Educator's Corner
Experiments

HEWLETT PACKARD

Search
Hewlett-Packard
Test & Measurement

Virtual Lab 6: Magnitudes, Phases Everywhere!

By: Steve Badelt and Daniel D. Stancil
Department of Electrical and Computer Engineering
Carnegie Mellon University
Pittsburgh, P   A

Purpose:
- Fast Fourier T   ransform
- Selection controls, and Records in HP VEE
- Completion of the spectrum analyzer

Equipment:
- HP 34401A Multimeter
- HP 54601A Oscilloscope with HP 54657A Measurement/Storage Module
- HP 8116A Pulse/Function Generator or HP 33120A Function/Arb Generator
- HP 6236B T   riple-output Power Supply
- Connectix V   ideo Camera
- Intel 100MHz Pentium computer   , 32MB Ram with HPIB Card
- HP VEE for W   indows software, V   ersion 3.2
- T   imbuktu (remote access) software
- QuickPICT software
- T   ext: Robert Helsel, "Graphical Programming: A T   utorial for HP V   EE", Pren
- HP VEE executable files

Introduction:

Fast Fourier T   ransform

In general, we can construct any repetitive waveform by adding an appropriately-weighted sum of sinusoids:

$$f(t) = c_0 + 2\sum_{n=1}^{\infty} c_n \cos\left(\frac{2\pi n}{T} t + \phi_n\right) \tag{1}$$

where T is the period of the waveform. This is called a *Fourier Series*. The coefficients can be obtained from

$$\hat{c}_m = c_m e^{j\phi_m} = \frac{1}{T}\int_0^T f(t) e^{-j\frac{2\pi mt}{T}} dt \tag{2}$$

As an example, consider a square wave that has the magnitude 1V between $t=0$ and $t=T/2$, and is zero between $t=T/2$ and $t=T$.
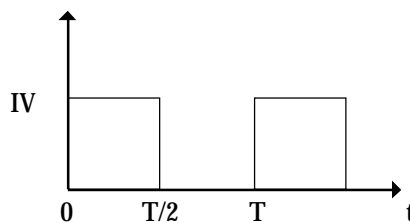
A straightforward calculation gives
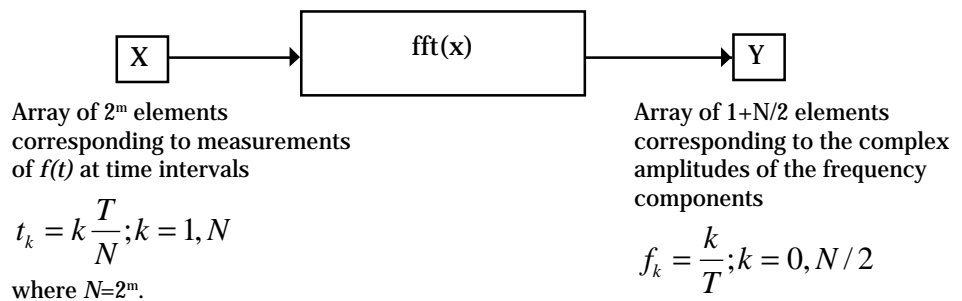
$$\hat{c}_m = \frac{j}{2\pi m}\left[(-1)^m - 1\right] \qquad (3)$$

The first few coefficients are:

$\hat{c}_m$ m	$\hat{c}_m$
0	1/2
1	-j/π
2	0
3	-j/(3π)
4	0
5	-j/(5π)

In the case of data we take off the digital scope, we don't have a continuous function; instead we have *discrete samples* of a continuous waveform. In other words, we only know the values of *f(t)* at discrete, uniformly-spaced time intervals:

$$t_k = k\frac{T}{N}; k = 1, N \qquad (4)$$

The *Discrete Fourier Transform* (DFT) is an adaptation of (2) for discrete time data, and yields the complex amplitudes of the frequency components that are harmonics of 1/*T*. A particularly efficient way of calculating a DFT was discovered several decades ago by Cooley and Tukey, and is called the *Fast Fourier Transform*, or FFT. The FFT has the restriction that *N* must be a power of 2; i.e., $N=2^m$. Both the digital scope and HP VEE have built-in FFT functions that work like this:

X → fft(x) → Y

Array of 2^m elements corresponding to measurements of *f(t)* at time intervals

$$t_k = k\frac{T}{N}; k = 1, N$$

where $N=2^m$.

