear non-zero turn off
- stated waveform for most systems

**Crone system – known waveform**

**Geonics system – generally accepted**

**Zonge system – only approximate as turn off is not linear**

**TerraTEM – assumed but not verified but turn off is probably not linear**

**FASTTEM – assumed but not verified but turn off is probably uncontrolled**

**Phoenix - only very approximate uncontrolled turn-off,**



## **4.5 Fourier series representations of the waveforms:**

### **4.5.1 Generation of Fourier coefficients:**

Based on the waveform, *FSEMTRS* generates the Fourier coefficients for the user once the waveform has been selected along with the various settings.

### **4.5.2 Basefrequency:**

The basefrequency of the EM system is set by the user by his/her selection of the fundamental harmonic which is communicated to the software through the input of the impulse or Earth response from the electromagnetic modelling program . The frequency domain response from the modelling program must consist of the responses for the fundamental harmonic plus additional harmonics in monotonic order with no gaps in the spectrum. The user may end the frequency domain series at any frequency desired. In *EMIGMA*, interpolation between harmonics is available and not all harmonics need be calculated in the simulation or modelling algorithms.

### **4.5.3. The Representation of the Time Series:**

Transforming the spectral responses  $F(T)$  of a function  $f(t)$  generates an approximation or representation of the function. How accurate this representation is to the true function depends on the form of the function,  $f(t)$  and the number of harmonics or frequencies used to represent the function.

*Physically it is always useful to remember that no physical system is band unlimited.*

## 5. Interpolation

set#-1 0.017Hz,.0.019.to 0.17Hz in increments of n where  $n = 0.02*(n\text{skip}+1)$   
 set#0 0.17Hz,.19Hz.. to in increments of n where  $n = .2*(n\text{skip}+1)$   
 set#2 17Hz,19Hz .. to 171Hz i1.71Hz in increments of n where  $n = .02*(n\text{skip}+1)$   
 set#1: 1.7Hz, 1.9Hz.. to 17.1Hz n increments of n where  $n = 2*(n\text{skip}+1)$   
 set#3 170Hz,190Hz .. to 1710Hz in increments of n where  $n = 20*(n\text{skip}+1)$   
 set#4 1700Hz,1900Hz. to 17,100Hz in increments of n where  $n = 200*(n\text{skip}+1)$   
 set#5 17KHz,19KHz.. to 171KHz in increments of n where  $n = 2000*(n\text{skip}+1)$   
 set#6 170KHz,190KHz to 1.71MHz in increments of n where  $n = 20000*(n\text{skip}+1)$   
 set#7 1700KHz,1900KHz to 17.1MHz in increments of n where  $n = 200000*(n\text{skip}+1)$

nskip ranges from 0 to 7 and thus the number of frequencies generated per set depends on the value of nskip.

nskip	# of frequencies per set	# total number of frequencies
0	80	80 x number of sets selected
1	42	x number of sets selected
2	29	29 x number of sets selected
3	23	23 x number of sets selected
4	19	19 x number of sets selected
5	16	16 x number of sets selected
15 8	8	8 x number of sets selected

