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Frequency Domain Using Excel
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Introduction:

Waveforms plotted in Excel generally show the magnitude (Y-axis) versus time (X-axis). (See Figure 1, Data in Time Domain.) Knowing the period T of the waveform, the frequency can be calculated.
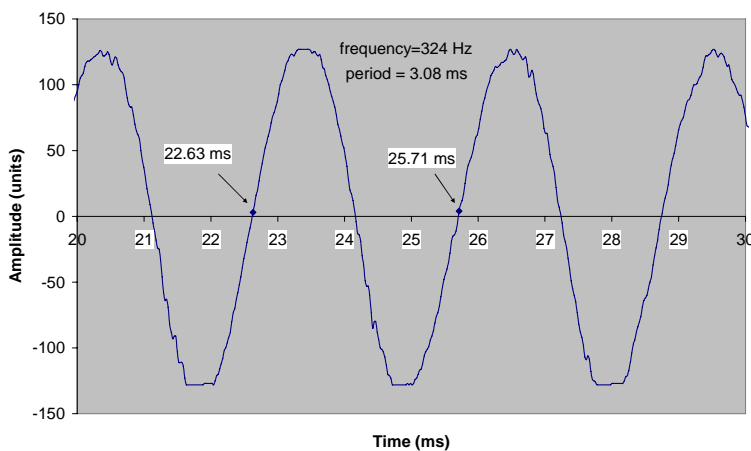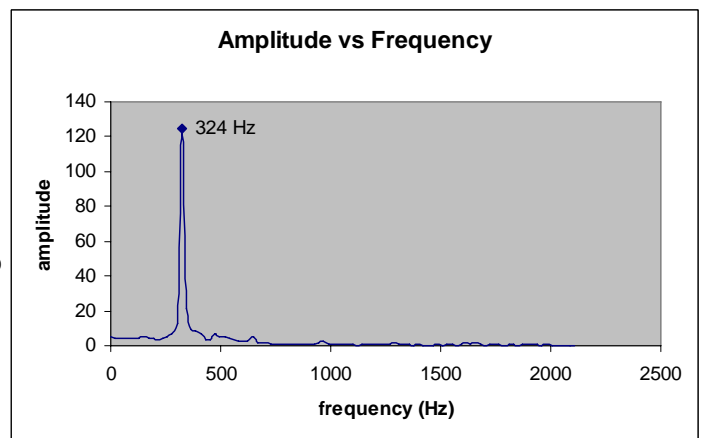
Figure 2: Data in Frequency Domain

Figure 1: Data in Time Domain

Sometimes experiments call for the "harmonic content" of a reproduced waveform. The harmonic content is a display of the magnitude of the waveform (Y-axis) versus the frequency (X-axis). This is sometimes called the frequency spectrum and it allows you to visualize a waveform according to its frequency content (see Figure 2, Data in Frequency Domain). The following steps will guide you to translate a waveform from the time domain to the frequency domain using Excel.

Setup Excel for Data Analysis

In EXCEL, if the **Data Analysis** command is not on the **Tools** menu, you need to install the Analysis ToolPak in Microsoft Excel. To install the Analysis ToolPak go to the **Tools** menu, click **Add-Ins**. Select the **Analysis ToolPak** check box.

Step 1: Label Columns

Label five columns in EXCEL as follows: **Time**, **Data**, **FFT freq**, **FFT mag**, **FFT complex**. This will correspond to columns A through E in the Excel spreadsheet.

Step 2: Import Data, determine sampling frequency, adjust number of samples to 2^n

Import the sampled data from your experiment into **Time** and **Data**. Let **D** correspond to the number of rows of data. Therefore, suppose in our example we have **D**=1000.

Note the time interval, **t**, of the data by subtracting the number in the first cell in the **Time** column from the number in the last cell in the **Time** column. For example, after subtracting the first cell from the last cell, suppose the difference in the time interval **t** is 0.02 seconds.

Determine the <u>sampling frequency</u>, **fs** by dividing number of data, **D**, by the time interval, **t**. In our example, suppose there are 1000 samples.

