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Discrete Signals and Systems II

TRANSFORMS, WINDOWS, MODULATION...

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Version 1.0
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For the Macintosh™ 512K and up

August 13, 1986

PLEASE READ BEFORE USING

Discrete Signals and Systems II
TRANSFORMS, WINDOWS, MODULATION... 1.0B

*** Note that the Transforms, Windows, Modulation... software is version 1.0B [beta]; the accompanying manual is for version 1.0. Therefore some options are not fully functional as described in the manual.**

*** Do not use Transforms, Windows, Modulation... 1.0B with System 3.2, Finder 5.3 since the screen will not refresh if File menu is used.**

*** The TWM data folder must be on the same disk as Transforms, Windows, Modulation... Otherwise, "File Error" will occur as you start the program and the program may crash if you proceed. This folder contains the "TWM Image Folder" and the "TWM Scrap Folder"; The images necessary for the operation of the program are stored in the TWM Image Folder.**

*** Make sure that the Discrete Signals and Systems disk is unlocked; otherwise "File Error" will occur when you attempt to store a signal in a Storage bin.**

[1] Note that due to a limitation of graphics routines and screen resolution, discrete data values may appear unevenly spaced when the display width exceeds 60 points; also, when an array is all negative, tickmarks may overlap. In the **"Point by Point"** mode, if the value entered falls beyond the specified boundaries, lines may be drawn over the scroll bar.

[2] All desk accessories are operational; however, if a desk accessory is moved around on the screen, the screen will not refresh until the accessory is put away.

[3] If infinite (INF) numbers are created during an operation, clear the signal in the graph window and proceed. If vertical lines appear on the screen, please save all signals and exit the program and restart. INF values may occur when using the exponential function generator or the exponential operation, if the base and/or the exponent are not carefully selected.

[4] The dialog boxes in this version can not be OKed by pressing the Return or Enter key and may close on alpha keyboard characters. Upon cancelling, new entries to a dialog box may be set instead of being ignored. Also, the dialog boxes are not fully protected against illegal entries. Some dialog boxes accept scientific notation (e.g.

1e-2 for 0.01). However, **if e is not preceded by a numeric character, the program may crash.** We suggest that you enter values according to the type of the default/set value in the dialog box. Whenever applicable, enter boundary values in the right order (larger number for the upper bound; smaller number for the lower bound etc.)

[5] Do not use **Open signal**, request **Last Signal** or return a signal to the Graph window when set in **Instantaneous Frequency** or **Power** in either domains. If you do, select **Real part** to activate normally available functions and operations. Also, if **Real part** is selected, yet normally available functions are not activated, select Real Part to activate them.

[6] To obtain the correct value of the Instantaneous frequency, multiply the signal (or **Y-axis scale**) by the Transform record length (i.e.128, 64, etc.)

[7] The **Window graph** option provides a number of commonly used data windows. In this version, windows with center symmetry (Bartlett, Generalized Hamming, Blackman) may not be centered properly. For an odd length window (e.g. from -30 to 30 [61 points] or 0 to 30 [31 points], subtract 1 from the window length, and enter window limits based on this value. **If the windowed signal is not centered, use x-axis shift to position it properly. If the tails of the windowed signal are not symmetric, use Edit Graph to correct for discrepancies (especially for Von Hann and Blackman.)** Also, in **this version, the Gaussian window assumes zero mean and is centered at the origin.**

[8] If more than one Storage bin are selected, the **Store graph** option will store the signal in the Graph window in all the bins; however, only the first bin will show the signal. Also, note that when **Oper.I** menu items operate on selected bins. Therefore, deselect bins if the operation is to occur on the signal contained in the Graph window.

[9] In this version, the **Semilog** and Decibel (dB) menu items under the **Display** menu are not available.

USAGE SUGGESTIONS

"Signal Operations 1.2" and "Transforms, Windows, Modulations... 1.0" are the first and second modules of the **Discrete Signals and Systems** package. The two programs can exchange data and complement each other in many functionalities. A particularly convenient approach is to install both applications on the Switcher^{TM}.

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TRANSFORMS, WINDOWS, MODULATION... ON THE MAC

The Transforms, Windows, Modulation... program for the Macintosh is part II of the Discrete Signals and Systems package. This package consists of a set of software prepared for engineering courses in discrete signals and systems. Transforms, Windows, Modulation... aims to provide an interactive environment whereby the student can experiment with a multitude of theoretical and applied concepts while routine computations and display tasks are performed by the computer.

With the Transforms, Windows, Modulation... module, discrete complex signals can be created on a working window called the Graph Window. These signals can be stored in any of five Storage bins at the bottom of the screen. Time signals can be transformed into the frequency domain and vice versa using the discrete Fourier transform implemented by the Fast Fourier Transform (FFT) algorithm. It may be advantageous to familiarize yourself with the FFT algorithm which was developed by J. W. Cooley and J. W. Tukey (see *Math. Comput.*, vol 19. April 1965, pp. 297-301). Many textbooks on discrete signals and systems discuss the algorithm. For a detailed presentation, you may refer to the book by E. O. Brigham entitled "The Fast Fourier Transform" (Prentice-Hall, Englewood Cliffs, NJ, 1974) or the one by R. W. Ramirez entitled "The FFT Fundamentals and Concepts" (Prentice-Hall, Englewood Cliffs, NJ, 1985).

Transforms, Windows, Modulation... is similar in screen layout and mode of operation to Signal Operations, which is part I of Discrete Signals and Systems package. The major difference between the two programs is the type of data. Transforms, Windows, Modulation... works on complex data while Signal Operations is limited to real data. However, the two programs can read data files created by each other; the Signal Operations program opens the real part of a complex signal saved by Transforms, Windows, Modulation... and Transforms, Windows, Modulation... opens a signal saved by Signal Operations as a real signal. (The imaginary part is set to zero.)

In this version of Transforms, Windows, Modulation..., a sampling frequency option is not included. We have decided to withhold this option from this educational version in order to present the actual results of the FFT algorithm independent of the sampling rate. If necessary, a sampling frequency can be used to scale the time and frequency axes as discussed in "Special Considerations" in the "Reference" section.

This module offers a number of signal operations, Discrete Fourier transformation, windowing and angle modulation options, which can be performed on both time and frequency signals. Some of the operations require only one signal whereas some operate on more than one.

One signal

- x-axis shifting
- x-axis scaling
- y-axis scaling (amplitude scaling)
- changing sign (rotating about x-axis)
- folding (rotating about y-axis)
- absolute value
- sum
- summation
- difference
- even part
- odd part
- logarithm
- exponentiation
- angle modulation
- Fast Fourier Transform (FFT)
- windowing

More than one signal

- addition
- subtraction
- multiplication
- division

Signal Windows

- Rectangular
- Bartlett (triangle)
- Generalized Hamming
- Blackman
- Gaussian

HOW TO USE THIS DOCUMENT

This documentation describes how to use the Transforms, Windows, Modulation... module as an interactive learning tool. Since this module is similar to the Signal Operations module, the documentation is also very similar. If you are already familiar with the Signal Operations module, you might want to concentrate on sections particular to the Transforms, Windows, Modulation... module. Various program features are described in "Using Transforms, Windows, Modulation..." section of this manual. "Solving Problems with Transforms, Windows, Modulation..." shows how you can use the module to solve problems in your textbook or those you make up yourself. An overview of the various features of Transforms, Windows, Modulation... (TWM) is provided by the "Menu and Siganl Generator Summary" in the "Reference" section.