*(Note: The number of frequencies required is shown on the Waveform page)*

## 5. The Errors (bandwidth)

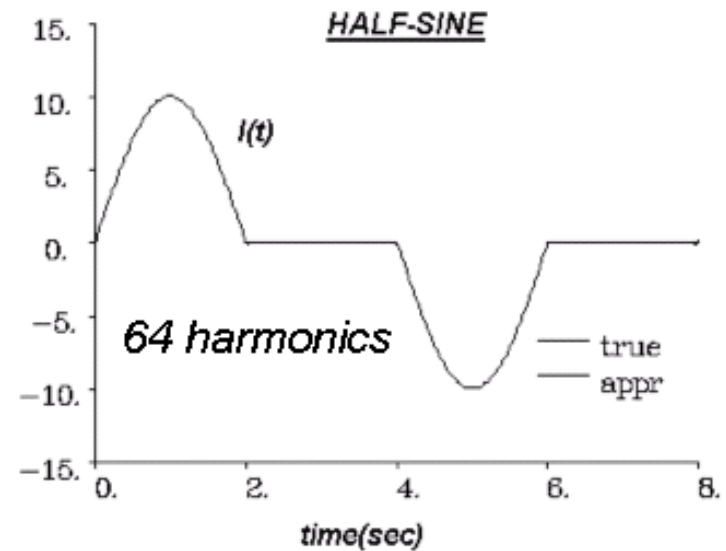
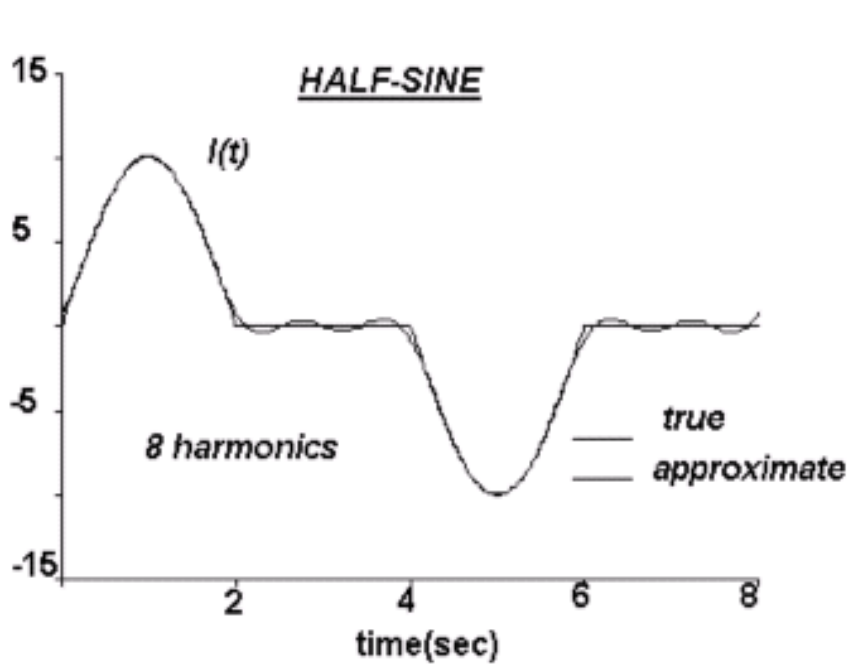


Figure 6.2 Fourier approximation of a half sine wave with 64 harmonics.

**Example, full waveform, half-sine waveform  
measuring the magnetic field (B) or a Voltage**

## 5. The Errors (bandwidth)

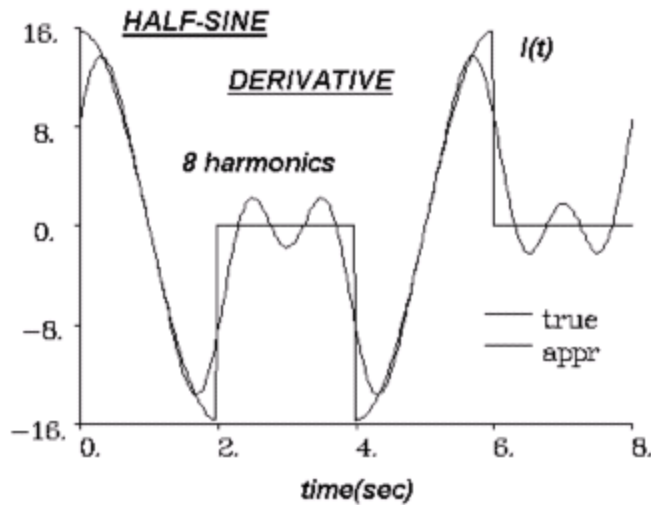


Figure 6.3 Fourier approximation of the time derivative of a half sine with 8 harmonics.

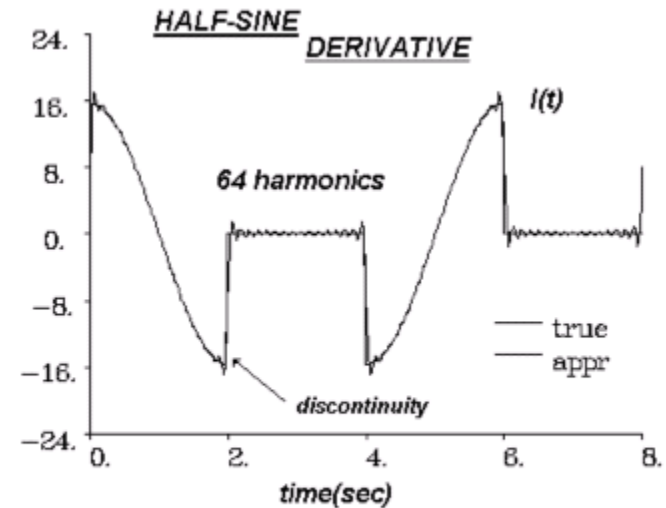


Figure 6.4 Fourier approximation of half sine derivative using 64 harmonics.

