Phoenix Geophysics Limited

Time Series To Fourier Coefficient Program – TSTOFT Program Description

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PHOENIX GEOPHYSICS

TIME SERIES TO FOURIER COEFFICIENT PROGRAM - TSTOFT

PROGRAM DESCRIPTION

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1. INTRODUCTION

The TSTOFT program calculates estimates of the magnetotelluric signal amplitude and phase ("Fourier coefficients" or "DFTs") as a function of time and frequency. It corrects for system parameters and responses so that the estimates are as nearly as possible independent of the measurement system. The program defines time windows and center frequencies in a way which is independent of the sampling rate or data acquisition start time, so that data from two different acquisitions is easily combined in subsequent processing.

A cascade decimation algorithm is used on each input time series, so that in each octave, the time interval between estimates is twice that used in the next higher octave. The user can specify the number of frequencies in each octave. These can be distributed in three different schemes: linearly related frequencies in each octave; harmonically related frequencies in each octave; and a "V-5 equivalent" scheme which is limited to two frequencies per octave. The number of frequencies calculated in each octave is the same, and the frequency set in that octave is obtained by halving the frequencies in the next higher octave; except that the number of frequencies in the highest octave may be different from the other octaves.

TSTOFT inputs an Ascii parameter (.PFT) file, the parameter table (.TBL) file generated during data acquisition, the MTU calibration (.CLB) file generated in the MTU box calibration mode, optionally the magnetic sensor calibration (.CLC) files generated in the MTU coil calibration mode, and one or all of the time series (.TSH. TSL, or .TS*n*) files. It outputs one or more Fourier coefficient (.FC*n*) files.

TSTOFT is a Windows 95 character mode application.

2. RUNNING TSTOFT

2.1 Command line

The TSTOFT program can be run using the following command line. Order of the parameters is not significant. Fields in italics are to be filled in with actual values determined by the user. Parentheses [ ] indicate optional parameters.

`TSTOFT [`*`pfile`*`.PFT]` *`tfile`*`.TBL [`*`spath`*`\*.TS[n]] [`*`bpath`*`\*.CLB] [`*`spath`*`\*.CLC] [`*`ffile`*`.FC[n]]`

where

pfile.PFT is the path and name of the parameter file. If this parameter is omitted, the default file name DEFAULT.PFT is used.

tfile.TBL the path and name of the MTU parameter table file.

*spath**.TS[n] is the path for the MTU time series files. Only the path is specified, with "*" in place of the actual file name, and the optional [n] is ignored.

*bpath**.CLB is the path for the MTU box calibration file. Only the path is specified, with "*" in place of the actual file name. The actual .CLB file name must be the serial number of the MTU box as it is stored in the .TBL file.

*spath**.CLC is the path for the MTU sensor calibration files. Only the path is specified, with "*" in place of the actual file name. The actual .CLC file names must be the serial numbers of the sensors as they are stored in the .TBL file. If FldType = 0 is specified in the .PFT file, no sensor calibration files are needed.

ffile.FC[n] is the path and name of the output Fourier coefficient files.

The Phoenix "Windows Off Line Startup Table Editor" can be used to examine the .TBL file to determine the box serial number, sensor serial numbers, dipole lengths, and other parameters, if necessary.

If an appropriate DEFAULT.PFC file is set up, the SYSCAL program can also be run under Windows 95 by dragging and dropping a .TBL file icon on to the program icon.

After successful completion, the SYSCAL program will display the message "Complete - Code 0". Other completion code values indicate an abnormal termination. (See Table 2.)

2.2 Directory defaults and search order

The program first attempts to open a .PFT processing parameter file. It first checks for a .PFT file name on the command line. If there is none, DEFAULT.PFT is assumed. The program attempts to open the file. If it is not successful, it checks for the same file name using the path specified by .TBL field; then the path specified by .TSn field; and finally the path of the TSTOFT program itself. When it finds a .PFT file, it opens the file and reads it.

To obtain the path and file name of the .TBL and .TSn files, the program checks first for a SiteFile line in the .PFT file, then for a .TBL field on the command line; then for a .TSn field on the command line. The file name extension is ignored by the SiteFile command.

To obtain the path of the .CLB box calibration file, the program checks first for a BoxCalPath line in the .PFT file (the path must end in : or \); then for a .CLB field on the command line; then for a .TSn field on the command line.

To obtain the path of the .CLC sensor calibration files, the program checks first for a SensorCalPath line in the .PFT file (it must end in : or \); then for a .CLC field on the command line; then for a .CLB field on the command line; then for a .TBL field on the command line; then for a .TSn field on the command line. If a .CLC file needed to calculate the calibration of a channel is missing, the program processes data but all the DFT's for that channel are marked as empty.