Array of 1+N/2 elements corresponding to the complex amplitudes of the frequency components

$$f_k = \frac{k}{T}; k = 0, N/2$$

The scope gives the magnitude only of the frequency components in dBV, where the reference is 1 V rms (i.e., $Y_n = dBV_n$). The conversion to the coefficients in (2) is given by:

$$\left|\hat{c}_n\right| = \frac{10^{\frac{dBV_n}{20}}}{\sqrt{2}} \qquad (5)$$

In the FFT mode, the scope always uses *N*=1024.
HP VEE gives the complex amplitudes, but the FFT is defined differently from above. If the HP VEE output array is Y_m, the conversion to the coefficients in (2) is given by:

$$\hat{c}_m = \frac{Y_m}{N} \qquad (6)$$

In addition, N is apparently not limited to a power of 2 in HP VEE, although the documentation does not indicate what algorithm is used.

You may have noticed that we only get 1 more than half the number of frequencies out than time samples in. This is the result of a fundamental principle called the Nyquist Theorem. According to this theorem, you need at least 2 points per period to uniquely define the frequency of a sinusoidal component. Hence with N points in, we get N/2 frequencies out plus DC (corresponding to 1+N/2 points.) Aliasing is a form of distortion that arises if you don't sample enough to satisfy this theorem at the highest frequency contained in the signal. If you don't know what the spectrum looks like before hand, how do you know if you have taken enough points? Generally you can tell by looking at the last few elements of Y. If these have negligible magnitudes compared to $\max(Y_k)$, then you are probably ok.

Another potential source of error is called *spectral leakage*. The FFT assumes the time signal is perfectly periodic with period T. If T does not contain an integral number of cycles of the waveform, a discontinuity is produced causing an error in the spectrum. The simple way to avoid this error is to always make sure an integral number of cycles are included in the time period T. Other techniques for minimizing this error involve using "windowing" functions to make sure the sampled signal goes smoothly to zero at the beginning and end of the sampled time period. A detailed discussion of these windows is beyond the scope of this lab. Suffice it to say that we will use the Hanning window in our scope experiments.

Selection Controls:

Radio Buttons, Cyclic Buttons (that change their label as you depress them), and Pop-up lists all allow the user to select an option from a list of possibilities. A selection control outputs the label that is chosen. If "Go to bed." is one of the options on the list, then "Go to bed." is the string output of the selection control. However, there is an accompanying number with each string output that may be obtained using the **Math→Real Parts→Ordinal(x)** function. This will extract a number indicating the order of the selection on the list.

Records:

A record is a conglomeration of data stored in fields. Each field can contain data of any type, but only of one type, and even another record. Multiple fields may exist within a single record. If you have had C programming experience, you are no stranger to records (data structures), and the HP VEE record is no different.

Procedure:

Part 1: Scope Practice

1. Set the function generator to generate a square wave with 50% duty cycle, frequency of 1 kHz, a 0.5 V amplitude, and an offset of 0.5 V. Examine this waveform on Ch 1 of the oscilloscope and verify that it is a square wave with max value of 1 V and minimum value of 0 V (similar to the example above). Note: the function generator settings are calibrated for driving a 50 ohm load; since the scope has a high-impedance input, you will have to compensate for this to obtain the desired waveform!
   [If you're using an HP33120A, go to **System Menu** and set output term to HI-Z.]

2. Set the time base on the scope so that exactly five periods are shown on the screen.

3. Press ±, then turn on **Function 2** to enable the math function 2.

4. Press the **Function 2 Menu** softkey.

5. Select Channel 1 using the **Operand** softkey.

6. Select FFT using the **Operation** softkey. This simultaneously diplays the time and frequency waveforms.

7. To turn off the display of channel 1 time waveform and "connect the dots" on the spectrum, press the channel 1 key and turn the channel off.