**Example, full waveform, half-sine waveform measuring the time derivative of the magnetic field. Now, the field has discontinuities and discontinuities of its gradient and representation with a few harmonics gets more difficult.**

## 5. The Errors (bandwidth)

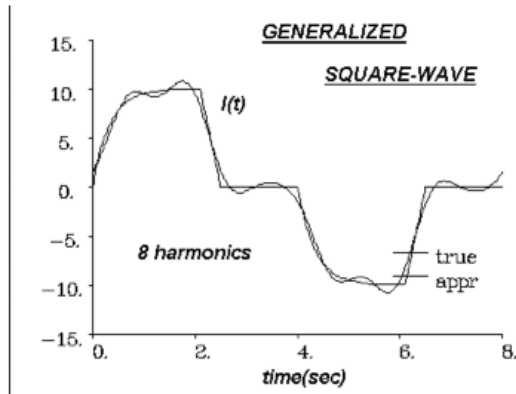


Figure 6.5 Fourier approximation of the Generalized Square Wave using 8 harmonics.

B-field

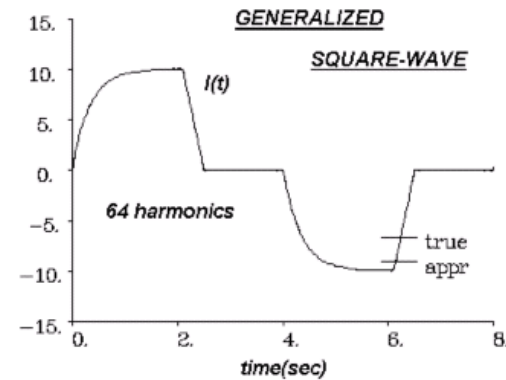


Figure 6.6 Fourier approximation of the waveform of Figure 6.5 with 64 harmonics.

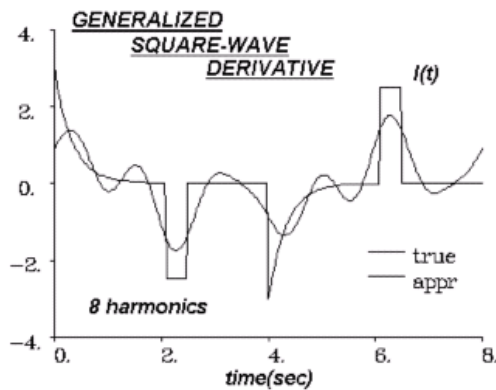


Figure 6.7 Fourier representation of the time derivative of the Generalized Square Wave of Figure 5 and 6 with 8 harmonics.

dB/dt

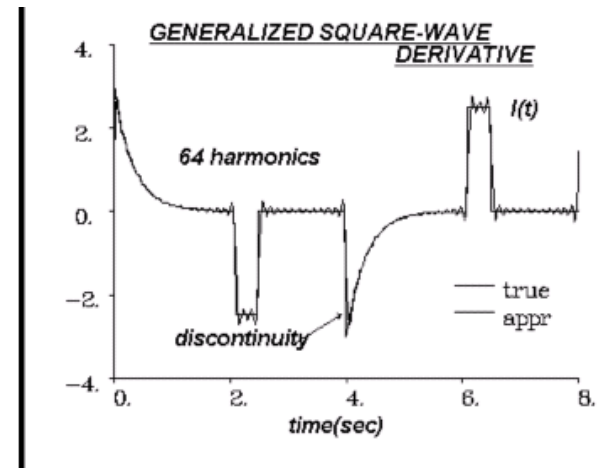


Figure 6.8 Fourier representation of derivative of the Generalized Square Wave using 64 harmonics.