To obtain the path and name to use for the .FCn output files, the program checks first for a DftPath line in the .PFT file; then for a .FCn field on the command line; then for a .TBL field on the command line; then for a .TSn field on the command line. If file name part of the path is "*" or blank in the DftPath line in the .PFT file, or if it is "*" in the .FCn field on the command line, the site name (.TBL or .TSn file name) is used with the path specified.

2.3 Screen output

The screen output from a typical TSTOFT run is shown below.

```
System 2000 DFT Calculation Program - Version 20

Parameter file lines read: 14

Calibrated response in Level 4 at   3.0 Hz:

Channel System      Receiver    Sensor      Sensor
                    /V          V/T or m    Serial
   1    1.33e+002   1.33e+000   1.00e+002
   2    1.33e+002   1.32e+000   1.00e+002
   3    1.10e+008   1.03e-001   1.06e+009   COIL1014
   4    1.09e+008   1.03e-001   1.06e+009   COIL1015
   5    1.02e+008   1.03e-001   9.90e+008   COIL1016

Level  6 2001/10/26 06:15:00  12%
```

The program prints a count of the number of parameter file lines read. If one of these lines contains an error which causes processing of the file to terminate with Code 1121, this count identifies the line which caused the error. Blank lines and comment lines are counted.

The program prints sample calibration information calculated at one frequency. For each channel, the amplitude calibration factor is printed for the system, the receiver channel, and the sensor channel. The system channel calibration factor is the product of the receiver calibration factor and the sensor calibration factor.

The value shown under "System" is the ratio of .TSn file time series amplitude (expressed as a fraction of full scale) to actual field amplitude. If FldType 0 has been specified in the .PFT file, the "System" value is expressed in V^{-1}. If FldType is $\neq 0$, the "System" value is expressed in T^{-1} for magnetic channels, or $(V/m)^{-1}$ for electric channels. If the value shown under "System" is blank for one or more channels, the calibration information for those channels is incomplete, no DFTs can be computed for those channels, and the corresponding DFT quality flags in the .FCn files will be 0 for every DFT derived from those channels.

The value shown under "Receiver" is the ratio of .TSn file time series amplitude (expressed as a fraction of full scale) to the signal voltage at the receiver input. It is expressed in V^{-1}.

The value shown under "Sensor" is ratio of the signal at the receiver input to actual field amplitude. The "Sensor" value is expressed in V/T for magnetic channels, or m (the dipole length) for electric channels. For magnetic channels, the sensor serial number is printed. This is the serial number which was specified at the time that the sensor as calibrated, and may be different from the .CLC file name. If FldType 0 has been specified in the .PFT file, no sensor information is needed, so that the “Sensor” value and “Sensor Serial” are blank. The “Sensor” value will also be blank if a sensor calibration could not be computed. For example, if no Hz sensor is used, these fields will be blank for channel 5, which is the Hz channel.

2.4 Processing parameter (.PFT) file

The processing parameter line formats are as follows; each field is terminated by a comma, space(s), or a comma followed by space(s):

keyword⟦,⟧ ⟦*level*⟦,⟧⟧ *value*⟦,⟧ *comments*

keyword is the case-independent keyword which indicates the processing parameter that is specified by this line.

level is the decimation level number or file number (“n” in file extension .TSn) to which this processing parameter applies. It is included only if ***keyword*** requires it.

value is the value of the parameter. It must be of the data type required by *keyword*: integer, real number (decimal or exponential format), string, or date/time (yyyy/mm/dd hh:mm:ss format). Except in the case of a date/time, it must not contain blanks or commas. The date/time contains one blank between date and time.

comments may be placed after the last field and are ignored.

Completely blank lines are allowed and are not processed.

Lines having a semicolon “;” as the first character are allowed and are not processed. Example:

```
; This is a comment.
```

The processing parameters are listed in the following table.

