

3 Using AutoTransient to Carry Out a Simple Transient Study

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3.1 Introduction

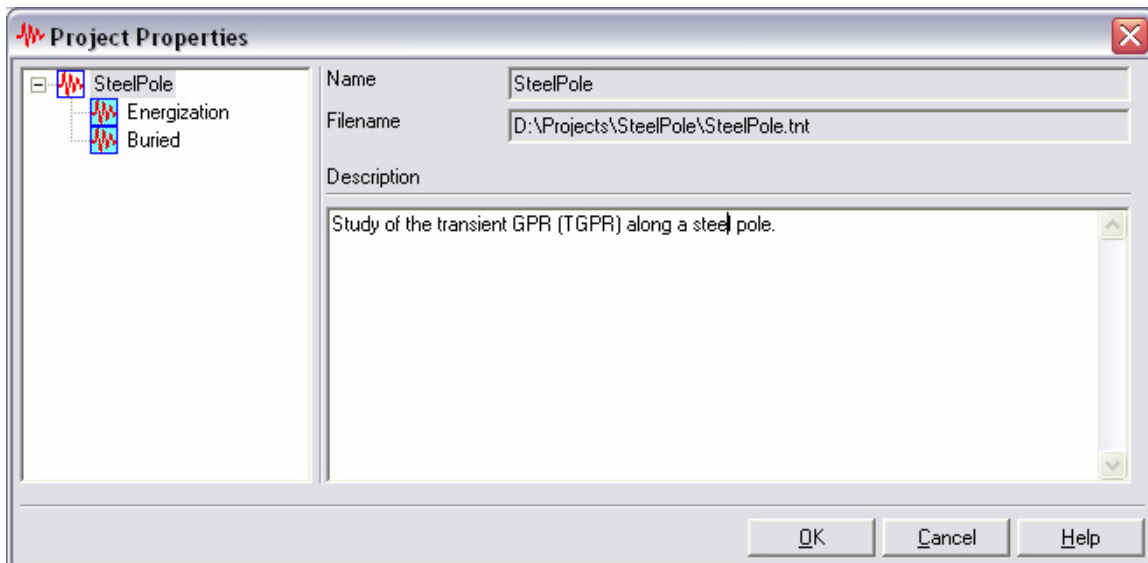
Last year at the CDEGS Users' Group Meeting we introduced an early version of AutoTransient (then known simply as "Transient"). This program simplifies the analysis of transient phenomena with HIFREQ and FFTSES by automatically running the programs, using the computation frequencies recommended by FFTSES as input to HIFREQ until some specified termination conditions are met.

This year is the first official release of this program. This article summarizes the enhancements that were made to the program since last year's Users' Group Meeting. It then goes on to describe a simple but complete transient study using AutoTransient.

3.2 AutoTransient Enhancements

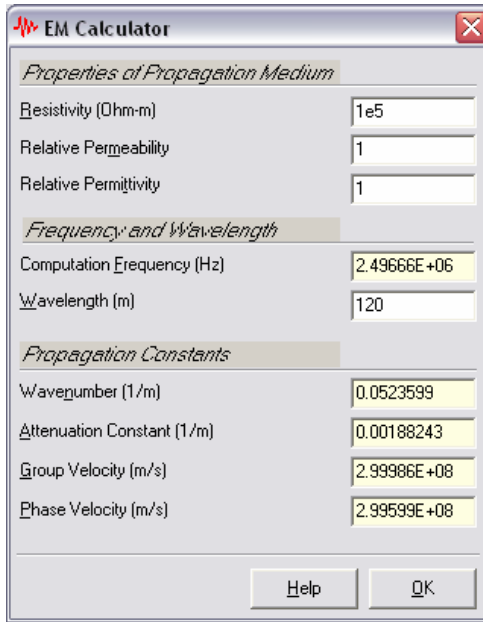
The following changes were made to the AutoTransient program since last year's CDEGS Users' Group Meeting:

- **Multiple Scenarios.** Multiple scenarios can now be defined in a project. This feature can be used simply to regroup similar studies together. More importantly, it can be used to share data between different studies.
- **Data Sharing.** Some data can be shared between different scenarios of a same project. The typical application of data sharing would be the case of a conductor network studied under several different lightning surges. When data sharing is enabled, the frequencies computed in one scenario can be re-used in another. This can reduce considerably the total computation time required to study the network response to several energizations.
- **Project Properties Dialog.** The new **Project Properties** dialog allows you to add descriptions and comments to all scenarios of a project.

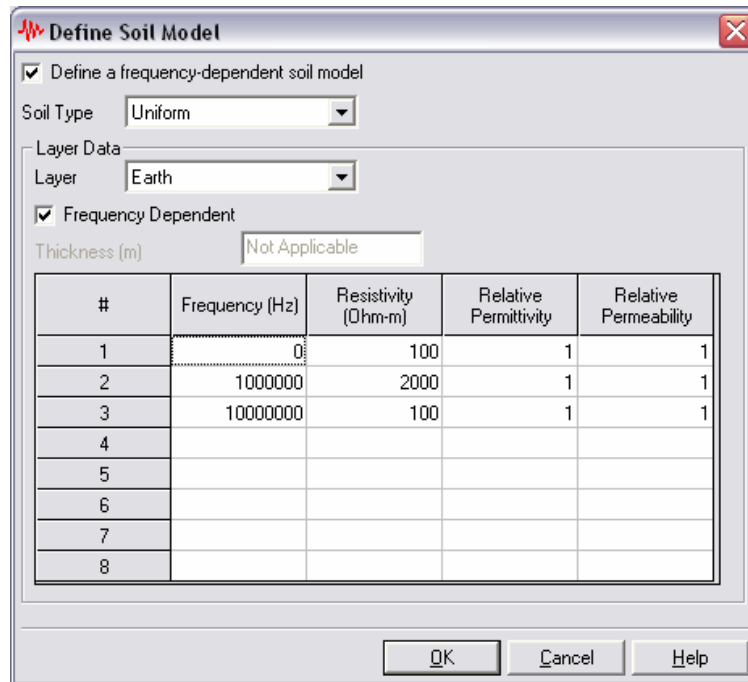


- **Access to Important Tools.** Several programs (SESCAD, Input and Output Toolbox, GrServer, ...) can now be started directly from the main interface of AutoTransient. These programs can be used to edit the input file templates, or to view the computation results.

- **The Electromagnetics Calculator Tool.** This simple tool allows you to quickly compute the propagation characteristics (wavelength, propagation speed, ...) of electromagnetic waves in a conductive medium.



- **Frequency-Dependent Soil Model.** You can now specify a soil model for which the electrical characteristics (resistivity, permittivity, permeability) of any or all layers can be a function of the computation frequency.



- **Support for Scripting.** More generally, you can specify any data in the HIFREQ input file as a function of frequency with the help of some programming (scripting). This advanced technique can have several applications. For instance, you can use this approach to easily model a travelling wave or to defined a complex frequency response for a lumped impedance.