Generalized square wave examples.

# The Software: FSEMTRS

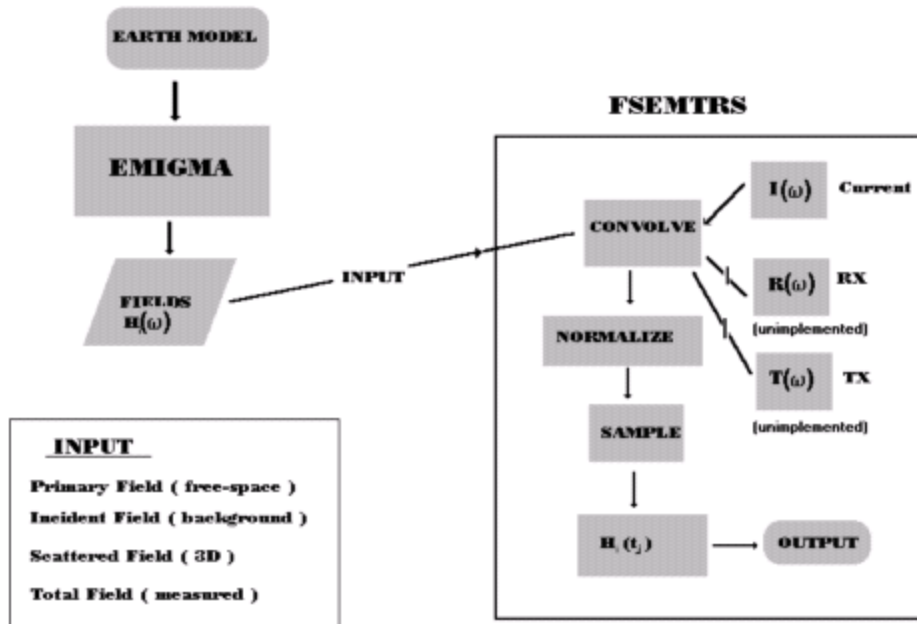
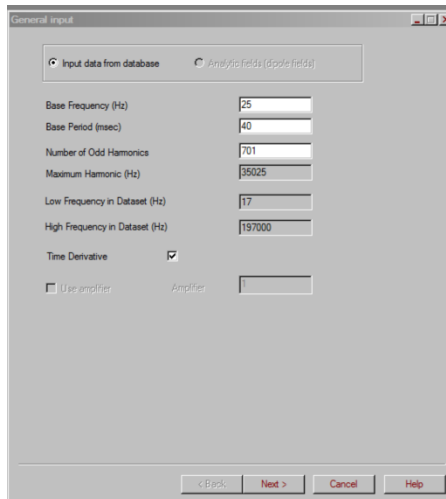


Figure 7.1

# Current Transform Instructions

Note that the following instructions are for the user controlled version of EMIGMA V10.0's FSEMTRS. A fast transform is now allowed in Forward Simulations. The fast transform option is default and performed automatically.

You control how this performed. If automatic, then the software will perform the simulation and then the transform and save only the final TEM output. In the advanced options, the intermediate Spectral data can be saved.. This will allow the frequency to time domain transform to be run automatically if either the model was built from imported time domain data or you used a previously transformed file as a starting model. Note that the following instructions apply to both the used controlled step by step version and the fast transform.



- 1) **Select spectral file** which is output from Forward Simulations consists of simulated data for a Spectral suite of frequencies i.e. you have chosen a start and an end frequency and the number of skips.
- 2) **Select the base frequency or period of your data.** This may automatically be found if a time domain survey is found by the software.
- 3) **Number of Odd Harmonics->** We have set a reasonable default of 2048 but this is not a maximum. When you adjust this number the Maximum Harmonic window is updated when you Click on that window
- 4) **The time derivative of the field is selected but may be turned off**  
If electric fields are read then time derivative is automatically de-selected. Note: If the user wishes to simulate B-fields for a time domain system then they must turn-off the derivative.
- 5) **Next>** automatically reads the file, makes correctons to settings and continues to next page. Read - reads the file makes changes but remains on this page for you to view changes or make additional changes.