Table 1. TSTOFT Processing Parameters			
Keyword	Data Type	Level needed?	Description
AllLevels	StrPT		Yes or True: Process all .TSn files with the specified base name; otherwise process only the file .TSn with n specified by FileLevel.
BadAction	IntPT		For future use.
Bandwidth	FltPT	Yes	The high frequency edge of the top band in the top octave, Hz. This parameter should always be written as precisely as possible, without rounding.
BoxCalPath	StPPT		Directory to search for the input .CLB file. Must end with : or \. Overrides the command line *.CLB parameter.
Concatenate	StrPT		Yes or True: Search for .TSn files preceding or following the specified files and treat the .TSn files as one continuous file. Assumes that the files names are in the format nnnnmddu where m is the month (1..C), dd is the day, and u is a uniqueness character (A..Z). Default No.
DeclDegGridN	FltPT		The declination of grid north measured clockwise from true north. Default 0, or DECL from the .TBL file if present.
DeclDegMgntN	FltPT		The declination of magnetic north measured clockwise from true north. Default 0, or DECL from the .TBL file if present.
DftPath	StPPT		Directory and file name of the output .FCn files. If the file name is blank or "*", the site name is used as the file name. If the file name is blank, the path must end with : or \. This parameter overrides the command line *.FCn parameter.
DirSearch	IntPT		Not yet implemented.
EndTime	AmxPT		Process data up to the record with this date/time. Default: ETIM in .TBL file.
FileLevel	IntPT		Process the .TSn file with n specified in the value field.
FldType	IntPT		Calculate output spectral densities from this type of field: 0 - the electrical input of the box (V); 1 - the unrotated fields at the sensors (V/m, T); 2 - fields rotated to true north; 3 - fields rotated to magnetic north; 4 - fields rotated to grid north. Sensor calibration (.CLB) files and sensor parameters EXLN, EYLN, EAZM, HAZM, HNOM are required for all field types except type 0. Parameters DeclDegMgntN and/or DeclDegGridN are required if the .TBL file azimuth parameters use a north reference different from the FldType option. When the .TBL file does not specify the north reference, grid north is assumed (NREF = 4).
FRatioMax	FltPT		For future use.
FreqPerOctave	IntPT		The number of frequencies in each octave.
FreqTopOctave	IntPT		The number of frquencies in the top octave. It may be more or less than the number of frequencies in the lower octaves.
InFileLevel	IntPT	Yes	Process file .TSn to produce output file .FCm, when m is the level field and n is the value field. Default: .TSn is processed to produce .FCn.
NOctave	IntPT	Yes	The number of octaves. If this is too large (e.g. > 10) the program may run out of memory, giving return code 1104, or there may be too many frequencies, giving return code 1102. If the value is 0, the specified level will not be processed. The default value for each level is 0.
Overlap	IntPT	Yes	The time interval between windows in an octave is based on the interval between frequencies in that octave. Time interval = 1/(Overlap x Frequency interval). Default = 1.
PromptUser	StrPT		For future use.

RecInterval	FltPT	Yes	The time interval covered by each record in the output file (s). It must be either a whole number, or a fraction < 1.
RefTime	AmxPT		The reference time for calculation of window index numbers. Default 2000-01-01 00:00:00. Always use the default!
SatAction	IntPT		For future use.
SelectCode	IntPT		Process a subset of the channels in the .TSn files: 0 - all input channels (default); 1 - E channels only; 2 - H channels only; 3 - Hx and Hy only.
SensorCalPath	StPPT		Directory to search for the input .CLC file. Must end with : or \. Overrides the command line *.CLC parameter.
SiteFile	StPPT		Path and name of the .TBL and .TSn files. Must end with : or \. Overrides the command line *.TBL parameter.
StartTime	AmxPT		Start processing at the first record at or after this date/time. Default: STIM in the .TBL file.
WindowScheme	IntPT		The window scheme to be used: 0 - V5 window scheme; 1 - uniform bandwidths in each octave; 2 - harmonically related frequencies.

2.4 Error codes

When the program terminates, a return code is output to the console. If there are no errors, the return code will be 0. Other possible values of the return code are listed in Table 2.

Table 2. Error Codes

Error name	Number	Description
BADCODPT	201	Internal error - Bad code in access to parameter table.
BADTYPPT	202	Internal error - Bad data type in access to parameter table.
BADHANDLEFT	1101	Internal error - Bad handle to the structure that defines the DFT file and its state.
TOOMANYFREQSFT	1102	Too many frequencies for one .FCn file.
NOMEMORYFT	1104	Error allocating memory.
BADDECOPRLEN	1105	Decimation operator length not acceptable.
DFTBUFOVRFT	1106	DFT output buffer overrun.
DFTFILGAPFT	1107	Indicates a large gap in the DFT sequence, which should not occur.
OUTOFORDERFT	1108	Internal error - The frequencies, decimation levels, or windows intervals are not in order.
TOOMANYCASCSFT	1109	Too many cascade decimation levels.
TOOMANYCHANSFT	1110	Too many channels in one .TSn file.
WINDOWERRORFT	1111	Internal error - Problem in dftprcft.c
BADOPRTYPEFT	1112	Bad operator type.
BADOPRVALFT	1113	Bad parameter value in dftopr.c
BADSCLROTFT	1114	Internal error - Bad scaling or rotation.
BADWINSCHFT	1115	Bad window scheme.
BADARRAYROTATEFT	1117	Can't rotate arrays of this type.
BADSENSORCHANFT	1118	Inconsisent channel type accessing multichannel sensor calibration.
NOBOXCALFT	1119	The box calibration file could not be opened.
BADOPRLENINTFT	1120	Operator length is too short or too long to be interpolated.
BADPROCPRMNAME	1121	Bad name in processing parameter file.
NOSITEFILEFT	1122	Can't open the site file, or none specified.
NOPROCPARAMFILEFT	1123	Can't open the processing parameter file.
CMDLINEERRORFT	1124	Error in command line arguments.
NOBOXCALPATHFT	1125	No .CLB file path specified.
NOSENSORCALPATHFT	1126	No .CLC file path specified.
NODFTPATHFT	1127	No .FCn file path specified.
FTFILEOPENERRORFT	1128	Can't open the output .FCn file.
NOCALFILEPATHFT	1129	When calculatating an Ascii system cal file, output file path not given
CALFILEOPENERRORFT	1130	When calculatating an Ascii system cal file, could not open output.