Therefore, the sampling frequency $fs = \dfrac{D}{t} = \dfrac{1000}{0.02} = 50,000$ samples/sec

$$\boxed{\begin{array}{l} \textbf{fs} = 50,000 \\ \textbf{D} = 1,000 \end{array}}$$

In the next step of Excel, one of the limitations of using the FFT function is that the number of data points operated on must be a number that is a power of two. For example, we must operate on either 256 data points (2^8), 512 data points (2^9), 1024 data points (2^{10}), 2048 data points (2^{11}) or any other power of two. In our hypothetical example, since 1000 data points is very close to 1024 data points, we could add dummy data by adding zeros in the Time and Data column to make 1024 data points. In the alternative, we could have used only the first 512 data points.

Since we've decided to use 1024 data points (2^{10} data points), add zeros in the Time and Data column from rows 1002 to 1025 as a filler. We now have 1024 "data points" even though the last 24 are zeros. This is done to enable the FFT function in Excel to work, otherwise an error results. Because we have chosen 2^{10} data points, then let **sa = 1024.** <u>Generally, the larger sa is, the better the accuracy.</u>

$$\boxed{\textbf{sa} = 1024}$$

Step 3: Fill in Column E called "FFT complex"

Using **Tools → Data Analysis → Fourier Analysis**, enter the **Input Range** of the Data. In our example, we have 1024 data points (2^{10}) in column B. Therefore, in this example, Input Range is the data located at **$B$2:$B$1025**.

Select the output range for the FFT complex number generated by Fourier Analysis to be located at **$E$2:$E$1025**. Select OK. Column E (called **FFT complex**) will now contain an FFT complex number.

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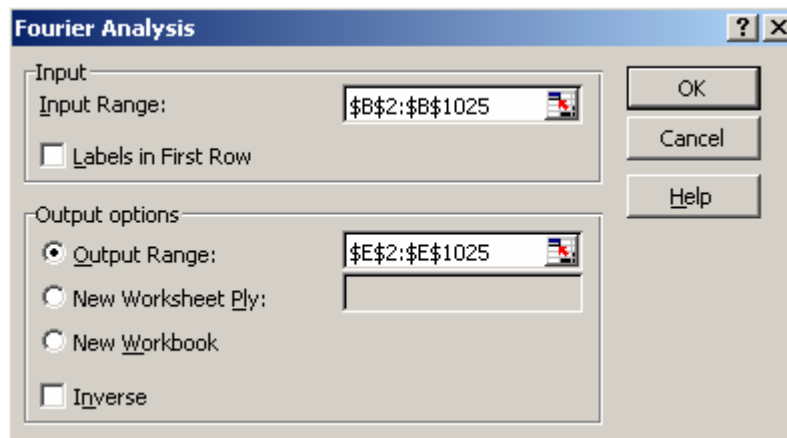
Step 4: Fill in Column D called "FFT mag"

Calculate the FFT magnitude (column D) by finding the absolute value of the FFT complex of column E and multiply it by 2/**sa**. In our example, **sa**=1024. Place the cursor in cell D2 and use the formula bar to enter the following formula: **=2/1024 * IMABS(E2)**. Click the checkmark to the left of the formula to enter the formula into cell D2. Then drag the formula in D2 down (click on the tab of the lower right-hand corner of D2) to D1025.

Drag this down to copy the formula to D1025
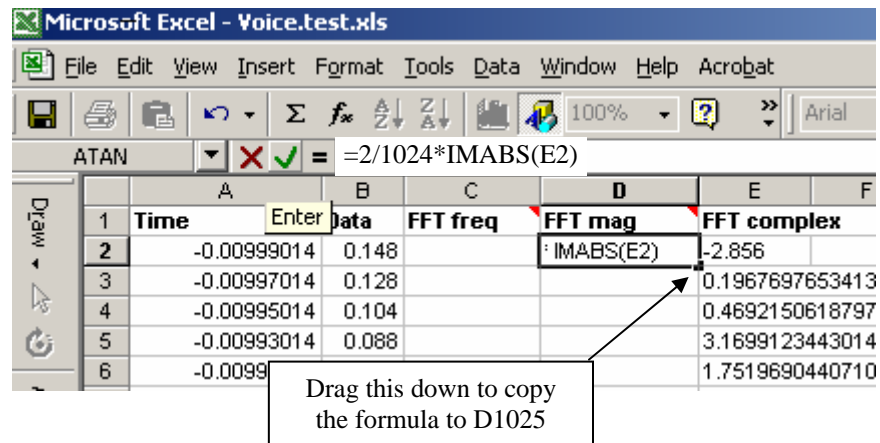
Step 5: Fill in Column C called "FFT freq"

The first cell of the FFT freq (C2) is always zero. Enter 0 for cell C2.
The second cell (C3) of the FFT freq is 1 x **fs** / **sa**, where **fs** is the sampling frequency (50,000 in this example), and **sa** is the number of 2^n samples, 1024 in this example).
Therefore, cell C3 is 1 x 50,000 / 1024 = 48.828125. The next cell C4 is 2 x fs / sa or 2 x 50,000/1024. The next cell C5 is 3 x fs/sa, and so on.