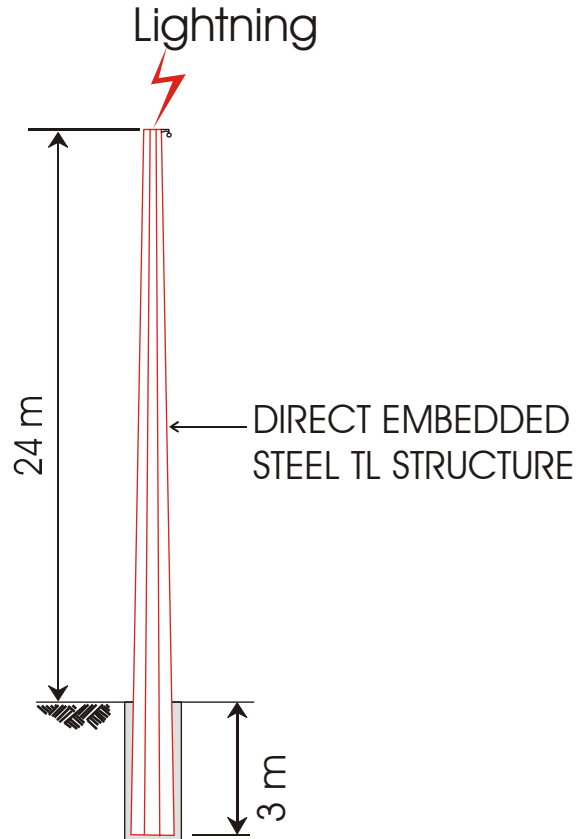
- **Documentation & Samples.** Detailed on-line help is available in all screens of the program. Also, three sample projects illustrating the capabilities of the program can now be found in the “Examples\Tools\AutoTransient” folder in your SESSoftware installation folder.

3.3 AutoTransient Example - Lightning Strike on a Pole

3.3.1 Description of the Problem

The problem studied here is that of a metallic pole being struck by lightning. We are interested in finding the Transient Ground Potential Rise (TGPR) at various points along the pole.

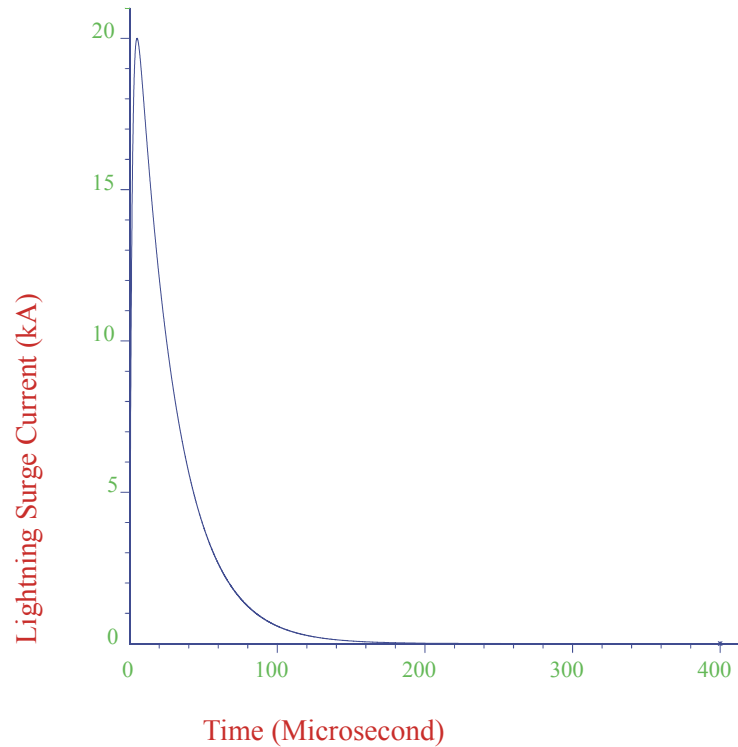
The detailed configuration of the system is shown below.



The steel pole is 27 m high with an embedded depth of 3 m. The pole is modeled as hollow steel conductors, in two sections, to simulate the taper of the pole. The conductor constituting the top section has an inner radius of 0.14 m and an outer radius of 0.2 m. The conductor in the bottom section has a 0.22 m inner radius and a 0.28 m outer radius.

The soil model is uniform, with a resistivity of 100 Ω -m.

The lightning surge used is a 5/25 μ s pulse of 20 kA peak amplitude.



3.3.2 Overview of the Steps in the Analysis

The steps required to carry out the study are as follows:

1. **Prepare the HIFREQ template file.** This file should define the conductors making up the pole, and define the energization point. It is not necessary to specify the computation frequencies, as AutoTransient automatically substitutes the proper frequencies into the template as part of the processing.
2. **Prepare the FFTSES template file.** This file should contain information regarding the input signal (i.e., the lightning surge) as well as data defining which quantities are to be computed (in this case, the conductor GPR).
3. **Create the AutoTransient project.** This consists mainly in defining the name and location of the project files, and in importing the template files.
4. **Run AutoTransient.** This creates all necessary output files.
5. **Examine the Results.** Use Output Toolbox, GrServer or FFT21Data to look at the computation results.

In the remaining sections, these steps are described in greater detail for the above example.

The files that are generated in this example are available on your CD-ROM, in the folder “Users Group 2004\Input Files\AutoTransient”.

3.3.3 Preparing the HIFREQ Template File

Overview

The HIFREQ template file is a normal HIFREQ input file (HI_*.F05) that is run repeatedly (at several frequencies) by AutoTransient to generate the frequency response of the conductor network. This file defines

the geometry of the network conductors, the characteristics of the conductors and the locations at which the conductors are energized.

This file can be prepared with either the Input Toolbox module of CDEGS or with the SESCAD. While it is often advantageous to use SESCAD for larger, more complex networks, the present case is relatively simple; we will use the Input Toolbox to enter the data. To begin, start CDEGS with the JobID “Template” in any working directory, and load Input Toolbox for HIFREQ.

Defining the Network Geometry

The geometry of the network being modelled in this example is quite simple: the network consists of a two vertical conductors of different radii. These conductors must be subdivided into a few segments in order for the program to calculate the current distribution in the network properly. An important aspect of a transient study is to determine an appropriate length for the segments.

A good rule of thumb is to make sure that the length of the segments doesn't exceed $1/6^{\text{th}}$ of the wavelength of electromagnetic propagation in the medium of interest, at the maximum frequency contributing significantly to the results. For a lightning study such as this one, a frequency of 1 MHz is usually acceptable since most of the energy delivered by a lightning strike is found at frequencies lower than this.

To help translate this value into a maximum segment length for HIFREQ, AutoTransient offers a simple tool that computes various electromagnetic propagation constants of an electrical medium of given characteristics. This tool can be accessed from the **Tools | Electromagnetics Calculator** menu item in AutoTransient.

To compute the maximum segment length:

1. Start AutoTransient (**Start | All Programs | SES Software 2004 | Tools | AutoTransient**).
2. Select the **Tools | Electromagnetics Calculator** menu item.
3. Enter '1e6' (1 MHz) in the **Computation Frequency** field.

The **Wavelength** field shows the value of the propagation wavelength in a 100 Ω -m soil, namely 31.5 m. A similar calculation using a very large value for the resistivity (say, 10^{10}) gives a wavelength of about 300 m in the air. Therefore, we should specify conductor segments no longer than about 5 m. To be on the safe side, we will use segments of 3 m above ground, and of 1.5 m in the soil.

Another important consideration when defining the coordinates of the conductors in the HIFREQ model is the relationship between the energization of the conductors and their orientation. The energization current is always assumed to flow from the origin of a conductor towards the end. Therefore, for an energization at the top of the tower, it is important to orient the conductors so that the origin is higher than the end.