GAPHT	1201	Internal use
NEARHT	1202	Internal use
EOFHT	1220	End of file in .TSn file.
ERRHT	1221	Internal error reading file; empty file.
BADHANHT	1222	The time series handle is bad.
BADLEVHT	1223	Attempt to access data or parameters from non-existent level.
BADBUFHT	1224	Internal error - buffer too small.
BADTAGHT	1225	Record tag in .TSn file has illegal values.
BADPRMHT	1226	The site name is illegal (too long).
TOOBIGHT	1227	A data structure e.g. parameter table is too big.
BADCALHT	1228	The calibration handle is bad.
BADFRQHT	1229	No cal available at that frequency.
BADCALTYPHT	1230	Internal error - Bad CalType parameter.
BADSERNUMHT	1231	Bad serial number string.
BADCHNRSPHT	1232	There is one or more bad channels in an otherwise good calibration.
BADPRMVALHT	1233	A bad value has been retrieved from a .TBL file or record tag.
NOMEMORYHT	1234	Unable to allocate required memory.
TBLOPENERHT	1235	Can't open TBL file.
TBLREADERHT	1236	Error reading .TBL file.
TSOPENERHT	1237	Error opening .TSn file.
TSREADERHT	1238	Error reading .TSn file.
CALOPENERHT	1239	Can't open CLB or CLC file.
CALREADERHT	1240	Error reading CLB or CLC file.
LASTFILEHT	1241	No contiguous time series file found after the current file.
FRSTFILEHT	1242	No contiguous time series file found preceding the current file.
BADFNCDEFHT	1243	Bad results processing AMT cal.
BADAMTCALHT	1244	Bad results processing AMT cal.
BADCALPRMHT	1245	Derived parameters/functions for calibration are bad or undefined.
CALNUMCHNHT	1246	Wrong number of channels in .CLB file.

3. WINDOWING SCHEMES

Three window schemes are supported: The V-5 window scheme (WindowScheme = 0), uniform bandwidths in each octave (WindowScheme = 1, recommended), and harmonically related frequencies (WindowScheme = 2). In each case, the DFT operators are based on "raised cosine" window function multiplied by a complex exponential having frequency equal to the nominal DFT frequency. The DFT operator is further constrained to have zero sum, so that a constant offset in the time series produces no effect in the output DFT. The nominal bandwidth of the DFT operator is 2/(window width).

3.1 V-5 Window scheme

The V-5 scheme has two frequencies per octave. The top two frequencies are (1/4) x sample rate and (3/16) x sample rate. The nominal bandwidth of the operators in the top octave is (1/16) x sample rate. The interval between window center times in the undecimated time series is 16 sample intervals, which is the inverse of the sample rate. To duplicate these frequencies and window intervals, the Bandwidth processing parameter must be set to (9/32) x sample rate. In V-5 processing of high range data, the top octave is not used, so Bandwidth must be set to (9/64) x sample rate to duplicate the V-5 frequencies.

3.2 Uniform bandwidths in each octave

The uniform bandwidths option is recommended. This scheme has some good properties when the window center times are spaced at one half of the total window width. Each point in the time series contributes to two output windows and the sum of its weight in these two output windows is one. Similarly, within an octave, each frequency makes significant contributions to the output of two operators, and the sum of these two amplitude responses is nearly uniform. The frequencies in an octave are:

$$f_{i,k} = b\,[\,(4n-1)/(2n+2m)\,]\,[\,(2n+2m-2i-1)/(4n-1)\,] \qquad \text{(top octave, } k = 0\text{)}$$

$$= b\,2^{-k}\,[\,(4n-1)/(2n+2m)\,]\,[\,(2n+2m-2i-1)/(4n-1)\,] \qquad \text{(other octaves, } k > 0\text{)}$$

where $f_{i,k}$ is the i-th frequency in the k-th octave, $k = 0, \dots,$
$i = 0, \dots, m-1$ in the top octave, $k = 0$ and
$i = 0, \dots, n-1$ in the other octaves, $k > 0$;
b is the overall bandwidth (Bandwidth parameter);
n is the number of frequencies per octave (FreqPerOctave parameter);
m is the number of frequencies in the top octave (FreqTopOctave parameter).

The bandwidths are given by:

$$b_k = b\,2^{-k} / (n + m)$$

where b_k is the bandwidth of the individual operators in the k-th octave.