8. Experiment with the **Ref Levl** and **Units/div** softkeys until you understand what they do.

9. Press the **FFT Menu** softkey, and experiment with the **Cent Freq**, **Freq Span**, and **Move 0Hz to Left** functions. Additional information can be obtained from "HP 54657A and HP 54658A Measurement/Storage Modules User's Guide," pp. 28-33.

10. Using the scope cursers, measure the amplitudes of the DC level and first five harmonics, and compare with the calculation in the first part of this lab.

11. Save scope screens showing the time waveform and the corresponding spectrum of your square wave.

Part 2: HP VEE Practice

1. Select **Data→Selection Control→Drop Down List**. From the control's object menu choose **Edit Enum Values**. Within that list enter the options "DC", "Sine", "Triangle", and "Square." The number (Enum Value) corresponding to each word should match its waveform selection number as in Lab 5.

2. Wire up a **Math→Real Parts→Ordinal(x)** object between the selection control and the Waveform input of your Lab 5 object. Choosing **Sine** from your list should now output "001:Sine" to the ordinal function, which will return 1 to your function (the appropriate number to tell the function generator to produce a sine output).

3. To each Wave output (from scope channels 1 and 2) wire up an **AdvMath→Signal Processing→fft(x)** object. To each of these wire a **Math→Complex Parts→mag(x)** object. To compare with our calculation, we also need to divide this result by N. Use **AdvMath→Array→totSize(x)** to accomplish this. We have now effectively taken the FFT and magnitude of that frequency distribution. Apply yet another function (using a formula object), 20*Log10(x), to this output (to get a reading in dB). Notice there is an option within that same menu to obtain the phase.

4. Choose an XYTrace object and add another input to accommodate the second channel. Wire the channel waveforms to the inputs. Also add a control input for the **Traces**.

5. To input the appropriate data to the XYTrace Traces control, we will need to create a record constant. Select **Data→Constant→Record**. From its object menu, create fields (labeled appropriately) for "TraceNum", "Name", "Pen", "LineType", and "PointType". All fields except the Name field should be integers (Int32). The Name field should be of type **Text**. To set these, just press the button for the appropriate field. Since we have two channels to label, we must create an array of such records two deep. In the **Edit Properties** dialog, **Configure** for a 1D Array, and a Size of 2. Fill in the field values for each channel (Use the **Next** and **Prev** buttons). You will need to experiment, but you can get hints by looking at the Traces options in the Waveform graph's **Edit Properties→Traces** dialog.

6. Wire your constant to the waveform graph. Try running your program at different frequencies. The x-axis frequency scaling should be taken care of by the HP VEE. Save your program as lab6pt2.vee.

Part 3: Assignment

Create a function that will display the phase, magnitude, or waveform from channel 1. Begin by constructing a flow chart for your program. The program should label the graph appropriately! To do this you need to know that the Title input is text, not in any sort of record format. The Scales control input is a record of two text fields. The first one is "Scale" (X or Y). The second field is "Name" (the label for that scale… Magnitude, Frequency, Seconds, etc.). Combine your function with the function generator control/waveform capture function from lab5pt2.vee to complete a spectrum analyzer. Also, wire up a **Start** button to the beginning of your program thread. Once you have a working program, add all the controls and the graph to the front panel and design a clean user interface. Save your program as lab6pt3.vee.

You should be able to:

- Show stored scope screens for time domain and FFT measurements.
- Compare scope FFT values to calculations.
- Demonstrate your two-channel XYplot function lab6pt2.vee.
- Demonstrate your spectrum analyzer program lab6pt3.vee. Checklist:
    1. Show flowchart
    2. Be able to select amplitudes, phases, or waveforms
    3. Graphs should be labeled correctly for the different plots
    4. Show that magnitudes and phases agree with calculations.