*Note> If you are transforming a file that has been imported, select the read button and most selections in the transform will be detected from the file and set for you. Check each to make sure the sections are correct.*

## >>> Page 2 - FSEMTRS - Set Numerical Filters

Apply Frequency Filters ?

Low Pass Filters

Apply Low Pass Filters

Cosine Bell Low Pass Filter

Minimum Frequency for Filtering

Band-width to filter

Lancos Damping

Notch Filters

Apply Notch Filter

Filter #

Notch Frequency

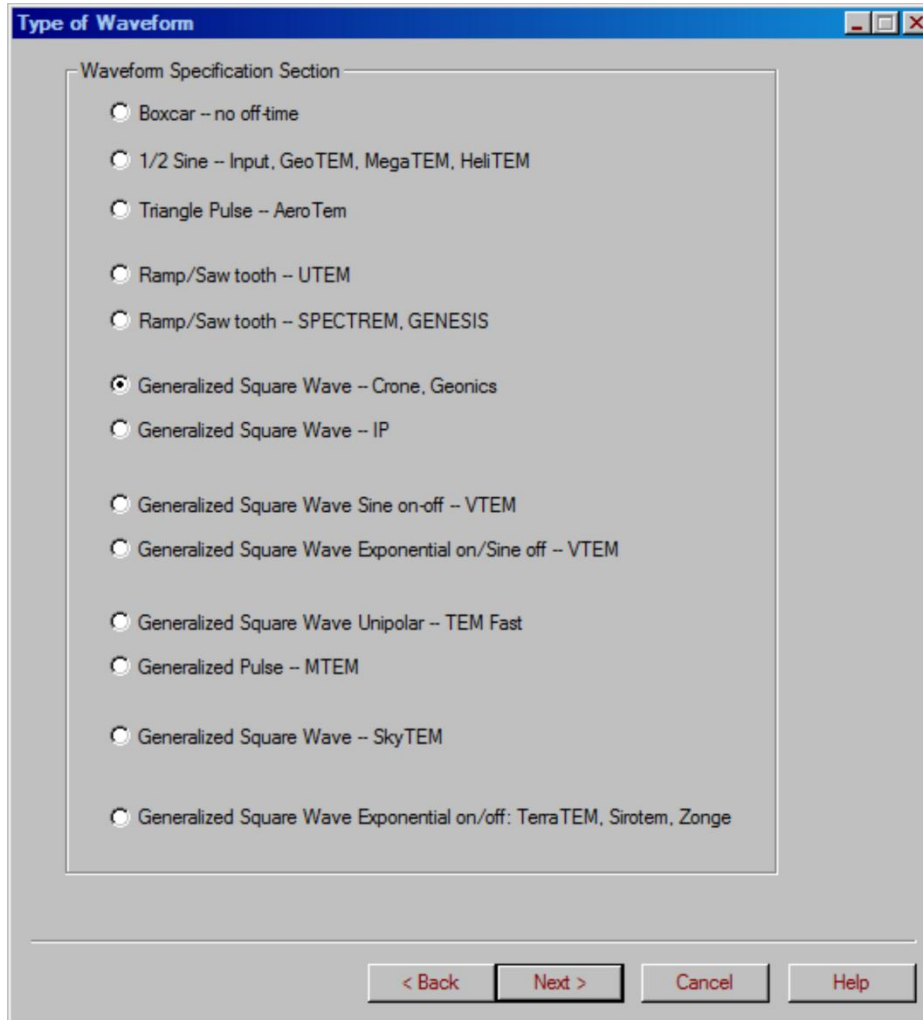
Notch-Width for Filtering

< Back   Next >   Cancel   Help

- 1) Select Low Pass and Notch Filters
- 2) No EM/IP or Resistivity system has an infinite bandwidth. Due to electrical and hardware limitations all systems either explicitly or implicitly apply some sort of Low Pass filters.
- 3) Low Pass Filters - each system has its own specific low pass filters but here we allow the setting of 2 types of low pass filters. The default filter is a Lancos filter which is a simple smooth low pass. The 2nd filter is a Cosine bell which may be selected by you.
- 4) Cosine bell - Set the initial frequency at which the low-pass begins and set its width. Beyond the initial+width frequency, no power will pass into the numerical transform.
- 5) Notch filters - These are standard notch filters with a centre point and a width. At the present time, only one notch is allowed but should you require more, please contact us and we will build a new application allowing the number that you may require.
- 6) Should you require a specialized low-pass filter, we would be happy to oblige. Please contact us with the details.