The interval between window center times is the inverse of the bandwidth, which gives a 50% overlap between consecutive windows, and gives each point of the time series an equal statistical contribution to the output DFTs. In the case of a long, continuous time series, there is no advantage to a higher density of windows, since the results in the additional windows are not statistically independent.

The window center times are fixed relative to UTC, and data must be available for the entire duration of the window to calculate a DFT. At each end of the time series, and on each side of any record discarded (e.g. due to saturations), there is a section of the time series that is not used in any window. At the lowest frequencies this can result in the loss of a significant part of the time series. In this situation, the Overlap parameter, which defaults to 1, can be set to 2 or 4. This increases the number of windows proportionately.

When .FCn files from two or more different receivers are combined in post processing, it is critical that the interval between window center times be *exactly* the same in the files from all receivers. The window center times are referenced to 2000-01-01 00:00:00 UTC, so at the higher frequencies where window intervals are as little as 1 ms, a small truncation error in the interval can cause a substantial error in the window center times. Since the window interval depends on the Bandwidth parameter, the Bandwidth should never be rounded.

If the window interval is very close to an integral number sample intervals, the program will recognize this and adjust the window center time to be an integral number of sample intervals exactly. This eliminates truncation errors in the calculation of window center times. Bandwidths which give window intervals that are an integral number of sample intervals are therefore preferred, especially at high frequencies.

3.3 Harmonically related frequencies

This option produces cosmetically neater data since the frequencies are uniformly spaced on a logarithmic plot. Statistically it is less desirable because the contribution of each time series point to the results is less uniform. This is because the window center time intervals are the same for all frequencies in an octave, but the window widths are not the same. They are inversely proportional to the bandwidths, which are harmonically related. The sum of the contributions of any frequency to the outputs of the two operators is nearly uniform. Statistically, this scheme does not make as good use of the data as the “Uniform bandwidths in each octave” scheme. However, is does not bias the data, since each frequency contributes equally to the results.

The “harmonically related frequencies” option is still under development.

4. TYPICAL PARAMETER FILES

4.1 V-5 Compatible windows

This .PFT file will generate windows and frequencies like those generated by the V5 using 60 Hz sample rates.

```
FldType         2               Calculate fields rotated to true north.
AllLevels       Yes             Process all .TSn files.
WindowScheme    0               Use V-5 compatible windows.
FreqPerOctave   2               Number of frequencies in each octave.
FreqTopOctave 3 2               Number of frequencies in the top octave.
Bandwidth     3 432             Top edge of first frequency band, Hz.
NOctave       3 3               Number of octaves.
RecInterval   3 1               DFT file record interval, s.
FreqTopOctave 4 2               Number of frequencies in the top octave.
Bandwidth     4 54.0            Top edge of first frequency band, Hz.
NOctave       4 3               Number of octaves.
RecInterval   4 4               DFT file record interval, s.
FreqTopOctave 5 2               Number of frequencies in the top octave.
Bandwidth     5 6.75            Top edge of first frequency band, Hz.
NOctave       5 8               Number of octaves.
RecInterval   5 60              DFT file record interval, s.
InFileLevel   6 5               Use .TS5 input to generate .FC6 output.
FreqTopOctave 6 2               Number of frequencies in the top octave.
Bandwidth     6 0.0263671875    Top edge of first frequency band, Hz.
NOctave       6 9               Number of octaves.
RecInterval   6 600             DFT file record interval, s.
Overlap       6 4               Interlacing option [1:50%  2:25%  4:12.5%].
```

For 50 Hz sample rates, substitute the following commands.

```
Bandwidth     3 360             Top edge of first frequency band, Hz.
Bandwidth     4 45.0            Top edge of first frequency band, Hz.
```

4.2 MTU-5A Processing

This .PFT file can be used for processing MTU-5A data (24 kHz sample rate in level 2). It has four frequencies per octave, and the frequencies are chosen to avoid the harmonics of both 50 Hz and 60 Hz since the comb filters at these frequencies create problems in correcting for the system calibration.

```
FldType         2                 Calculate fields rotated to true north.
AllLevels       Yes               Calculate DFTs for all levels available.
WindowScheme    1                 Windows of equal width in each octave.
FreqPerOctave   4                 Frequencies per octave.
Bandwidth     2 11200             Top edge of first frequency band, Hz.
FreqTopOctave 2 3                 Frequencies in the top octave, level 2.
NOctave       2 4                 Number of octaves, level 2.
RecInterval   2 0.1               DFT file record interval, s.
Bandwidth     3 900.0             Top edge of first frequency band, Hz.
FreqTopOctave 3 2                 Frequencies in the top octave, level 3.
NOctave       3 4                 Number of octaves, level 3.
RecInterval   3 1                 DFT file record interval, s.
Bandwidth     4 70.0              Top edge of first frequency band, Hz.
FreqTopOctave 4 3                 Frequencies in the top octave, level 4.
NOctave       4 8                 Number of octaves, level 4.
RecInterval   4 10                DFT file record interval, s.
```