If you are not familiar with the Macintosh™ computer, it might be advantageous to review *Macintosh* , the owner's manual. It teaches the basic techniques you will use to create signals -- clicking, selecting, choosing menu commands, obtaining hardcopy of the screen contents, saving the contents of the screen as a MacPaint™ document, etc.

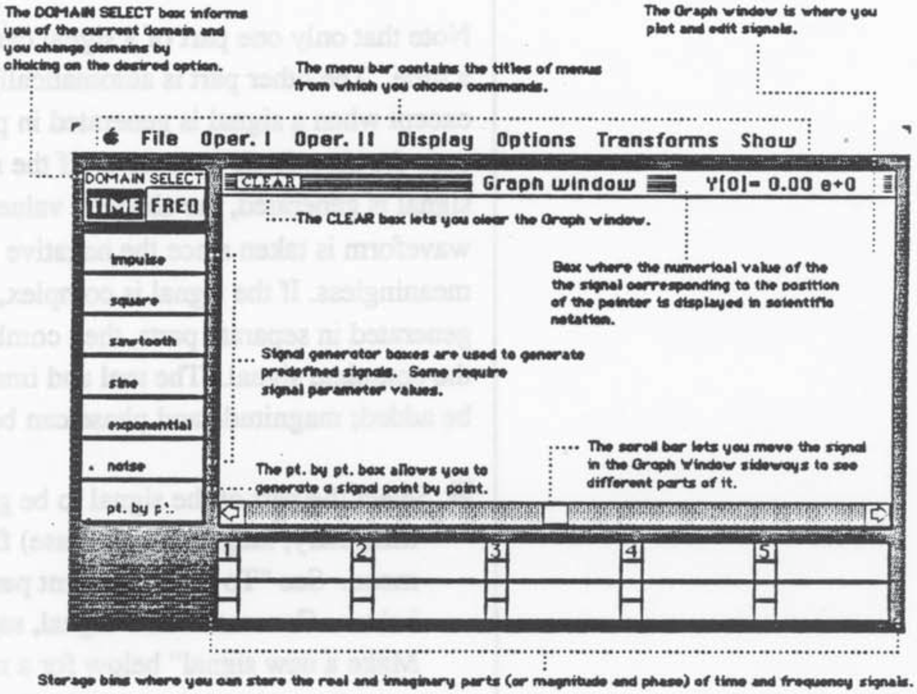
USING TRANSFORMS, WINDOWS, MODULATION...

How to begin:

- Insert the Discrete Signals and Systems II disk.
- Open the Discrete Signals and Systems II disk icon.

Check that the Transforms, Windows, Modulation... data folder is on the disk. This folder contains images necessary for the operation of the program.

- Open the Transforms, Windows, Modulation... module icon.



The DOMAIN SELECT box informs you of the current domain and you change domains by clicking on the desired option.

The menu bar contains the titles of menus from which you choose commands.

The Graph window is where you plot and edit signals.

The CLEAR box lets you clear the Graph window.

Box where the numerical value of the the signal corresponding to the position of the pointer is displayed in scientific notation.

Signal generator boxes are used to generate predefined signals. Some require signal parameter values.

The pt. by pt. box allows you to generate a signal point by point.

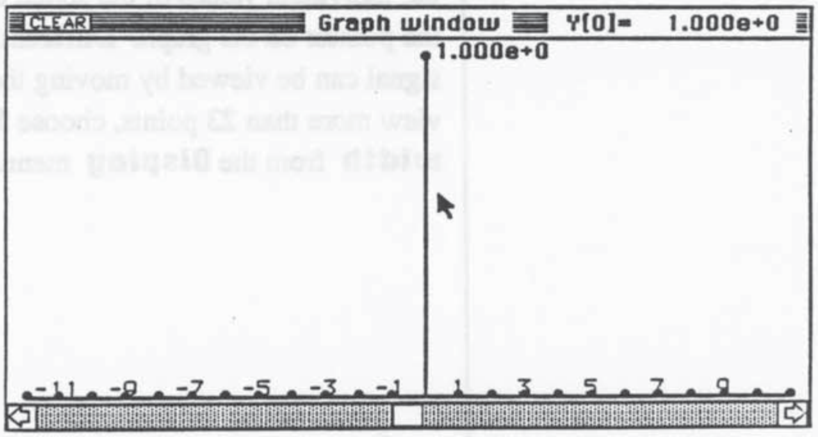
The scroll bar lets you move the signal in the Graph Window sideways to see different parts of it.

Storage bins where you can store the real and imaginery parts (or magnitude and phase) of time and frequency signals.

To generate a signal:

- Click the signal generator box named "impulse".

The impulse signal will appear in the Graph window:



Signals can be generated either in time or frequency domain.

■ Click **FREQ** in the **DOMAIN SELECT** box. It will become highlighted.

The impulse generated earlier has become a frequency function. The domain of signals can be switched at any point in the program.

Note that only one part of a signal can be generated at a time. The other part is automatically set to zero, except when a signal is generated in phase. In this case the magnitude is set to 1. If the magnitude of a signal is generated, the absolute value of the waveform is taken since the negative magnitude is meaningless. If the signal is complex, it can be generated in separate parts, then combined to obtain the complete signal. The real and imaginary parts can be added; magnitude and phase can be multiplied.

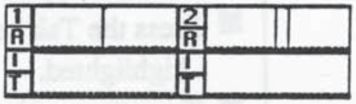
■ Select the part of the signal to be generated (real, imaginary, magnitude or phase) from the **Show** menu. See "To view different parts of a signal" below. Generate a new signal, say a pulse. See "To Make a new signal" below for a more convenient procedure to assign parts of a signal.

The total number of points in any signal is 129 [extending from -64 to +64 x-axis units]. You can read the individual values of the signal array by moving the pointer on the graph. Different portions of the signal can be viewed by moving the scroll bar. To view more than 23 points, choose **Set display width** from the **Display** menu.

To Store a signal on the screen:

- ■ Click Storage bin #1.
- ■ Choose **Store Graph** from the **Options** menu.