## >>> Page 3 - FSEMTRS - Set Current Waveform



### Select Your current waveform

- 1) The Boxcar is simply ON then -On with no off-time
- 2) 1/2 Sine can be tailored to suit only INPUT data, new and old GEOTEM data or Questem data or merely any waveform of the 1/2 sine type. Remember that if you are measuring with a coil you are sensing the derivative of the magnetic field and the free-space waveform of B is a half-cosine.
- 3) The AeroTem system has a small triangular pulse prior to turning off while the VTEM is turned on with a half sinewave and off similarly. Generally, it is about a 40% duty cycle.
- 4) Ramp/Saw tooth
- 5) Ramp/Saw tooth – SPRECTREM,GENESIS
- 6) The Generalized Square Wave is a very generic waveform and many systems conform to this waveform. You will be asked to set characteristics on the next page. Includes a precise current ramp - Crone, Geonics
- 7) IP - although IP utilizes the Generalized Square wave, we have made some default settings to ensure that the turn-on and turn-off characteristics can generally be ignored by the user.
- 8) Two types of VTEM waveforms
- 9) Generalized Square Wave but unipolar
- 10) Generalized Pulse – MTEM
- 11) SkyTEM – another Generalized Square Wave
- 12) Generalized Square Wave – BUT with an exponential turn-off  
- TerraTEM, Zonge, Sirotem

#### ➤ Page 4 - FSEMTRS - Set Waveform characteristics

On this page, you will select specifics of your chosen waveform. The details of this page are waveform dependent.

*NOTE: Remember that all these systems switch polarity every half-cycle. This is to allow with stacking, the removal of all DC offsets. Thus, every half-cycle is repeated in every period but with opposite polarity.*

Waveform Type: General Square Wave

Half Period (msec) 20

Exponential Rise Time-Constant (msec) 1

Turn-off Time (linear ramp) (msec) 0.175

Frequency for Sine On/Off (Hz) 1

Time to Sine On/Off (msec) 1

Off time per 1/2 cycle (msec) 5.821

Ramp Turn-off Begins at (msec) 10

Normalize

< Back Next > Cancel Help

- 1) INPUT waveform - The length of a half-cycle is displayed. You may select the width of the sine pulse while the amount of off-time is automatically updated as the width of half-cycle minus the width of the sine pulse.
- 2) UTEM - no page appears for this waveform
- 3) SPECTRUM - no page appears for this waveform.
- 4) Generalized Square Wave -
  - time constant for turn ON.
  - Ramp Time - length of the linear ramp from ON to OFF
  - OFF-Time - length of time the current is off
  - Beginning of Ramp - Half-Period - Off-time - Ramp-time
- 5) IP - can only be selected for Electric field data - please contact us if you have questions
- 6) Normalize - if you wish to Normalize your Output please check this Box

## >>> Page 5 - FSEMTRS - Set Measurement Windows

*Note: If your data contains measured field data or a previous time-domain simulation, this page is already selected as the time windows are detected in the time domain survey. Otherwise follow the instructions below.*

The screenshot shows the 'Digitizing' window with the following settings:

- Time-channel Parameter File
- Time-channel from Survey
- Center of Time Window Is:
  - Arithmetic center
  - Geometric center
- Time units in file:
  - Seconds
  - Milliseconds
- Time origin on parameter file at:
  - 1/2 Sine or Triangle Pulse:
    - Beginning of Pulse
    - End of Pulse
  - Boxcar/Generalized square wave:
    - On-Time Beginning
    - Beginning of Turn Off
    - End of Turn Off
  - Delay Time (msec): 0
- 
- Digitize time-channel values ?
- Number of points for Digitizing per Half-Cycle: 0
- Digitizing Rate (pts/sec): 0
- 

**1) Time-Channel Parameter File:** This file is a simple ASCII file containing the number of time window gates, the beginning gate of each time window and its ending gate. You will find several examples of them in your EXAMPLES directory in a the sub-directory.