4.3 MTU-5 Processing

This .PFT file can be used for processing MTU-5 data acquired with V-5 compatible 60 Hz sample rates (3072 Hz sample rate in level 3). It has four frequencies per octave, chosen to avoid the harmonics of 60 Hz since the comb filters at these frequencies create problems in correcting for the system calibration.

```
FldType          2             Calculate fields rotated to true north.
AllLevels        Yes           Process all .TSn files.
WindowScheme     1             Windows of equal width in each octave.
FreqPerOctave    4             Number of frequencies in each octave.
Bandwidth      3 384           Top edge of first frequency band, Hz.
FreqTopOctave  3 4             Number of frequencies in the top octave.
NOctave        3 3             Number of octaves.
RecInterval    3 1             DFT file record interval, s.
Overlap        3 1             Interlacing option [1:50%  2:25%]
Bandwidth      4 48.0          Top edge of first frequency band, Hz.
FreqTopOctave  4 4             Number of frequencies in the top octave.
NOctave        4 3             Number of octaves.
RecInterval    4 4             DFT file record interval, s.
Overlap        4 1             Interlacing option [1:50%  2:25%]
Bandwidth      5 6.0           Top edge of first frequency band, Hz.
FreqTopOctave  5 4             Number of frequencies in the top octave.
NOctave        5 8             Number of octaves.
RecInterval    5 60            DFT file record interval, s.
Overlap        5 1             Interlacing option [1:50%  2:25%].
InFileLevel    6 5             Use .TS5 input to generate .FC6 output.
Bandwidth      6 0.02343750    Top edge of first frequency band, Hz.
FreqTopOctave  6 4             Number of frequencies in the top octave.
NOctave        6 6             Number of octaves.
RecInterval    6 600           DFT file record interval, s.
Overlap        6 4             Interlacing option [1:50%  2:25%  4:12.5%].
```

4.4 MTU-5 Processing for MTR

This .PFT file will generate windows and frequencies from 3,000 s to 40,000 s period to extend the range covered by the MTU-5 processing in the previous section.

```
FldType          2             Calculate fields rotated to true north.
AllLevels        No            Process only the .TSn file specified by FileLevel.
WindowScheme     1             Windows of equal width in each octave.
FreqPerOctave    4             Number of frequencies in each octave.
FileLevel        7             Process the .TSn file with n specified.
InFileLevel    7 5             Use .TS5 input to generate .FC6 output.
Bandwidth      7 0.0003662109375 Top edge of first frequency band, Hz.
FreqTopOctave  7 4             Number of frequencies in the top octave.
NOctave        7 4             Number of octaves (to 40,000 s).
RecInterval    7 1800          DFT file record interval, s.
Overlap        7 4             Interlacing option [1:50%  2:25%  4:12.5%]
```

5. FOURIER COEFFICIENT (.FCn) FILE FORMAT

5.1 Window parameters

The window and frequency parameters for any one Fourier Coefficient file are:

- basic window interval - s;
- basic window width - s;
- basic frequencies - Hz;
- special frequencies - Hz;
- number of octaves.

The input time series is decimated by 2, several times, to generate more time series, so that the total number of time series is equal to the "number of octaves".

The window and frequency parameters apply to the undecimated time series. For the n-th decimated time series, the window parameters are multiplied by 2^n, and the basic frequencies are multiplied by 2^{-n}. The special frequencies apply only to the undecimated time series.

For any one time series (decimation level) the window center times are

$$t_{ni} = 2^n Dt \ (k + i + ½) + t_r$$

where Δt is the basic window interval, i takes integer values so that the window center times t span the duration of the time series, and t_r is 0000 UTC, January 1, 2000.

A feature of this windowing scheme is that, because of the term ½ in the above formula, the window times at any decimation level do not coincide with the window times at any other level; in fact, they fall halfway between two window times at the next higher level. This limits the number of window center times which can fall in a small time interval, which in turns makes the formatting of the records of the Fourier coefficient file more efficient.

5.2 DFT file format

This file type contains variable length records consisting of a header of type DftTagFT followed by a variable number of entries of type DftFT. These formats are defined in file DFTFILFT.H. The header contains all the parameters needed to specify the position of the MT station, the precise center time and frequency, of each time window for which DFTs are given in the record, and various other parameters. Each DftFT entry contains one Fourier coefficient (a complex number) with a quality flag (one byte). The DftFT entries are stored in the record in order of the center time of the window being analyzed (most significant), the center frequency, and the channel number (least significant).

- The tag format DftTagFT is a follows:

Byte 0-7: UTC time of the time window centers for the data in this record, in the format second, minute, hour, day, month, year (last two digits), day of week, century, one byte per field.

Byte 8-9: Serial number of the MTU (16 bit integer).

Byte 10-11: Number of DFTs contained in this record. (Some may be empty.)