These considerations lead to the following table of conductor data:

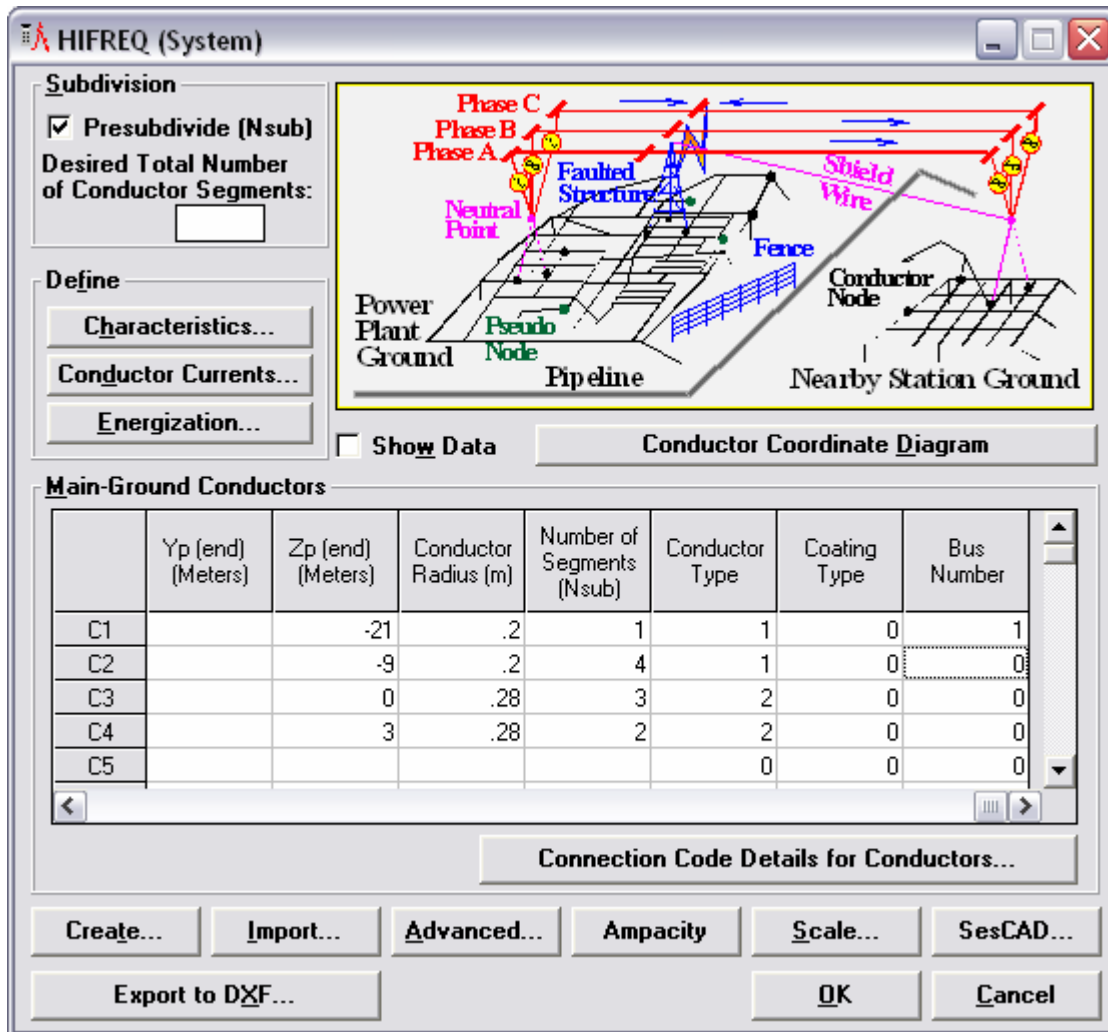
Zs (Origin)	Zp (End)	Conductor Radius	Number of Segments	Conductor Type	Bus Number
-24	-21	0.2	1	1	1
-21	-9	0.2	4	1	0
-9	0	0.28	3	2	0
0	3	0.28	2	2	0

To enter the conductor data:

1. Click on **System** in the HIFREQ main screen of Input Toolbox.
2. Enter the data of the above table in the **Main-Ground Conductors** data grid. Fill only the columns shown in the table, and leave the remaining data to their default value.

Note the following:

- The Z coordinates is negative going up in HIFREQ. Hence, the conductors from top to bottom in the table are physically organized from top to bottom as well, and their origin is higher than their end.
- The first segment is energized (it has a **Bus Number** of 1), and its orientation is from top to bottom, as required.
- The inner radius of the conductor is not specified directly in this table. Rather, it is specified indirectly through the **Conductor Type** code assigned to the conductors. The actual value of the inner radius will be specified in the next section, when defining the characteristics of the conductors.



Defining the Characteristics of the Conductors

There are two types of conductors in the network, with different inner and outer radii. Both are made of steel, with a resistivity 13 times higher than that of annealed copper. These types were identified as types 1 and 2 in the previous section. This section shows how to define the characteristics of those two conductor types.

The following table shows the required data:

Identification	Relative Resistivity	Internal Radius
Top	13	0.14
Bottom	13	0.22

To define the conductor types:

1. Click on **Characteristics** from the **HIFREQ (System)** screen.
2. Enter the data shown in the above table in the corresponding columns of the **Conductor Types** data grid. Click **OK**.



Defining the Network Energization

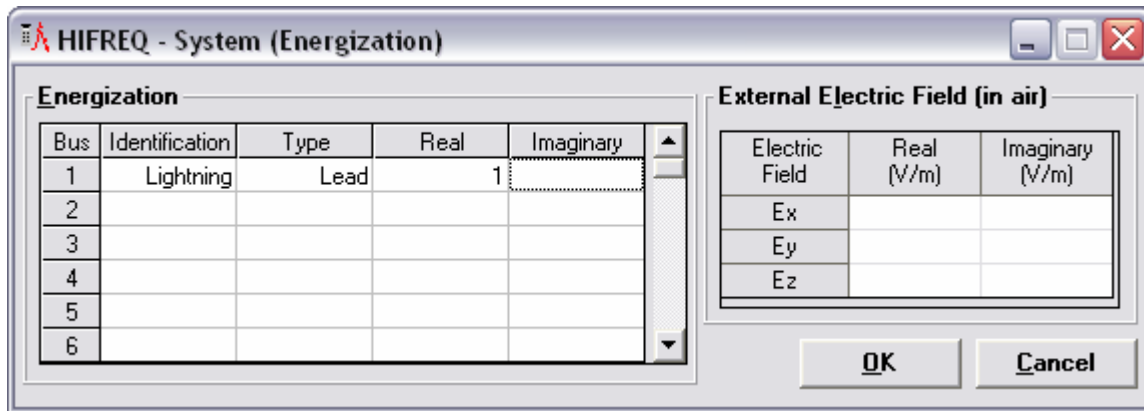
The first conductor in the network was defined to be energized by specifying that it is connected to Bus #1. This section shows how to define the properties of this energization.

In a transient study, it is usually preferable to specify a unit energization strength, and let FFTSES rescale the results appropriately at all frequencies to get the proper network response. In fact, AutoTransient issues a warning if this condition is not respected, or if there are several energizations defined in the HIFREQ file.

Therefore, what we want is to specify an energization current of 1 Amp. This can be done with a LEAD energization in HIFREQ.

To define an energization of 1 Amp:

1. Click on **Energization** in the **HIFREQ (System)** screen.
2. Enter the following data in the first row of the **Energization** data grid:
 - o **Identification:** Lightning
 - o **Type:** Lead
 - o **Real:** 1
3. Click **OK**.



Defining the Requested Computations

We are interested in computing the transient GPR on the pole. By default, HIFREQ computes the conductor GPR; therefore, there is nothing to specify. If other quantities (earth potential, electric or magnetic fields) were desired, then the **Computations** screen of HIFREQ should be used to request them.