**2) Specific waveform settings:** The time gates are relative to some time origin in the waveform. You may select from several suitable time origins for either the 1/2 sine or the generalized square wave. As an example, if you wish to generate ON-time measurements in a GEOTEM survey, simply select "Beginning of Sine Pulse" as the origin and set all of your window times relative to the beginning of the sine-pulse

**3) Editing the parameter file:** After selecting a time-channel file, select the Create/Edit button and you will be taken to an interface allowing you to edit this time-window information. Allowing to modify times, add new windows or delete windows and finally to save the resulting changes.

**4) Digitize Time-Channel Values:** If you desire to calculate several measurements in a given time window which are later bined and average (so-called integrated measurements), you may do so here.

## >>> Page 6 - FSEMTRS - Normalization Procedures

If your data is normalized, then you must set the normalization criteria on this page.

*NOTE: If your data contains measured data or a previous time-domain simulation, then this page is automatically set from your previous data or simulation*

*NOTE: This page varies with waveform*

Normalization for Boxcar/General Square Wave

Normalization

Divisor

Freespace  Total  Host

At Channel Time (msec)  
(To Given Time-origin)

Use Absolute Values

Normalization Component

Same Receiver  
 Multiple Components

X  Y  Z

Norm. Convention

PPM  Percent  Ratio

< Back Next > Cancel Help

### 1) 1/2 sine:

- a) Divisor :
  - This may be either Free-Space or Total Field (i.e. measured at survey height)
- b) Norm convention : - output units
- c) Normalization component:
  - your data may be normalized either to same component as measured or to Multiple components ( i.e. X,Y and Z)

### 2) UTEM data: is normalized reduced prior to normalization

- a) Reduction - subtract Ch1 or Free-space prior to normalization
- b) Divisor - divide by Ch1 or Free-space utilize the actual value of the absolute value of the divisor
- c) Normalization component - same as above
- d) Type of Normalization - Time
  - continuous time or fixed time
- e) Type of Normalization - Position
  - continuous or fixed RX
  - Note: Fixed Rx not available at present (please contact us)
- f) Normalization convention - output units

### 3) Generalized Square Wave:

- a) Divisor - divide by Ch1 Free-space, Total Field or just Host (Background) utilize the actual value of the absolute value of the divisor  
Here you must set the time which you wish to use for normalization.  
The Default for this time is during the On-time relative to your selected time-origin on the previous page
- b) Normalization component - same as above
- c) Normalization convention - output units

### 4) IP waveform: - same as (3) above

## >>> Page 7 - FSEMTRS - Output settings

The screenshot shows the 'Output' dialog box for FSEMTRS. It features a title bar with standard window controls. The main area contains several sections: 'Data set name' with a text box containing 'Transformed Time'; 'Current Status' with a text box and a 'Normalize' button; a large empty rectangular area; 'Output fields' with checkboxes for 'Total' (checked), 'Total-Freespace', 'Total-Freespace (Analytic)', 'Scattered' (checked), 'Host or Background', and 'FreeSpace'; 'Units for H-Dipole (Absolute)' with radio buttons for 'Amps/m/s [H]' and 'nanoTesla/s [B]'; 'Max frequency (Hz)' and 'Number of frequencies' with text boxes; a 'Run' button; and a 'Show Warnings' checkbox. At the bottom, there are four buttons: '< Back', 'Finish', 'Cancel', and 'Help'.

1) **Output dataset name** - we have selected a default but you may edit this

2) **Units** - this depends on the type of data being transformed

a) **Magnetic Field Data**

- for coil data the selections are

Amp/m/sec or nanotesla/sec

- if magnetic field data is required (no time derivative) then

the units are Amp/m or nanotesla/sec

b) **Electric Field Data**

- Volts or mV or if time derivative Volts/sec or mV/sec

*NOTE: If the data is normalized then these units cannot be selected*

3) **Output fields**

- Total refers to the simulated total field - Host + Scattered

- Host or Background - is the field measured in the absence of any 3D anomalies

- Total - FreeSpace - Calculated Total - Calculated FreeSpace

- Total - FreeSpace (analytic) - This field is calculated in frequency domain prior to transformation

*NOTE: When selections are complete, the proper sequence is to select the RUN button. Messages will indicate successful completion and writing of the output file. You may then return to the first page to select another file or select FINISH to close the application.*