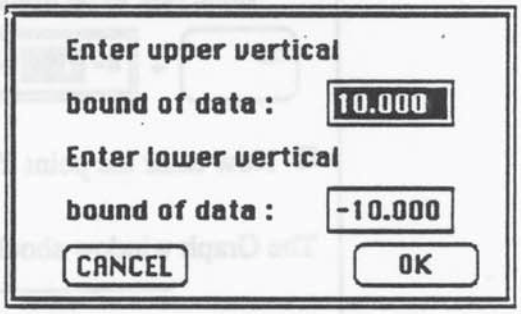
A small plot of the signal in the Graph window will appear in Storage bin #1 to help you recall its contents. Letters appear on the left side of the storage bin to indicate the domain of the signal (T for time domain, F for the frequency domain) and the type of coordinates used, (R for real, I for imaginary) in rectangular coordinates, (M for magnitude, Ø for phase) in polar coordinates.



Unlike the Signal Operations module, TWM signals stored in bins are also saved as disk files. The storage of one complex signal requires at least 3K of disk space.

To create a signal point by point:

■ Click the signal generator box named "Pt. by Pt." A dialog box like this will appear on the screen:



Enter upper vertical bound of data : 10.000

Enter lower vertical bound of data : -10.000

■ Type the numbers 2 and -2 for the upper and lower bounds of data respectively. Note that the Tab key selects the second entry in the dialog box. Click **OK** or press the Return key.

A blank Graph window is now ready for you to enter points. You can do this in either one of two ways: by pointing to the location and clicking, or through the tiny dialog box in the upper right corner of the Graph window.

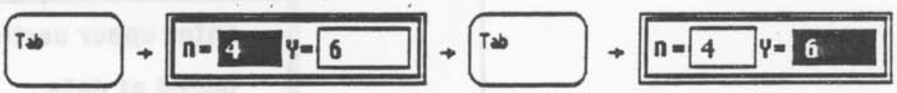
To enter the point Y(0)=1.25:

■ Position the pointer on the y-axis and drag until **Y = 1.2500** is displayed in the dialog box. Release the mouse button. Note that the point you just entered is displayed in the dialog box. If y≠1.25, try again by repositioning the pointer, dragging, and releasing. Your first entry will be replaced by your second entry.

If you are not satisfied with the resolution of the mouse, you can enter the exact values through the dialog box.

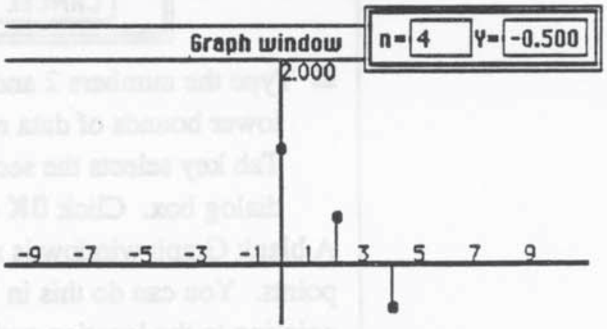
To enter the point Y(2)=0.500:

- ■ Move the pointer along the x-axis until **n = 2** is displayed in the dialog box. Note that the values of n and Y are continuously updated.
- ■ Press the Tab key. The **Y**-value box will became highlighted.
- ■ Type the number 0.5. [Note that this dialog box also accepts scientific notation, e.g. 5e-1 is equivalent to entering 0.5].]
- ■ Press the Enter or Return key to enter this point into the signal array. Pressing the Tab key once causes either the **n**- or **Y**- value box to be highlighted. Pressing it again causes the other value box to be highlighted.



- ■ Now enter the point Y(4)=-0.5 into the signal array.

The Graph window should now look like this:



n= 4 Y= -0.500

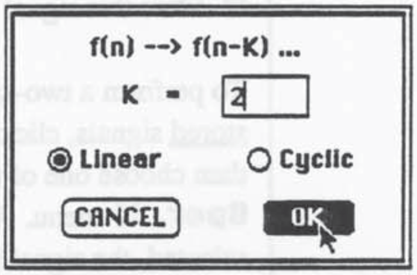
- ■ Click the box in the lower left corner of the screen when you have finished entering points.

To Edit a signal:

Editing is performed the same way as point by point entry. The only difference is that you make changes on an existing signal rather than starting from a blank window. You can edit signals by choosing **Edit graph** from the **Options** menu.

To perform an operation on one signal:

- Choose **X-axis shift** from the **Oper. I** menu. All signal operations requiring only one signal are grouped under the **Oper. I** menu. Type the number 2 for the value of K in the dialog box, then click the radio button for linear shift.



f(n) --> f(n-K) ...

K = 2

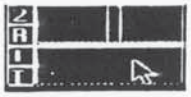
● Linear ○ Cyclic

The signal in the Graph window will be shifted to the right by two x-axis units.

To perform an operation on two signals:

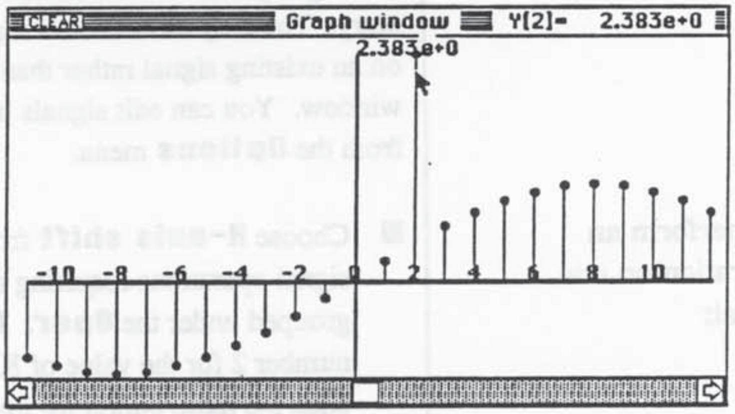
- To review, generate an impulse as a real time signal. Shift it to the right by two time units and store this signal in bin #2.
- Click the signal generator box named "sine" while set in the time domain and in real part.

A dialog box with default values will appear. Click **OK**. A sine with these default values should appear on the graph window.



- Select Storage bin #2 by clicking it.
- Choose Add from the **Oper. II** menu. All operations requiring more than one signal are grouped under this menu.

The result of the addition will appear in the Graph window:



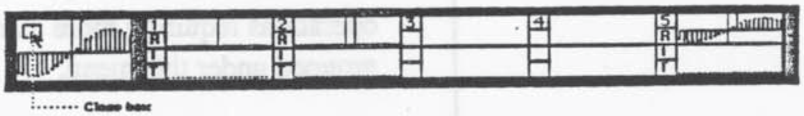
- Store this signal in any empty Storage bin (say, #5).

To perform a two-signal operation on two or more stored signals, click on two or more Storage bins and then choose one of the signal operations from the **Oper. II** menu. When only one Storage bin is selected, the signal in the Graph window becomes the second signal, by default.
If an operation between two signals defined in two different domains is requested, a "mixed mode" warning is issued and results are set to the current domain of the program.

To retrieve the Last Signal:

Whenever a new entry is made into the Graph window, the previous contents of the window are temporarily stored until another new entry to the Graph window is made. To retrieve the original sine waveform:

- Choose **Last Signal** from the **Show** menu. Transforms, Windows, Modulation... will return the sine to the Graph window, and a small window will appear at the bottom left corner of the screen:



This is the Last Signal window. Transforms, Windows, Modulation... automatically stores the previous contents of the Graph window here. It now contains the result of the addition.