Saving the File

To complete the data entry for the HIFREQ template file:

1. Click **OK** in the **HIFREQ (System)** screen.
2. Click **OK/Submit** in the HIFREQ main screen. The HIFREQ template file is now saved as HI_Template.F05 in your working directory.

3.3.4 Preparing the FFTSES Template File

Overview

The FFTSES template file is an ordinary FFTSES input file (FT_*.F05) that is used by AutoTransient to generate the time-domain input surge signal and to compute its frequency spectrum. It is also used to extract the frequency response of the network from the HIFREQ computation database files, and to convert this frequency-domain response into a time-domain response.

The simplest way to prepare the FFTSES template file is to use the Input Toolbox module of CDEGS. To begin, start CDEGS with the JobID “Template” in the same working directory as for the HIFREQ file, and load Input Toolbox for FFTSES.

Specifying the Lightning Surge

This section shows how to enter the data for the lightning surge described earlier.

There are two main aspects to consider when defining a lightning surge or any other time-domain input signal:

1. The shape and amplitude of the surge.
2. The desired time and frequency resolution.

Shape and Amplitude of the Surge

There are several built-in wave forms for the input signal in FFTSES. The desired surge (5/25 μs pulse of 20 kA peak amplitude) can easily be specified using the “Standard Surge” option. This type of surge defines a wave shape with a specified rise-time, decay time and amplitude; the signal is expressed as a double exponential function.

To specify the shape of the input surge:

1. In the main screen of FFTSES, click **Computations**. In the **FFTSES (Computations)** screen, a “Standard Surge” is already selected by default (in the **Type** drop-down menu under **Surge Type and Parameters**).
2. Type ‘20000’ for the **Maximum Magnitude**.
3. Type ‘25’ under **Fraction Time**.

Time and Frequency Resolution

The FFTSES program analyses the input signal by discretizing it in the time domain. The result of the analysis is the (discrete) frequency spectrum of the signal. The number of samples used when discretizing the signal determines the time resolution, i.e. the shortest event in time that can be modelled with the program. In FFTSES, this number must be a power of 2, and is expressed as the **Sampling Exponent**.

In principle, this number should be made as large as possible. However, the resulting database size grows very fast as a function of the **Sampling Exponent**. In this case, we will use 11 for this value (corresponding to 2048 samples).

Two criteria govern the selection of the **Time Duration** parameter:

- The **Time Duration** determines the *frequency resolution* (i.e., the difference in frequency between two successive points in the frequency spectrum). The precise relationship is $\Delta f = 1/T$.
- The **Time Duration** should be selected so that the input signal is very small at the end of the time window.

To improve the frequency resolution, the time duration of this signal should be increased. Note that this automatically *reduces* the time-domain resolution (T/N , where N is the number of samples). Therefore, the number of samples should be increased at the same time, to compensate.

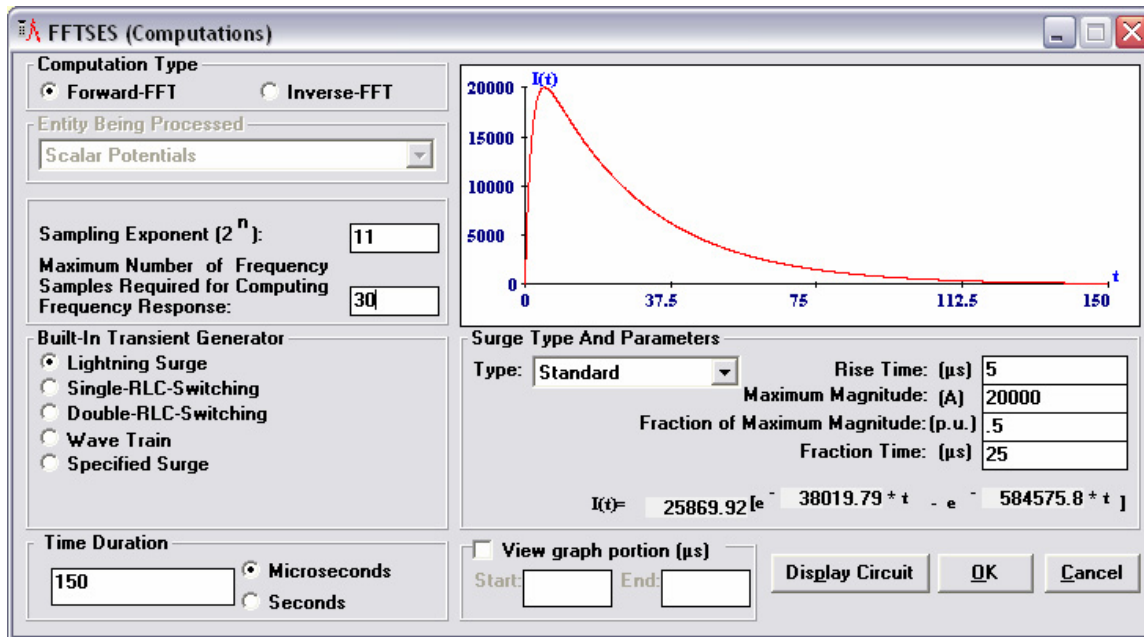
In the current study, a **Time Duration** of 150 μs will be used.

To specify the time duration and resolution properties of the signal:

1. The **Time Duration** field is already at the correct value (‘150’ μs)
2. The **Sampling Exponent** field should be set to ‘12’.

Summary

Once all the data is entered, the FFTSES (Computations) screen should look as follows.



Requesting the Desired Computations

This section shows how to select the data that should be collected and analyzed by FFTSES. This is also done in the **FFTSES (Computations)** screen, using the **Inverse-FFT** option.

The two most important points to remember here are:

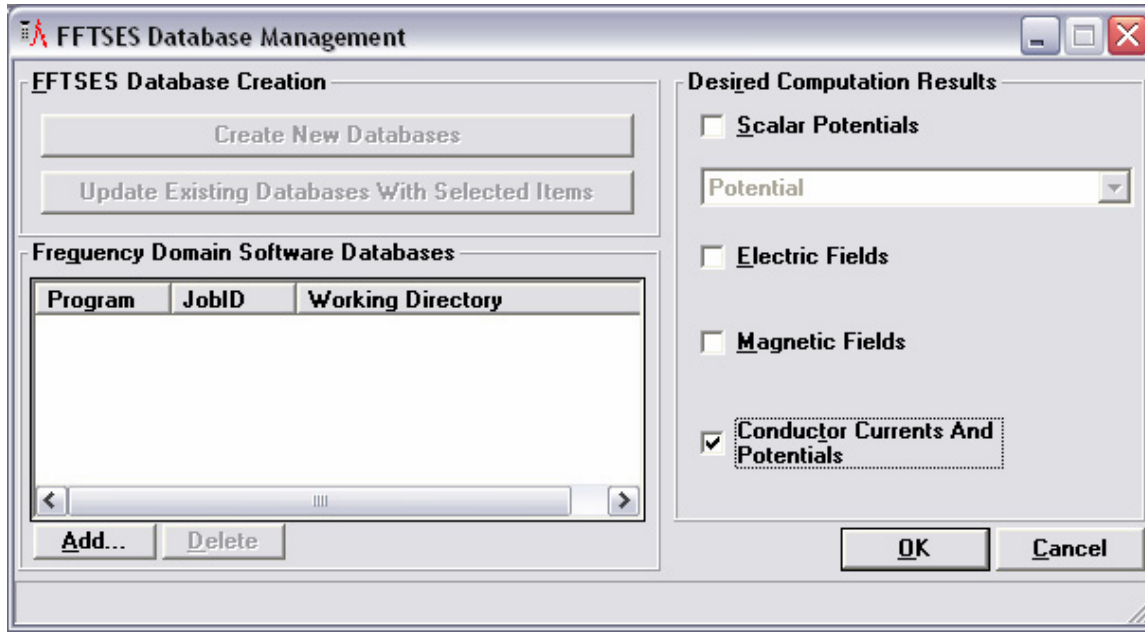
1. Make sure to only request quantities that were also requested in the HIFREQ template.
2. Refrain from requesting data from several points or segments simultaneously. This is because it complicates the analysis of the response curves, and may cause FFTSES to recommend an excessively large number of computation frequencies. It is recommended to process a single point or segment at a time.