Byte 12: Number of channels of data.

Byte 13-14: The tag length in bytes.

Byte 15: = 10, the length of the data structure used to contain one DFT result, including a quality flag. The length of the data part of the record is Byte 15 * Bytes 11..10.

Byte 16: Contains 16 to indicate that this is an FCn file. Values 17, ... , 31 are reserved for future use to identify .FCn files with different tag formats. Note that time series files have 0 in this field.

Byte 17: Units and rotation. 0 = Unrotated components, V/√Hz, no coil calibration has been applied to H channels. All other values indicate that the units are V/m/√Hz (E channels) or T/√Hz (H channels). 1 = Unrotated components; 2 = rotated to true north; 3 = rotated to magnetic north; 4 = rotated to survey grid north.

Byte 18-33: Flags indicating the type of data for each channel of up to 16 channels.

Bit 0 - 3: 00 = Ex, 01 = Ey, 02 = Hx, 03 = Hy, 04 = Hz (other values reserved).

Byte 34-37: The least significant 32 bits of the window index number for the first set of DFTs in this record. Always an even integer.

Byte 38-45: Latitude (north), deg, 8 byte floating point. South is expressed as a negative number.

Byte 46-53: Longitude (east), deg, 8 byte floating point. West is expressed as a negative number. -180.0 < Longitude <= 180.0.

Byte 54-69: Parameters for special array configurations, which are indicated by special values in bytes 18-33.

Byte 70-71: Number of time windows for which DFTs are given in this record, integer.

Byte 72-75: Number of seconds of data in each record in this file, 4 byte integer.

Byte 76-83: UTC reference time for calculation of window center times, normally 2000/01/01 00:00:00. Format the same as bytes 0-7.

Byte 84-91: Time interval between consecutive window center times in the time series with the highest sample rate, 8 byte floating point, s. In each subsequent decimation, the interval doubles.

Byte 92-99: Length of windows for the time series with the highest sample rate, type double, s. In each subsequent decimation, the window length is assumed to double.

Byte 100-101: Number of frequencies analyzed in the highest octave. This will be 2 for V-5 compatible windows. Integer.

Byte 102-103: Number of frequencies analyzed in each octave except for the highest. This will be 2 for V-5 compatible windows. Integer.

Byte 104-105: Total number of frequencies analyzed in this file. Integer.

Byte 106-109: Reserved.

Byte 110-237: Frequencies analyzed in this file, in descending order, 4 byte floating point, Hz.

- The DFT format DftFT is as follows:

Byte 0: Data quality flag, = 0 if the DFT is “blank” because it could not be calculated for any reason. For example, the time window could overlap the beginning or end of the data, or a gap in the data; a sensor calibration file could be missing; or an EXLN or EYLN parameter could be zero.

Byte 1-4: Real part of DFT.

Byte 5-9: Imaginary part of DFT.

The units of the DFT real and imaginary parts are:

- If *fieldtype* = 0, V/√Hz.
- If *fieldtype* ≠ 0, for electric channels, V/m/√Hz.
- If *fieldtype* ≠ 0, for magnetic channels, T/√Hz.

6. RELEASE NOTES

Version 15

- Versions before this were experimental.
- Supports standard MTU, MTU-A, and MTU-LR, including .CLB files for three channel sensors.
- In LRs, allows a calibration performed at any decimation level to be used for any time series file.
- The standard technique for detecting an LR box is to check for the substring “LR” in the HW parameter of the .TBL file.
- Detects early MTU-5LRs, in which the HW parameter was “MTU52”, by checking for the existence of the parameter SRPM in the .TBL file.
- Detects early MTU-5LRs (by checking for existence of SRPM parameter and VER = 5LR01 or 3100C0), and calculates calibrations as if TALS = 3. These boxes had TALS = 1, which was incorrect.
- Detects .CLB files made with non-LR software on LR boxes (by checking the .CLB file for VER = 3100 ... or 5LR01) and calculates gains correctly.

Version 16

- In the case of concatenated .TSn files, this version and earlier versions do not search backwards in time, but only forwards.
- DFTs in which half the input data points are from bad records are marked “empty”. DFTs in which any of the input data points from bad or saturated records are marked “compromised”. Formerly, saturated record flags were ignored, and any bad data would cause the DFT to be marked “empty”.
- Computes field strengths correctly from MTU-5A data. Formerly they were 6.4/2.45 times actual values. They are now correct.
- Supports 3112A2 software, TCMB = 4. This is MTU-5A software with a two zero notch at the line frequency in level 4 and a two zero high pass filter in level 2.
- The output .FCn file format is changed. The size of the DFT frequency list in the tag can be increased; formerly it was limited to 32 frequencies. The tag can specify a .FCn file record interval which is a fraction of a second; formerly it was an integer. The version of the TSTOFT program is written in the tag.
- The Overlap parameter in the .PFT file is implemented.