- Choose **Last Signal** again to exchange the contents of the Graph window with the contents of the Last Signal window.

To retrieve a signal stored in a bin:

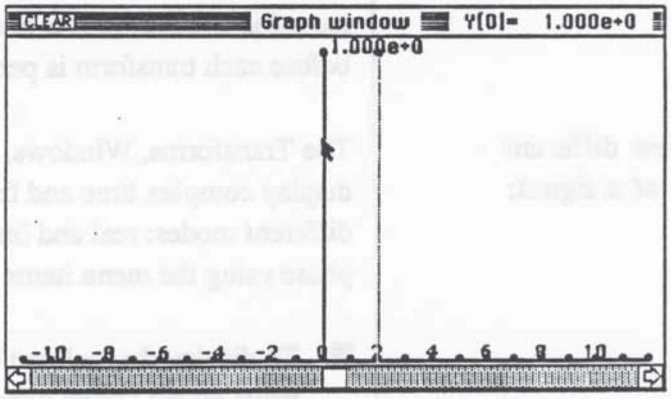
You can return any stored signal to the Graph window at any time by clicking on the number in the upper left corner of its Storage bin or by opening the bin using **Open signal** menu item under the **File** menu. The domain of the program is switched to the domain of the retrieved signal.

To Compare two signals:

Transform, Windows, Modulation... also lets you display two signals in the Graph window simultaneously.

- Click the signal generator box named "impulse" again to generate an impulse, or click on the number 1 in the upper left corner of bin #1 to return the impulse to the Graph window.
- Select Storage bin #2 which contains the shifted impulse.
- Choose Compare graph from the Options menu. A dialog box will ask which part of the signal in the bin you want to compare with the signal in the Graph window. Choose the real part by clicking the corresponding radio button.

The Graph window will look like this:



The shifted signal has been superimposed in lighter color on the original impulse.

To perform a transformation on a signal:

Transforms, Windows, and Modulation... allows you to take the Fast Fourier Transform (FFT) of the signal in the Graph window. Depending on the domain of the signal, this will be either a forward FFT (FFT) or an inverse FFT (IFFT). The FFT algorithm can be set to operate on 4, 8, 16, 32, 64, and 128 points. If the transform record is less than 128 points, the remainder of the signal is filled with zeros. This causes defacto zero-padding of the transform results.

In this implementation two kinds of phase reference can be chosen. One is with respect to the zero-point on the graph window (fixed zero) and the other is with respect to the first point of the record specified by the user (free zero). The **Set transform record** menu item will define the interval over which the FFT is to be performed and the phase reference.

■ Click the sine to generate a sinusoid. Click **OK** in the dialog box, which will generate the default sine wave of period 32. Now choose **Set transform record** from the **Transforms** menu. Check to see that the default value for the number of points is 128 and the phase reference is set to the zero-point on the graph (fixed zero), or set to **Free zero** with record starting at zero. Now choose **FFT**. Upon completion, the graph window will display the magnitude of the spectrum of the sine wave. Note that **Set transform record** preserves the last setting until a change in record is entered, so it is not necessary to reset it before each transform is performed.

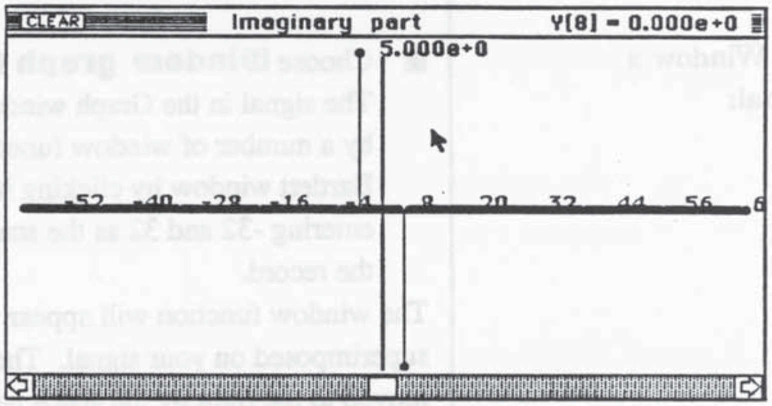
To view different parts of a signal:

The Transforms, Windows, Modulation... module can display complex time and frequency signals in different modes: real and imaginary, magnitude and phase using the menu items under the **Show** menu.

■ To display the real part of the spectrum of the sine wave on the Graph window, choose **Real part** from the **Show** menu. The real part of the spectrum should be all zeros as expected.

■ Now choose **Imaginary part**.

The graph window should look like this:

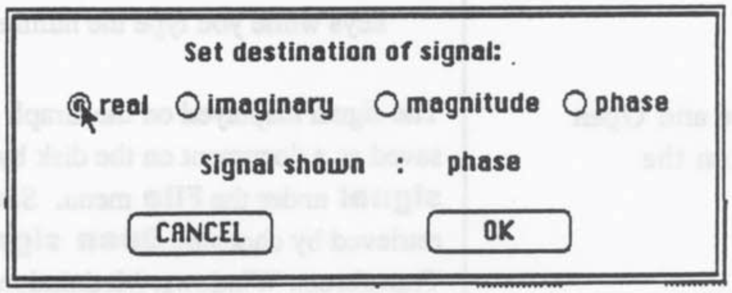


Repeat for Magnitude and Phase. Note that the phase units can be set to degrees or radians using options under the **Display** menu.

Power and **Instantaneous Frequency/ Group Delay** are computed from the current signal array for observation and comparison purposes only. In order not to alter the current signal, no operations, editing or windowing are allowed on these plots.

To make a new signal:

- Generate a real sine wave. Display its phase by choosing **Phase** from the **Show** menu. [By convention, negative real values are assigned a phase of -π radians at positive frequencies and π radians at negative frequencies.]
- Choose **Make Signal** from the **Options** menu. This will allow a new signal to be created from part of an existing signal (real or imaginary, magnitude or phase parts). A dialog box will appear to help you set the part of the destination (i.e. the new signal). Note that the radio button for phase has been selected as the default. Click the radio button for real as shown in the figure below:



Set destination of signal:

● real ○ imaginary ○ magnitude ○ phase

Signal shown : phase

The phase of the sine wave has become the real part of the new signal and its imaginary part is set to zero.

To Window a signal:

■ Choose **Window graph** from the **Options** menu. The signal in the Graph window can be multiplied by a number of window functions. Select the Bartlett window by clicking its radio button and entering -32 and 32 as the start and end points of the record.

The window function will appear in grey superimposed on your signal. The window can be moved to the right by the space bar and to the left by the backspace key. Try moving it around by using these keys.

■ After you have positioned the window properly, click the rectangle on the lower left corner that says "**CLICK HERE WHEN FINISHED**". The program will multiply your signal with the window and display the result.