Instead of manually filling in the rows, we can automatically fill the "FFT freq" column using the Excel *Series* function. Leave C2 as always zero. C3, calculated in our example, is 48.828125. To automatically fill from C3 down, make sure C3 is selected, use **Edit → Fill → Series** to automatically fill the remaining column as shown below.

Step value = fs/sa
Stop value = fs

Do not round values up or down. Use all digits in the calculations.
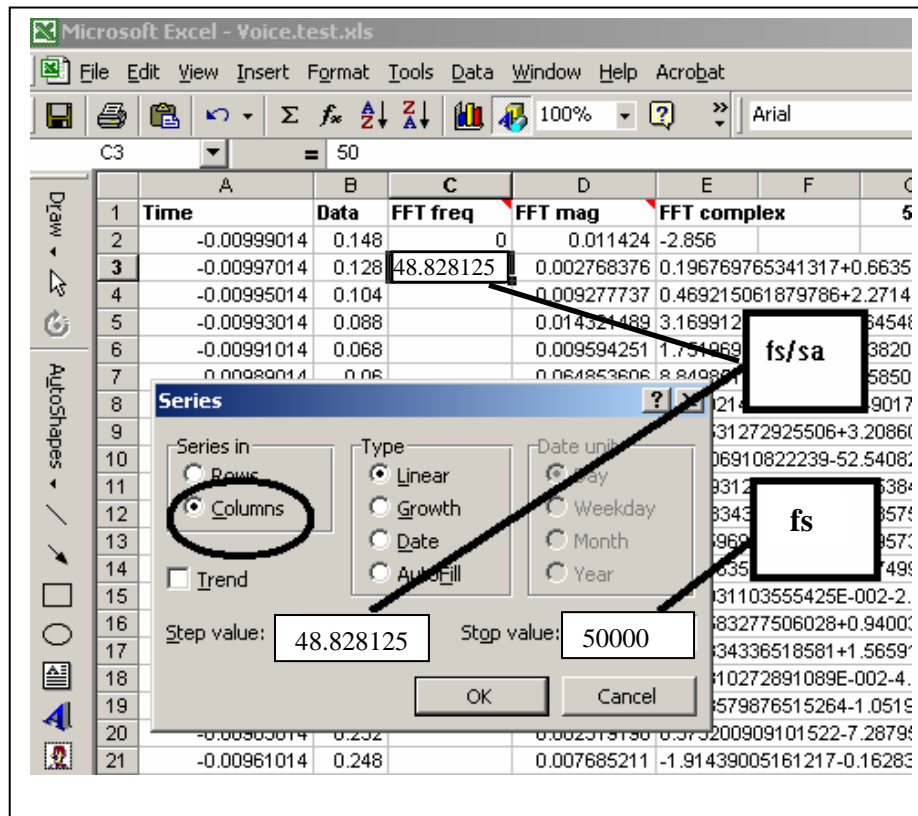
Step 6: Plot Waveform in the Frequency Domain

Select values in columns C (**FFT freq**) and D (**FFT mag**) and plot using Chart Wizard as usual using XY (Scatter plot). Plotting more rows is not necessarily better, depending on the plot results desired. Experiment creating different plots: with the first 128 rows; with the first 256 rows; with the first 512 rows; etc. The plots will be the frequency spectrum (magnitude vs frequency) with different views. See sample below. Or try first 100 rows, first 200 rows, first 300 rows, etc.

Do not plot more than sa/2 rows. If more than sa/2 rows are plotted, *the FFT representation begins to duplicate itself.*

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Example Of A Voice Pattern Plotted
With Different Number Of Rows

FFT Vowel A: 512 samples

390 Hz

FFT Vowel A: 64 Samples

390 Hz

FFT Vowel A: 256 samples

390 Hz

FFT Vowel A: 32 samples

390 Hz

FFT Vowel A: 128 samples

390 Hz

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