Version 17

- Corrects return code 5 result from data from MTU-A boxes with software version 3112A2.
- Corrects problems with fractional RecInterval values.

Version 18

- In earlier versions, the default magnetic declination is 0. if it is not specified in the .PFT file. From this version, the DECL parameter from the .TBL file is used. If there is also no DECL parameter, DECL = 0. is assumed.

Version 19

- This version contains major enhancements to the use of MTU-A box calibration data. Previously, in both MT and AMT data, there was no attempt to correct for the input low pass filter on the electric channels. Also, in the MTU-A box, the frequency response is dependent on the gain setting at higher frequencies. This version analyzes the MTU-A calibration data and corrects for both effects.
- MTC-30 coil calibrations performed with MTU-A software versions earlier than 3112B0 (including all the 3112A and 3112BX versions) contained some errors. This version of TSTOFT will check a .CLC file to determine the version of software used to acquire it, and will correct the errors if the early versions of MTU-A software were used.
- The execution time on large AMT time series files has been reduced by half or better.
- To simplify the program, provisions for some quirks of early MTU-LR data have been removed. See Version 15 notes.
- The program now correctly handles the case where the HNOM parameter specified during the calibration of a sensor is different from the HNOM parameter during acquisition. This situation can arise when data is acquired with two MTC-50s (HNOM = 1000) and an air loop (HNOM = 500). The HNOM value in the sensor calibration (.CLC) file is always considered correct.
- The program now checks the number of channels in the .CLB file against the number of channels defined in the .TBL file and terminates if they do not agree.
- In this document, the RecInterval parameter in the sample AMT processing parameters (Section 4.2) has been changed to 10 s from 60 s. The 60 s value gives very large records in the .FC4 file.
- If a coil calibration file is missing, or if an E-line length EXLN or EYLN is zero, the program processes data but all the DFT's for the affected channel are marked as empty. Sections 2.2 and 5.2 have been updated to document this.

Version 20

- This version contains major enhancements to the use of MTU-A box calibration data. Previously, in both MT and AMT data, there was no attempt to correct for the input low pass filter on the electric channels. Also, in the MTU-A box, the frequency response is dependent on the gain setting at higher frequencies. This version analyzes the MTU-A calibration data and corrects for both effects.
- The program now closes the input parameter .PFT file before it begins writing output files, and closes output files when they are completed, instead of at the end of the program.
- The program will not produce a .FCn file if the NOctave parameter for level n is 0. SInce the default value for NOctave is 0, a .FCn file is not generated if there is no corresponding NOctave line in the .PFT file.

- In the .PFT processing parameter file, a line will be treated as a comment if its first character is “;” or if it is completely blank.
- TSTOFT prints a count of lines read from the .PFT file. The count includes comment lines.
- TSTOFT prints amplitude calibration information at a sample frequency (3 Hz) to help the user detect missing calibration information.
- The AllLevels No processing parameter line was sometimes not interpreted correctly. This has been corrected.
- The MTU-A software versions 3112A0 and 3112A1 used a low pass filter defined by the parameter LPFR on the magnetic and electric channels. Subsequent versions used the low pass filter only. TSTOFT Version 19 assumed that no low pass filter was used on the magnetic channels. Version 20 checks the acquisition software version and correctly handles the magnetic channels.
- On the command line or in the DftPath parameter file line, if the file name part of the path is “*” or blank, the name is filled in from the site name.

Version 21

- The name of the site file is printed.
- This version will modify the Bandwidth parameter in the .PFT file by up to one part in 10^6 to make the window interval an integer multiple of the sample interval. As each level is processed, the window interval is printed. If it is an integer multiple of the sample interval, the word “exactly” is printed. Window intervals which are an integer number of scans are preferred (essential, at high AMT frequencies) becasue they prevent the accumulation of truncation errors in the calculation of window center times.

Version 22

- Fix bug which caused concatenation to be enabled when no Concatenate Yes line was present in teh .PFT file.
- Show correct level numbers in the window interval printout.

Version 23

- In the case of concatenated .TSn files, this version returns to the first file in a concatenated sequence when an input band is reused. It will not search for files before the first file in the sequence.

Version 24

- Corrects an error in the handling of concatenated .TSn files when passing 0000UTC in months >7.

Version 25

- Allows the .TBL file parameter ATYP = 2 for configurations in which a 5-channel box is used to acquire HX, HY, HZ only.

Version 26

- Supports the new version 2 parameter file format.

Version 27

- Fix bug in file concatenation which caused problems at the end of each month.

Version 28

- Fix problems with V8/RXU MT/AMT processing relating to parameter CHEZ.

Version 29

- Correct bug which sometimes caused error 1106, especially when the data had gaps.

Version 30

- Fix problems with V8/RXU MT/AMT processing relating to parameter EZLN.
- Correct problem which sometimes caused *.FC7 files to contain no data.