AutoTransient monitors Item 1, and will warn you (or forbid running the case) if there is a mismatch between the computation quantities requested in HIFREQ and FFTSES. The program also issues a warning if Item 2 is not respected, although running is allowed in this case.

In this study, we are interested in the GPR of the conductors. We will therefore request the computation of the GPR for the conductor segment that is directly energized, i.e. segment #1.

To request the computation of the GPR:

1. On the **FFTSES (Computations)** screen, select the **Inverse-FFT** option under **Computation Type**.
2. Select **GPR of Conductor Segment** in the **Entity Being Processed** drop-down menu.
3. Under **Specify Input Type**, select **Extract from Database**.
4. Click on **Database Management**.
5. In the **FFTSES Database Management** screen, check the **Conductor Currents and Potential** option, and click **OK**.

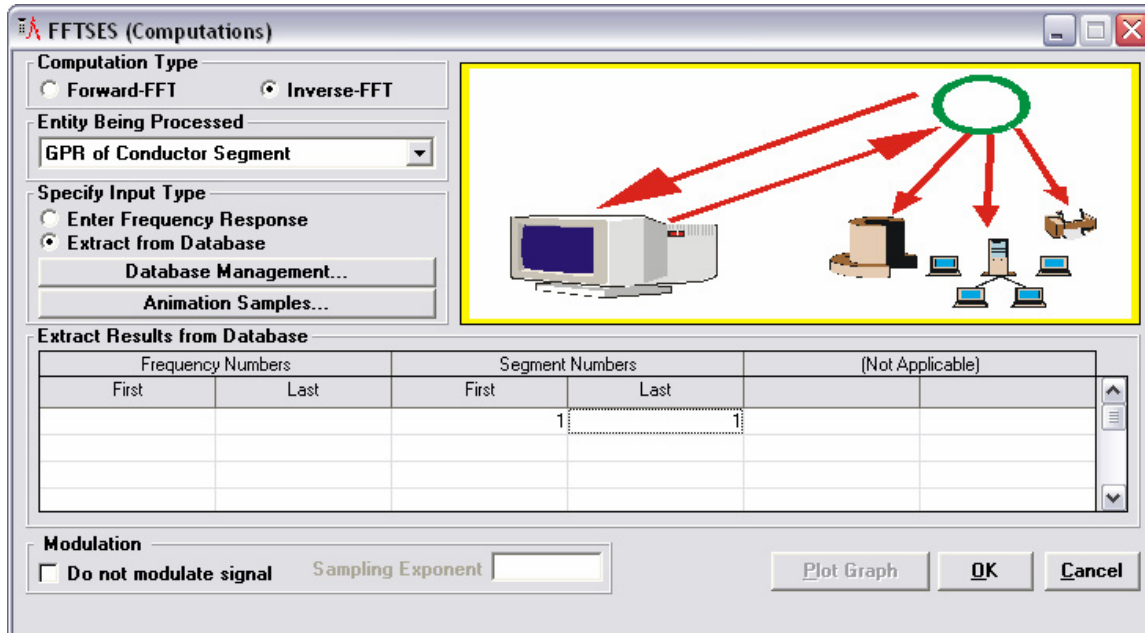


Note that it is not necessary to specify anything in the **FFTSES Database Creation** section of this screen: AutoTransient automatically manages the databases. Note also that it is possible to select several different **Desired Computation Results** simultaneously, as long as the corresponding quantities are also requested in HIFREQ. This would not cause the recommended frequencies problem described above.

To request computations for segment # 1:

1. Enter '1' in both the **First** and **Last** sub-columns of the **Segment Numbers** column in the **Extract Results from Database** data grid.

Note that it isn't necessary to specify a range of frequency, as AutoTransient automatically determines the relevant frequency range.



Saving the File

To complete the data entry for the FFTSES template file:

1. Click **OK** in the **FFTSES (Computations)** screen.
2. Click **OK/Submit** in the FFTSES main screen. The FFTSES template file is now saved as FT_Template.F05 in your working directory.
3. Click **Submit All (SICL)** in the Input Toolbox screen to close Input Toolbox.

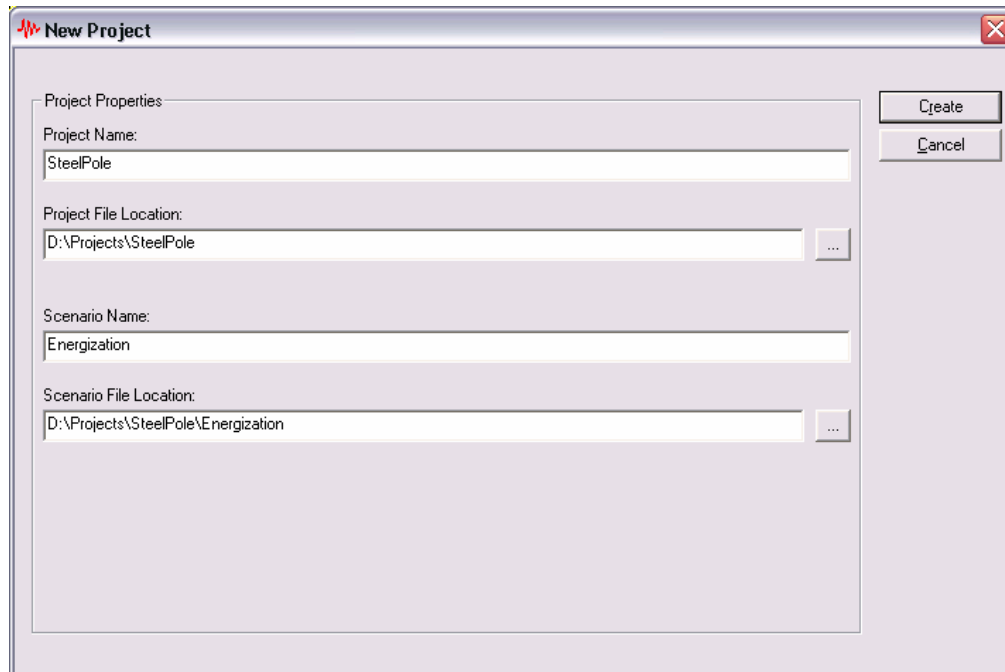
3.3.5 Creating the AutoTransient Project

The data used by AutoTransient is organized into scenarios and project. An AutoTransient scenario contains all the data required to carry out a complete transient study with HIFREQ and FFTSES, including the template files for those programs. An AutoTransient project is simply a collection of related scenarios.