To recover the original signal, select **Last signal** from the **Show** menu.

The Gaussian window accepts the mid-point between start and end points as its mean value and half of the window length as its standard deviation.

To print a signal:

■ To print the entire screen: With Caps Lock down, hold down both the Command and Shift keys while you type the number 4.

■ To print the contents of the Graph window: Hold down both the Command and Shift keys while you type the number 4.

■ To create a MacPaint™ document with the contents of the screen: Hold down both Command and Shift keys while you type the number 3.

To Save and Open signals on the disk:

The signal displayed on the Graph window can be saved as a document on the disk by selecting **Save signal** under the **File** menu. Saved signals can be retrieved by choosing **Open signal**. Note that Transforms, Windows, Modulation... can be opened from the desktop by double clicking on the document. The Signal Operations and the TWM modules can open signal documents saved by each other; the Signal Operations opens the real part of a complex signal saved by the TWM program; the TWM program opens a signal saved by Signal Operations as a real signal (the imaginary part is set to zero).

Leaving Transforms, Windows, Modulation...

■ Choose **Quit** from the **File** menu. Upon quitting the program, if you have any signals stored in the bins, they will be saved as scrap files in the <u>scrap folder</u>. You may delete all but the scrap #0 file in this folder, if you delete all scrap files the program will create an unnamed folder to place these scrap files next time you quit. Upon quitting, the scrap files already on the disk will be deleted before writing the new scrap files.

If you are forced to exit the program due to a system error, the signals stored in the bins will still be kept in the scrap folder under the bin # name and can be retrieved by the **Open Signal** command next time the program is started.

SOLVING PROBLEMS WITH TRANSFORMS, WINDOWS, MODULATION...

Since the Transforms, Windows, Modulation... module is similar to the Signal Operations module in its screen layout and philosophy of operation, users who are familiar with the first module should not need further instruction to operate this program. The major differences are the addition of two more pull-down menus to accomodate the Fast Fourier Transform and to view different parts of signals. Additional items under the **Option** menu are **Window graph** and **Make signal. Window graph** is a collection of popular data windows and **Make signal** serves to create a new signal out of an existing signal. Additional items have also been added to the **Display** menu.

The problems below are similar to the ones solved in an introductory level signals and systems course. The intent is to illustrate the applications of this program and to help visualize theoretical concepts, verify anticipations, and reinforce comprehension of the subject material. You need not follow the given steps since each user will develop a different approach to the problems.

Q1) This problem is to study the symmetry properties of the Fourier Transform of a real discrete signal. Using a square pulse, demonstrate that:
Even $\{y[n]\} = y_e[n] < F > $ Real $\{Y[N]\}$
Odd $\{y[n]\} = y_o[n] < F > $ Imag. $\{Y[N]\}$
where F stands for discrete Fourier transform and N for discrete frequencies.

A1) Generate a square pulse of width 8 and starting from zero in the time domain and in real part. (These are the default values for the square pulse generator.) This is y[n]. Store y[n] in bin #1. To take the Fourier Transform of y[n], select **FFT** from the **Transforms** menu. Note that the transform is taken over 128 points, which is the default of the transform record. The magnitude spectrum is shown in the Graph window. To see the real (i.e. Real {Y[N]}) and the imaginary (i.e. Imaginary {Y[N]}) parts of the spectrum, select **Real** and **Imaginary** menu items from the **Show** menu. Store the spectrum in bin #2. (See Figure 1)

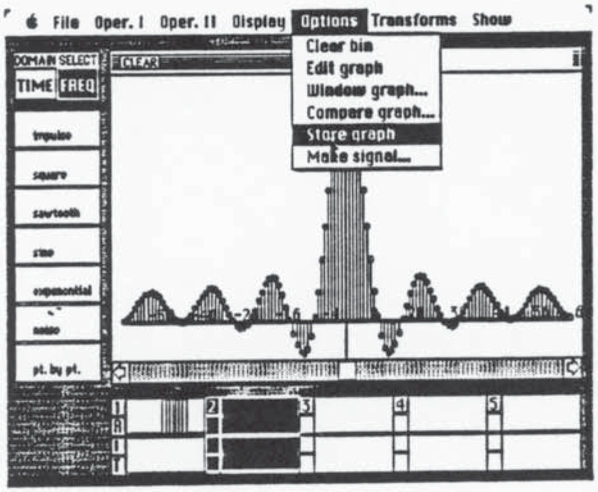


Figure 1

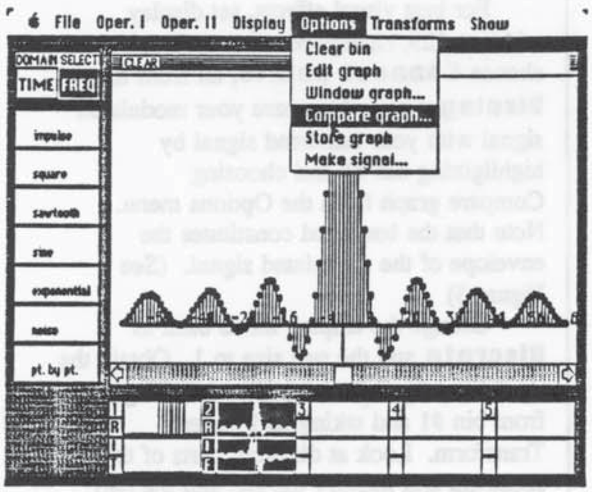


Figure 2

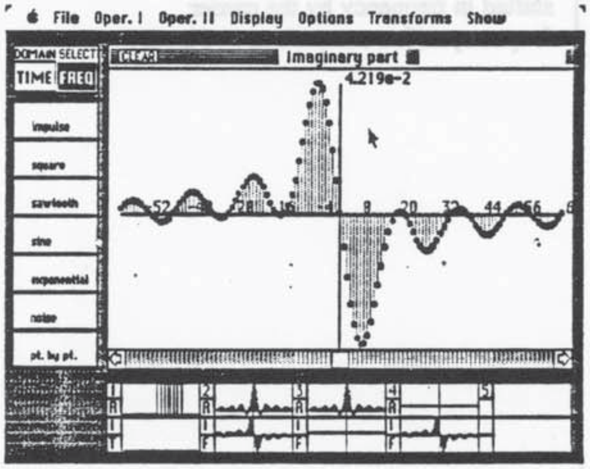


Figure 3

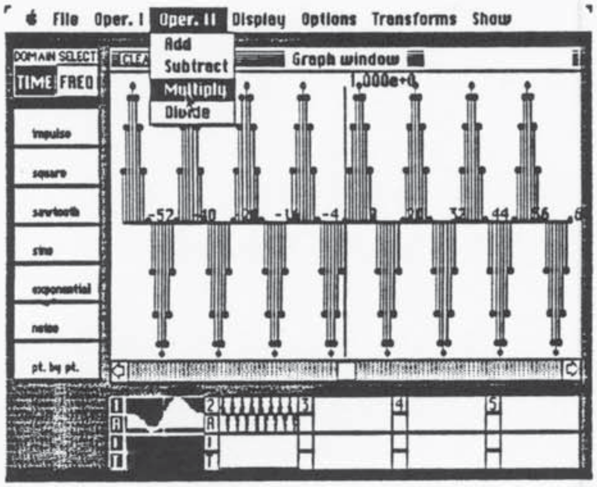


Figure 4

Recall y[n] from bin #1 by clicking on the bin number. Take the even part of y[n] by choosing **Even part** from the **Oper. I** menu. This is $y_e[n]$. Take the transform of y_e [n]. Observe the real and imaginary parts of Y_e [N]. As expected, the real part of Y_e [N] is identical (within truncation limits) to the real part of Y[N] and the imaginary part is zero. Compare Real{Y[N]} and Real{Y_e [N]} as in Figure 2.