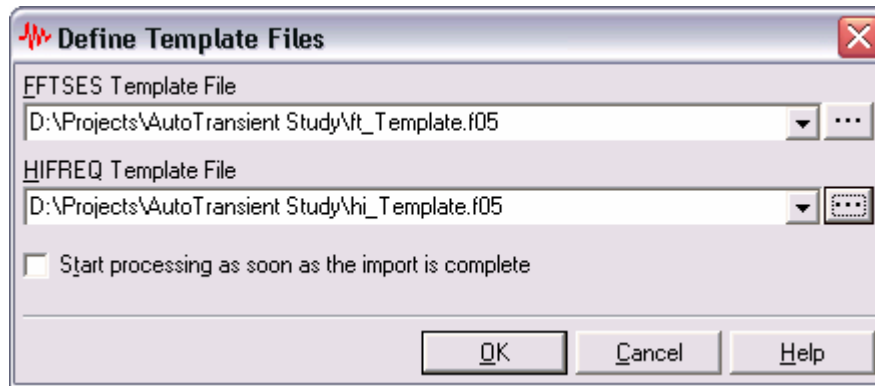
Before anything can be done with AutoTransient, a new project must be created, or an existing one must be opened. The HIFREQ and FFTSES template files for the transient study should be ready before creating the new project (or more generally a new scenario), since you are prompted for the location of those files as part of the creation of the scenario.

To create a new AutoTransient project:

1. In AutoTransient, select **File | New Project**.
2. In the **New Project** dialog, enter (or browse to) a folder for the **Project File Location**. In this example, this is set to “D:\Projects”.
3. Enter ‘SteelPole’ under **Project Name**. Note that the **Project File Location** automatically updates to “D:\Projects\SteelPole”.
4. Enter ‘Energization’ under **Scenario Name**. (Since we are studying the GPR of segment #1, i.e. the energized segment). Note that the **Scenario File Location** automatically updates to “D:\Projects\SteelPole\Energization”.



5. Click **Create**.
6. In the **Define Template Files** dialog, enter or browse to the filename of the FFTSES and the HIFREQ template files created in the previous sections, then click **OK**.



The AutoTransient project is now ready to use.

3.3.6 Editing Scenario Data

Most of the data required in a transient analysis is defined in the FFTSES and HIFREQ template files. Very little data needs to be defined in AutoTransient, and in most cases, it is unnecessary to enter any data in the program other than the paths to the template files.

The following data can be edited in AutoTransient:

- Description of the project and scenarios, and other comments. (Use **Project | Properties**).
- Options controlling how the automated process is carried out. (Use **Project | Edit Scenario Processing Options**).
- Selection of the database files, output files and plot files that should be kept at the end of a run. (Use **Project | Edit Scenario File Management Options**).

Consult the program's on-line help for more details.

3.3.7 Running the Analysis

To run the scenario select **Project | Start Processing**.

Messages are issued on a regular basis in the **Program Output** and **Messages** sections of the main screen to keep you posted on the progress of the computations.

NOTE: While the program is processing, it is advisable to avoid using any engineering CDEGS programs or Output Toolbox, as these programs could interfere with AutoTransient and cause serious malfunctions.

The processing of this example should take a few minutes on most computers. For larger cases, the processing could take several hours, even days. AutoTransient can allow you to stop and restart the processing with minimal loss of data by saving the state of the computations to disk when stopping. Consult the on-line help for the **Stop Processing** feature for more details.

During the processing, the program copies selected output and database files to the *Results* sub-folder of the scenario folder ("D:\Projects\SteelPole\Energization\Results", in the present case). The files in this folder can be used to visualize the results. Some important database files are also copied to the *History* sub-folder of the scenario folder. These files are used when the scenario needs to be restarted, and can also be used to continue the analysis manually, if desired.

3.3.8 Examining the Results

Once the scenario has finished running, you can examine the computation results stored in the *Results* and *History* folders using Output Toolbox, GrServer or FFT21Data. You can launch these programs directly from AutoTransient using the functions of the **Tools** menu.

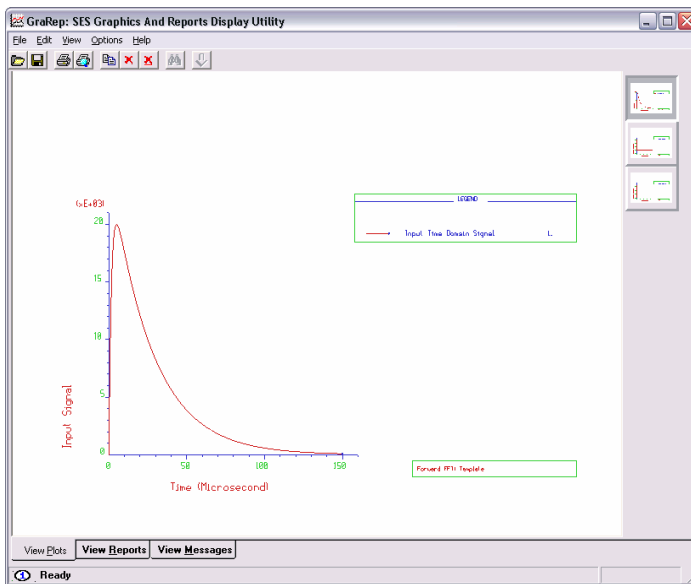
There are three main types of results that you can examine:

- **Forward FFTSES Results:** (With Output Toolbox) Shows the characteristics of the input surge and of its frequency spectrum.
- **HIFREQ Results:** (With Output Toolbox or GrServer) Displays the response of the conductor network at a given frequency.
- **Inverse FFTSES:** (With Output Toolbox) Displays the frequency spectrum of selected parts of the network (or observation points) as well as its time-domain response.

You can also display animation-style plots of the time-domain results with FFT21Data.

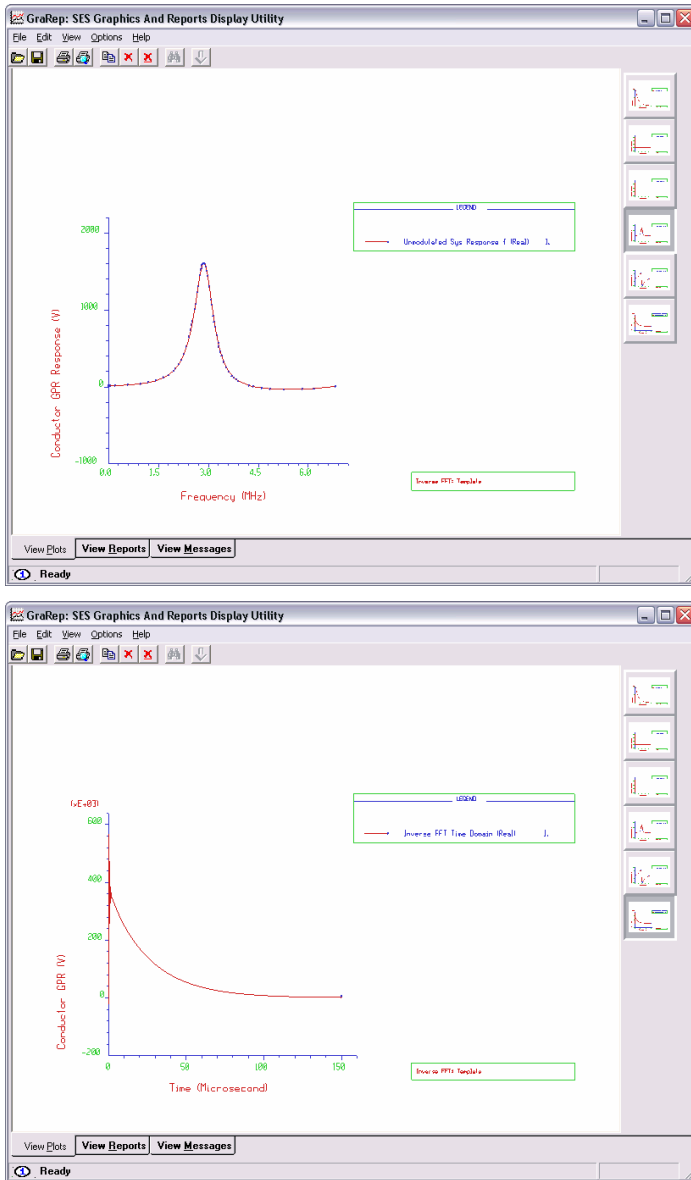
To examine the Forward FFTSES Results:

1. In AutoTransient, select **Tools | View/Plot FFTSES Forward Results | With Output Toolbox**. This will start both CDEGS and Output Toolbox, and load the computation database for the Forward FFTSES operation of the scenario.
2. In the **FFTSES (Graphics)** screen of Output Toolbox, click **Draw**. This generates 3 plots (displayed in GraRep): the time-domain surge and the real and imaginary part of the frequency spectrum of the surge.
3. Click **OK** to close Output Toolbox and CDEGS.



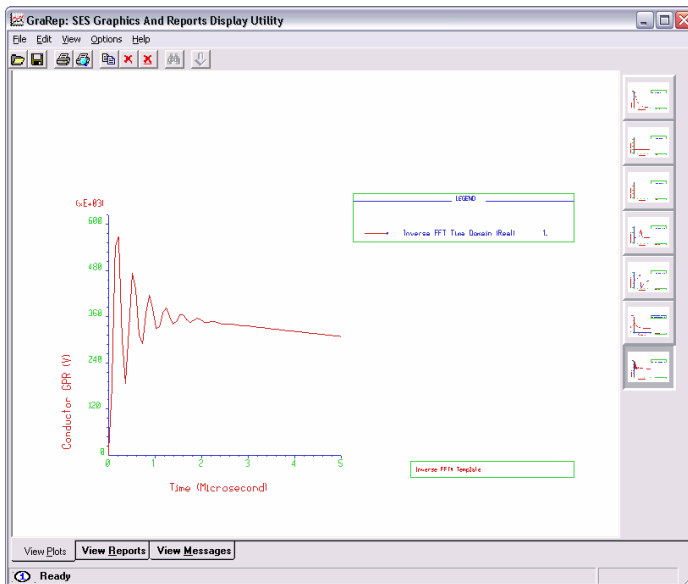
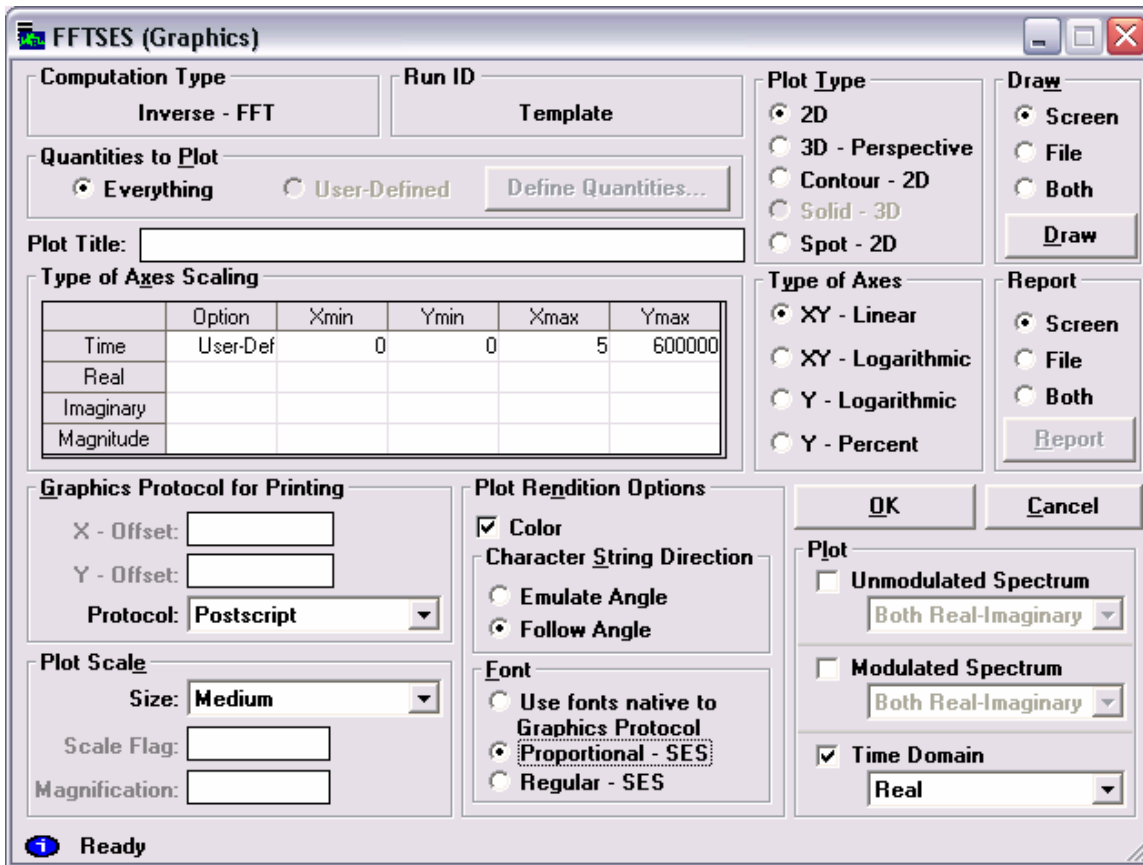
To examine the Inverse FFTSES Results:

1. In AutoTransient, select **Tools | View/Plot FFTSES Inverse Results | With Output Toolbox**. This will start both CDEGS and Output Toolbox, and load the computation database for the last Inverse FFTSES operation of the scenario.
2. In the **FFTSES (Graphics)** screen of Output Toolbox, click **Draw**. Again, this generates 3 plots in GraRep: the real and imaginary parts of the frequency spectrum of the GPR of segment #1 in the network, and its time-domain response. (The pictures below show the real part of the frequency response, which exhibits a resonance around 3 MHz, and the time-domain response).



To get a better view of the early time-domain response:

1. Clear the **Unmodulated Spectrum** check-box, since we only want the time-domain response of the network.
2. Enter the data shown in the screen below for the **Type of Axes Scaling**.
3. Click **Draw**.



Click **OK** to close Output Toolbox and CDEGS.

3.3.9 Continuing the Analysis

The files in the *History* sub-folder of the scenario folder can be used to restart the analysis, either manually or with AutoTransient. As an example, this section walks you through the steps needed to compute the transient GPR at segments 4 and 10 with AutoTransient. These segments are the two segments of the pole that are buried.