Repeat the same steps for the odd part of y[n]. You will see that Y_o [N] has zero real part and its imaginary part is identical to the imaginary part of Y[N] as compared in Figure 3.

Q2) This problem illustrates the concept of amplitude modulation (AM). Simulate in discrete time the amplitude modulation (AM) process $\sin w_c t\,(1+\mu m[t])$, where $\sin w_c t$ is the sinusoidal carrier and m[t] stands for the baseband message to be transmitted and μ is the modulation index which is set to 1 in this example.

A1) Suppose the message consists of two sinusoids added together, one with a period of 128 points and the other with half the period, 64 points, i.e.
$m[n] = \sin(2\pi/128)n + 0.5 \sin(2\pi/64)n$.
Generate a sine by clicking on the "sine" box, enter 128 for the period. Store this sine in bin #1. Generate another sine of amplitude 0.5 with period 64 in the same way. Add the two together by highlighting bin #1 and choosing Add from Oper. II menu. Store the result in bin #1 again.

D.C. can be generated from the square wave with the following parameters in the dialog box: Period: irrelevant, width: irrelevant, amplitude: 0, delay: irrelevant, DC offset: 1. Add this to the contents of bin #1 and store the result in bin #1 again. Your baseband signal is now in bin #1.

Generate a sinusoid with amplitude of 1.00 and a period of 16 points to serve as a carrier. Store the carrier in bin #2. Multiply the carrier with the baseband signal. (See Figure 4) This is the modulated carrier. Store the result in bin #3.

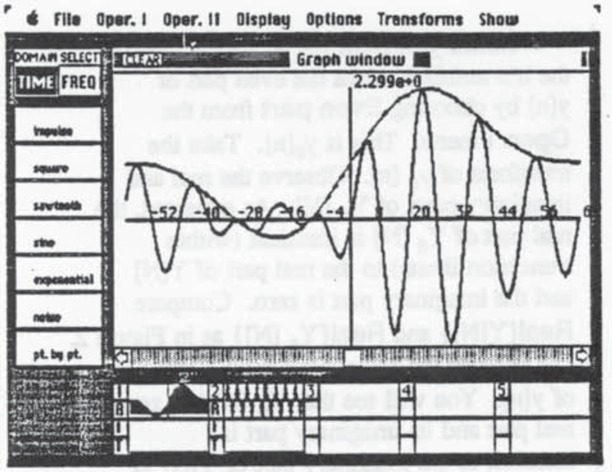


Figure 5

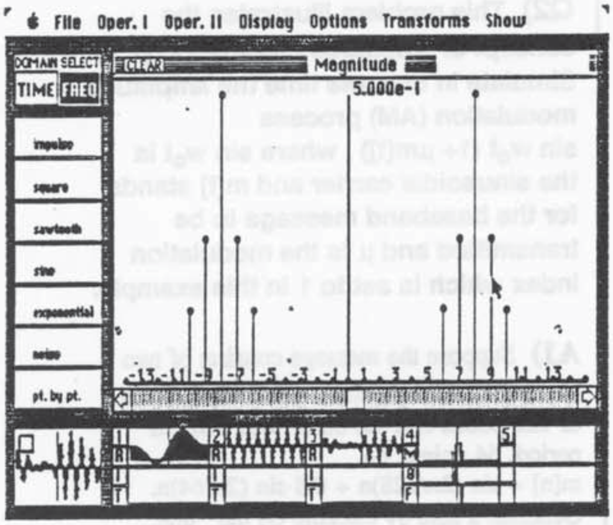


Figure 6

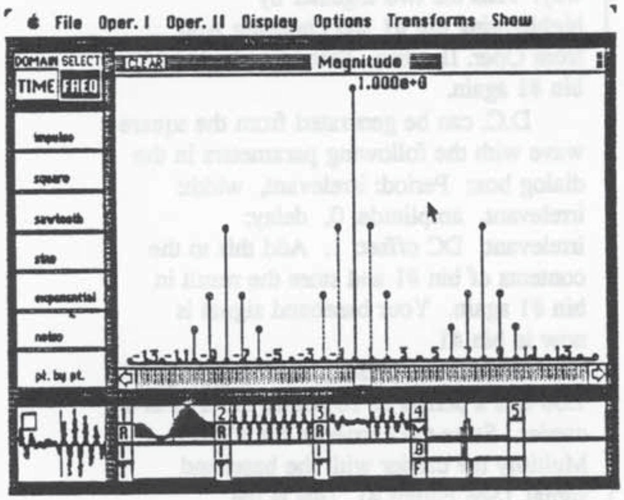


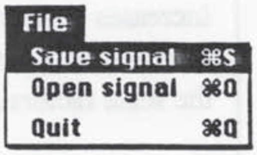
Figure 7

For best visual effects, set display width to 129, change pen size to 2 and choose **Connect points**, all from the **Display** menu. Compare your modulated signal with your baseband signal by highlighting bin #1 and choosing Compare graph from the Options menu. Note that the baseband constitutes the envelope of the modulated signal. (See Figure 5)

Change the display mode back to **Discrete** and the pen size to 1. Obtain the spectrum of your baseband by recalling it from bin #1 and taking its Fourier Transform. Look at different parts of the spectrum and identify the DC and the two harmonics and store it in bin #4. Then obtain the spectrum of the modulated carrier stored in bin #3. (See Figure 6) Note that the baseband spectrum has been shifted in frequency by the carrier frequency. (See comparison in Figure 7)

REFERENCE

Menu Summary



Save signal ⌘S

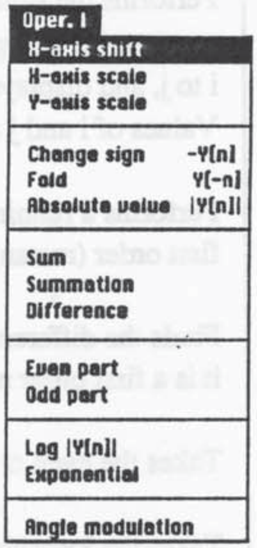
Saves the signal in the Graph window to the disk.

Open signal ⌘O

Opens a stored signal into the Graph window. The real part is displayed.

Quit ⌘Q

Exits the program and returns to the desktop. The signal in the Graph window and the signals in the storage bins are saved as scrap files in the scrap folder.



X-axis shift

Moves the signal on the x-axis (time axis) K integer units, i.e. changes the signal from f(n) to f(n-k). Displays a dialog box to specify the type of shift, linear or circular, i.e. wrap-around, and the integer value of K.

X-axis scale

Expands or compresses the x-axis, i.e. changes the signal from f(n) to f(An/B). Displays a dialog box to enter positive integer values of A and B. Expanding the horizontal scale will place zeros between points. (See "Special Considerations" in the "Reference" section of this manual.)

Y-axis scale

Increases or decreases the amplitude of the signal, i.e. changes the signal from f(n) to (A/B)f(n) according to the scale factors A and B entered through a dialog box.

Change sign   -Y[n]

Rotates the signal around the x-axis, i.e. changes the signal from f(n) to -f(n).

Fold   Y[-n]

Rotates the signal around the y-axis, i.e. changes the signal from f(n) to f(-n).

Absolute value |Y[n]|

Takes the absolute value of the signal array, i.e. changes the signal from f(n) to |f(n)|.

Sum

Performs the sum of values from one specified point to another, i.e. computes $Y(n) = \sum f(k)$, where k goes from i to j, and displays Y(n) as an impulse at the point j. Values of i and j are entered trough a dialog box.

Summation

Performs a running sum of a signal array, i.e. it is a first order (rectangular) numerical integrator.

Difference

Finds the difference of the points in a signal array, i.e. it is a first order numerical differentiator.

Even part

Odd part

Takes the even or odd parts of a signal array.

Log |Y(n)|

Takes the logarithm of a signal. Base values (e,10, etc.) are entered through a dialog box. Zero signal values can be set to user defined values using **Set display zero.**

Exponential

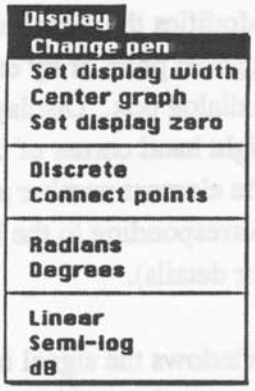
Takes the exponential according to the specifications in the dialog box. You can toggle between $f(n)^B$ or $B^{f(n)}$ modes, and specify the base or the exponent as 10, e, or as another number. If the exponent is not an integer and the base is negative, the absolute value of the base is taken to avoid generating complex numbers.

Angle modulation

Angle modulates (phase or frequency) a sine wave carrier with the signal in the graph window. The part of the signal which modulates the sine wave is indicated through a dialog box. The carrier sine wave and other modulation parameters are entered in the same dialog box.

Add
Subtract
Multiply
Divide

Performs the addition, subtraction, multiplication, and division respectively of two or more signal arrays. In the case of division by zero, a warning is issued and the results are set to zero. If only one bin is selected, the signal in the Graph window becomes the second signal by default.



Change pen

Changes the thickness of the graph lines.

Set display width

Changes the number of points shown in the Graph window. [The number of points in a given signal is 129 (extending from -64 to +64 on the x-axis).]

Center graph

Re-centers the signal in the Graph window after it has been moved with the scroll bar.

Set display zero

For graphing purposes, values less than a user defined minimum are considered zero. The default is set to 10^{-6} (or in scientific notation 1e-6).

Discrete

Plots the signal at discrete points. (This is the system default since all digital computer operations are inherently discrete.)

Connect points

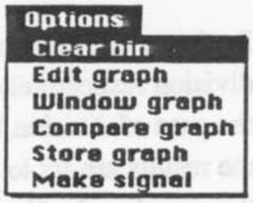
Connects the discrete points by drawing a straight line between two adjacent points. This is only a visual effect. The signal remains discrete.

Radians
Degrees

Selects the units in which the phase information is displayed.

Linear
Semi-log
dB

Plots the magnitude and power of a signal linearly, semi-log, or in decibels. For other signal parts (i.e. real, imaginary and phase) only linear option is available.



Clear bin

Clears the contents of the selected storage bin.

Edit graph

Modifies the signal in the Graph window by clicking on a given point or by entering numerical values through a dialog box. Displays a small dialog box in the upper right hand corner of the Graph window that displays the element number and the x and y values corresponding to the location of the pointer (see text for details).

Window graph

Windows the signal in the Graph window. A choice of commonly used 'signal windows' are available through a dialog box.. The user specifies the window type and enters the width of the window. The specified window appears in grey, superimposed on the displayed signal. The window can be moved through the keyboard. Pressing the space bar or backspace displaces the window to the right or left by one unit, respectively. Upon clicking on the box "**CLICK HERE WHEN FINISHED**", the signal is multipled with the window function. The Gaussian window accepts half of the window length as its standard deviation. Note that other windows can be designed using 'signal generator boxes' and the appropriate combination of signal operations. Once designed, they can be applied onto the signal using the 'multiplication' option.

Compare graph

Superimposes, in lighter intensity, the selected signal (from a storage bin) on the signal in the Graph window.

Store graph

Stores the contents of the Graph window in the selected storage bin(s).

Make signal

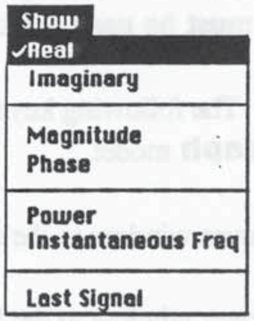
Makes a new signal out of the signal contained in the Graph window. The contents of the window are assigned to either real or imaginary part or magnitude or phase of a new signal by responding to a dialog box. The domain (i.e. time or frequency) can be selected by clicking on the DOMAIN SELECT box. Note that making 'phase' from another signal will automatically fill the magnitude of the resulting signal with ones since phase cannot exist without a nonzero magnitude. In other cases (i.e. real, imaginary and magnitude), the second part of the signal will be set to zero.

FFT

Takes the Discrete Fourier Transform of the signal in the Graph window using the Fast Fourier Transform (FFT) algorithm. In the frequency domain this menu item changes to **IFFT**, to take the inverse transform using the same algorithm with appropriate scaling.

Set transform record

Defines the record, i.e. the signal interval over which the FFT will be performed. The starting point and the number of points in the record are entered in a dialog box. The user can set the starting point of the record anywhere on the x-axis using Free zero option. This mode is consistent with the conventional FFT algorithms that operate on data taken from an event and the start of the record is selected as the zero point. Fixed zero refers to the zero point as seen on the graph.



Real
Imaginary
Magnitude
Phase

These options are self explanatory. Note that when the imaginary part of a signal is zero, the convention for assigning phase is: negative real values for negative time or frequency are assigned +180°; those for positive time or frequency are assigned -180°.