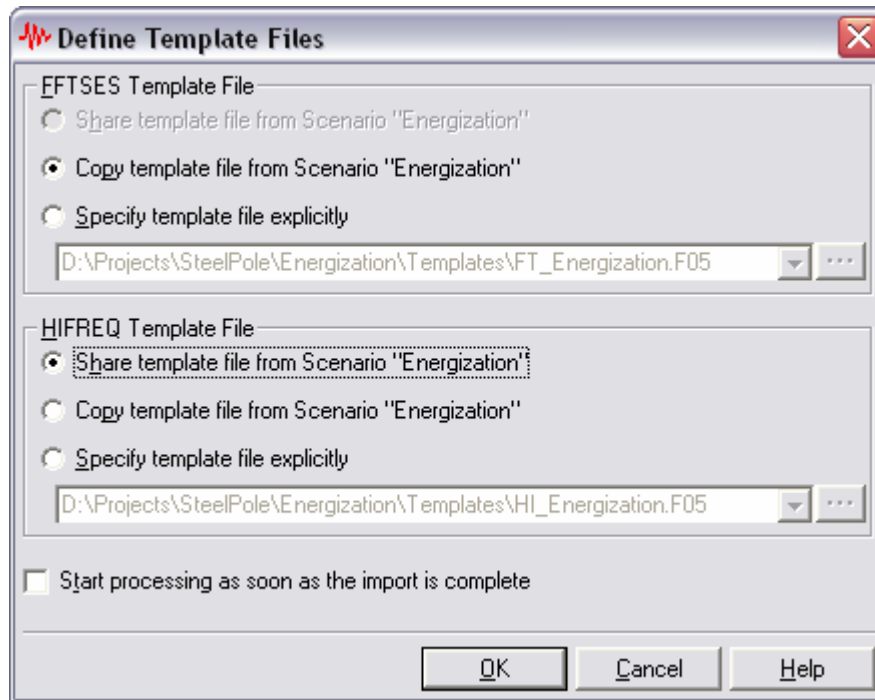
The procedure is in three main steps:

1. Create a new AutoTransient Scenario. To reduce the computation time, the results that were already computed in the previous scenario are used as a starting point.
2. Modify the FFTSES template to request segments 4 and 10.
3. Process the scenario, and examine the results.

Creating a Second Scenario

To create a second scenario in the project:

1. In AutoTransient, select **Project | New Scenario**.
2. In the **New Scenario** dialog, enter ‘Buried’ under **Scenario Name**. Note that the **Scenario File Location** automatically updates to “D:\Projects\SteelPole\Buried”. Note also that the **Reference Scenario** is set to the “Energization” scenario by default. This is important in the next step. Click **Create**.
3. In the **Define Template Files** dialog, select **Copy template file from Scenario “Energization”** under **FFTSES Template File**, and select **Share template file from Scenario “Energization”**. Click **OK**.



A second scenario is created in file “Buried.tns”. Initially, this scenario uses the same FFTSES template file as the first scenario. Also, this new scenario shares the HIFREQ template (and HIFREQ databases) with the first scenario.

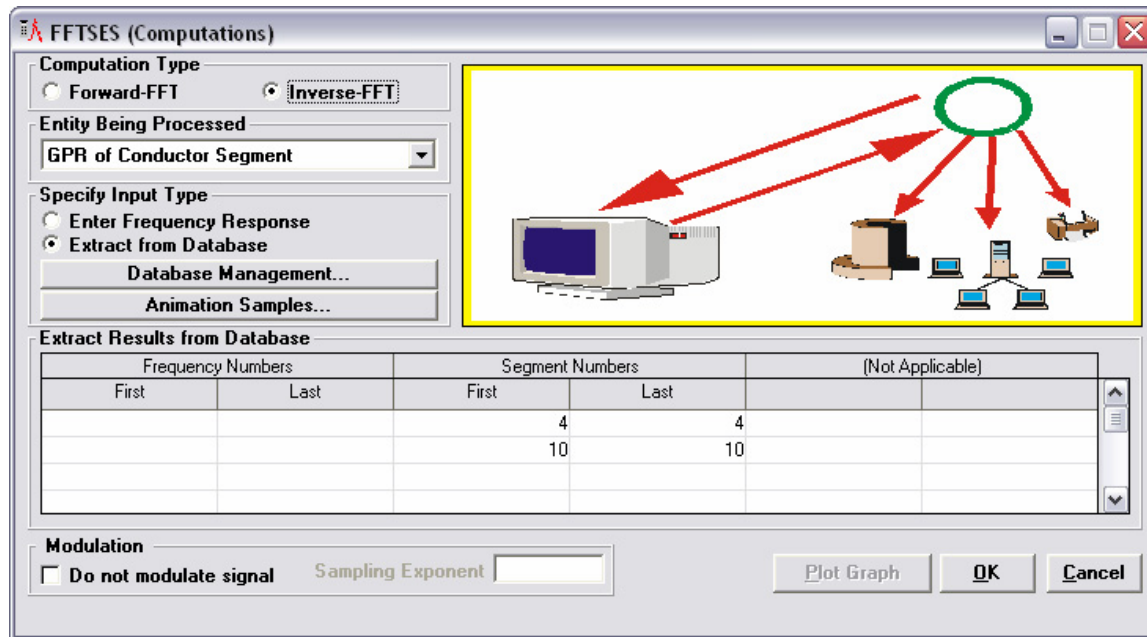
Modifying the FFTSES Template

This section shows how to modify the FFTSES template file to request the GPR for segments #4 and #10.

To modify the FFTSES template file:

1. In AutoTransient, select **Tools | Edit FFTSES Template File**. This loads the FFTSES template file in Input Toolbox, and allows you to edit it.

- In the FFTSES main screen, click **Computations**.
- In the **Computations** screen, enter two lines in the **Extract Results from Database** data grid; the first having both the **First** and **Last** sub-columns of the **Segment Numbers** column set to 4, and the second with both those columns set to 10. Click **OK**.



- Click **OK/Submit** on the FFTSES main screen in Input Toolbox, then click on Submit All on the Toolbox itself to save the changes.

Processing the “Buried” Scenario

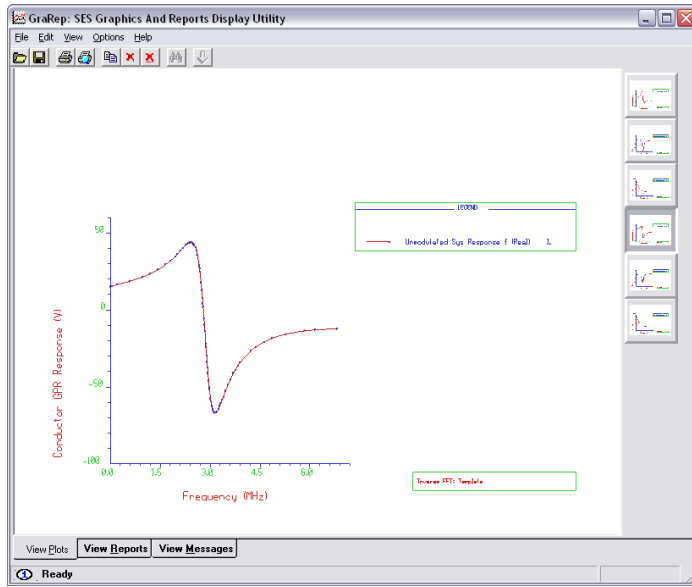
To process the scenario:

- In AutoTransient, click **Project | Start Processing**.

The program recomputes the FFTSES databases for the new points, based on the existing HIFREQ results. It then proceeds as usual, namely it detects if any more computation frequencies are required, and if so, runs HIFREQ at those frequencies.

In this example, two extra HIFREQ runs are required (for a total of 12 frequencies).

The results can be examined as before. The following plot shows the real part of the frequency-domain response of segment # 10.



3.4 Conclusion

This concludes the study of a transient behaviour of a steel pole using AutoTransient. To save the project, select **File | Save Project**.

This example used only some of the features of the program. More powerful features are available, particularly as regards the specification of frequency-dependent parameters in the conductor network. Consult the program's on-line help for more details.