Power
Instantaneous Freq
Group Delay

These options are for viewing purposes only; menus and menu items that would alter the original signal are disabled. **Power** displays the square of the magnitude of the signal on the graph window. **Instantaneous Freq** (or **Group Delay**) approximates dø/dt or dø/dw by the **difference** of the phase array, depending on the domain of the waveform displayed, multiplied by the appropriate factors. (See "Special Considerations".)

Last signal

Replaces the signal in the Graph window with the signal in the Last Signal window. (The Last Signal window contains the contents of the Graph window prior to the most recent entry.)

SHORTCUTS

Option + #

■ Press the Option key and a number to select a Storage bin directly from the keyboard.

Enter + #

■ Press the Enter key and a number to store a signal in a Storage bin directly from the keyboard.

Return + #

■ Press the Return key and a number to return the contents of a Storage bin to the Graph window directly from the keyboard.

Note: When using these shortcuts, the number 0 must be used for the 10th bin.

■ The following keys are functional in **Window graph** mode:

Space bar

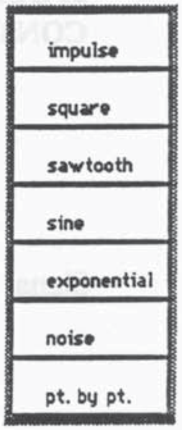
moves window to the right along the x-axis.

Backspace

moves window to the left along the x-axis.

Return

= **"CLICK HERE WHEN FINISHED"**



Signal Generator Summary

impulse Generates the unit sample function.

square Generates a square pulse train according to specifications entered through a dialog box.

sawtooth Generates a triangular pulse train according to specifications entered through a dialog box.

sine Generates a sinusoidal function. The harmonic number and the peroid must be positive integer values. The amplitude is entered in decimal or scientific notation (i.e. 0.002 can be entered as 2e-3). The phase is entered in degrees or radians (as multiples of π [3.14159...] or directly in radians) and automatically converted to the other unit.

exponential Generates the exponential sequence B^{An}. The base is specified as 10, e, or by typing any number. If the exponent is not an integer and the base is negative, the absolute value of the base is taken to avoid generating complex numbers.

noise Generates pseudorandom noise function.

pt. by pt. Arbitrary functions can be generated point by point using this option. See "To create a signal point by point" in the "Using Transforms, Windows, Modulation" section of this manual.

SPECIAL CONSIDERATIONS

As in any other software application, the "Transforms, Windows, Modulation" program has features which at times may appear as program 'limitations'. These limitations are due in major part to peculiarities of the hardware and software used as well as the overall design and philosophy of the program. In order to facilitate the program operation and enhance important features, we have adopted an approach which has resulted in the following limitations.

Signal Array Size

In order to limit the size of the program, signal arrays are limited to a total of 129 points extending from -64 to +64. Due to this limitation, signals that actually extend beyond the limits of the array will be represented as pulses from -64 to +64. For example, if a sine is generated, the outcome is a sinusoid pulse that extends from -64 units of time to +64 units of time. Similarly, if a unit step is generated, the outcome is a rectangular pulse that goes from 0 to +64. This limitation has important implications in the following operation:

X-Axis shift

If the actual signal extends beyond +64 or -64 and linear x-axis shifting is specified, this operation may bring in zeros rather than filling in with appropriate values. For example, a unit step shifted to the left by 10 units will result in a rectangular pulse from -10 to +54. Linear x-axis shift in the direction of the extension is not reversible. As an example, try shifting a unit step to the right by 10 units and then shift the result to the left by 10 units. However, if cyclic shift is chosen, the latter shortcoming is eliminated.

FFT/Set transform record

If the FFT algorithm is used with a transform record length less than 128 points, the remainder of the signal is filled with zeros. This defacto zero-padding is necessary because the program is set to operate only on the fixed array size of 129 points.

X-Axis Scale and X-Axis Shift

The x-axis scale and x-axis shift dialog boxes accept only integer values. Rounding to the next integer will occur for decimal entries greater than or equal to a half. Furthermore, x-axis scale will take the absolute value of the scale factors. Rounding to the next integer value might result in some inconsistencies. For example, a sequence, f[2n-3] can be represented as f[2(n-3/2)]. However, time scaling the original sequence, f[n], by 2 and then shifting it right by 3 is different from shifting f[n] right by 1.5 first and then time scaling it by 2. Whenever a fraction is entered into the x-axis scale dialog box, [i.e. A=2 and B=3 hence A/B=2/3] it should be in reduced form [i.e. A/B=2/3 instead of 4/6 or 12/18]. Also please note that expanding the horizontal scale will create zeros between points. This is due to the limitation of the graphics routines used in the program.

Log|Y(n)|

Note that this operation replaces the contents of the array by the logarithm of the signal. However, since negative values cannot exist in Magnitude, when the log of a magnitude plot is requested, values between 1 and 0 (i.e. numbers with negative logarithms) will be assigned to positive values. In order to display the logarithm of the magnitude, choose instead Semilog option from Display menu.

Make Signal

Make Signal menu item allows Instantaneous Freq. / Group Delay and Power to be assinged to the real or imaginary parts or magnitude or phase of a new signal. However, since Instantaneous Freq. / Group Delay and Power are computed values, the reverse is not possible.

FFT and Sampling Frequency

A sampling frequency option is not included in this educational version in order to present the actual results of the FFT algorithm independent of the sampling rate. If a sampling frequency f_s (or sampling interval, T) is specified, scale the x-axis units of the transformed signal by f_s/N or 1/TN where N is the Transform record length. For example, if the sampling frequency f_s =10Hz (or sampling interval T=0.1s) and the transform length is N=32 points, multiply x-axis units by 10/32 to obtain correct scale in Hz.

Instantaneous Frequency and Group Delay

These functions are computed as the difference of the phase array. Depending on the Transform recard size N, a scale factor of N is used for the instantaneous frequency and N/2π for group delay.

The Desktop

Upon leaving the program, you will find a folder named Scrap on the desktop. The bins are stored in this folder as scrap files when you leave the program. The first scrap document (scrap #0) must not be removed from the scrap folder in order for the program to store scrap documents in this file the next time.

You are also provided with a **Transforms, Windows, Modulation... Data Folder** on the desktop which contains images that the program needs for certain dialog boxes. If that folder is not on the <u>same</u> disk as the program, the program will bomb whenever a dialog box that requires those images is brought up.

Dialog Boxes

Some of the dialog boxes may alter the values of the parameters (default values) even if they have been cancelled.

In General

- <u>Signal generation in</u> Magnitude: If a signal is generated in Magnitude mode, the program will take the absolute value of the waveform. This is due to the fact that magnitude, by definition, is non-negative.
- <u>Graphics</u>: Due to the available graphics resolution, only three decades (10^3) of a given signal can be distinguished on the screen. However, the pointer monitor on the upper right hand corner of the Graph window shows values in scientific notation. The default machine zero is set to 10^{-6}, which can be changed by using Set display zero.